WAVE PROCESSES AND BEACH RESPONSES

ON A COARSE GRAVEL DELTA

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The wave, as it advances, possesses a kind of power, which some call the purging of the sea, to eject all foreign substances. It is by this force that dead bodies and wrecks are cast on shore. But on retiring it does not possess sufficient power to carry back into the sea either dead bodies, wood, or even the lightest substances, such as cork, which may have been cast out by the waves.

Strabo:
Book I Chapter III

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ABSTRACT

where is it?

The coastal environment around the Hapuku Delta is represented as a process-response model. Field data, collected over a period of one year, are ~~is~~ expressed in the form of nine wave processes and six beach responses. These are described and inter-related statistically so that sediment gains and losses, foreshore texture, foreshore slope, shoreline position, and degree of cusp development may be predicted from given values of wave height, period, and direction. Additionally, the degree of interdependence among the variables is examined.

Some modifications to standard field techniques are developed to overcome the problems presented by the coarse gravel foreshores, and considerable emphasis is laid on the need for excluding a priori assumptions from the functional analysis.

Notable among a number of conclusions, is the relative unimportance, of wave steepness as a predictor of foreshore behaviour, and the strong association of well developed cusps with oblique waves on one of the beach sites.

In general, the process inter-relationships

are spatially and temporally less complicated than either those describing the responses, or those describing the process-response pairs. Seventeen predictor equations are significant at either the .05 or the .01 level for the processes, and fifteen for the responses. Fifty-eight equations relating process to response are significant at the .01 level.

The Hapuku River is the source of all beach sediment on the delta front. Silt is mainly transported offshore, sand and small pebbles move south onto the beaches, and cobbles and boulders move north. Many of the larger grains however, are permanently lost offshore.

The shoreline is retreating near the rivermouth, but towards the north it becomes increasingly more stable both because of the higher proportion of large boulders on the foreshore, and because of the presence of an offshore reef which saps the energy of approaching waves. In the extreme south the shoreline is advancing, but at the northern extremity of the area, pronounced shoreline retreat is taking place from the erosion of the glacio-fluvial deposits on the backshore.

CHAPTER I

INTRODUCTION

A Conceptual Framework and Some Methodological Considerations

In most natural environments topographic change due to geomorphic forces takes place with protracted slowness. The beach environment is one of the few exceptions, and quite striking changes in beach geometry can be observed within a very short span of time, often as little as one hour.

The mercurial characteristics of the land-water interface, both of the forces that shape the beach (chiefly wave and current action), and of the resultants of those forces (changes in beach geometry and sediment distribution), are of such magnitude, and so blatantly perceptible, that upon first consideration, it would seem relatively easy not only to measure and quantify them, but also to formulate some sort of statement that would comprehensively describe the dynamics of the coastal zone. Researchers have been doggedly courting these elusive goals for years now, so far, with only limited success.

Interest directed specifically toward

beach sediment dynamics goes back at least as far as Henry Palmer who, in 1834, distinguished between accretion, erosion, and longshore transport on the coasts of Kent and Sussex:

> ". . . it appears that the actions of the sea upon the loose pebbles are of three kinds: the first heaps up, or accumulates the pebbles upon the shore; the second disturbs, or breaks down the accumulations previously made; and the third removes, or carries forward the pebbles in a horizontal direction."[1]

More recently, a good deal of work has been done, chiefly in North America and Europe, with a view to describing and defining the conditions under which changes to the beach take place. Direct field measurement, observation, and description was popular up until recent decades, and besides Palmer, studies by Cornish (1898), and Fenneman (1902), and Johnson's (1919) classic work, contributed towards a fuller understanding of the beach system. The shortcomings of these qualitative accounts became noticeable though, whenever the construction of piers and other coastal works was undertaken. What was needed was less qualitative description and more quantitative fact on the effects of wave forces on

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[1]Palmer, H.R., 1834; p.568.

coasts and engineering structures. These matters received additional attention between the First and Second World Wars when such things as the necessity for quantitatively predicting wave and nearshore characteristics for establishing beach-heads became urgent.

One approach that has been tried, that is both intuitively acceptable and also lends itself to effective quantitative treatment, is the conceptual visualization of the coastal zone as a process and response system. The marine forces are regarded as processes, and any resultant beach modifications, the responses. Wave characteristics thought to be important in this relationship can thus be measured, and their effect on the beach appraised. Research experience has shown that although this conceptual model has important advantages over earlier, more descriptive accounts, some major complications arise when an attempt is made to link wave "process" with beach "response".

The quantitative inter-relation of wave and beach measurements has proved difficult for a number of reasons. In the first place, it is not entirely clear exactly what characteristics of the waves are most important in initiating changes on the beach. Nor is it known whether these characteristics have threshold values below which they are ineffectual on particular kinds of beach deposits. It is likely that they do, and it is even more likely that they induce different changes on different kinds of beaches. Moreover, the cause and effect link between the waves and the beach can be complicated by feedback (King, 1970), so that the "effect" of waves of a particular kind on, for example, the slope of the nearshore bottom becomes a "cause" which drastically alters the flow characteristics of the waves. Another problem is that the beach does not respond instantaneously to changes in the waves (Schwartz, 1968). There is a lag, however slight, between marine "cause" and beach "effect". Indeed, the lag itself is likely to change depending upon what features of the wave and beach are being measured. To make things even more interesting, all of the wave and beach variables are uncontrolled. They change at nature's whim, and the cause and effect relationships rarely progress to states of dynamic equilibrium.

One way of systematizing these variables is to resort to the use of hardware model studies in the laboratory. Under these conditions, the variables can be controlled, and those thought to be influential in effecting beach change can be isolated and studied separately, while other variables are excluded or held constant. Implicit in this approach is the capability of allowing process-response pairs to run to completion or equilibrium, and also the opportunity to study changes in process intensity on particular response features.

Studies using hardware models of the beach have made some major quantitative contributions to unravelling the intricacies of beach dynamics. Notable among such work is that of Bagnold (1947, 1940), and Inman and Bowen (1963). It has been shown, however, that hardware model studies are not wholly satisfactory and the conclusions are sometimes at variance with what happens on natural beaches. The reason for this is that the physical conditions of a natural beach cannot be exactly replicated in a model. Scale theory must be used, and this involves speculative assumptions about the nature of the behaviour of individual particles in the fluid medium.

The literature on coastal research is replete with examples of other techniques that have been used for studying the beach system, and among these, simulation or stochastic-process models, and physical process models, which are mathematically deterministic, deserve mention. One method of evaluating wave processes with respect to beach responses which seems to offer some advantages over those previously mentioned, is the statistical model. It is the method used in the present study.

The statistical method has one initial advantage over some of the approaches previously discussed in that it can be applied directly to measurements taken from the natural beach. Scale theory is not involved, nor is there a need to resort to computer simulation of natural processes or to physical laws which describe the movement of solid particles in fluids. Rather, the association between process (independent) variables and particular response (dependent) variables is expressed in probabilistic terms.

Krumbein[1] gives a generalized example of a statistical process-response model as it might be applied to a beach study. The process variables interacting in the model are expressed as a function of the form:

$$f(p,G,P,S,T) = 0$$

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[1]Krumbein, W.C., 1961; p.6 ff.

where $p_1, p_2, p_3, \ldots\ldots p_n$ represent a number of physical, chemical, and mineralogical properties of the beach sediments; $G_1, G_2, G_3, \ldots\ldots G_n$ represent geometrical properties of the grains; $P_1, P_2, P_3, \ldots\ldots P_n$ represent individual geomorphic processes; S_1, S_2, and S_3 are geographic coordinates including elevation; and T represents a time factor. The function is implicit in that the number of process factors is unspecified, and others may be included as needed. Biological variables, for instance, would likely be included in some instances. If all of the process factors can be included, then the function becomes explicit and defines the totality of change in the response variable being studied.

Besides being highly suited to the treatment of observations taken directly from nature, the model can be structured to include a large number of process variables, and with the aid of statistical correlation and regression techniques and access to computer facilities, the most statistically significant process variables affecting particular beach responses can be "screened out" from those that are less significant.

Krumbein (1963, 1961), and Harrison and Krumbein (1964), were among the first to implement this technique. A number of acceptable methods for statistically implementing the model are valid. In the sources just cited, sequential multiple regression was used, but in an addendum to the 1964 reference, Harrison and Pore point out that this technique severely limits the number of process variables that can be handled.[1] They tested the same data set using a stepwise multiple regression program and found that as high or higher correlations resulted as with the sequential procedure.

From these initial studies, Harrison and his associates have gone on to refine their treatment of beach data (Harrison, 1970; Harrison, 1969; Harrison, Rayfield, Boon III, Reynolds, Grant, and Tyler, 1968; Harrison, Pore, and Tuck, 1965), and have proposed predictor equations which express the statistical dependence of several beach responses upon a number of wave process variables.

Although this research has made some aspects of coastal dynamics more intelligible, it has not been an unqualified success. Harrison himself draws attention to a number of deficiencies that deserve further work.[2] Among them is the

[1] Harrison, W., and Pore, N.A., 1964; p.A-1.

[2] Harrison, W., 1970; p.233.

probability, already mentioned above, that the wave processes will not proceed to a completed state of beach response. Another problem is that the process variables are not mutually exclusive and therefore there is a certain amount of unknown interdependency among them, whereby a change in one wave process induces a change in another. Harrison also points out that the linear regression model may not be the best one to use and suggests that non-linear relationships need investigation.[1]

Notwithstanding the attention that coarse-grained beaches have received in British coastal research, most of the studies in the literature have to do with sand beaches. This is to be expected since coarse-grained shingle beaches are relatively rare in temperate latitudes.[2] Because of this, shingle beaches are also less well understood than their sandy counterparts.

In New Zealand, shingle beaches do occur, and they have been the subject of a number of directed studies. Patrick Marshall (1927, 1929),

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[1]Harrison, W., 1969; p.550; Harrison, W., *et al.*, 1965; p. 6108.

[2]Davies, J.L., 1972; p.110.

described at length some experiments on the wearing of beach gravels due to abrasion, impact, and grinding on some North Island beaches. Jobberns (1928) gives a very extensive description of the beaches, many of which are composed of gravel, of the north-east coast of South Island, from Banks Peninsula to the Wairau River north of Cape Campbell. Bartrum (1947), and Shelley (1968) have examined the rounding and fitting, respectively, of beach boulders. More recently, and specifically with relation to coarse beaches, Dickson (1969) has studied the morphogenesis of the beach and river pebbles of the Hapuku River north of Kaikoura, and Kirk (1970) examined the flow regimes in the swash-backwash zone of a mixed sand-shingle beach in the same general area. McLean (1970) has published a study on the variations in grain size and sorting, and McLean and Kirk (1969) collaborated in a published account of the relationships between size, sorting, and foreshore slope on the sand and shingle beaches of the Kaikoura area.

These studies have examined particular aspects of coarse-grained beaches. To date, no work has been done on attempting to quantify the broad relationships which exist between the gross characteristics of wave process and the topographic and textural response of a coarse beach to those characteristics. The concern of this study is to describe and analyze a number of these relationships.

Of recent research, the most closely akin in concept and methodology to the present study is that of Harrison and his associates, and it is for this reason that his statistical process-response model has been used as an example, and has been discussed in moderate detail. However, the present study differs in two major respects from Harrison's work.

First, there is a fundamental difference in the physical characteristics of the beaches in the two studies. The data set which has received most attention from Harrison is the twenty-six day series of observations taken at Virginia Beach, near Chesapeake Bay, Virginia (Harrison et al., 1968). It is a medium-sand beach with nominal foreshore grain diameters ranging from 0.25 to 0.37 millimetres (2.0 to 1.4 phi).[1] The beaches of the study area, on the other hand are much coarser, and the foreshore deposits range from coarse sand to large boulders. The mean foreshore grain diameters of the four beach pro-

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[1]Harrison, W., et al., 1968; p.2.

file sites of this study are -2.5 phi, -3.4 phi, -5.7 phi, and -2.5 phi.

The second major difference is one of statistical methodology. It has already been mentioned that a need has been recognized for investigating curvilinear relationships between process and response. The present study, as well as extending the application of stepwise multiple regression techniques to gravel beaches, emphasizes the advantages of describing a number of curvilinear relationships not only between process and response variables, but also between process pairs, and response pairs. Specifically, successive orders of polynomial equations are used in this thesis to approximate the functional inter-relations between the variables. It is pertinent here, to briefly enlarge upon some of the implications of these methods.

Some previous studies have postulated the existence of non-periodic functional relationships between selected variables from the coastal zone. An example is the logarithmic relationship proposed by Bascom (1951) between sand size and beach-face slope. Griffiths, however, has quite properly pointed out that the kind of functional relationship between two variables is rarely known in advance in experimental research.[1] Moreover, it is presumptuous to assume that where a significant relationship does exist between pairs of variables, it can be described best by a smooth, non-periodic curve.[2] Indeed, there is enough evidence published to date from the beach environment to suggest that at least some process-response relationships are not non-periodic over the range of the independent variable. A relevant example is provided by Kemp (1961) who has shown that increasing breaker height (wave period is held constant) is not accompanied merely by corresponding incremental changes in the intensity of the flow pattern on the foreshore, but that the hydraulic behaviour of the swash zone progresses through three states, which have diverse characteristics, and each of which has a distinctly different effect on the mobility of the beach deposits.

Polynomial equations can accomodate both periodic and non-periodic functions and testing successive orders of polynomials, from simple

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[1]Griffiths, J.C., 1967; p.441.

[2]There are advantages, of course, in being able to express relationships in this way, and probably chief amongst them is that the function can be easily reduced to the linear form by a suitable scale transformation of one or both variables.

non-periodic relationships to more complex periodic ones, therefore provides a highly effective way of mathematically specifying the most predictive functional relationship between pairs of variables.

This screening technique has the distinct advantage that it allows the data to find expression in a wide range of succeedingly more complex functions which can then be scrutinized and the "best" one selected. In this way, a minimum of *a priori* decisions are made which fix the functional form of the predictor equation, and this lack of statistical restraint permits, and is reflected in, relatively high correlations, and low standard errors. Comparison of the results of these methods with those achieved by the more usual techniques of multiple correlation and regression is also possible, and in this study is featured in Chapter V, which discusses the inter-relationships between the processes and the responses.

Polynomials do have the disadvantage that they only treat two variables at a time, but inasmuch as multiple regression equations are also included in this analysis, this is not considered to be a serious limitation. In any event, considering that in spite of a great deal of research effort, wave processes and beach responses have so far been inter-related with only moderate success, it would seem prudent at this stage, to adopt more modest goals by examining the process-response pairs individually before evaluating them collectively.[1]

The Physical Setting

The area in which this study was undertaken extends for 3.5 miles northwards along the east coast of South Island, New Zealand, from a point five miles north of the town of Kaikoura. It includes all of the active fan of the Hapuku River as well as the deltaic margins to the north and south. Relative to the present-day location of the river-mouth, the boundaries of the study area lie one mile to the south, and two and a half miles to the north. The study area in relation to New Zealand, is depicted in Figure 1:1.

In the context of world coastal classification, the area can be described as part of an east coast swell environment with low to medium-high energy levels,[2] although locally, around the delta

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[1]With particular reference to the problem of relating changes in one variable to changes in another, Lastrucci (1967; p.111) observes that in areas where relatively little is known, it is safer as well as being easier to test the influence of one variable at a time. He goes on, gastronomically, to add that, "small bites taken into the pie of knowledge are less apt to result in mental indigestion".

[2]Davies, J.L., 1972; pp.39, 43.

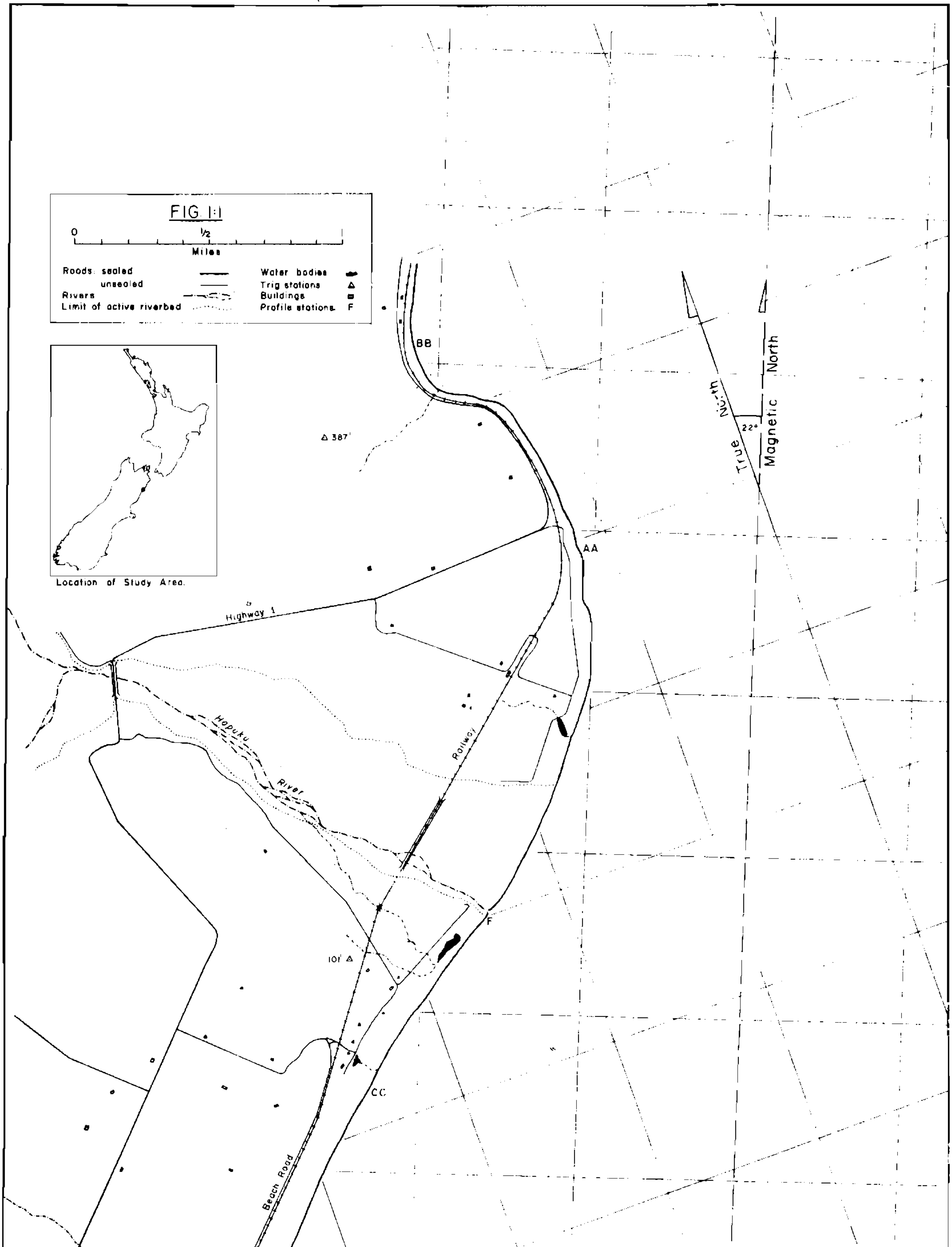
FIG. 1:1
0
1/2
Miles
Roads: sealed
unsealed
Rivers
Limit of active riverbed
Water bodies
Trig stations
Buildings
Profile stations F
Location of Study Area.
BB
AA
CC
F
△ 387'
101' △
Highway 1
Hapuku
River
Railway
Beach Road
True North
Magnetic North
22°

itself, the shore is one of comparatively high energy. Locally generated waves are common, and deep-water swell from more distant storm centres can also reach this section of coast from the eastern sector of an arc extending from north to southwest. Fetch lengths in these directions are virtually unlimited.[1]

The general geology of the area has been described by Suggate (1965), and the local geomorphology of Kaikoura has been recently summarized by Chandra (1969). The beaches, which are the concern of this study, form the seaward margin of a narrow alluvial fan of coarse gravel and sand of late Quaternary age, and the fan is bordered on its landward side by the massive and indurated Jurassic greywackes of the Seaward Kaikoura Range, which rises steeply to over 8,000 feet.

Plate 1:1 shows the Hapuku Delta looking south from the northern boundary of the study area. The active alluvium of the present-day river channel can be seen in the background.

The area was selected as being a good one for a process-response study for at least three reasons.

First, in terms of the response of coarse

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[1]McLean, R.F., 1971; p.3.

PLATE 1:1

Caption?

beach sediments to wave action on an exposed coast, the delta can be studied as a well-defined geomorphic unit. To the north of the study area the coastline is rocky, and unconsolidated beach deposits are intermittent; to the south the wave-shadow effect of the Kaikoura Peninsula becomes important in modifying incoming waves.

Second, it is interesting to speculate on the source(s) and subsequent movement of the deltaic sediment. Figure 1:1 shows that the coast presents a convex outline to the sea. This implies that sometime in the recent past, the coastal sediments were either resistant to erosion by marine forces, or that the rate of shoreline advance exceeded the competence of the waves to remove them. On the other hand, considering the exposed aspect of the delta, and the relatively small area of the Hapuku catchment, it might well be expected that the wave energy levels would be more than sufficient to rapidly remove the beach deposits and by so doing, straighten the coastline. Without indulging in the controversy surrounding eustatic changes in sea level over the past 10,000 years, it should be possible to resolve this enigma and to deduce the present state of shore-normal shoreline stability by examining contemporary sediment dispersal around the delta.

Finally, reference has already been made to the dearth of published research on very coarse beaches. If the process and response relationships of the coastal zone are ever to be comprehended for these as well as for sandy beaches, then there is obviously a pressing need for further research on foreshores composed of gravel and shingle.

The Aims of the Study

There are two objectives to this thesis. One is descriptive, the other analytic. The first is to describe the terrestrial and marine characteristics of a section of coastline. The second is to inter-relate these characteristics within the formal structure of a process-response model, and to disclose and interpret statistically significant associations among them.

Two specific purposes of the study, allied with the objectives expressed above, are to gain a temporal and spatial understanding of the dynamics of sediment dispersal in the area, and also to develop a set of equations that can be used to predict particular beach responses from given processes.

It should be stressed at the outset, that although it will be shown that some of the process functions are quite strongly predictive of specific responses, this fact alone does not imply an unqualified cause-and-effect relationship. On the other hand, valid statistical relationships are worth establishing. Krumbein (1961) suggested that:

> ". . . where the independent variable has physical meaningfulness in the problem, it is not extreme to infer that the strength of the mathematical relation is also a measure of the strength of the physical relation."[1]

The process variables selected for use in this study were deliberately chosen because intuitively they do have "physical meaningfulness" to the measured responses. Likewise, some process variables were purposely omitted because they lacked it. For example, although there is reliable evidence that wind can be an influential factor in transporting grains on the subaerial beach (Jennings, 1957), it was not included here because it was felt that its effect on the large grains of the coastal strip around the Hapuku Delta would be negligible.[2]

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[1]Krumbein, W.C., 1961; p.27.

[2]Wind direction also modifies the wave characteristics, with an onshore wind steepening, and an offshore wind flattening the wave form. (King, 1953). However, since the nearshore wave characteristics themselves, were measured during this study, the additional inclusion of wind measurements was considered redundant.

It has already been pointed out that the process-response model has been used by other writers as an analytical tool in the earth sciences. Examples include studies by King, (1970); Dolan, (1965); Harrison and Krumbein, (1964); Krumbein, (1961); and Miller and Zeigler, (1958). Also, as mentioned earlier, predictor equations have been developed before, chiefly by Harrison and his associates, (Harrison, 1970; Harrison, Pore, and Tuck, 1965; and Harrison and Krumbein, 1964). The differences referred to earlier, between this study and those just cited are essentially that the beaches described here are composed of much coarser deposits, having a wider range of material size than those of most other studies, and the mathematical description of the inter-relationships among the variables is not restricted either to the linear or to the non-periodic case. In respect of the first difference, this study has been purposely designed to deal with and over-come some of the problems presented by very coarse sediments. In respect of the second, it will be shown that there are important advantages, related to the predictive power and levels of significance of the resulting equations, that ensue from exploring the periodic and curvilinear possibilities.

The Beach Environment and the Profile Sites

In general, the most striking characteristic about the beaches in the study area is their wide range of sediment size. Abundant amounts of material ranging from silt and clay sizes to boulders up to about two or three feet in diameter occur widely on the beaches, at least some of which is delivered to the coast by the Hapuku River. Much of it is continually moved over the beach by wave action. Figure 1:2 taken from a plane-table survey done in the early phases of this study, shows the typical topography around the river-mouth as well as the kinds of surficial sediments that exist on the beach and backshore.

Four beach sites were chosen to represent the whole range of foreshore and local wave characteristics which typify this stretch of coast. The locations of these are shown in Figure 1:1 and the bulk of the data of this study was gathered from repeated beach profile surveys taken at these sites. Measurements of the surface texture of the foreshore and the wave characteristics were taken concurrently with the profiles.

The profile sites are referred to extensively throughout the thesis as CC, F, AA, and BB, and a detailed synopsis of their features, as well as their nearshore wave environments, is

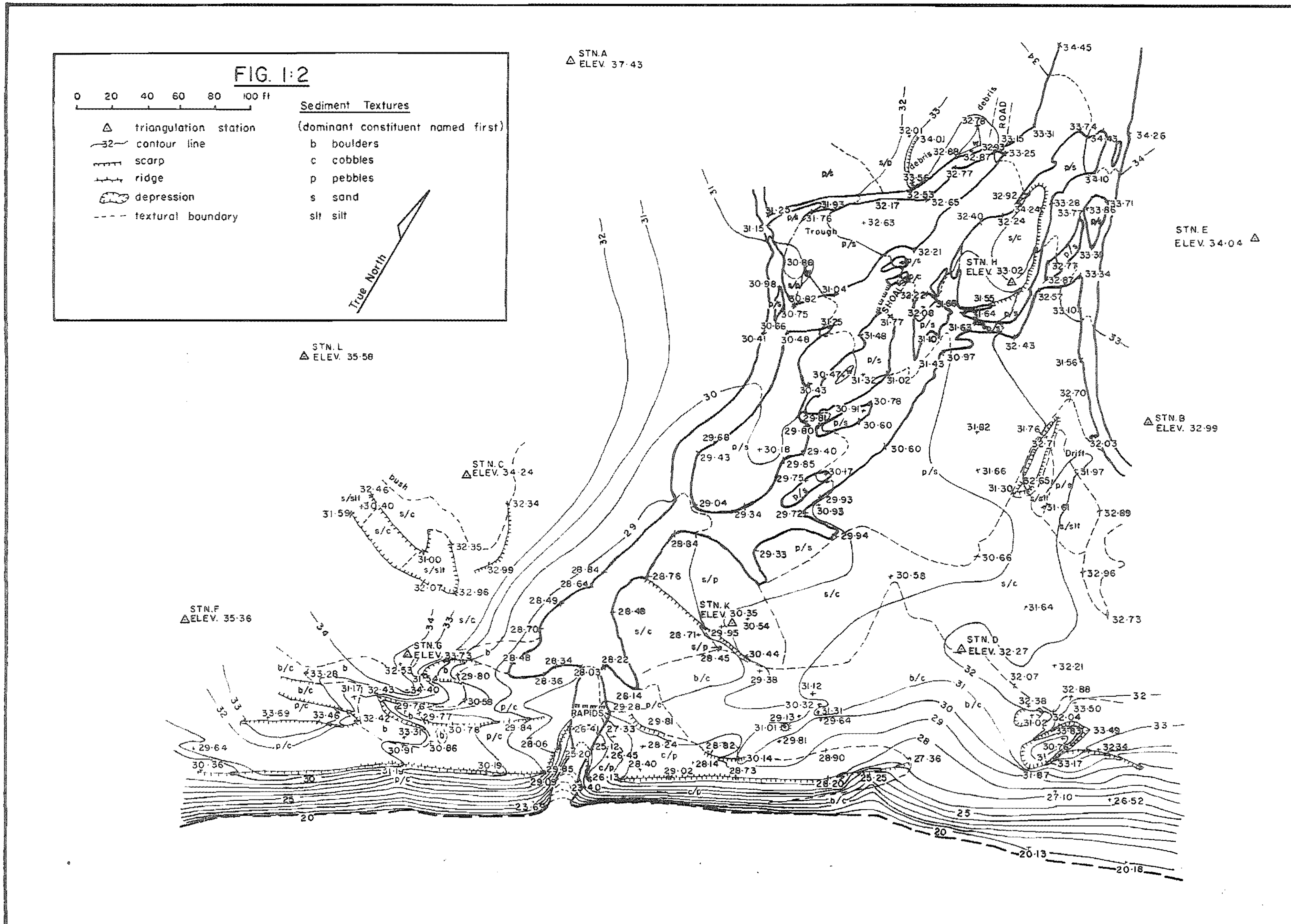

FIG. 1:2
0 20 40 60 80 100 ft
triangulation station
contour line
scarp
ridge
depression
textural boundary
Sediment Textures
(dominant constituent named first)
b boulders
c cobbles
p pebbles
s sand
slt silt
True North
STN. A ELEV. 37·43
STN. E ELEV. 34·04
STN. H ELEV. 33·02
STN. L ELEV. 35·58
STN. B ELEV. 32·99
STN. C ELEV. 34·24
STN. F ELEV. 35·36
STN. G ELEV. 33·73
STN. K ELEV. 30·35
STN. D ELEV. 32·27
ROAD
debris
Trough
SHOAL
Drift
bush
RAPIDS

given in later chapters. However, so that they can be appreciated as more than just alphabetical abstractions, a brief description of each is given here, commencing with CC in the south, and progressing to BB, the profile at the northern limit of the study area.

The site of profile CC is shown in Plate 1:2 from ground level, and in Plate 1:3 from the air.[1] This profile is representative of the extreme southern margin of the delta. It is considered to be the southern limit of deltaic exposure to the open sea. Further south than this, the wave-shadow effect of the Kaikoura Peninsula is no longer negligible.

CC is a wide beach, composed mainly of medium to coarse sand[2] with minor amounts of pebbles and small cobbles. The pebble and cobble constituents make up less than five per cent of the surface exposure of the backshore (landward of the winter berm crest), but become increasingly common at the seaward end of the profile. The foreshore is commonly composed of

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[1]Unless otherwise stated, the scale of all vertical airphotos in this thesis is one inch to one hundred and fifty-five feet.

[2]These textural terms are used in the colloquial sense here. In later chapters, they will be formally defined.

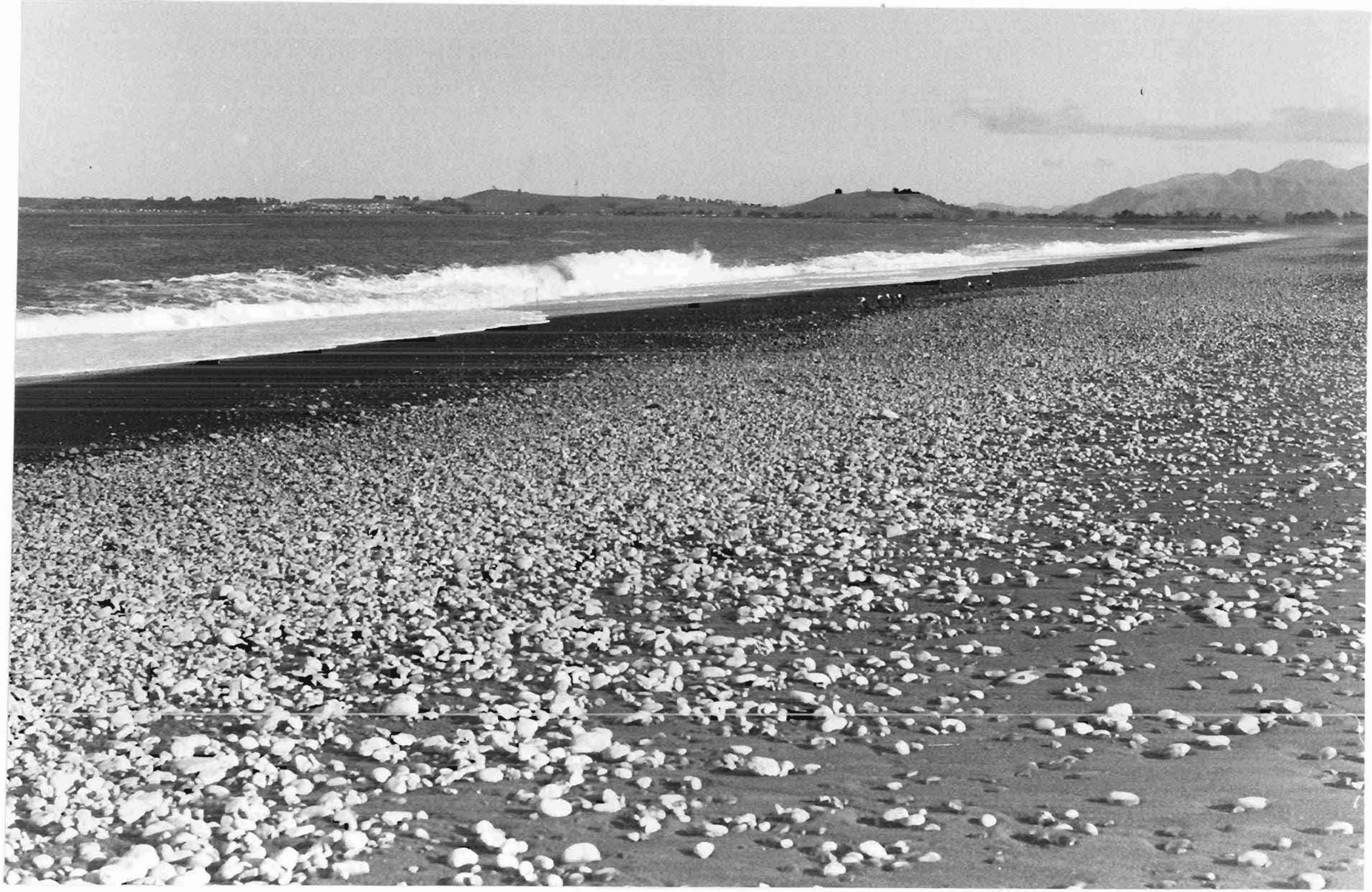


PLATE 1:2

PLATE 1:3

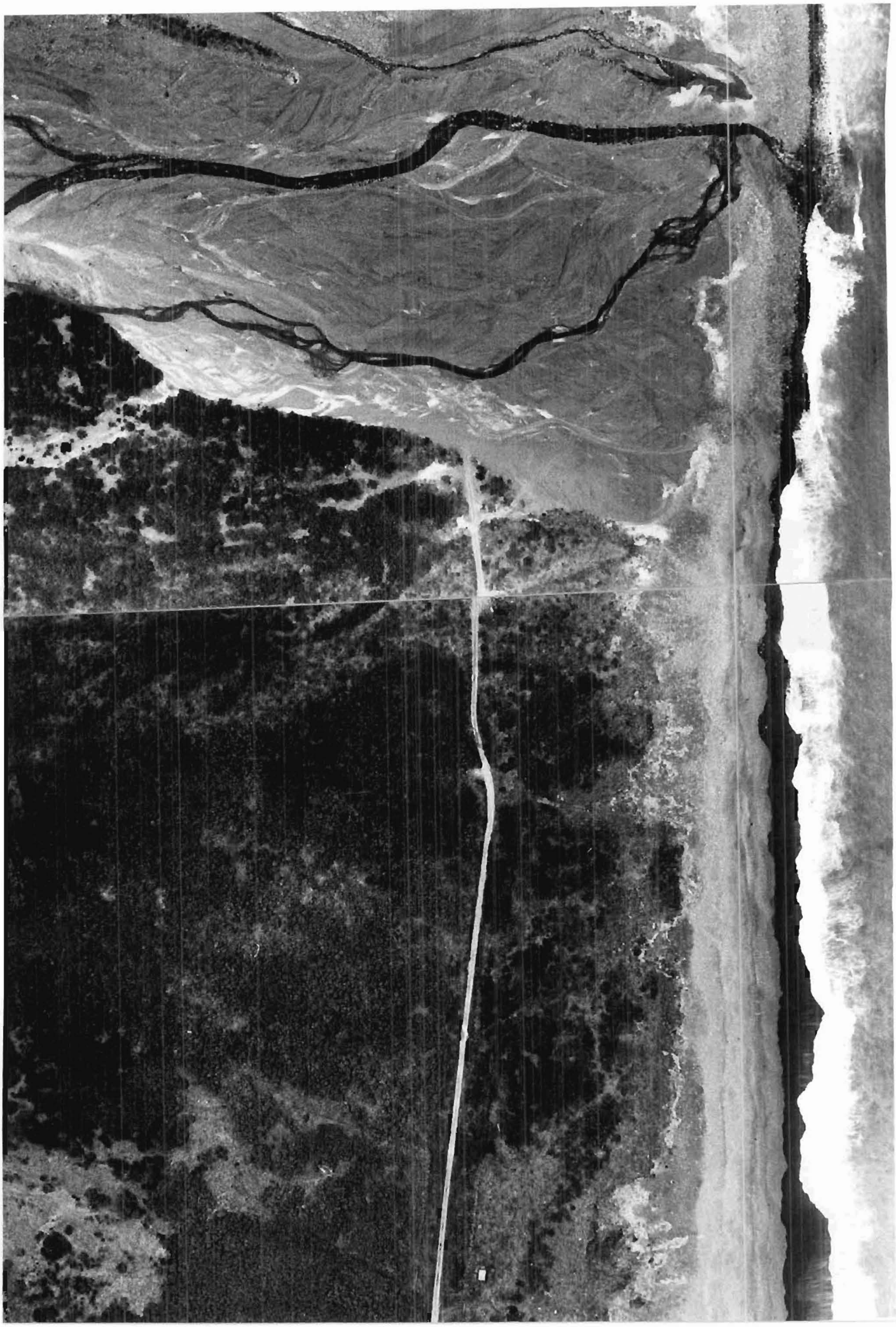
coarse sand and granules intermixed with the aforementioned pebbles and cobbles, and the coarser fractions of this sediment are often sorted into small discontinuous shore-parallel ridges at the upper limit of the swash. Large cusps, visible in the plate, are sometimes a feature of this profile. The waves which break on the foreshore are generally high and usually of the plunging type. Surging breakers are less common, and spilling breakers are very rare. A pronounced "step" is characteristic of the lower foreshore.

Progressing towards profile F further north, the foreshore material becomes gradually coarser, with pebbles and cobbles rather than sand becoming the main constituent of the beach deposits. Profile F, shown from the ground in Plate 1:4 and from the air in Plate 1:5 (which also shows the mouth of the Hapuku) is narrower, and composed of much coarser sediment than CC. It was selected as being typical of the exposed part of the delta, and also because it is close enough to the main outlet of the Hapuku River to show the changes on the foreshore that can take place when the river is in flood.

Although all size fractions are well represented on this profile, pebbles and cobbles constitute most of the beach deposits, especially

PLATE 1:4

PLATE 1:5



on the upper foreshore, and well defined berms and cuspate forms are common. The foreshore is also much steeper and more concave than that of CC. Wave energy is high at profile F, and occasionally breakers, which are usually of the plunging type, exceed ten feet in height.

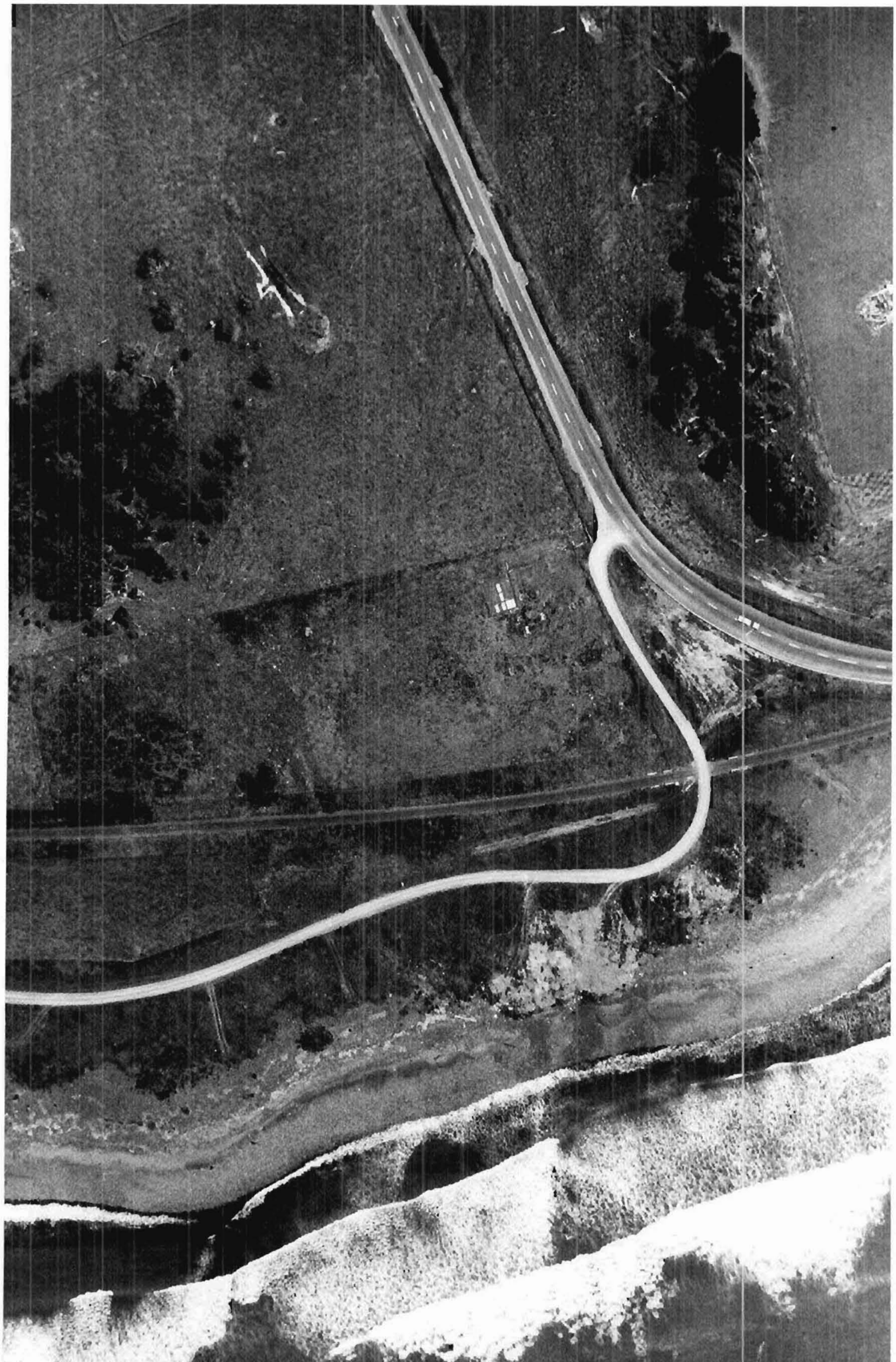
Between profiles F and AA, the foreshore is composed predominantly of large cobbles and boulders, and except in times of flood when the river may breach these deposits and reach the sea, and in spite of the uniformly high wave energy levels, changes on the foreshore are too slow and of too small a magnitude in relation to the particle size of the sediments and the surveying methods to be measurable.

Profile AA, however, while retaining the coarse-grained features of the foreshore further south, also occasionally undergoes profile changes which are measurable, and it was selected mainly so that the role that surficial boulders play in foreshore responses could be studied.

Plates 1:6 and 1:7 show profile AA from the ground and air respectively. This profile has coarser sediment than any of the others, and the lower foreshore is always composed of boulders from one to two feet in diameter. Higher up on the profile, finer grains, chiefly large

PLATE 1:6

PLATE 1:7



cobbles, are more common, but sand is almost always absent from all but the backshore. The waves that break on shore at AA, are invariably of the spilling type and weak. They undergo considerable modification before reaching shore due to an offshore reef which sometimes initiates breaking and consequent loss of wave energy by turbulence and bottom friction.

The most northern profile, BB, is shown from the ground in Plate 1:8 and from the air in Plate 1:9. A wide range of sediment size occurs on this beach. It was included in the study because it was thought that it might be supplied with deltaic sediment from the south by longshore transport. It is the narrowest of all the beach profiles and is composed mainly of sand, although large amounts of pebbles and cobbles are also present. The coarser fractions are often sorted from the fines and form semi-permanent cusps on the upper foreshore. The beach is backed on the landward side by an erosional scarp about four feet high, and this is visible in the plate. There is nothing particularly distinctive about the waves at BB. They are generally low to moderate in height and they spill or surge rather than plunge.

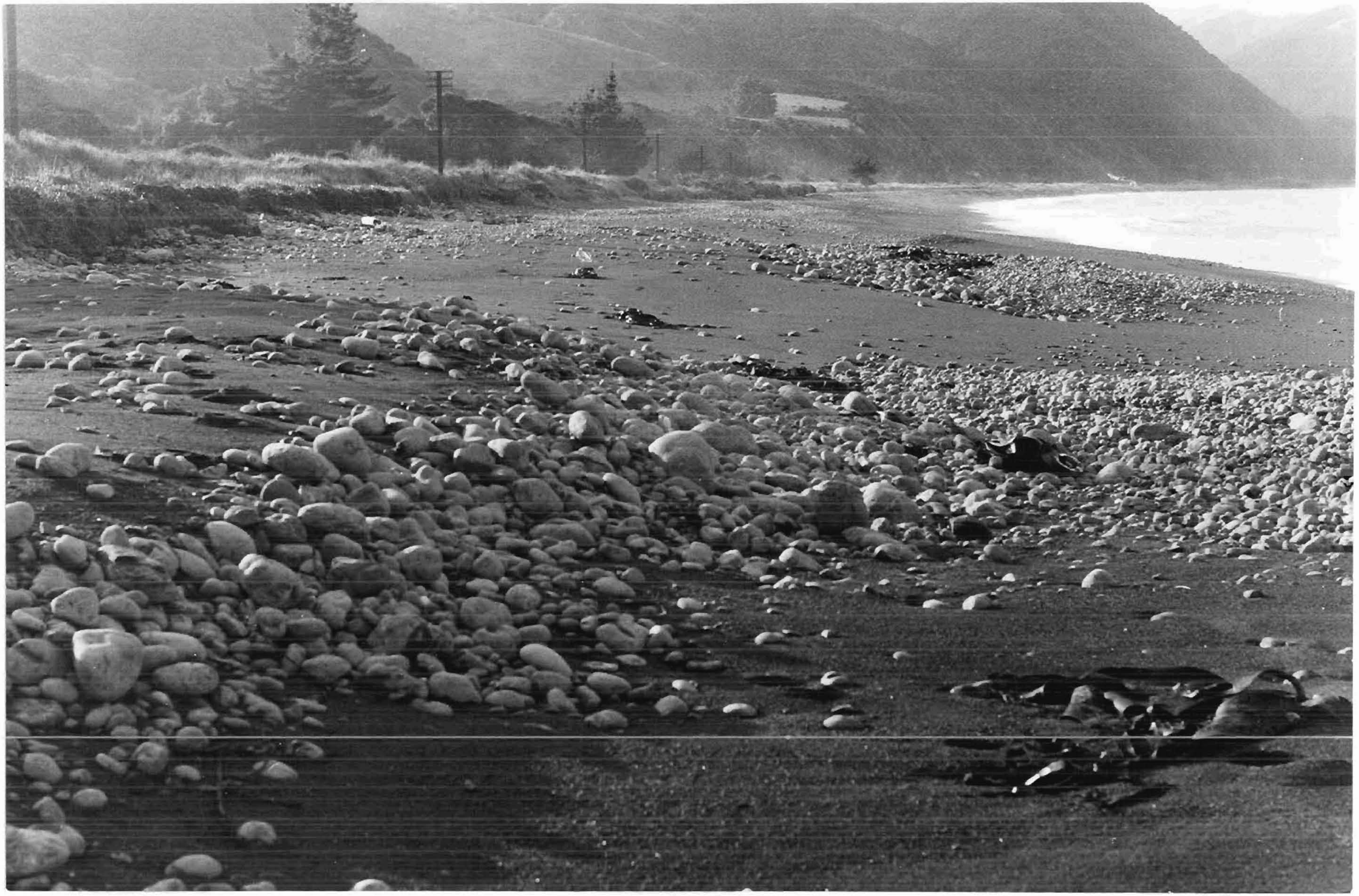


PLATE 1:8

PLATE 1:9

The Organization of the Study

Apart from this introductory chapter, the thesis is divided into five main sections, with a chapter devoted to each. There are features of the beach sediments, and certain logistic demands of the field area in general, that compelled some methodological departures from standard field and laboratory techniques. These are described in detail in Chapter II.

Chapter III deals with the process elements of the study. The process variables are derived and discussed, and then used to describe the similarities and differences of the process environments at the individual sites. The process variables are also statistically inter-related in order to show their degree of inter-dependence.

Chapter IV is organized with respect to the response variables much as Chapter III is to the process variables. In addition, the mechanics of sediment distribution around the delta is discussed.

The association between process and response is explored in detail in Chapter V and a number of predictor equations are given.

The thesis is concluded in Chapter VI, which summarizes the main results of this study, and also suggests areas where further research inquiry might be fruitful.

CHAPTER II

RESEARCH METHODS

This chapter describes the field and laboratory methods that have been used in the study. The establishment of survey stations from which the profiles extend, and the network of control stations are treated first. This is followed by descriptions of the measurement of wave height, period, and direction, and a brief account of the large scale, thirty feet to the inch, mapping that was done during the early phase of the study.

A description and evaluation of a new technique for beach profiling follows this, and forms a major part of this chapter.

The way in which the foreshore was defined is given, and the quantitative measurement of foreshore slope is discussed.

A classification scheme for recording the textures of the beach deposits is developed in some detail and extended to include a realistic, quantitative index for foreshore texture. Cusp classification is also briefly discussed. This is followed by a short account of the way that volumetric changes at each profile site were measured. The chapter concludes by outlining the program of offshore sounding and sampling and aerial photography, and a summary is given at the end.

The Survey Stations

Figure 1:1 shows the study area and the four places on the delta that were used as profile sites. A first-order survey hub was located on the backshore at each of; CC, F, AA, and BB, and their elevations were established at 43.19 feet, 35.88 feet, 36.40 feet, and 32.83 feet, respectively. These, and all elevations used in this study were tied to, and are compatible with, the benchmarks of the Marlborough Catchment Board. Each of the hubs was located well above the highest spring tides, and consists of a two foot length of wooden post, two inches square, sunk in the ground. Seaward of each of these first-order stations, and also on the shore-normal, a second-order hub was placed at each profile site. In practice, this was used as a base station for the profile surveys because only the section of profile seaward of this point was subjected to wave action. The horizontal positions and elevations of these second-order hubs were checked periodically from the base stations, and had they changed position or been washed out, they could easily have been replaced. This never had to be done. The positions and elevations of these hubs are: CC + 150.0 feet (elevation 36.66 feet); F + 36.9 feet (elevation 35.69 feet); AA + 45.0 feet (elevation 33.08 feet); and BB + 32.1 feet (elevation 30.80 feet).

At the time these stations were put in, there was a tide gauge located ten miles to the south, at the end of the New Wharf in Kaikoura, and elevations were carried to this with a view to incorporating the tide gauge record with wave action on the delta. Shortly after the gauge was tied in to the rest of the network though, the sensing head fell off. After that, although it was replaced, it never really worked very well, and so apart from establishing the elevation of mean sea level at 26.00 feet, and the spring tidal range as 4.7 feet, the records were not used.

The Measurement of Wave Variables

Wave height, wave period, and wave direction were measured and used to describe the nearshore wave regime. Average wave height, to the nearest half foot, was estimated as the mean height of the highest one third of the waves from trough to crest just before the wave broke. Wave period was measured with a stop-watch by noting the length of time it took for ten waves to reach shore and taking the mean wave period. Wave direction was measured with a magnetic compass and is expressed as the true azimuth from which the waves approach shore.

Large Scale Mapping

The measurement of the processes and responses on the delta was first approached with a view to describing the large scale changes in the area. It was noticed that some of the most drastic modifications to the distribution of the deltaic sediments occur at times of river flooding. During these times, the Hapuku forms many new channels and, if the flood is severe enough, it may empty into the sea at as many as three or four places.

The flood peaks are reached in very short times, usually within three to four hours, and initially the river has no difficulty in scouring a number of new channels to the sea. The floods subside less quickly, and as the river becomes progressively less competent to maintain open channel flow through the beach, drainage to the sea reverts to interstitial flow through the beach sediments. In the final stages, direct access to the sea exists only at one or two places, and a semi-permanent lagoon often forms at the river-mouth.

It can be appreciated that much modification of the backshore sediments as well as changes in the channels takes place at times such as these, and at first it was hoped that these changes could be mapped when they occurred, and related to a comtemporaneous record of river discharge and wave action. With this in mind, a triangulation net was put in over the whole delta to serve as the horizontal and vertical control from which changes in the active part of the delta could be rapidly mapped with a plane table and alidade at a scale of thirty feet to the inch. Although this was done on a number of occasions (see Figure 1:2), and it was possible to monitor the typical sediment and river channel changes that occurred over the whole delta during times of flood, it was not possible at the same time to obtain reliable measures of river discharge or wave action, and so, although this part of the fieldwork yielded a reliable picture of the overall behaviour of the delta in times of flood, the emphasis of the study was shifted to the beach.

Beach Profile Surveying

The way in which beach profiles were surveyed is somewhat unorthodox compared to traditional methods of benchmark levelling using a telescopic level and either a Philadelphia or stadia rod, and it is sufficiently different from these to be discussed in some detail.

There are two major advantages in the method to be described. First, and more important, it requires only one man as opposed to the two required for other levelling procedures. Second, it is much faster than benchmark levelling methods, even when the stadia intercept is used to obtain horizontal distances. It has other advantages as well, however. The equipment is compact, and far less costly than other instruments that do much the same job. At the same time it has more versatility, because it can be used in azimuth as well as for elevations. Since everything is enclosed, it is well protected from the elements, and it is more rugged and needs less upkeep than a telescopic level, a Brunton, or an Abney.

The main disadvantage of the method is that it is not as accurate as benchmark levelling because angular error accumulates along the profile. The assessment of this accumulated error is discussed later.

The equipment used consists of a dozen lengths of aluminum tubing, each twenty-eight inches long by three quarters of an inch in diameter. About an inch of brightly coloured plastic tape is wound around the top of each tube for easy visibility, and the tops are also prominently numbered from one to twelve. Number 8 fencing wire is run through each of the tubes so that about eight inches protrudes from the bottom, and a loop is formed on the top of the wire to prevent it from falling through the tube.

The sighting instrument is a clinometer manufactured by Suunto of Helsinki, and is widely available. It is of the floating card type, graduated both in degrees and per cent grade. It is usually used as a hand-held device, but it was felt that the design of the instrument allowed for much more precise readings than could be realized by hand-holding it. The exigency of collecting a large amount of beach profile data in a short time without the aid of a field assistant, led to the design and subsequent use of a simple device that would allow the profiles to be surveyed quickly and relatively accurately.

A brass frame was designed to be used with a ball joint on the bottom. This is mounted on a standard camera tripod from which the pan head has been removed. The frame holds the clinometer by means of a knurled grub screw, and is hinged so that the clinometer may be tilted with a tangent screw. A stainless steel spring holds the two hinged sections together, and provides a resistance against which the screw turns. The hinge axis on the frame is placed so that it intersects the optical axis of the instrument, and the "height of instrument" thus remains constant as the clinometer is adjusted onto the target. The hinge-pin was tapped to accept a small bolt, from the centre of which, extends a twelve inch length of nylon monofilament. A small glass spirit level is encased in plastic tubing for protection, sealed at each end with nylon plugs, and permanently mounted on the monofilament.

The beach profile is surveyed by walking it four times.

On the first leg, the number one rod is run into the ground at the base station so that the bottom of the tube rests on the station, and the rod is vertical. At the first break in slope, the number two rod is similarly placed so that the bottom of the tube rests on the ground. The rods are placed consecutively down the profile at each break of slope, and in a plane at right angles to the shoreline, until a rod has been placed at the top of the swash zone. An extra rod is also left here, for later placement in the swash zone itself.

On the second leg, which is a return trip to the base station, the slope distances between stations are chained and entered in the field book.

On the third leg, the instrument is set close to, and directly beside each station. A consideration of the geometry of the system will show that it is important that the hinge axis of the instrument be horizontal and that it pass across the top of each rod. Coarse adjustment consists of pushing the appropriate tripod leg deeper into the ground. Fine adjustment of horizontality is done with the ball joint which is then locked in place. The height of instrument is now adjusted so that the hinge axis is level with the top of the aluminum rod. This is done by means of the rack and pinion on the centre post of the tripod. On clear days the sea-sky horizon is used as a reference. On cloudy days, or when the horizon is obscured, the monofilament is laid across the top of the aluminum rod and the centre post racked up or down until the spirit bubble is centred. The top of the next rod on the profile is then sighted from this setup and the clinometer brought on target by means of the tangent screw. The vertical angle is then read to the nearest one tenth of a degree, and entered in the fieldbook. This is done at each profile station until the one at the top of the swash zone is reached. Here the instrument is set up as before and the most seaward station is placed and chained as the backwash recedes. The point in the swash zone that is chosen for placement of the final station usually depends not only upon how well the rod will stand up in the saturated sediment, and the speed with which the operator can return and read the vertical angle, but also to some extent upon his fear of annihilation from the next oncoming wave. Plate 2:1 shows the instrument in use.

This completes the actual surveying of the profile, and all that remains on the fourth and final leg is to pick up the equipment. The field notes contain vertical angles and slope distances between each pair of numbered stations. These represent one angle and the hypotenuse, respectively, of a series of right angled triangles. Because the aluminum rods are all the same length, are placed vertically, and the instrument readings

PLATE 2:1

are taken from their tops, the method eliminates one of the time-consuming steps in benchmark levelling, namely the necessity of calculating the height of instrument at each turning point. The horizontal distance between stations may easily be found by multiplying the slope distance by the cosine of the vertical angle, and the difference in elevation by multiplying the slope distance by the sine of the vertical angle.

The Accuracy of the Profiling Method

In most coastal work, beach profiles are surveyed with a telescopic level, employing either the stadia interval or a chain to obtain horizontal distances. Though not often quoted, the errors are well known[1] and lie well within the tolerance limits necessary for reliable beach profiling. As far as the author knows, no source exists which discusses the errors of the technique used in this study. Since the profile surveying is a means to an end, whereby among other things, volumetric gains and losses of sediment to the beach can be derived, it is crucial to ensure that the errors either in the methods used or in the equipment itself, are small in comparison

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[1]See for example, Kissam, P., 1956; p.16, p.253 ff.

with the changes in the beach profiles. This can only be done if the errors are known.

Errors in surveying technique can be grouped into three general classes. There are systematic errors, involving such things as errors in the instrument itself, bias in reading the instrument, and errors caused by parallax. There are accidental errors which obey the laws of chance and are related to the physical capabilities of the instrument or the operator. They are normally distributed and tend to be self-cancelling. Finally, there are blunders or mistakes either in the calculation of field notes or in direct observation, as, for example, when a "3" is read for an "8".

Systematic errors, once they are discovered, can be eliminated by applying a correction factor to the final reading. The instrumental error in the clinometer was found by halving the difference obtained between two reversed readings. A correction factor of + 0.5 degrees was added to each reading taken in the field. The parallax in sighting the target was reduced by using one eye instead of two. With practice this was found to be just as fast as the more usual method of using two eyes. Bias in reading the angle was avoided by ensuring that whenever a reading was taken, the cross-hair was in the centre of the ocular.

Accidental errors were derived empirically by comparing individual readings obtained with the clinometer, estimated to 0.1 of a degree, to the same readings taken through a theodolite. The maximum difference in these readings was 0.2 of a degree. In addition to this angular error, there are two other possible sources of accidental error caused by the rods at each station being not quite vertical or having sunk slightly below the ground surface. On anything coarser than sand, there is no possibility of the rods sinking below the ground surface, but some care must be taken to keep them vertical. On sand, on the other hand, it is easy to keep the rods vertical, but because inter-granular space is small, percolation is less rapid than on coarser material, and low on the foreshore there may be only a short time after the passage of backwash when the ground is firm enough to support them without sinking. By taking care on coarse material, and being quick on fine, both these sources of accidental error were virtually eliminated.

For the purpose of testing the accuracy of the method, the maximum possible error that could be introduced from accidental sources was estimated to be equivalent to the displacement subtended by a vertical angle of 0.25 of a degree at the instrument.

Blunders can not be entirely eliminated from field procedures until such time as men become infallible, but with care their incidence can be reduced. In this study such care was taken.

It is all very well to specify the error existing in particular field methods but it is also necessary in most cases to express this figure in terms of the units that are ultimately used for analysis.

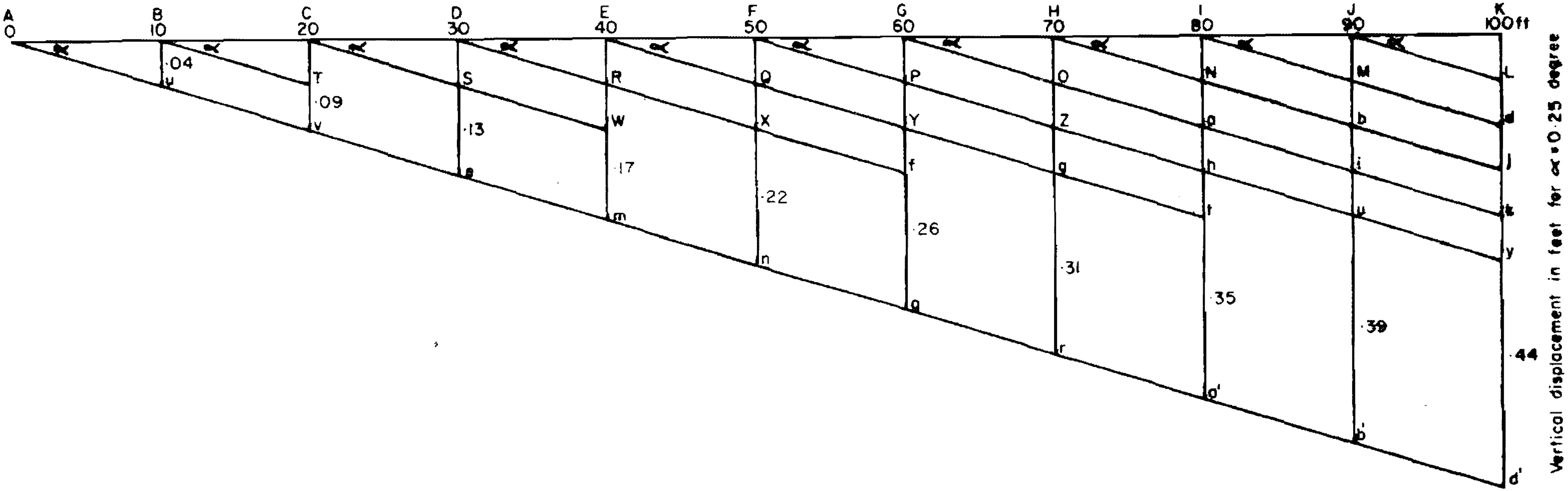
The survey data from the beach profiles is used in this study in two ways. First, the shore-normal movement of contours is plotted; second, changes in the profiles from day to day are translated into volumetric changes expressed in cubic feet of material per foot of shoreline length. With this in mind, it is important that the errors in the surveying procedure be related to the magnitude of errors that can be expected in both the numerical designation of the contour lines, and in the volumetric estimates. The error determination in the contours will be discussed first.

This involves some complications. Since the calculated elevation of each instrument set-up relies upon measurements made at all previous stations, the total error in elevation at the end of a profile depends upon (a), the cumulative effect of the error in each angular measurement, and (b), the total profile length. For the first of these, the assumption will be made that the maximum angular error, that is 0.25 of a degree, is made at each station. Furthermore, it shall be specified that in no case is this error to be compensatory. In other words, it shall be a constant error of either plus 0.25 of a degree, or minus 0.25 of a degree. This reduces the number of constituent variables in the error determination to one, namely the profile length.

The situation may be shown diagrammatically for station spacings from ten to one hundred feet at ten foot intervals. Figure 2:1 illustrates an idealized example of a profile with a horizontal length of one hundred feet.

In this example an error of 0.25 degrees will result in elevation errors of 0.04, 0.09, 0.13, ... 0.44 feet at 10.0, 20.0, 30.0, ... 100.0 feet respectively, from the instrument. As far as the total error in the whole profile is concerned, it is noteworthy that the number

FIG. 2:1


A 0
B 10
C 20
D 30
E 40
F 50
G 60
H 70
I 80
J 90
K 100ft
·04
·09
·13
·17
·22
·26
·31
·35
·39
·44
Vertical displacement in feet for α = 0·25 degree

of stations in the profile is irrelevant. This is true because the error in elevation is a linear function of the distance from the station hub. For example, if there are only two stations in the profile, its cross section is represented by Ad'K, and the total error in elevation is 0.44 feet. If, on the other hand, the profile is measured in four shots, with stations at 0.0, 20.0, 30.0, 50.0, and 100.0 feet the four respective cross sections are AvC, CSD, DXF, and FyK. The elevation errors in each of these are: Cv = 0.09 feet, DS = Bu = 0.04 feet, FX = Cv = 0.09 feet, and Ky = Fn = 0.22 feet. Their sum is 0.44 feet, equal to the total error with only two stations in the profile.

The maximum error in the elevations shown by the contours can now be specified. It is defined by the line Ad', and the vertical displacements in feet represent the maximum error that can occur at successive distances of ten feet from where the profile is started. The maximum positional error in feet, for $\alpha = 0.25$ degrees, is given by:

$$y = 0.0044x \qquad (1)$$

where y is the maximum vertical error in feet, of the numerical value of a contour line, and x is the total horizontal distance of the profile in feet.

The maximum error in the volumetric estimates is similarly derived except that the error is a more complex function of the distance from the station hub. Figure 2:2 is an analogue of Figure 2:1, but because volumetric estimates are involved, the error functions are non-linear, and the total error depends upon the number of stations in the profile. For a given angular error, the volumetric error accumulates along the profile as a function of the profile length. The error in the general case is given by:

$$y' = x^2 \tan\alpha/2$$

where y' is the maximum volumetric error in cubic feet per foot of shoreline, x is the total horizontal distance of the profile in feet, and α is the angular error in sighting the instrument. For $\alpha = 0.25$ of a degree, this reduces to:

$$y' = 0.00218x^2 \qquad (2)$$

Each of the curves shows how volumetric error accumulates as calculated by equation (2)

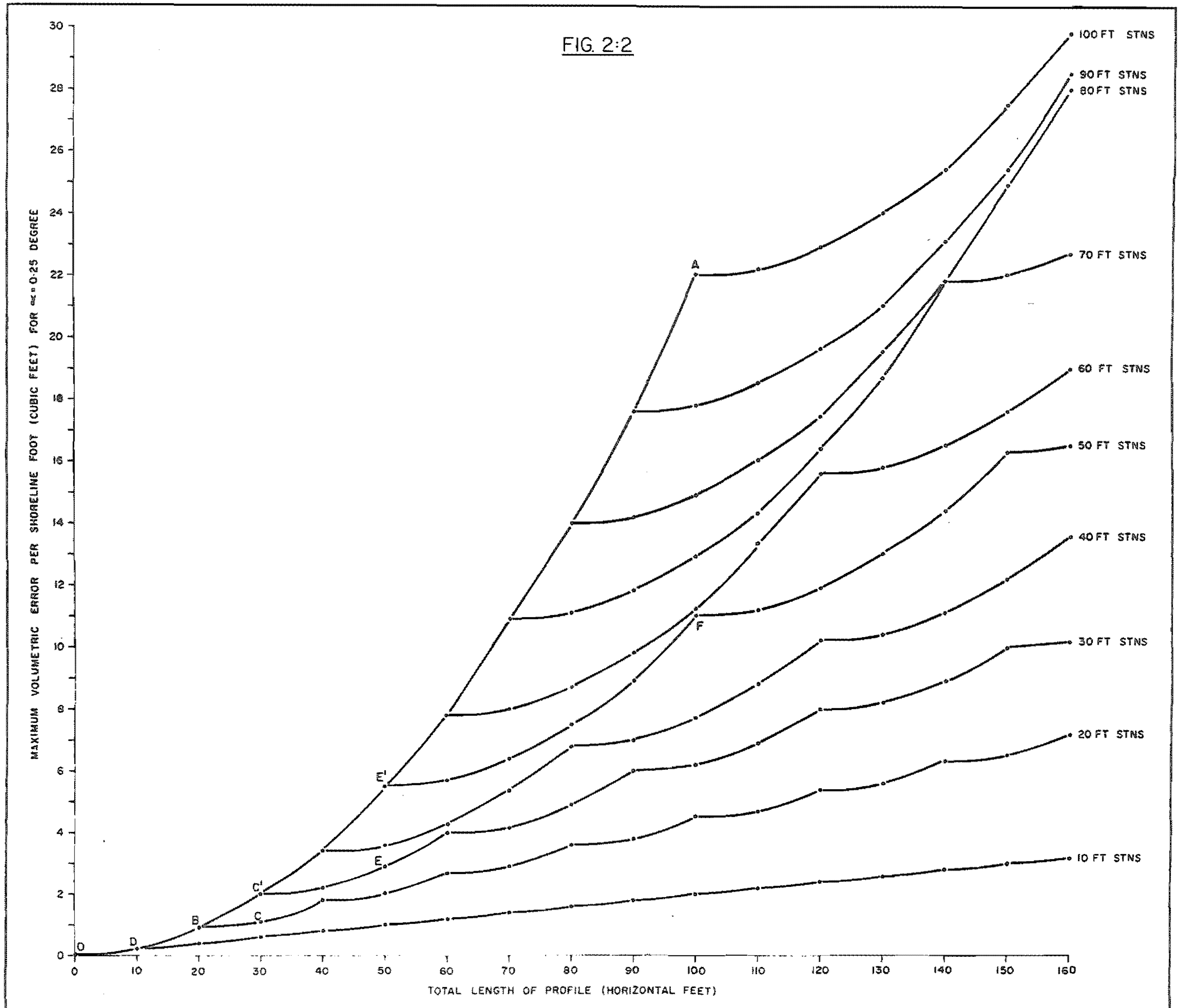


FIG. 2:2
MAXIMUM VOLUMETRIC ERROR PER SHORELINE FOOT (CUBIC FEET) FOR α = 0·25 DEGREE
TOTAL LENGTH OF PROFILE (HORIZONTAL FEET)
100 FT STNS
90 FT STNS
80 FT STNS
70 FT STNS
60 FT STNS
50 FT STNS
40 FT STNS
30 FT STNS
20 FT STNS
10 FT STNS
A
B
C
C'
D
E
E'
F
O
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

for successive ten foot station spacings up to a total profile length of one hundred and sixty feet. In practice, however, breaks in slope are rarely, if ever evenly spaced, and since the total error depends on the station spacing, (unlike the example of Figure 2:1), no single curve in Figure 2:2 shows the error accumulation along an actual beach profile. The total volumetric error depends upon the cumulative effect of three things: the error in the measurement of the angle, the distance between stations, and the total profile length. Thus, to take the same two examples as before, that is, a profile that is surveyed in one shot from zero to one hundred feet, and the same profile surveyed in four shots, with stations at 0.0, 20.0, 30.0, 50.0, and 100.0 feet, the following volumetric errors will result.

OA represents the total volumetric error in the first case. It amounts to 21.8 cubic feet, and is equivalent to the area of AKd' (Figure 2:1) multiplied by one foot of shoreline length. In the second case, where five stations are used, the error increases along OB for the first shot, and this amounts to 0.9 cubic feet. For the second shot, the error increases along BC = OD, and amounts to 0.2 cubic feet. On the third shot, error increases along C'E = OB, and is 0.9

cubic feet. On the fourth and final shot, from 50.0 to 100.0 feet, the error increases along E'F = OE', and this adds a further 5.5 cubic feet. The sum of these incremental errors is 7.5 cubic feet, and this is the maximum amount of error present in the volumetric estimate. Compared to the 21.8 cubic foot error allowed by the previous method, it is very much less.

It is self-evident that in terms of practical field procedure, in studies where the vertical displacement of a target, or the position of its intersect with a horizontal datum, is the main concern, the greatest accuracy will be achieved by using as few stations as possible. Where volumetric changes are important, greater accuracy will result from the use of many stations in the profile.

The maximum extent to which these errors influence the position of contours on the foreshore and the volumetric figures at each of the stations, is given in Table 2:1. The maximum error figures for the contour lines were calculated directly from Equation (1), and those for the volumetric estimates taken from the appropriate curves of Figure 2:2.

It is worth drawing attention to the fact that the errors listed in the table should be

TABLE 2:1

MAXIMUM ERRORS IN CONTOUR LINES AND VOLUMETRIC ESTIMATES ATTRIBUTABLE TO THE SURVEYING METHOD AT EACH PROFILE SITE

Profile	CC	F	AA	BB
Mean horizontal distance of surveyed profiles (feet)	162.6	74.3	67.4	43.0
Maximum error in contour line (feet)	± 0.72	± 0.33	± 0.30	± 0.19
Estimated mean inter-station distance (feet)	35	20	10	20
Maximum error in volumetric estimate (cubic feet/shoreline foot)	± 12.0	± 3.2	± 1.2	± 1.8

regarded in the light of the actual textural characteristics of the foreshore on which the profile was measured. For volume, for instance, the most reliable figures are those for AA. The next most reliable are those at BB and F, and CC has the least reliable figures. In practice, however, because the foreshore at AA is usually composed of boulders, the decision of where the surface lies is somewhat subjective and therefore, although the surveying method allows for a high degree of accuracy at this station, the texture of the foreshore mitigates against it. In the case of CC, the foreshore is fine textured and the beach surface can be more accurately specified. So in spite of its length, the actual errors at CC are likely to be less than the maximum values shown in the table, and those at AA, more.

Most importantly, it will be recalled that most of the errors are accidental, and not systematic. They are normally distributed, and all errors for a given profile length, in theory, fall within the limits, either plus or minus, of the maximum error limits given in Table 2:1. The tabled values can therefore be thought of as the values occurring at the tails of a normal distribution, either side of the mean or true value.

The probable error, (the value for which the chances of obtaining a larger accidental error are equal to the chances of obtaining a smaller one), that occurs on any single profile, is impossible to specify at this stage, because the standard deviation of the curve is not known. Nor can it be derived theoretically. It could be found empirically with thirty or more repeated surveys at each station-spacing from ten to one hundred feet, but this was not done. The point here is, that because accidental errors tend to be self-cancelling, the errors in the field method are likely to be substantially less than the values given in Table 2:1.

The equipment and procedures just described are not meant to replace standard benchmark levelling techniques. The methods used in this study are more specialized. It is suggested, however, that they offer considerable advantages where a number of profiles need to be surveyed in a short time with limited personnel. The technique is very well suited either to profiling of a reconnaissance nature, or, as in this study, the collection of a relatively long-term record of topographic change. Although developed for coastal work, its use is by no means restricted to this field. The basic principles can be applied in many areas of geomorphology especially where large scale, and rapid changes in configuration take place. Studies involving the transport and modification of surficial sediments come most easily to mind. The speed and ease with which cross sections could be measured on solifluction lobes, braided river channels, and the like, means that reliable, quantitative data could be gathered more frequently than would otherwise be possible with more sophisticated equipment.

As far as coastal work is concerned, the method is especially applicable to high energy coasts, or on foreshores that have coarse textures. Inasmuch as these two are usually associated, the method should have wide application. There seems to be little point in paying in time, money, effort, and manpower by using a level and rod, and reading to the usual 0.01 foot when the diameters of individual pebbles on the foreshore are ten times this amount.

The instrument has been designed to accomodate both a compass and a clinometer, and the investigator hopes at a later date to extend the methods described here to include surveys involving horizontal as well as vertical control. For the present, the equipment and techniques developed for this study fill a long-neglected gap in field methodology between the hand level and benchmark levelling procedures.

An Operational Definition of "Foreshore" and "Foreshore Slope"

The foreshore is usually defined as that part of the coast that lies between low tide and high tide levels (Bird, 1968; American Geological Institute, 1966). There is no precise definition of the term however,[1] and writers have tended to use it both loosely to refer to the portion of the shore that undergoes wave action, and more specifically as needed. One of the response variables in this study is "foreshore slope". It is appropriate to define this variable and to discuss how it was measured.

During the initial stages of the work, the slope of the foreshore was measured at that point on the beach estimated to have undergone wave action at mid-tide. This method was used by Bascom on the beach at Halfmoon Bay, California (Bascom, 1951). He advocated the use of a "reference point" located midway between mean highest high water and mean lowest low water for taking samples of foreshore slope and sand. Of the

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[1] cf. Shepard, F.P., 1948; p.82.

beaches around the Hapuku delta, only one, CC, is normally composed of sand-sized sediment. On this profile, the reference point can probably be located to within eight or ten feet of horizontal distance, and the slope measurement taken with an Abney level mounted on a short stick to minimize local slope variations. This is not true at the other stations, especially those composed of coarser materials. At F and BB the foreshores are steeper and more concave than at CC and consequently an eight or ten foot margin of error in locating mid-tide elevation introduces too much inaccuracy into the measurement. In addition, these beaches are often occupied by cusps. An error of a foot or less in selecting the reference point can mean slope readings differing by as much as five degrees. At AA, another problem exists because the foreshore is composed almost entirely of boulders a foot or more in diameter. Trying to get a slope measurement on this material with "an Abney mounted on a short stick" is both ineffectual and stupid.

Still, it was felt that attempts to evaluate processes and responses without including foreshore slope would be inadequate.

It was finally decided to calculate fore-slope from the ratio of the horizontal distance on the beach considered to be affected by wave action, to the corresponding vertical distance. This ratio is the cotangent of the slope angle, α.

The tide gauge located at the New Wharf in Kaikoura was operating long enough for elevations to be established for mid-tide and high and low springs. The mid-tide elevation, corrected to survey datum, is 26.00 feet and the intersection of this elevation with the ground surface may be regarded as the position of the shoreline. The elevation of mean high water spring tides is 2.35 feet above this and mean low water springs, 2.35 feet below. Swash and backwash were each estimated to operate over an additional two feet of vertical height. The total vertical distance defined as the "foreshore" for purposes of measuring foreshore slope, was thus delimited. Its upper limit is 30.4 feet in elevation, its lower limit is 21.6 feet in elevation. The horizontal distance between these elevations was measured from each plotted profile, and using cotangent tables, "foreshore slope" was calculated to the nearest tenth of a degree.

<u>Textural Classification</u>

Beach sediments have long been recognized as being relatively well sorted when compared with other subaerial sediments. The mechanism by which the sorting takes place has been explored by several researchers, (see Eagleson, et al., 1961; Miller and Zeigler, 1958; Ippen and Eagleson, 1955). But it is not the purpose of this study to explore the flow regimes responsible for sorting on the Kaikoura beaches. This has been investigated by Kirk (1970). The fact that well sorted sediments over a wide range of sizes are present on the foreshore suggested that field identification of textural categories was a feasible method of documenting textural change and relating it to gross changes in wave action, and so a system of classification was devised and used each time a profile was surveyed.

It is easy to set up a classification scheme. It is less easy to construct one that has just enough taxonomic complexity to effectively separate real differences in individual samples without involving too much subjectivity in the decision, and just enough simplicity to allow ease of use consistent with preventing the inclusion of samples of different characteristics in the same category. If the classification scheme is too complex, differences between categories will be more apparent than real; if oversimplified, they will be more real than apparent. In addition to these requirements, of course, the scheme must be problem-directed.

There are four main sizes of sediment present on the beaches of the Hapuku Delta. In the present discussion they may be loosely referred to as boulders, cobbles, pebbles, and sand. Furthermore, these constituents are present on all the profiled beaches in the study area in varying proportions and may be easily identified, and so the same classification can be applied at all profile sites. Because of the good sorting, they tend to occur either as pure members, or as assemblages with their next coarsest or next finest neighbour. On the foreshore, material consisting of widely varying size composition is rare, in contrast to the backshore deposits which are often poorly sorted. On the basis of the relative proportions of each of the four textural members, sixteen classes were established, ranging in size from boulders through to sand. They are subdivided into four tiers or sub-classes with the first named constituent being dominant. In order of increasing fineness, the boulder tier consists of: boulders, boulders-cobbles, boulders-pebbles, and boulders-sand; the cobble tier: cobbles-boulders, cobbles,

cobbles-pebbles, and cobbles-sand; the pebble tier: pebbles-boulders, pebbles-cobbles, pebbles, and pebbles-sand; the sand tier: sand-boulders, sand-cobbles, sand-pebbles, and sand.[1] As previously described, field notes were taken on the fourth leg of each profile traverse, and these specified both the textural categories of each part of the profile and their location relative to the profile stations. Later, when the profile was plotted, the textures were recorded as well.

There is little doubt that for the Hapuku Delta, the scheme fulfills its design requirements. From day to day quite obvious changes take place in foreshore texture, and the classification is a sensitive qualitative measure of those changes. Categorization by visual estimation in no way detracts from its usefulness, nor does the fact that the scale only achieves ordinality. In the physical sciences, visual estimation has been used by Folk to specify the size category of clastic rocks (Folk, 1954), and Moh's scale of hardness which is universally

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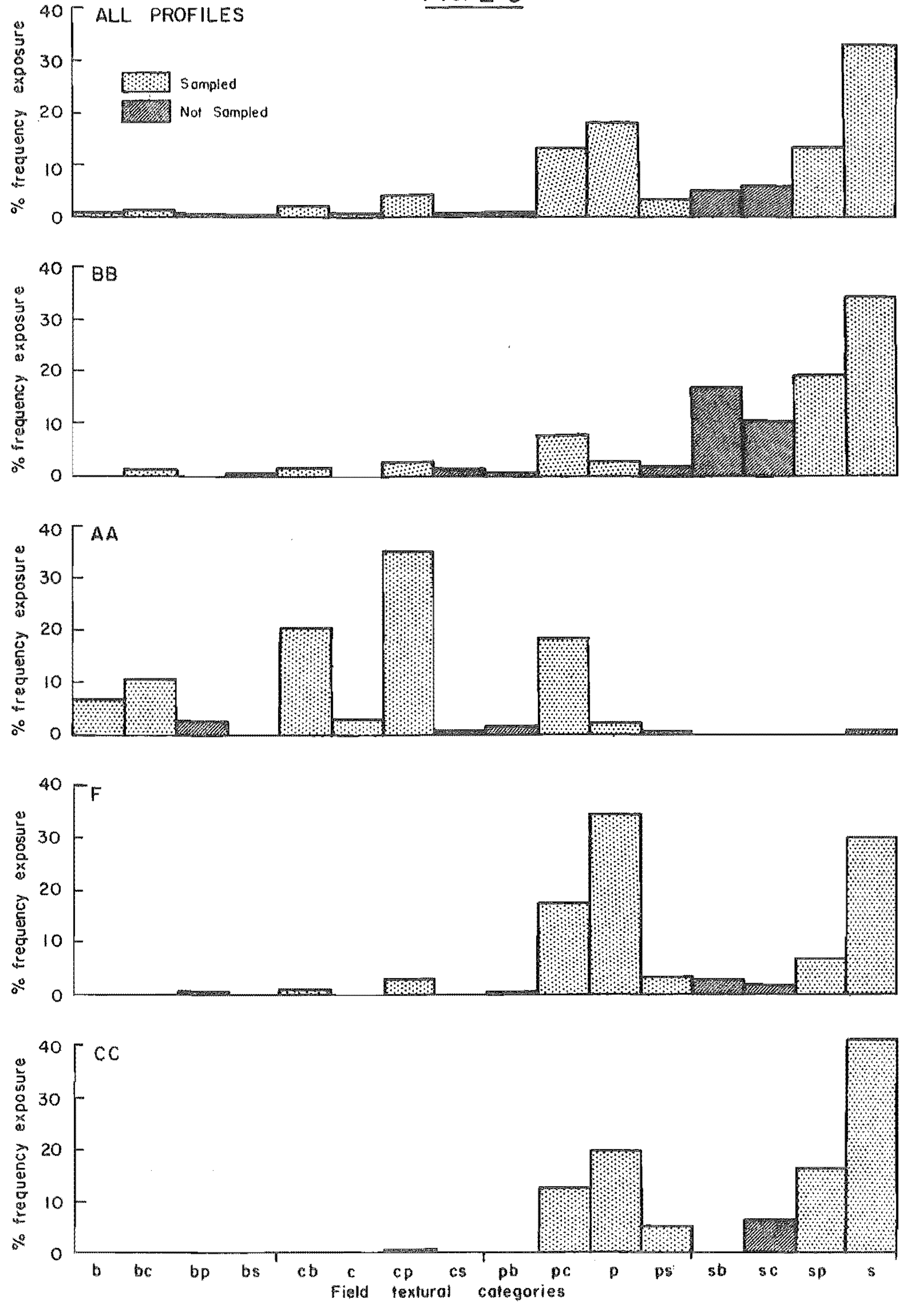
[1]It should be emphasized that the grain-size terminology used here was specifically devised for the field identification of the Hapuku beach sediments. The terms are not synonymous with standard size grades.

used is an ordinal scale. These measures are more suited to description than to quantitative analysis though, and since the approach in this thesis is to quantitatively relate various process values to certain response values, a means was sought whereby the sixteen textural categories could be assigned numerical indices.

As a starting point, the data set consisting of all the profiles surveyed during the year was used and the horizontal exposure of each sediment class on each of the profiles was measured. These were tabulated and the exposure of each class was expressed as a per cent of the total foreshore exposure for the year. This was done for all the profile sites, and then for each of the sites individually. The results are shown in Figure 2:3. The stipled bars refer to material that was sampled directly, the cross-hatched bars, to material that was identified on the beach, but for reasons that will become clear in the following discussion, was not sampled. A sampling program was envisioned that would measure the size characteristics of each of the textural categories. Implementing such a program involved sampling representative examples of each of the sixteen classes in the field. Since the texture of the beach surface was to be mea-

FIG. 2:3


ALL PROFILES
Sampled
Not Sampled
BB
AA
F
CC
% frequency exposure
40
30
20
10
0
b
bc
bp
bs
cb
c
cp
cs
pb
pc
p
ps
sb
sc
sp
s
Field textural categories

sured, the samples were taken areally rather than volumetrically, and an attempt was made to keep the method consistent. This proved to be difficult mainly because there were three kinds of samples to treat, each of which, in terms of the practical difficulties involved in obtaining a representative sample, presented a different problem. The three kinds of samples were:

a) material coarser than pebbles-sand and composed either of a pure textural member or a textural member and its next coarser or finer neighbour. Seven of the sixteen classes are included in this group, namely: boulders, boulders-cobbles, cobbles-boulders, cobbles, cobbles-pebbles, pebbles-cobbles, and pebbles.
b) pebbles-sand, sand-pebbles, and sand.
c) materials of any size class composed of constituents whose sizes differed by more than one textural member. Six classes are included in this group, namely: boulders-pebbles, boulders-sand, cobbles-sand, pebbles-boulders, sand-boulders, and sand-cobbles.

Because of the wide range of sizes, no

single sampling method is applicable to all three cases above. It is as impractical to measure sand and smaller sized grains individually as it is impossible to seive boulders. Two different sampling methods were used.

The material in group (a) above was sampled by direct measurement in the field. In order to make the sample for each size category as universally applicable to all profiles as possible, the sample for any one size category was taken as a composite of individual measurements taken at all profiles on which that size category occurred. The total number of grains measured at each profile site was in proportion to the per cent frequency occurrence at all sites for that size category.[1] Implicit in the size classification is the assumption that each of sixteen classes can be readily identified _in situ_, and typical examples of most of the classes can be found on any given day on one or other of the profile sites. Several trips were made into the field and a number of grains were selected for measurement from typical examples at each profile of

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[1]Thus at profile F (see Figure 2:3), the greatest number of cobbles-pebbles in the composite sample was measured at AA, and the least at CC.

each of the seven classes. This was continued until two hundred grains had been measured for each class. A total of 1,400 measurements of the diameter of the intermediate axis of each grain was thus accumulated. The actual measurement of the grains was done in millimetres using a metre stick for larger cobbles and boulders, and a vernier calipers for the smaller cobbles and pebbles. Selection of the grains to be measured was randomized as much as possible by lowering the stick, without looking, towards the ground. The first grain that it touched was selected for measurement. These size ranges are often present as a fairly thin veneer, deposited (or left as a lag deposit) over a horizon or coarser or finer grains, and so to avoid taking a volumetric sample, selection was done with replacement. The intermediate axis diameters in millimetres, were later converted to phi-units by means of a phi-millimetre conversion table (Page, 1955), and for the larger sizes (>100.0 mm), a graph constructed by the writer. Mean phi and sigma phi values were then calculated by the method of moments (Folk, 1968), by computer.

The material in group (b) compelled a different sampling approach. Whereas typical examples of the larger size categories are easy to identify, those in the smaller size categories, by virtue of their small size, are not. A visual assessment of the relative similarity between cobbles, or pebbles, or boulders, at different sites is fairly straight-forward. With sand-sized material, it is more difficult. For this reason visual identification of typical size categories was not relied upon for the sand sizes, and instead, separate bulk samples were taken at each of the four profile sites for pebbles-sand, sand-pebbles, and sand.[1] As with the larger sizes, an attempt was made to minimize the effect of grain peculiarities related to the foreshore where they were sampled. This was done by taking a very shallow channel-sample of the surface layer of the foreshore in the plane of the profile. These samples were sieved at half-phi intervals, for fifteen minutes on an Endecott sieve shaker, and mean phi diameter and sigma phi values were calculated from the weight percentages of each fraction.

The material in group (c) is characterized

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[1]Pebbles-sand is relatively rare on most profiles (see Figure 2:3), and a composite sample was taken from CC, F, and AA. Sand-pebbles and sand, on the other hand were sampled individually at CC, F, and BB.

by extreme size bimodality. In the writer's opinion, sampling it presents insurmountable difficulties if the sample is expected to contribute worthwhile results consistent with the other sampled classes. Sieving is impractical because of the large size of one of the constituents. Individual measurement, likewise, is unfeasible for the smaller grains. A combination of sieving and individual measurement is possible, but because of scale problems, the definition of what constitutes a surface sample becomes blurred, and an attempt to sample the small grains under the same conditions as the large would mean taking volumetric samples of the smaller sizes. In addition, to be representative of the proportion of large to small grains, the sample would have to be very large. It is also possible to sample these categories indirectly by photographic means (Iriondo, 1972), but here too, it is doubtful whether the results would be consistent with those categories sampled directly. The final decision was to fit curves to the relationship between the field classification and the mean phi values calculated from direct sampling, and to derive the sizes of the remaining six classes in group (c) above, by interpolation.

The computed values for mean phi diameter and sigma phi, for each of the ten classes is shown in Table 2:1. The plot of the field classification against the calculated values of mean phi diameter is shown in Figure 2:4. One standard deviation (sigma phi), is also shown either side of the mean for each sample. For the sand and sand-pebble classes, individual samples were taken at each profile station, (except at AA, where sand occurs on the foreshore only 0.4 per cent of the time) and the curves are fitted to allow for the mean phi differences in these classes at each station. The data sets used for each station are identical for all categories from boulders to pebbles-sand. The mean phi values for sand-pebbles and sand however, were substituted for the stations concerned, and the three most significant regression lines were plotted. They are all significant at the 0.01 level and the per cent explained variation is given in brackets, along with the standard error of the estimate. The equations were used to predict adjusted mean phi-equivalent values for each of the field classes at each station, and these are shown in Table 2:3.

This classification scheme was developed so that a realistic quantitative measure of foreshore texture could be used as one of the response variables. No classification scheme is perfect,

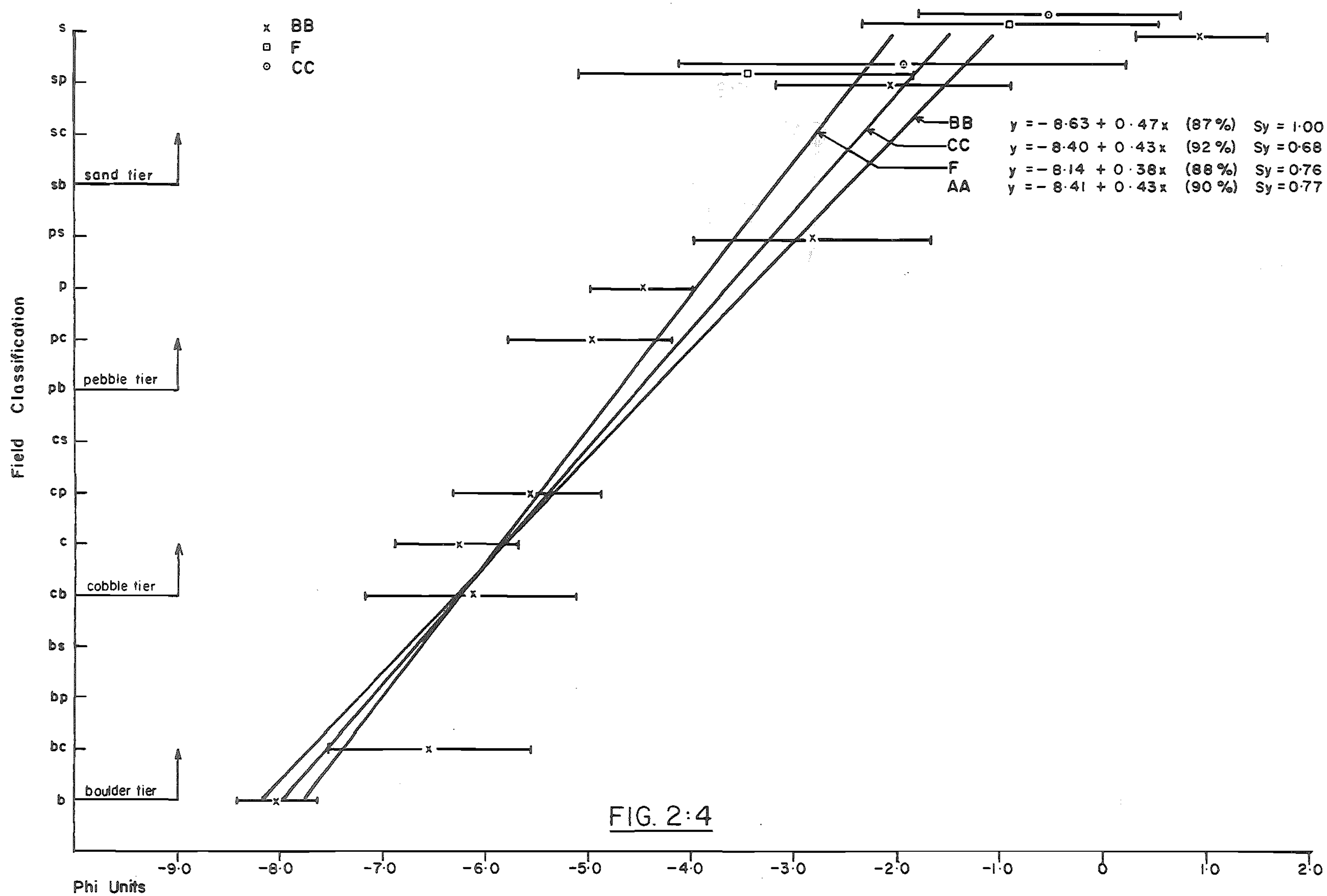
x BB
□ F
⊙ CC
BB y = − 8·63 + 0·47x (87%) Sy = 1·00
CC y = − 8·40 + 0·43x (92%) Sy = 0·68
F y = − 8·14 + 0·38x (88%) Sy = 0·76
AA y = − 8·41 + 0·43x (90%) Sy = 0·77
Field Classification
s
sp
sc
sb
sand tier
ps
p
pc
pb
pebble tier
cs
cp
c
cb
cobble tier
bs
bp
bc
b
boulder tier
Phi Units
-9·0
-8·0
-7·0
-6·0
-5·0
-4·0
-3·0
-2·0
-1·0
0
1·0
2·0

FIG. 2:4

TABLE 2:2

MEAN PHI DIAMETER AND PHI STANDARD DEVIATION FOR SAMPLED FORESHORE SEDIMENTS

TEXTURE	MEAN PHI DIAMETER (Mϕ)	PHI STANDARD DEVIATION ($\sigma\phi$)
B O U L D E R T I E R		
boulders	-8.02	0.40
boulders-cobbles	-6.55	0.97
boulders-pebbles		
boulders-sand		
C O B B L E T I E R		
cobbles-boulders	-6.14	1.02
cobbles	-6.28	0.60
cobbles-pebbles	-5.58	0.71
cobbles-sand		
P E B B L E T I E R		
pebbles-boulders		
pebbles-cobbles	-4.98	0.80
pebbles	-4.47	0.50
pebbles-sand	-2.83	1.17

S A N D   T I E R

TEXTURE	MEAN PHI DIAMETER (Mϕ) CC	F	BB	PHI STANDARD DEVIATION ($\sigma\phi$) CC	F	BB
sand-boulders						
sand-cobbles						
sand-pebbles	-1.96	-3.48	-2.08	2.20	1.63	1.15
sand	-0.56	-0.92	0.93	1.29	1.47	0.64

TABLE 2:3

ADJUSTED MEAN PHI-EQUIVALENT DIAMETERS FOR EACH FIELD TEXTURAL CLASS

FIELD TEXTURE	ADJUSTED MEAN PHI-EQUIVALENTS			
	CC	F	AA	BB
B O U L D E R T I E R				
boulders	-7.97	-7.76	-7.98	-8.16
boulders-cobbles	-7.54	-7.38	-7.55	-7.69
boulders-pebbles	-7.11	-7.00	-7.12	-7.22
boulders-sand	-6.68	-6.62	-6.69	-6.95
C O B B L E T I E R				
cobbles-boulders	-6.25	-6.24	-6.26	-6.28
cobbles	-5.82	-5.86	-5.83	-5.81
cobbles-pebbles	-5.39	-5.48	-5.40	-5.34
cobbles-sand	-4.96	-5.10	-4.97	-4.87
P E B B L E T I E R				
pebbles-boulders	-4.53	-4.72	-4.54	-4.40
pebbles-cobbles	-4.10	-4.34	-4.11	-3.93
pebbles	-3.67	-3.96	-3.68	-3.46
pebbles-sand	-3.24	-3.58	-3.25	-2.99
S A N D T I E R				
sand-boulders	-2.81	-3.20	-2.82	-2.52
sand-cobbles	-2.38	-2.82	-2.39	-2.05
sand-pebbles	-1.95	-2.44	-1.96	-1.58
sand	-1.52	-2.06	-1.53	-1.11

and this one is no exception. Its two main weaknesses are that it has no provision for the occurrence of grains of granule size, and that direct measurement was not made of the six categories composed of very different grain sizes. Granules do occur on the beaches; most frequently at CC. They were not included in the classification scheme because to do so would have resulted in a system with five end-members and this was judged to be erring on the side of unwarranted complexity in view of the added information it would have given. As for the second shortcoming, it was thought at first that the inability to effectively sample six of the classes (equivalent to thirty-eight per cent of the classification) would render any conclusions based on interpolated values largely conjectural. However, the point has already been made that these six classes do not occur as commonly as most of the other textural categories (Figure 2:3). In terms of per cent frequency exposure, they represent eleven per cent of the total foreshore exposure at all profiles except BB. The likelihood then, that aberrant phi-equivalent values derived by interpolation for these classes will lead to significantly large misinterpretations of foreshore textural change, is slight at all profiles except

BB, where the classification should be used cautiously.

An Operational Definition of "Foreshore Texture"

With "foreshore" defined, and a textural classification scheme that has close quantitative relevance to the sediments on the beaches, attention can now be directed to the method that was used for calculating an index of foreshore texture. The foreshore textural index is given by:

$$\mathcal{T}_{fs} = \sum(M\phi \text{ equiv.}(H.D.))/\sum(H.D.)$$

where: $\mathcal{T}_{fs}$ is the daily index of foreshore texture in phi units,

$M\phi$ equiv. is the mean phi-equivalent diameter given in Table 2:3, of each of the textural classes represented on the foreshore for that particular day,

and H.D. is the horizontal exposure in feet of each of the textural classes represented.

Appendix 2:1 summarizes the daily foreshore slope and textural data at each profile, as well as giving the mean monthly values of slope and texture.

Cusps

Cusps are frequent coastal features on the delta. It was hoped that a rigorous classification scheme could be implemented in much the same way as for texture. Several approaches were tried and eventually discarded, either because the individual taxons did not sufficiently differentiate between cusps of various sizes and at different stages of development, or because a comprehensive description became too time-consuming to carry out and too multi-dimensional to be practical.

The best system, consistent with time available and usefulness, was one that classified the cusps in relation to their "degree of development". Six classes were used: undeveloped (i.e. no cusps present), very poorly developed, poorly developed, moderately developed, well developed, and very well developed. Precise definitions can not be given for each of these. The decision as to which class a particular cuspate form was assigned, depended primarily upon its relief. Thus, well developed cusps were those with high relief and poorly developed ones those with low relief.

The system strives to be universally applicable over the whole study area so that inter-profile as well as intra-profile comparisons could be made, and it succeeds at the expense of obscuring small but perhaps significant changes in cusp form at some of the stations. The foreshore at CC for instance, seldom achieved a rating above "poor". At F, the cusps were often "well" or "very well" developed. But the foreshore at CC is composed of much finer material than that at F, the cusps are more widely spaced, and if a datum plane for the "normal" foreshore could be defined, the volume of material in individual cusps at CC would probably far surpass that at F. It is therefore possible to argue that a change at CC, from say, "very poor" to "poor" is more significant in terms of foreshore dynamics, than a change at F from "very poor" to "well".

Exploration of cusp behaviour is an appealing avenue of research. To do it justice though, more detailed measurements than have been done in this study would be necessary. For comprehensively describing cuspate forms, the six classes are inadequate. They have one advantage over a classification consisting of merely "cusps present" or "cusps absent" in that they do differentiate between incipient cusps and ones that are more "mature", but as a diagnostic tool, the classification leaves something to be desired because it does not distinguish between cusps that are just forming, and ones that are in the last stages of decay. In spite of its weaknesses though, it does provide an expedient framework within which recognizable beach responses can be compartmentalized.

Accretion and Erosion of Beach Profiles

Repeated surveys of the beach profiles at the four selected profile sites, served for subsequent calculations of how much material was gained or lost in the period between surveys. Superimposing successive profiles allowed areal change to be measured with a planimeter, as that area bounded by the two profiles and the twenty-one foot elevation plane. This was converted to a volumetric measure of cubic feet of material either gained (+), or lost (-), to the beach per linear shoreline foot. Sediment textures, the classification of which has already been discussed, were also plotted on each profile.

Offshore Sounding and Sampling

The physical changes that take place on the coast are not confined to the subaerial beach.

Changes also take place in the offshore zone and the zone of breaking waves. In the context of this study, the definitive explanation of coastal change would require simultaneous data collection from all three zones. As this was not possible, the study has been confined for the most part, to the exposed shore above low tide. However, to provide additional data pertinent to the study, a program of offshore sampling and sounding was undertaken with the generous cooperation of one of the local fishermen. Offshore depths were taken with an echo sounder and thirteen bottom sediment samples collected using a sampling dredge provided by the New Zealand Oceanographic Institute. The offshore depths and sample positions are shown in Figure 2:4. The samples were sieved at half-phi intervals, and the results appear in Appendix 4:4.

Aerial Photography

Neither daily nor net coastline change over a period of one year can be expected to be representative of the long term trend. Some clues can be had of the relative permanence of this portion of coast from intuitive familiarity with the processes and responses gained during various stages of fieldwork. Subsequent analysis either confirms or denies these impressions, but additional useful information can be gained if some first hand evidence can be gathered over a relatively long time period.

The most recent aerial photos of the complete section of coast covered in the study, at a large enough scale to permit shoreline position to be accurately compared with the present position of the shoreline, are those commissioned by the New Zealand Department of Lands and Survey, and flown on December 10, 1942. A thirty year time period is a better basis upon which to assess long term coastal change than is one year's field observations, and so an aircraft was hired, and a continuous set of vertical airphotos of the coastal strip was taken by the writer. A comparison between the configuration of the entire coastline of the study area in 1942 and its configuration in 1973 is shown in Plate 4:1. Elsewhere in the study, individual photos are used to illustrate specific points or direct attention to certain features apparent from the air but discernible only with difficulty from the ground.

Summary

The complex of survey stations to which all measurements are related has been described.

All stations are tied to the Marlborough Catchment Board benchmarks and this gives a zero elevation datum at 26.00 feet below mean sea level. The mean sea level elevation was taken from the tide gauge chart on the wharf at Kaikoura.

The method of measuring the wave variables was by visual estimation in the case of height and direction, and by means of a stopwatch in the case of wave period. Some of the limitations of these measurements have been briefly discussed.

The tactical approach to understanding the geomorphic changes in the area began with a program of large scale mapping, but this was discontinued.

Beach profiles contribute much of the data for the study, and because the technique for measuring them departs from traditional methods, it has been described in some detail. The method significantly increases the surveying accuracy normally obtainable from a hand-held clinometer. This increase is the result of improving the precision in using the instrument system and although some concession is made to the accuracy obtainable with level and rod, the techniques developed for this study offer five main advantages over other methods. These are:

1) Only one man is needed to take the

readings and record them.

2) The method is faster than benchmark levelling.

3) The instruments are both less costly, (especially in the case of a self-levelling level) and less cumbersome.

4) The methods and instrumentation are designed to be easily adaptable to surveys requiring horizontal as well as vertical control.

5) The instrument system is maintenance-free, and there is nothing to go out of adjustment.

The maximum error that can accumulate for a profile one hundred feet long, is 0.44 feet vertically in the two dimensional case, and twenty-two cubic feet for each foot of section in the three dimensional case. In practice, however, inaccuracies of this magnitude are rare because of the self-cancelling characteristics of accidental error. The error can also be minimized in the three dimensional case by using more, rather than fewer stations in the profile. The method is an important contribution to geomorphic field methodology.

Bascom's "reference point" cannot be used as a means for taking foreshore slope readings on the delta. Instead, the derivation of a numerical index of foreshore slope is used wherein "foreshore" is defined as that part of the beach lying between 30.4 feet in elevation and 21.6

feet in elevation.

A textural classification scheme has been outlined which consists of sixteen textural categories ranging in coarseness from boulders to sand. The rationale for using the scheme on the Hapuku Delta is that all four end-members can be easily identified visually, and occur at all profile sites. Graphs were constructed and they indicate which textures occur most frequently. A sampling program was based on the relative frequency of occurrence of each texture. Standard field and laboratory procedures were used to obtain size and sorting values for the samples and regression equations were plotted of field size class versus size of the directly measured samples. Adjusted size values for each of the field categories were then calculated.

The texture of the foreshore has been defined quantitatively as the weighted average of all the textural exposures that occur between the foreshore elevations on any particular profile. The weights assigned to each field classification are the phi-equivalent diameters derived from the regression equations.

A concept involving the "degree of development" was used in the field to classify cusps. Although not as explicit, and perhaps more subjective than might be wished, the classification is better than one that just records presence or absence of cusps. There are six classes of development ranging from an absence of cusps to very well developed cusps.

Gains and losses of beach deposits on each profile were measured by superimposing successive surveys and measuring the cross-sectional area with a planimeter. The equivalent volumetric figures are expressed in cubic feet per shoreline foot.

The last two research methods in the study are offshore sounding and sampling, and aerial photography. The first of these provides supplementary information related to the foreshore profiles and sediments, the second facilitates the recognition of gross physiographic features which would otherwise be difficult to identify on the ground, and by providing a long term measure of coastal change, lends an additional interpretive dimension to the study.

CHAPTER III

THE PROCESSES

This chapter examines the process variables that are used in the process-response model. Consideration is first directed towards obtaining a representative sample from the total data set that will describe the typical wave conditions over the period of the study year at each profile site. Next, the process variables are derived and quantitatively defined. A detailed description of the wave climate at each profile is given next, and the along-shore variation in the processes is also discussed. This is followed by an examination of the degree of functional relationship between pairs of process variables. Temporal variation in process intensity is also described, both from day to day, and from month to month throughout the year. Finally, the characteristics of the waves in the study area are set in context both with other New Zealand work and with studies done overseas. The chapter ends with a summary.

The Data Set for Describing Wave Characteristics for the Year

Appendix 3:1 lists all of the observations of both the process variables and the response variables for the period of the study year. A total of 619 process measurements were made, and 283 profile surveys were done to provide the response measurements. At CC, processes were measured on 154 days, and responses on 85 days. At F, the respective totals are 157 and 92; at AA, 154 and 29; and at BB, 154 and 78.

It is tempting to employ the frequency distribution of the total data set at each station as the best description of yearly wave conditions at that station. However, because short-term, day to day, variations are also of interest in this study, sampling was carried out more frequently during the latter part of the year than it was earlier. It is quite possible that the observations taken late in the year are unusual in some respect and therefore capable of introducing bias into the total sample simply because they are disproportionately represented.

One way of testing for this effect is to split the total sample into two sub-samples, one consisting of the observations from the 3/1 to the 8/8 (Appendix 3:1), and the other, (whose sample density with time is greater), from the 9/9 to the 30/11. These sub-samples can then be tested against each other to see if their distribution curves are similar enough to rule out a significant element of bias. If they are, then it is reasonable to use the total data set as being reasonably representative of the year's wave conditions. Alternatively, if it is found that there is a significant amount of bias present, then some other sample must be chosen as the best average indicator of the year's wave data.

The Chi-square test of two samples is usually used in situations like this, but here it is unsuitable because some of the wave-variable classes have no cases in them. Hence, for these, the expected frequencies can be zero, and Chi-square becomes both infinitely large and useless. The expedient of increasing the class interval between frequency classes to ensure that all of them have at least one observation, is self-defeating because it obscures some of the important dispersive characteristics, such as bimodality, that the data might otherwise show.

The Kolmogorov-Smirnov two-sample test provides a way around this difficulty.[1] The

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[1]See, for example, Miller, R.L., and Kahn, J.S., 1962; p.464.

test, in effect, superimposes the cumulative frequency distributions of each sample. If the sample distribution of one is similar to that of the other, then the two cumulative functions, F_1 and F_2, will also be similar. If they are different, then they will differ by an amount, Dn, which will vary from class to class depending upon their degree of dissimilarity. Calculated values of Dn are used as the K-S test statistic, and are tabulated for various sample sizes at different significance levels. The maximum deviation observed between F_1 and F_2, Dn(max), can be compared with these values of Dn, and if Dn(max) > Dn, then F_1 is considered to be significantly different than F_2.

The requirements of the test are that:

(a) the samples are random,

(b) the two samples are mutually independent,

(c) the measurement scale is at least ordinal,

(d) the random variables are continuous, rather than discrete.

The collected data of breaker height, period, and direction fulfil all of the above with the exception of (a), and in the case of wave height,[1] (d).

With respect to (a), although the sample data is systematic in the sense that measurements were taken each day at the time of low tide, their measurement relative to either a flood or an ebb tide state is more or less random. Therefore, any systematic bias (such as increased wave height during ebb tide), is unlikely to exist in the data. Because of this, the wave measurements are considered to closely approximate those of a random sample.

With respect to (d), it will be recalled from Chapter II that wave height was measured in half-foot categories, and is therefore a discrete variable, and according to most sources, not amenable to treatment by this test. Noether[2] has shown, however, that the Kolmogorov-Smirnov statistic is also valid in the discrete case as long as the stated level of significance is regarded as the maximum, rather than the exact, probability of committing a Type I error. The test is therefore valid but more conservative in the discrete case.

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[1]Because it is of major importance as one of the variables directly measured rather than derived, "wave height", unless otherwise specified refers to the height of the breakers (Hb) not to the deep water value (Ho).

[2]Noether, G.E., 1967; p.17.

The sample sizes of n_1 (the 3/1 to the 8/8), and n_2 (the 9/9 to the 30/11) are, respectively, 75 and 79[1] at CC, AA, and BB, and 78 and 79[1] at F. Use of the K-S statistic requires the calculation of $n = n_1 n_2 / n_1 + n_2$, and $Dn = \lambda/(n)^{1/2}$, where λ is a numerical value which depends upon the level of confidence being used.[2]

For CC, AA, and BB:

$$n = 75(79)/154 = 38.47$$

$$Dn_{.05} = 1.36/6.20 = 0.219$$

$$Dn_{.01} = 1.63/6.20 = 0.263$$

For F:

$$n = 78(79)/157 = 39.25$$

$$Dn_{.05} = 1.36/6.26 = 0.217$$

$$Dn_{.01} = 1.63/6.26 = 0.260$$

Table 3:1 shows the values for Dn(max) and the critical Dn values at ninety-five and ninety-nine per cent significance for breaker height, wave period, and direction at each of the four

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[1]There are 83 days between the 9/9 and the 30/11 but unavoidably four of these (from the 13/10 to the 16/10) were missed during the period of daily sampling. The effect of this discontinuity in n_2 however, is not considered to be appreciable.

[2]Values of λ at various levels of significance are given in Fisz, M., 1967; p.664.

TABLE 3:1

CRITICAL AND MAXIMUM OBSERVED VALUES OF THE KOLMOGOROV-SMIRNOV STATISTIC FOR TWO CUMULATIVE SAMPLE FUNCTIONS

	CC	F	AA	BB
	CRITICAL VALUES OF Dn			
$Dn_{.05}$	0.219	0.217	0.219	0.219
$Dn_{.01}$	0.263	0.260	0.263	0.263
	BREAKER HEIGHT			
Dn(max)	0.150	0.264**	0.084	0.112
	WAVE PERIOD			
Dn(max)	0.155	0.134	0.164	0.216
	WAVE DIRECTION			
Dn(max)	0.222*	0.237*	0.233*	0.295**

* $F_1 \neq F_2$ at the .05 level of significance.

** $F_1 \neq F_2$ at the .01 level of significance.

stations. The asterisks show the levels of confidence for which the two cumulative functions are significantly different.

At the ninety-five per cent level, the two samples are from different populations in five cases, but even if rejection of the null hypothesis of no significant difference is reserved until the ninety-nine per cent level, the same conclusion is reached in two cases: breaker height at F, and wave direction at BB. It is thus concluded that the complete data set should not be used as a typical measure of wave conditions. To obtain a truer picture of the distribution of the wave regime for the year, it is better to use a sampling technique that reduces the high sample density of the latter part of the year to a level more in line with that of the earlier part.

To achieve this, the year was simply divided into six day periods. If measurements occurred on from two to six of the days in that period, then one of these was selected at random. If only one measurement occurred, then it was selected, and if no measurements occurred then, obviously, none could be selected. This technique yielded 38 readings at profiles CC and F, and 39 observations at AA and BB. This is the data set that is considered to give the best estimation of the year's conditions.

The Process Variables

Nine process variables are used in the study. The first three in the following discussion were measured directly in the field, and an account of how they were measured is included as part of the chapter dealing with research methods. They are also included here for the sake of completeness. The symbols and the dimensions of all of the variables, as well as how the calculated values were derived are as follows:

The Measured Process Variables

(1) Breaker height, (Hb), was measured in the field and is the mean trough-to-crest distance of the wave at break point, of the highest one-third of the waves. It is expressed in feet.

(2) Wave period, (T), is the mean period, in seconds, of ten incoming waves.

(3) Wave direction, (θ'), is the direction from which the dominant wave train approaches the shore. The units are degrees of true azimuth.

The Derived Process Variables

(4) Angle of wave approach, (θ), is the

acute angle between the shoreline and the wave orthogonal, and is given in degrees of arc. It was calculated by taking the difference between θ' and the true azimuth of the respective shoreline.

(5) Deep water wave height, (Ho), is given in feet and is calculated from the equation relating breaker height, deep water wave height, and deep water wave-length:[1]

$$Hb/Ho = 1/(3.3(Ho/Lo)^{1/3})$$

For deep water:

$$Lo = 5.12T^2$$

Substitution gives:

$$Ho = 3.3Hb((Ho/5.12T^2)^{1/3})$$

Which reduces to:

$$Ho = (2.65Hb^{3/2})/T \qquad (1)$$

(6) Deep water wave-length, (Lo), is expressed in feet and is given by:

$$Lo = 5.12T^2 \qquad (2)$$

---

[1]This, and subsequent wave variable relationships are taken from C.E.R.C. Tech. Rept.4, 1966.

(7) Deep water wave steepness, (So), is the dimensionless ratio of the deep water values of height and wave-length:

$$So = Ho/Lo$$

(8) The total potential and kinetic energy contained in a wave, (Eo), in foot-pounds per linear foot of crest per wave-length is:

$$Eo = \rho gLoHo^2/8 \qquad (3)$$

where ρ is the mass density of seawater = 2.0 slugs per cubic foot, and g is gravitational acceleration = 32 feet per second per second. ρg is therefore the weight (force) of one cubic foot of seawater = 64.0 pounds. Substituting Equation (2) in this expression gives:

$$Eo = 41Ho^2T^2 \qquad (4)$$

(9) The areal equivalent of the above variable is Eo', the total potential and kinetic energy contained in a wave in foot-pounds per square foot of sea surface. It is independent of wave-length and derives from Equation (3) by dividing the right hand side by Lo:

$$Eo' = 8Ho^2$$

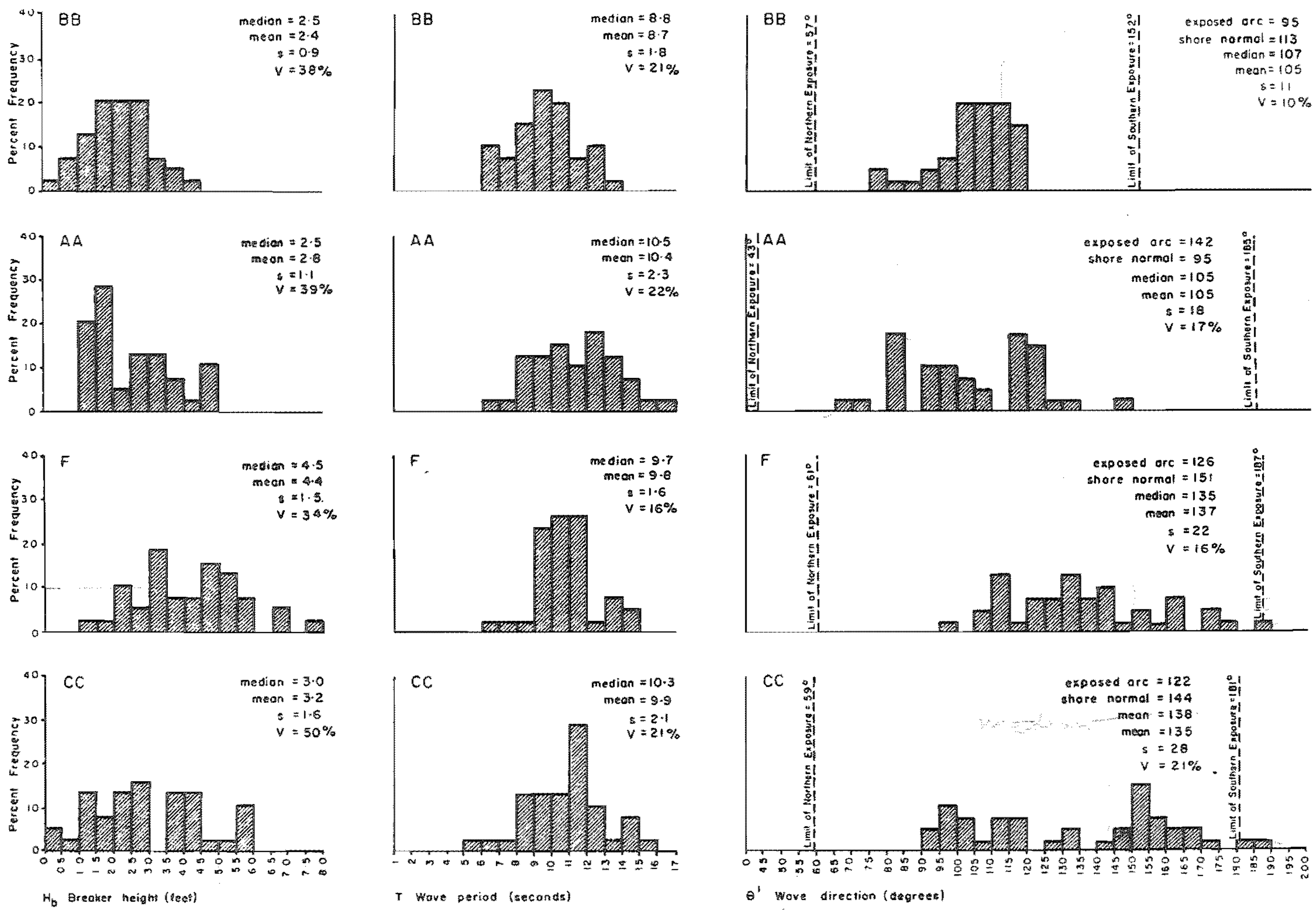
In theory, there is a restriction on the application of the energy equations because Equation (3) only applies to waves of small steepness, but in practice, the errors introduced by applying it to waves of large steepness are insignificant compared to the limitations of wave measurement.

Characteristics of the Wave Climate at Each Station

Histograms are given showing the distributional characteristics of the waves (Figures 3:1, 3:2, and 3:3). The mean, median, standard deviation (s), and coefficient of variation (V), for each variable, are given along with the histograms, and the direction of the shore-normal, and the exposed arc have been included on the wave direction graphs.

Histograms are not very well adapted to making direct inter-station comparisons of the statistics though, and so Figures 3:4, 3:5, and 3:6 are provided to show the absolute variation of the means, medians, and standard deviations, from station to station, as well as the relative dispersion of the values about their means, shown by the coefficients of variation. Skewness can be inferred from these latter three figures from the relative positions of the mean and median values. When the mean is to the right of (greater

FIG. 3:1



BB
median = 2·5
mean = 2·4
s = 0·9
V = 38%
BB
median = 8·8
mean = 8·7
s = 1·8
V = 21%
BB
Limit of Northern Exposure = 57°
Limit of Southern Exposure = 152°
exposed arc = 95
shore normal = 113
median = 107
mean = 105
s = 11
V = 10%
AA
median = 2·5
mean = 2·8
s = 1·1
V = 39%
AA
median = 10·5
mean = 10·4
s = 2·3
V = 22%
AA
Limit of Northern Exposure = 43°
Limit of Southern Exposure = 185°
exposed arc = 142
shore normal = 95
median = 105
mean = 105
s = 18
V = 17%
F
median = 4·5
mean = 4·4
s = 1·5
V = 34%
F
median = 9·7
mean = 9·8
s = 1·6
V = 16%
F
Limit of Northern Exposure = 61°
Limit of Southern Exposure = 187°
exposed arc = 126
shore normal = 151
median = 135
mean = 137
s = 22
V = 16%
CC
median = 3·0
mean = 3·2
s = 1·6
V = 50%
CC
median = 10·3
mean = 9·9
s = 2·1
V = 21%
CC
Limit of Northern Exposure = 59°
Limit of Southern Exposure = 181°
exposed arc = 122
shore normal = 144
mean = 138
mean = 135
s = 28
V = 21%
Percent Frequency
H_b Breaker height (feet)
T Wave period (seconds)
θ' Wave direction (degrees)

FIG. 3:2

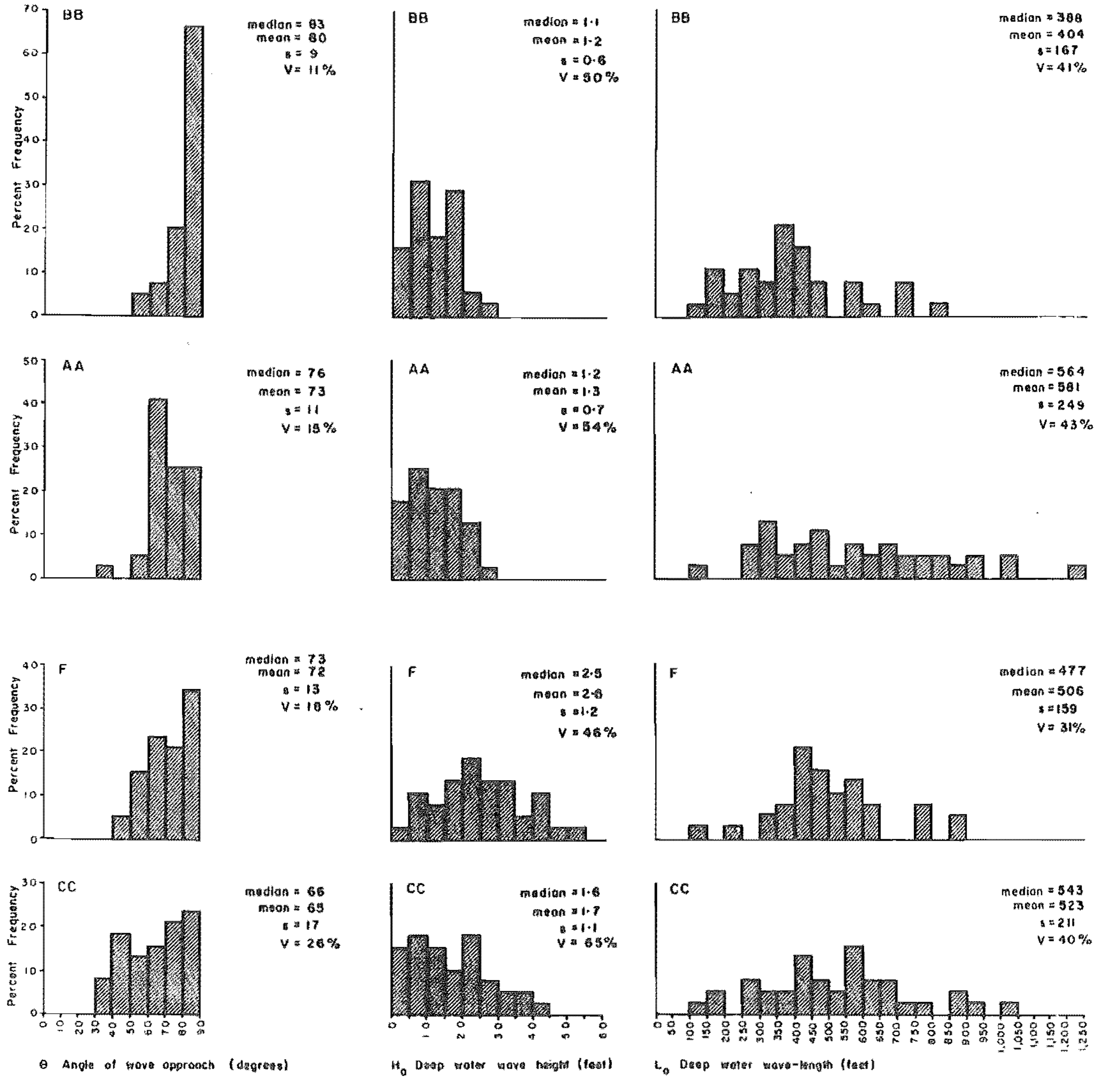

BB
median = 83
mean = 80
s = 9
V = 11%
median = 1·1
mean = 1·2
s = 0·6
V = 50%
median = 388
mean = 404
s = 167
V = 41%
AA
median = 76
mean = 73
s = 11
V = 15%
median = 1·2
mean = 1·3
s = 0·7
V = 54%
median = 564
mean = 581
s = 249
V = 43%
F
median = 73
mean = 72
s = 13
V = 18%
median = 2·5
mean = 2·6
s = 1·2
V = 46%
median = 477
mean = 506
s = 159
V = 31%
CC
median = 66
mean = 65
s = 17
V = 26%
median = 1·6
mean = 1·7
s = 1·1
V = 65%
median = 543
mean = 523
s = 211
V = 40%
Percent Frequency
θ Angle of wave approach (degrees)
H_0 Deep water wave height (feet)
L_0 Deep water wave-length (feet)

FIG. 3:3

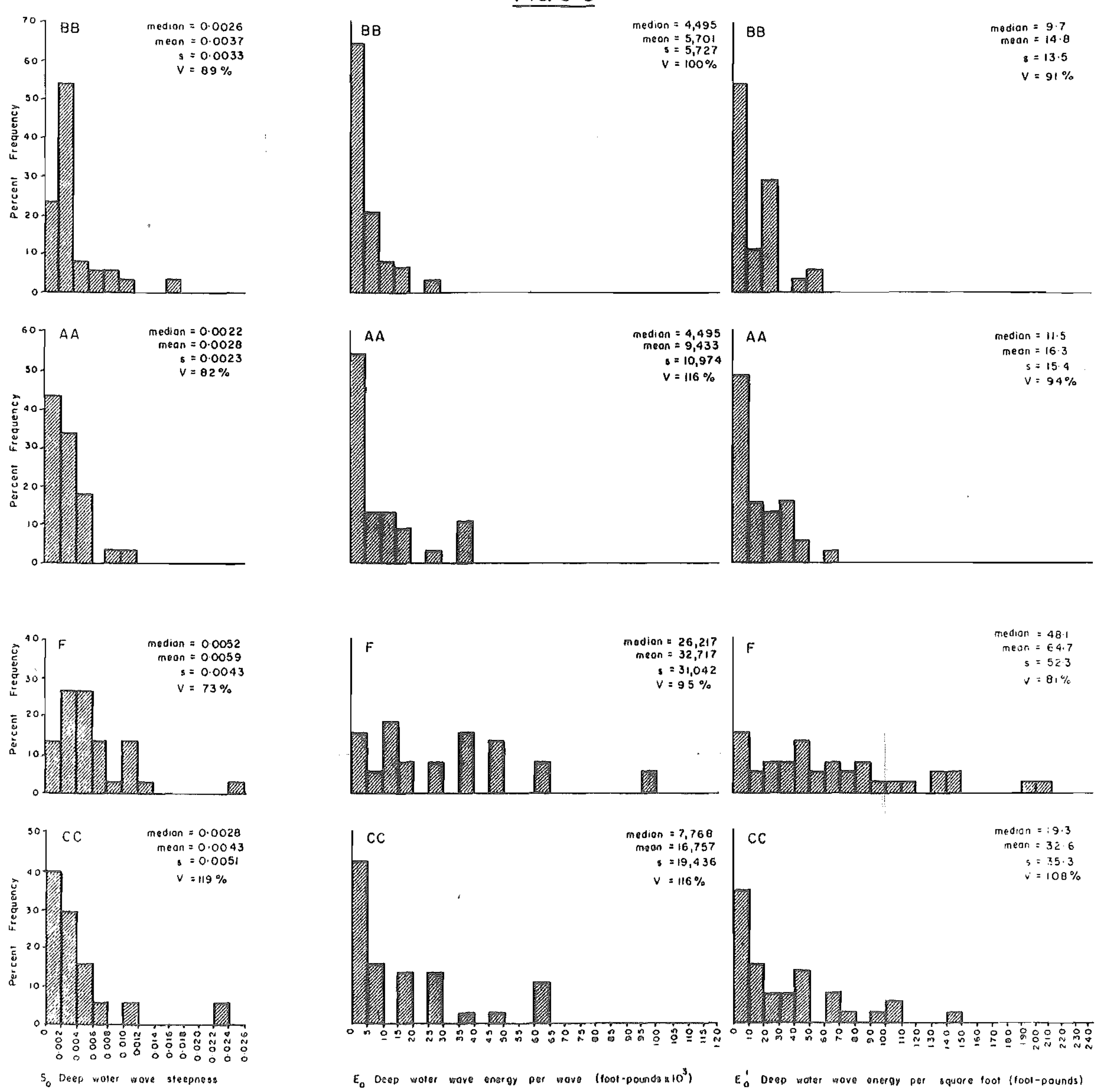
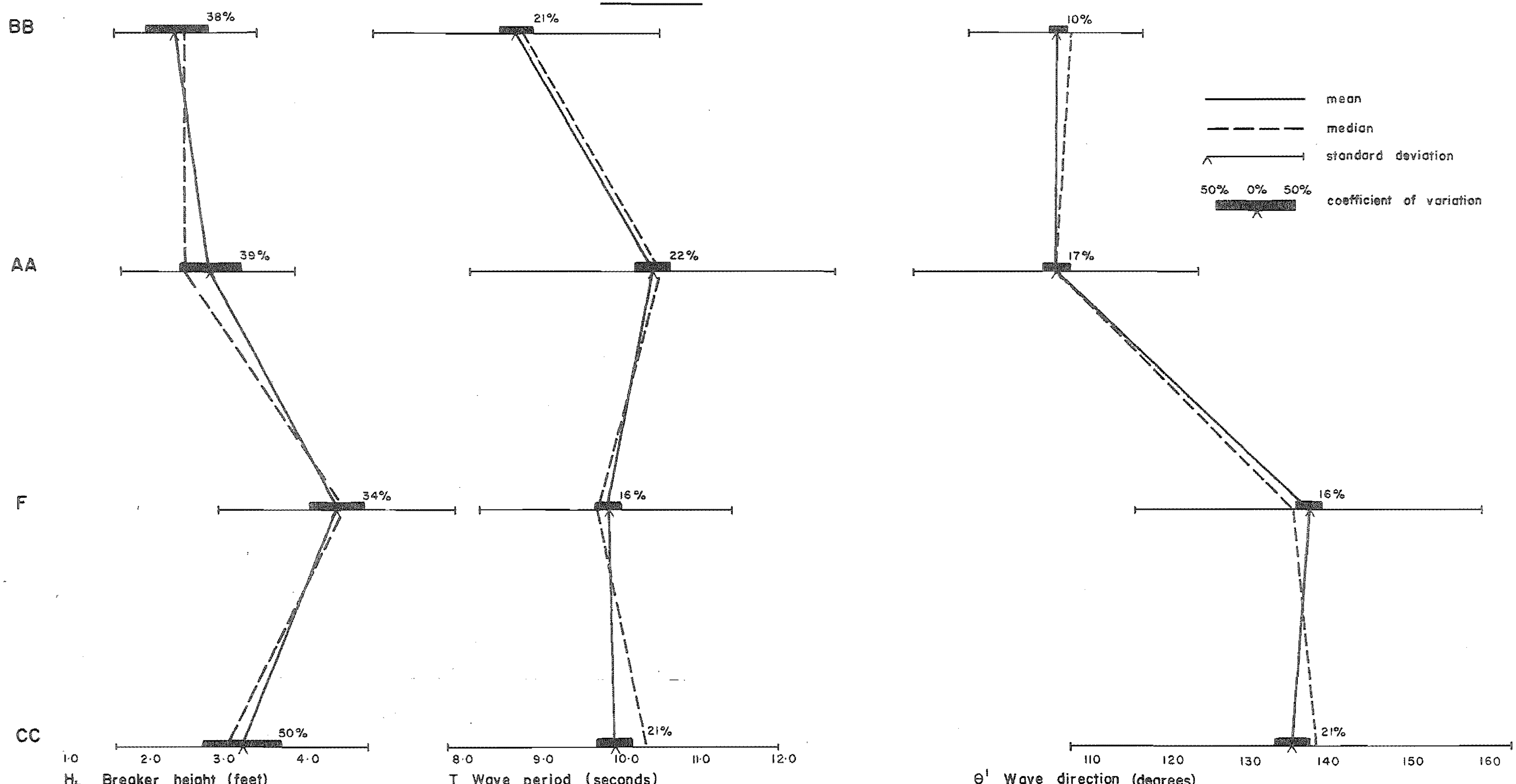

BB
median = 0·0026
mean = 0·0037
s = 0·0033
V = 89 %
BB
median = 4,495
mean = 5,701
s = 5,727
V = 100%
BB
median = 9·7
mean = 14·8
s = 13·5
V = 91 %
AA
median = 0·0022
mean = 0·0028
s = 0·0023
V = 82 %
AA
median = 4,495
mean = 9,433
s = 10,974
V = 116 %
AA
median = 11·5
mean = 16·3
s = 15·4
V = 94%
F
median = 0·0052
mean = 0·0059
s = 0·0043
V = 73 %
F
median = 26,217
mean = 32,717
s = 31,042
V = 95 %
F
median = 48·1
mean = 64·7
s = 52·3
V = 81 %
CC
median = 0·0028
mean = 0·0043
s = 0·0051
V = 119 %
CC
median = 7,768
mean = 16,757
s = 19,436
V = 116%
CC
median = 19·3
mean = 32·6
s = 35·3
V = 108%
Percent Frequency
S_0 Deep water wave steepness
E_0 Deep water wave energy per wave (foot-pounds x 10^3)
E'_0 Deep water wave energy per square foot (foot-pounds)

FIG. 3:4



BB
AA
F
CC
38%
39%
34%
50%
21%
22%
16%
21%
10%
17%
16%
21%
mean
median
standard deviation
50% 0% 50%
coefficient of variation
1·0
2·0
3·0
4·0
H_b Breaker height (feet)
8·0
9·0
10·0
11·0
12·0
T Wave period (seconds)
110
120
130
140
150
160
θ' Wave direction (degrees)

FIG. 3:5

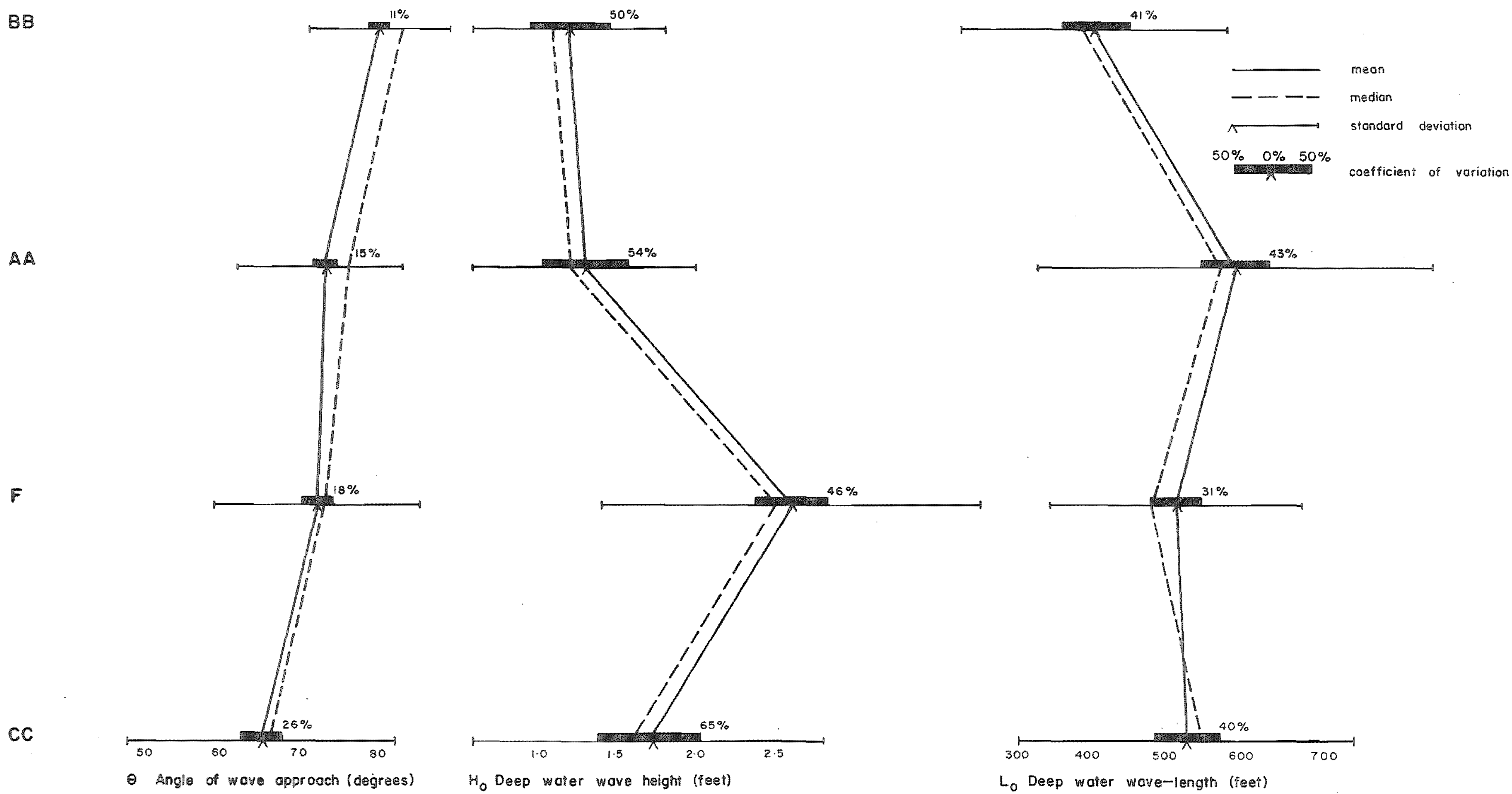
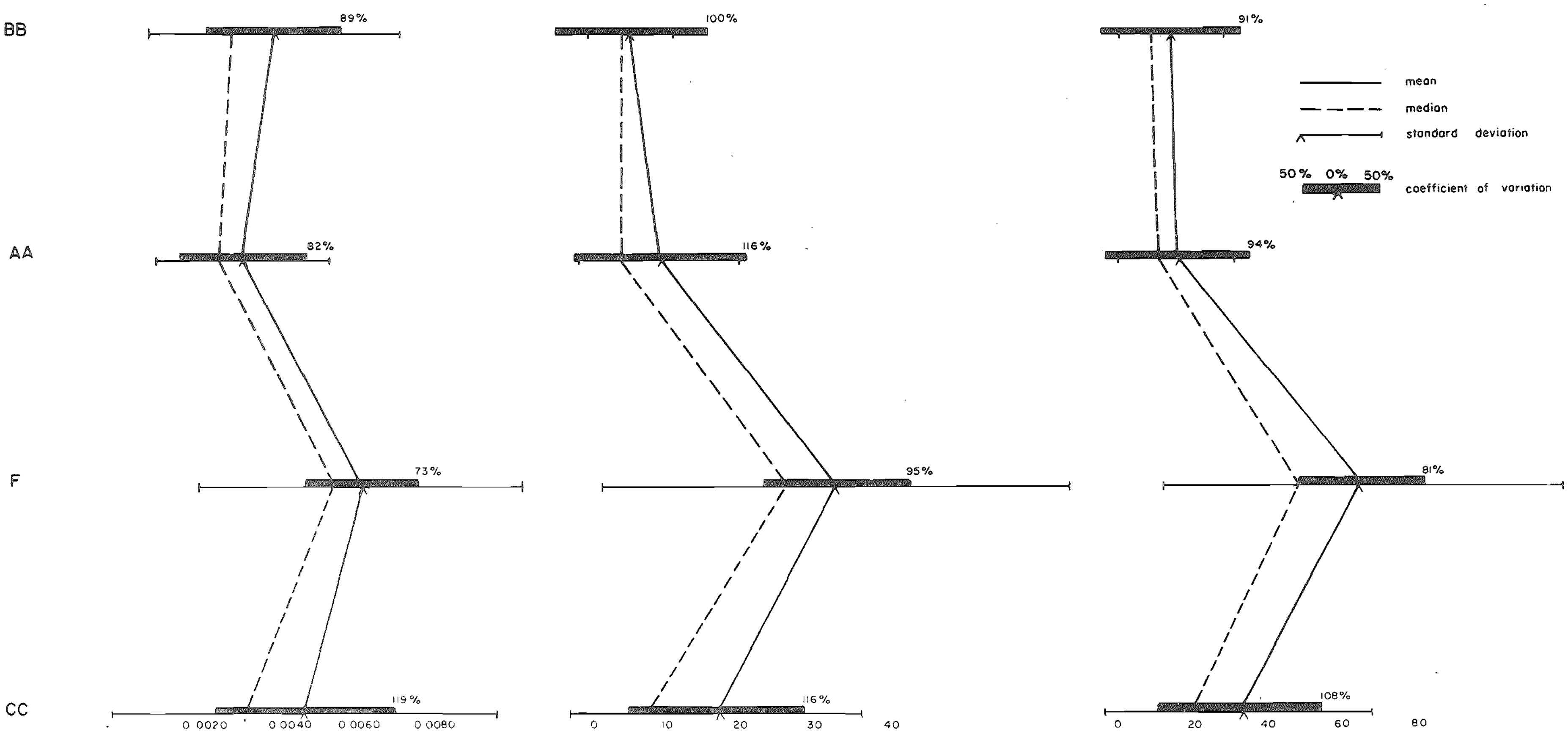

BB
AA
F
CC
11%
15%
18%
26%
50%
54%
46%
65%
41%
43%
31%
40%
mean
median
standard deviation
50% 0% 50%
coefficient of variation
50 60 70 80
θ Angle of wave approach (degrees)
1·0 1·5 2·0 2·5
H_o Deep water wave height (feet)
300 400 500 600 700
L_o Deep water wave-length (feet)

FIG. 3:6



S_0 Deep water wave steepness

E_0 Deep water wave energy per wave (foot-pounds x 10^3)

$E_0^{\prime}$ Deep water wave energy per square foot (foot-pounds) than), the median, the distribution is positively skewed; when to the left, it is negatively skewed.[1]

The figures show that CC receives waves from the widest variety of directions and the distribution is somewhat bimodal. Greater numbers of waves arrive from the 150° to 165° sector to the south, and the 95° to 120° sector to the north, than they do from other directions (Figure 3:1). Relatively few arrive in the 25° sector immediately to the north of shore-normal. The existence of two direction modes which occur on either side of the shore-normal direction means that waves quite commonly arrive rather obliquely to the shore at CC. This is shown in Figures 3:2 and 3:5, where the median value for the angle of wave approach is 66°, considerably less than that of any other station. Wave direction is also more variable at CC than elsewhere. The coefficients of variation for wave direction and angle of wave approach are twenty-one per cent and twenty-six per cent respectively, higher in both cases than the other stations. The median

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[1]The point is made here, that a positively skewed distribution implies that more often than not, the data values are less than their mean value, while a distribution that is negatively skewed implies the opposite. The usefulness of this observation will be enlarged upon in Chapter IV.

wave period at CC is 10.3 seconds, but waves as short as five and as long as sixteen seconds do occur. The median breaker height is 3.0 feet, higher than at AA or BB, but not as high as the breakers at F. CC however, has the greatest variation in breaker height, fifty per cent. One curious feature of the breakers at CC is the absence of heights in the 3.0 to 3.5 foot category. The deep water wave heights, and the deep water wave-lengths at this station exhibit, by and large, the same general characteristics as breaker height and wave period. The steepness and energy values (Figure 3:6) show that CC ranks higher than either AA or BB, but less than F. Occasionally, fairly steep waves, having values between 0.022 and 0.024, and comparable to the steepest waves at F, arrive at CC, and these help to account for the very high variability of steepness values at this station. But in the long run these occurrences are offset by the much higher frequency of very flat waves of lower energy.

The distinguishing features of the waves at F is that on the average, they are higher, steeper, and have more energy than other waves on the delta. The median breaker height is 4.5 feet, half again as high as those at either of the two northern stations. One other important feature of the waves at F is the relationship of median direction to the shore-normal direction. At F (Figure 3:1), the shore-normal direction lies to the south of the median direction, indicating that most of the time, waves at F approach from north of shore-normal. At CC, the opposite is true, and most of the time, waves come from south of the shore-normal direction. Both these facts have important implications regarding the movement of sediment in the nearshore zone, to be discussed in the next chapter. The mean wave steepness at F is 0.0059, quite large compared to the values at the other stations. That relatively high, steep waves, are characteristic of F, is confirmed by Figures 3:13, 3:14, and 3:15, where the differences in mean breaker height, deep water height, and steepness between F and the rest of the stations is greater over most of the year than those same differences between CC, AA, and BB. Height and steepness are also more consistently higher, with coefficients of variation of thirty-four per cent and seventy-three per cent, respectively, less even than AA or BB (Figures 3:4 and 3:6). The energy values also eclipse those elsewhere (Figure 3:3). If considered from the standpoint of surface area, the mean energy value is 64.7 foot-pounds per square foot, essentially twice that of its nearest neighbour, CC, and four times as large as either AA or BB. Considered as the total energy per wave, the mean value is 32,717 foot-pounds, again at least twice as large as the other stations. One other feature of the waves at F which deserves mention, is the consistent wave period. The median value is 9.7 seconds and the mean, 9.8 seconds. Both in absolute, and in relative terms, there is little departure from these values. The standard deviation for this distribution is 1.6 seconds either side of the mean, and the coefficient of variation is sixteen per cent (Figure 3:1). Both are less than wave period values anywhere else. As would be expected, the deep water wavelength at F has a similarly small dispersion.

AA is the most exposed of all the stations on the delta (Figure 3:1). It is open to incoming waves through an arc of 142°. In spite of this however, waves arrive at AA from a relatively narrow sector. Only BB, which is quite sheltered in terms of exposure, receives waves from a smaller range of directions. Another curious thing about AA is that it is the only station where the median (and mean) wave direction lies to the south of shore-normal (Figure 3:1). As at CC there is a bimodal profile to the directional distribution, with southerly waves arriving mostly from 115° to 125°, and northerlies arriving from 80° to 85°. The median wave period at AA is 10.5 seconds, longer than at any other station. The breaker height distribution has a prominent positive skew, and the high proportion of one to two foot waves brings both the median breaker height, at 2.5 feet (Figure 3:1), and the mean deep water wave height, at 1.3 feet (Figure 3:2), into close similarity with the corresponding values at BB. The deep water wave-lengths and the wave periods at AA are longer than at other stations, but their variation from the mean length and period is quite in keeping with variation at all the other stations except F (Figures 3:5 and 3:4). AA has the flattest waves of any of the stations, with a mean steepness of 0.0028. The wave energy values are also low, and in general, comparable to those at BB.

BB is the most sheltered station in the study. It presents a shoreline open to oncoming waves through an arc of only 95° (Figure 3:1). Most waves approach shore-normally and the ten per cent variation from this direction is the smallest of all the stations. Figure 3:2 shows that the median angle of wave approach at BB is

83°, very close to shore-normal. The average wave period, and the deep water wave-length, with respective medians of 8.8 seconds (Figure 3:1), and 388.0 feet (Figure 3:2), are also less than anywhere else on the coast. The short wave periods and wave-lengths at this station are as anomalous with respect to conditions elsewhere in the study area, as high steep waves are to F (Figures 3:13 and 3:14). Insofar as height, steepness, and energy are concerned, the waves at BB are comparable to those at AA.

Along-shore Variation in the Process Variables

Figures 3:4, 3:5, and 3:6 show the way in which process intensity changes from CC, the most southerly station, to BB, the most northerly. Some of the specific process characteristics have already been mentioned in connection with particular stations. Taking the more general view of the study area as a whole, a few broad trends can be recognized.

Except for F, where the waves are unusually high, wave heights, both at the break-point (Figure 3:4), and in deep water (Figure 3:5), decrease from south to north. By and large, this trend is reflected in the energy values as well (Figure 3:6). Figure 3:6 also shows that the south-to-north decrease in process intensity is not as evident in the steepness values. The reason for this relates to the unusually short wave-lengths (and periods) predominating at BB. Finally, as can be seen in Figure 3:5, there is a noticeable tendency for waves to approach the coast more and more shore-normally from south to north. It is recognized, of course, that this effect relates only to their direction just before breaking, after considerable refraction has taken place. It is expected that their deep water directions, for which no data are available, would be in close agreement.

The "Best Predictor Equation"

Before venturing into a discussion of functional inter-relationships among the variables it should be mentioned that their mathematical associations are sometimes quite complicated. In this chapter the most significant equations are easily identified, and for the most part, are simple linear functions, but for inter-relations among the response variables (Chapter IV), and among process-response pairs (Chapter V), this is not so. Correlation and regression runs in these latter two situations sometimes give a number of polynomial equations of various degrees, all significant at a high confidence level, and since it is desirable to have a standard method for selecting the best predictor equation from among them, it is fitting at this juncture to define the standards under which these selections have been made.

There is no universally accepted consensus among statisticians for doing this. A number of methods are available and Draper and Smith (1966) discuss several of them. An argument in favour of consistently using one method appropriate to the study at hand, is their observation that the methods in general use do not all necessarily lead to the same solution even when applied to the same problem.[1] An idea of the subtleties involved in making such discriminitive decisions is illustrated by three accepted approaches, which all seemed to offer promising solutions to choosing the best equation:

(a) define the best predictor equation as the lowest degree polynomial that is significant at a pre-determined confidence level.

(b) select the equation at some specified confidence level, that explains the greatest amount of variation in the dependent variable relative to the unexplained or residual variation.

(c) delete from the predictor equation any coefficients of the independent variable that are not significantly

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[1] Draper, N.R., and Smith, H., 1966; p.163.

greater than zero.

For this study, (b) was selected as the best compromise. The first method is, in effect, trading off the higher degree polynomials for less predictive but simpler equations. The loss in predictive power using this method can be considerable.[1] The last method requires a separate significance test for each x-coefficient in the equation, and it was felt that the considerable extra effort required would not give correspondingly better results. Although method (b) has some weaknesses, one of its main advantages is that it does give the best equation in the sense that the one that is selected always tends to explain the largest amount of variation in the dependent variable at the greatest level of confidence attainable. The procedural steps for choosing the best predictor equations are now described.

To assess the degree of association among the variables, they were subjected to a polynomial correlation and regression program,[2] and as a test

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[1]There are numerous examples of this in the appendices. A typical one is that of gains (indep.) and slope, β (dep.) at CC. Appendix 4:1 shows that at the .01 level, both the first and second order polynomials are significant. The first order equation, however, only explains nine per cent of the variation in slope, while the second order equation explains twenty-five per cent.

[2]I.B.M. Scientific Subroutine "POLRG".

of significance, an F-ratio[1] was calculated for each fitted curve. Tables of F list the critical F-ratios at different degrees of freedom for which these calculated values are significant if they exceed the tabled value. The calculated F-ratio that exceeded the tabled value by the largest amount at the highest level of significance attained (either .05 or .01) during the screening run, was used as the criterion for selecting the best functional relationship between the dependent and independent variable.[2] The equation describing this relationship is the "best predictor equation".

Functional Relationships Among Breaker Height, Wave Period, and Wave Direction

The description of the similarities and differences of the waves around the delta goes part of the way towards an understanding of the

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[1]The ratio of the mean variation "explained" by the regression equation to the mean residual ("unexplained") variation.

[2]A subtle but important fact should be noted here. Since the degrees of freedom, and therefore the critical F values, change with each successively higher order of polynomial, the highest absolute value of the calculated F-ratio does not always indicate the best predictor equation. Appendix 3:2 shows for example, that the third degree equation between height (indep.) and period (dep.) at BB is the best predictor, even though the first degree equation has a higher absolute F-ratio.

process side of the process-response model. Having now discussed the best predictor equation, the way is clear to consider the process variables as they relate to one another. It should be borne in mind in the following discussions having to do with statistical relationships, that the terms "independent" and "dependent" must be used prudently when taken out of their statistical context. In particular, it is especially easy, and quite unwarranted, to equate "independent" with "cause", and "dependent" with "effect". As discussed in Chapter I though, and notwithstanding this distinction, correlation between sets of variables is useful in order to verify or reject suspected relationships on other than subjective grounds. On intuition alone, for example, one tends to associate high waves with southerly conditions. It is useful to be able to test the degree of this association quantitatively.

Three sets of process variables have been tested in this way. They are: height-direction, height-period, and period-direction.

It is not axiomatic that the strength of the association between two variables will be the same regardless of which is considered the dependent and which the independent variable. Because of this, both arrangements were tested at each station. Appendix 3:2 lists the independent and dependent variables that have been considered and the sample size at each station. For each order of polynomial, the per cent explained variation,[1] the standard error of the estimate, the F-ratio, and the level of significance are given, and the best predictor equation is also indicated.

The seventeen best predictor relationships are shown schematically in Figure 3:7. The arrows point in the direction of the dependent variable (predicand), and the numbers refer to the per cent explained variation of the dependent variable by the independent variable (predictor). The dashed line indicates that though significant, the relationship is less significant than the converse.

The best predictor equations for these seventeen pairs of process variables are given below. Five important conclusions can be drawn from them.

The interdependence of breaker height and wave direction is ubiquitous. First, southerly waves have higher breakers:

at CC; $Hb = 0.176 + 0.023\theta'$

at F; $Hb = 1.057 + 0.024\theta'$

at AA; $Hb = -0.386 + 0.038\theta'$

at BB; $Hb = -1.558 + 0.038\theta'$

---

[1]Equivalent to r^2, the coefficient of determination.

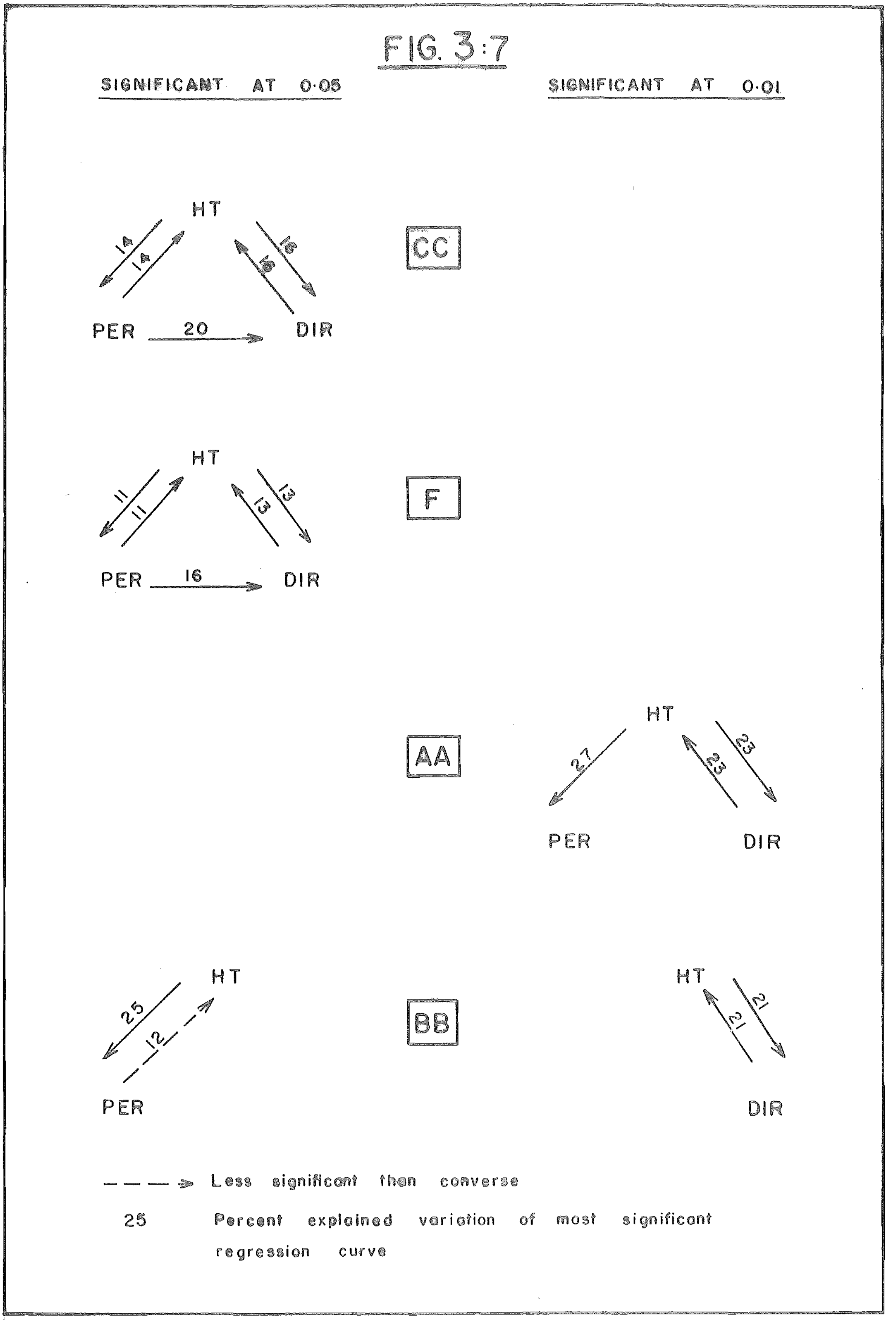


FIG. 3:7
SIGNIFICANT AT 0·05
SIGNIFICANT AT 0·01
HT
PER
DIR
14
16
20
CC
11
13
16
F
AA
27
23
BB
25
12
21
Less significant than converse
25
Percent explained variation of most significant regression curve

Second, higher breakers come from the south:

$$\text{at CC;} \quad \theta' = 111.41 + 7.135Hb$$

$$\text{at F;} \quad \theta' = 113.03 + 5.412Hb$$

$$\text{at AA;} \quad \theta' = 83.706 + 7.634Hb$$

$$\text{at BB;} \quad \theta' = 92.155 + 5.446Hb$$

Third, the higher breakers, in general, have longer periods. At CC and F, the relationship is linear, at AA, the equation is a second degree parabola, and at BB, it is cubic:

$$\text{at CC;} \quad T = 8.281 + 0.497Hb$$

$$\text{at F;} \quad T = 8.276 + 0.350Hb$$

$$\text{at AA;} \quad T = 16.009 - 4.801Hb + 0.860Hb^2$$

$$\text{at BB;} \quad T = 2.077 + 9.224Hb - 4.048Hb^2 + 0.561Hb^3$$

Fourth, longer period waves have higher breaker heights.[1] This relationship is significant only at the two southern stations and at BB:

$$\text{at CC;} \quad Hb = 0.525 + 0.274T$$

$$\text{at F;} \quad Hb = 1.399 + 0.305T$$

$$\text{at BB;} \quad Hb = 0.943 + 0.169T$$

---

[1] In this connection, Wiegel, 1960; p.14, notes that this relationship is true of waves generally, although the highest waves tend to have periods close to the mean.

Fifth, at the two southern stations, waves of particular periods come from a characteristic direction. Direction is a second degree parabolic function of the wave period in both cases:

$$\text{at CC;} \quad \theta' = 313.0 - 39.073T + 2.034T^2$$
$$\text{at F;} \quad \theta' = 325.64 - 36.791T + 1.744T^2$$

These five associations are shown graphically in Figures 3:8, 3:9, 3:10, 3:11, and 3:12. The percentage of the variation explained by the independent variable along with the level of significance is also shown on each curve.

Of all possible functional relationships between the process variables, the only one that has no significance at any station and thereby acquires a certain conspicuousness, is the dependence of period upon direction. Southerly waves have higher breakers than other waves, but they do not have significantly longer periods than waves from any other direction.

Process Variation with Time

The typical wave characteristics, their spatial variation, and their functional relationships, although adequately describing the main features of the processes at each station, tell nothing of how they change through time. The tem-

FIG. 3:8

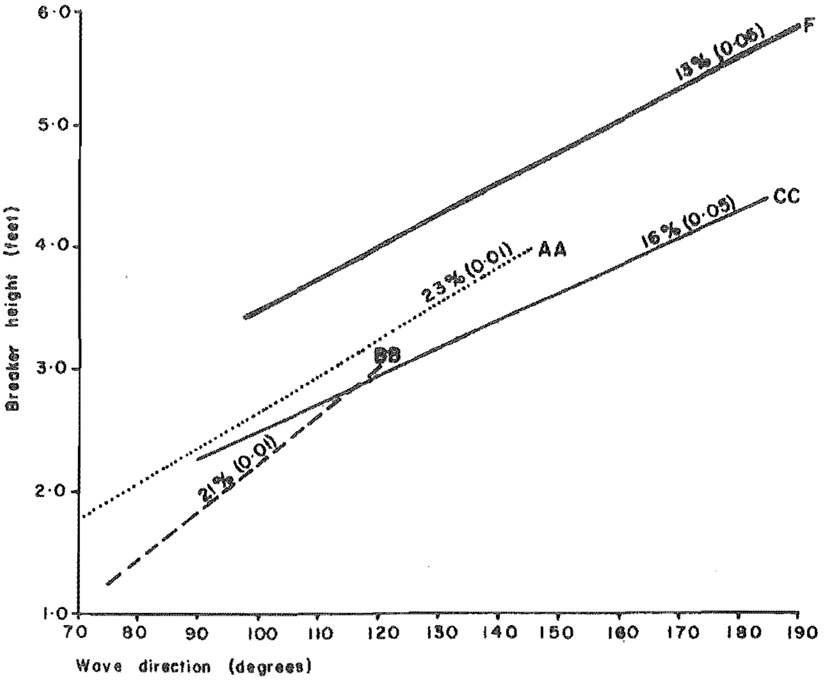

6·0
5·0
4·0
3·0
2·0
1·0
70
80
90
100
110
120
130
140
150
160
170
180
190
Breaker height (feet)
Wave direction (degrees)
13% (0·05)
F
16% (0·05)
CC
23% (0·01)
AA
BB
21% (0·01)

FIG. 3:9

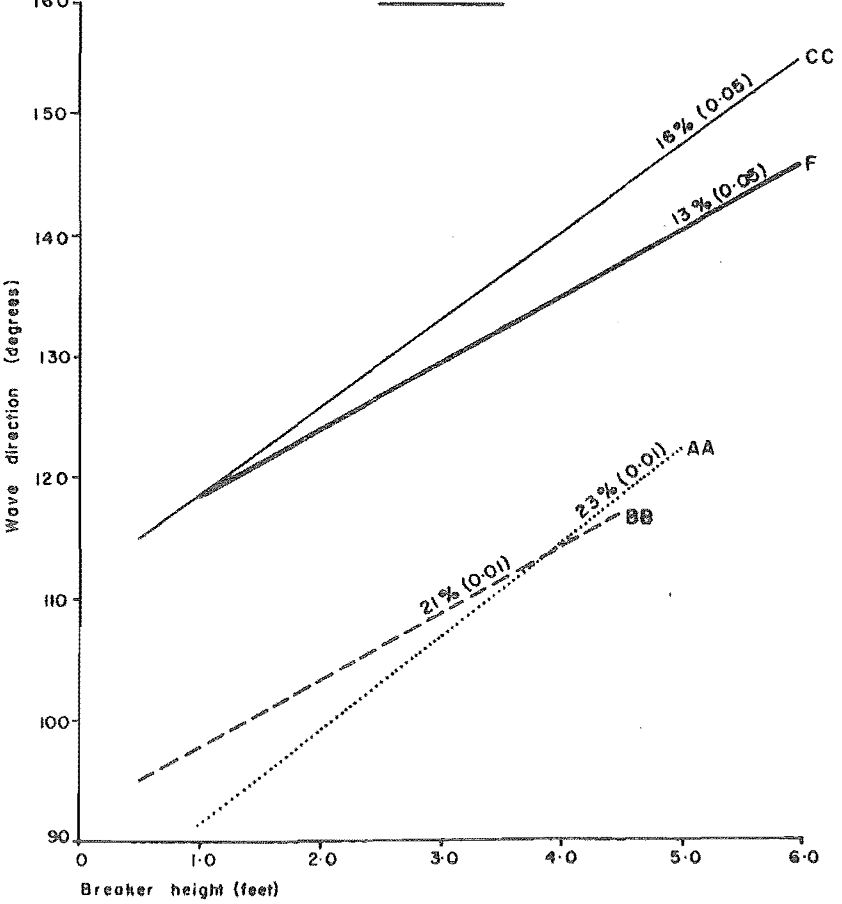
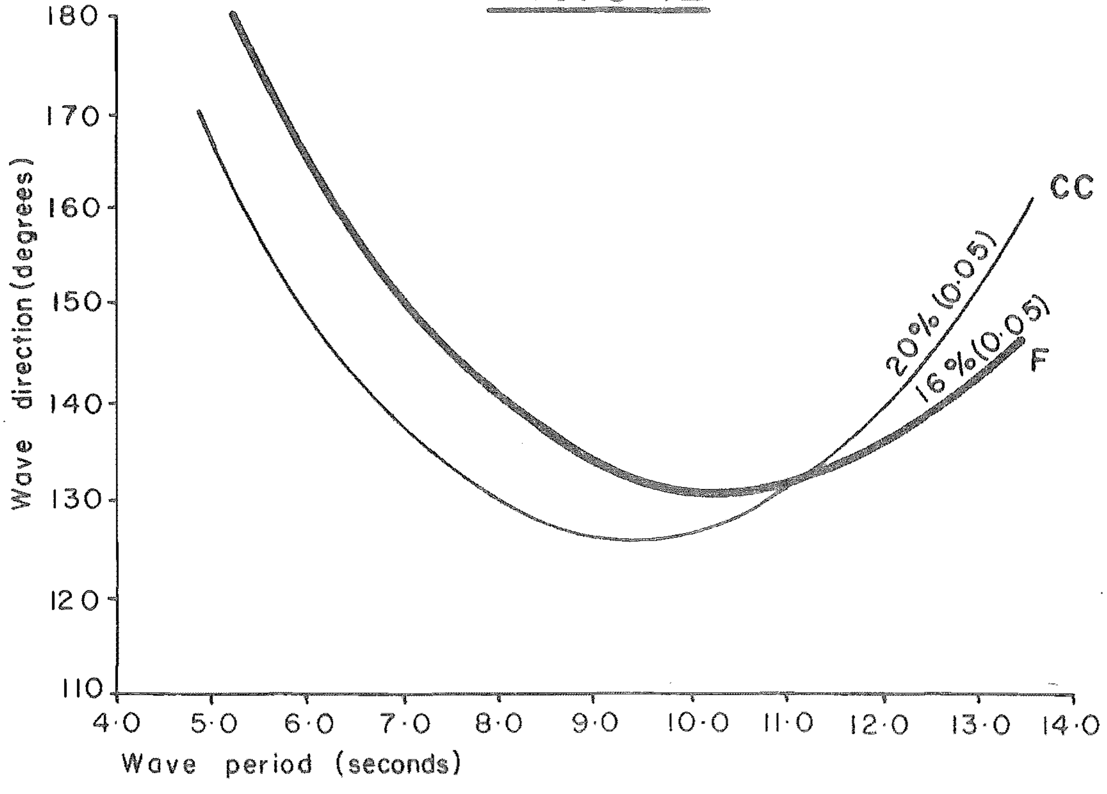

160
150
140
130
120
110
100
90
0
1·0
2·0
3·0
4·0
5·0
6·0
Wave direction (degrees)
Breaker height (feet)
16% (0·05)
CC
13% (0·05)
F
23% (0·01)
AA
BB
21% (0·01)

FIG. 3:12


180
170
160
150
140
130
120
110
Wave direction (degrees)
4·0
5·0
6·0
7·0
8·0
9·0
10·0
11·0
12·0
13·0
14·0
Wave period (seconds)
CC
20% (0·05)
16% (0·05)
F

poral aspect of the wave processes, to be examined now, will be discussed first from the standpoint of long term (seasonal) change, then from the standpoint of day to day variation.

Process Changes Over the Period of One Year

Figures 3:13, 3:14, and 3:15 show the month to month change in mean process intensity for the nine process variables at each of the four stations, as well as the yearly means, and the mean monthly values are listed in Appendix 3:3. Some general trends are obvious. Of the three variables measured directly in the field, the most clear-cut seasonal fluctuation is that of breaker height. Figure 3:13 shows that breaker heights were above the yearly mean from May to November at CC and AA, from May to December at F, and from May to October at BB. At other times, mainly during the summer months, they were below the yearly mean height.

There is a lack of any very obvious seasonal trend in either the wave period or direction graphs although there is a suggestion that wave periods were longer in early winter (June and July), and also that the northern part of the delta received more southerlies during this period than at other times of the year. The remaining six process variables correspond in the main to the trends shown by the first three.

FIG. 3:13

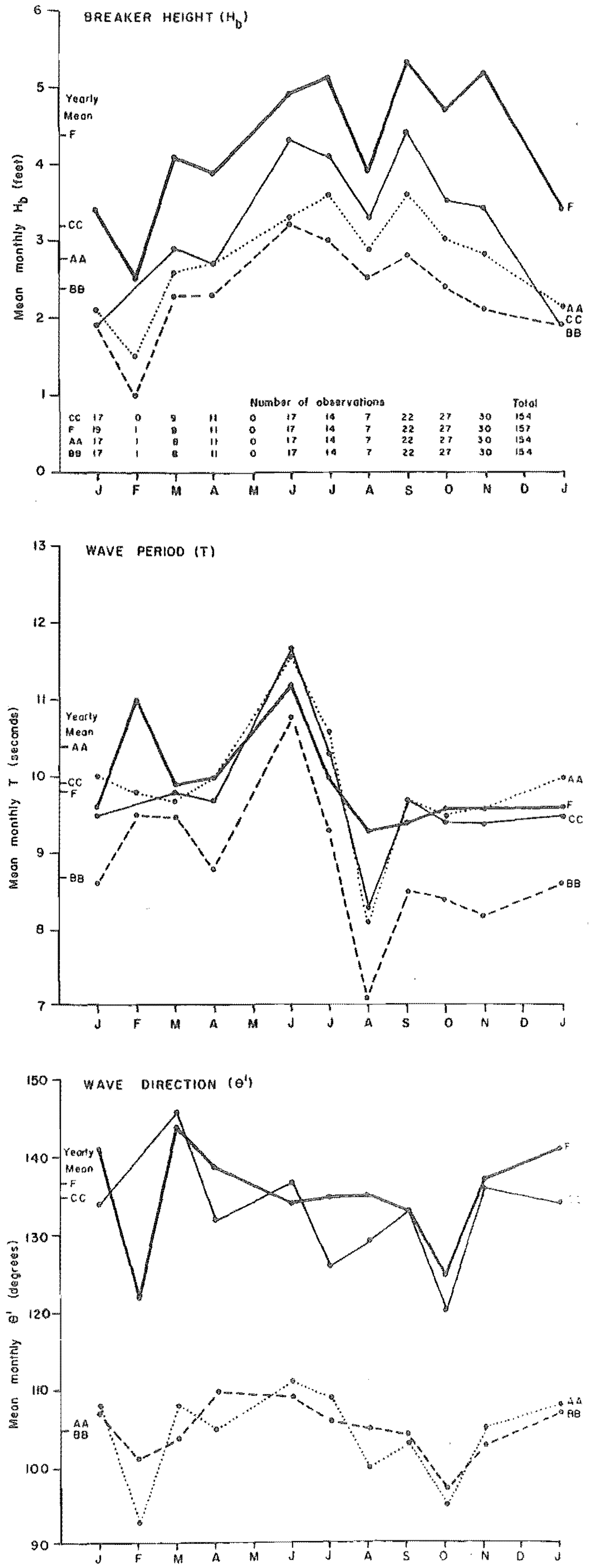

BREAKER HEIGHT (H_b)
Mean monthly H_b (feet)
Yearly Mean
F
CC
AA
BB
Number of observations
Total
CC 17 0 9 11 0 17 14 7 22 27 30 154
F 19 1 9 11 0 17 14 7 22 27 30 157
AA 17 1 8 11 0 17 14 7 22 27 30 154
BB 17 1 8 11 0 17 14 7 22 27 30 154
J F M A M J J A S O N D J
WAVE PERIOD (T)
Mean monthly T (seconds)
Yearly Mean
AA
CC
F
BB
J F M A M J J A S O N D J
WAVE DIRECTION (θ')
Mean monthly θ' (degrees)
Yearly Mean
F
CC
AA
BB
J F M A M J J A S O N D J

FIG. 3:14

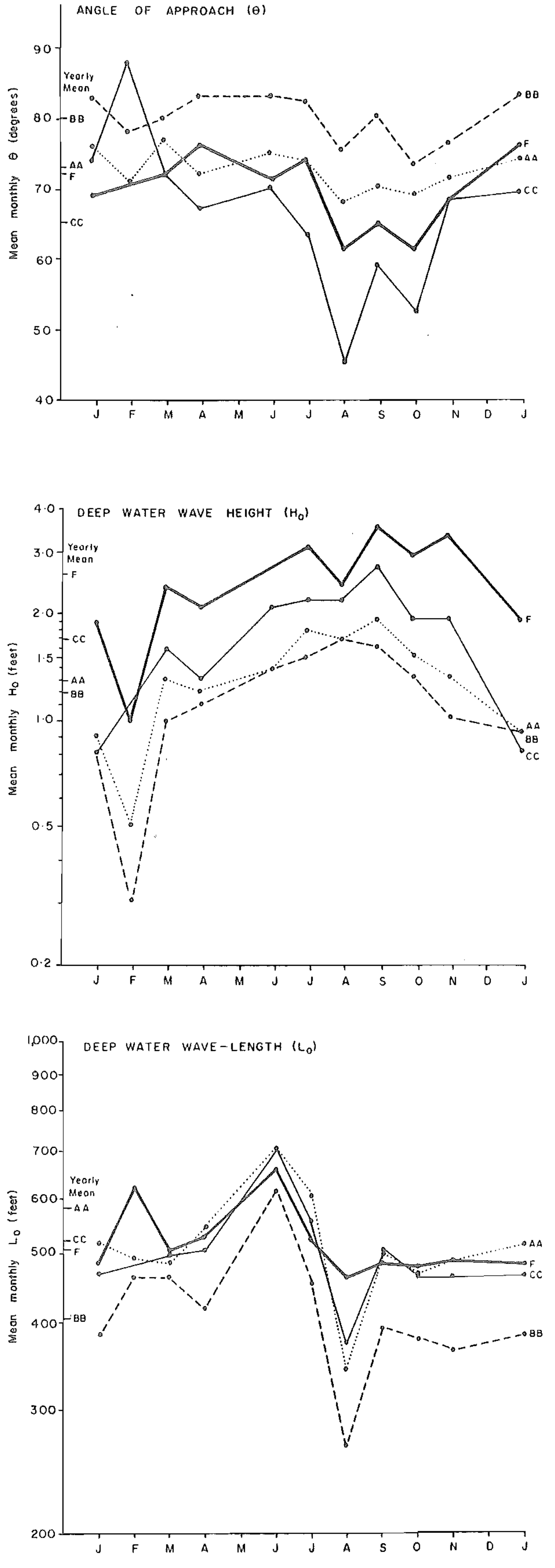
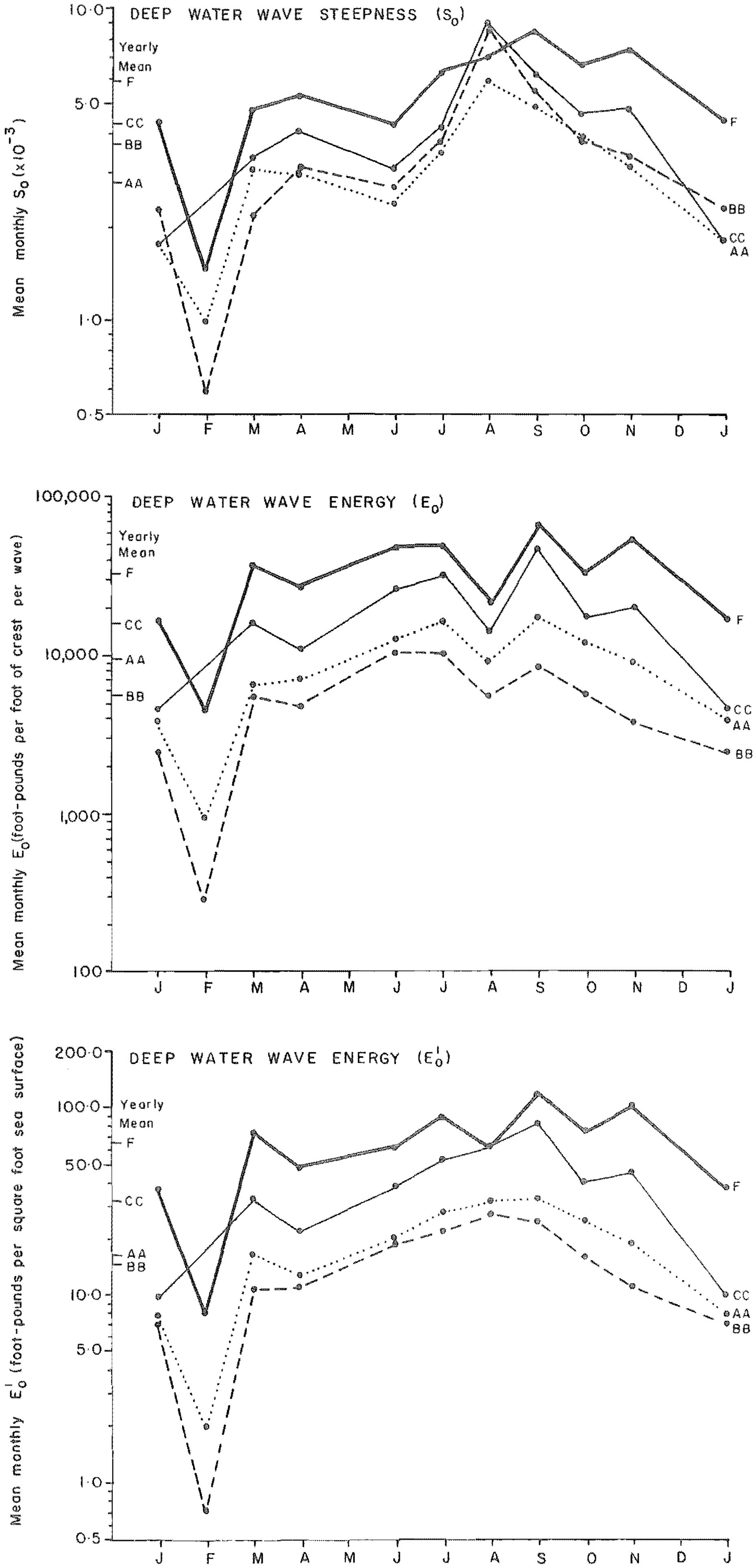

ANGLE OF APPROACH (θ)
Mean monthly θ (degrees)
Yearly Mean
BB
AA
F
CC
DEEP WATER WAVE HEIGHT (H_0)
Mean monthly H_0 (feet)
DEEP WATER WAVE-LENGTH (L_0)
Mean monthly L_0 (feet)
J F M A M J J A S O N D J

FIG. 3:15



DEEP WATER WAVE STEEPNESS (S_0)
Mean monthly $S_0 (\times 10^{-3})$
Yearly Mean
F
CC
BB
AA
10·0
5·0
1·0
0·5
J F M A M J J A S O N D J
DEEP WATER WAVE ENERGY (E_0)
Mean monthly E_0 (foot-pounds per foot of crest per wave)
100,000
10,000
1,000
100
DEEP WATER WAVE ENERGY (E_0^1)
Mean monthly E_0^1 (foot-pounds per square foot sea surface)
200·0
100·0
50·0
10·0
5·0
1·0
0·5

As would be expected, the deep water wave height and deep water wave-length curves are very similar to those for breaker height and period (Figure 3:14). The angle of wave approach is only partially related to wave direction since the orientation of the shoreline also plays a part. Figure 3:14 shows that waves tended to approach the shore more obliquely during the months between July and October. This effect is most noticeable at CC, less so at the other stations. As Figure 3:13 shows, this cannot be explained simply by a higher incidence of southerly waves at CC during this period. Northerlies also contributed substantially; otherwise the mean monthly wave direction curve for CC (Figure 3:13), would show a southerly peak during these months. It has already been demonstrated (Figures 3:2 and 3:5), that this part of the coast is unusually open to waves coming from many directions.

The steepness and energy curves (Figure 3:15), show higher than average values from July to November. The steepest waves occurred at all stations during the winter months of August and September, and have values between 0.008 and 0.009 at CC, F, and BB. Waves at AA however, were flatter than this. The highest energy waves, both per wave, and considered on the basis of total energy per square foot of sea surface, occurred during the month of September.

Day to Day Process Changes

During the course of the fieldwork it became obvious that, if it were possible, daily measurement of all the process and response variables at all of the stations was likely to yield a data set amenable to the detailed examination of short-term beach modification. During the latter part of the field season, when the measuring techniques had reached a zenith of efficiency, an intensive assault was made on data collection both for the processes and for the responses. Except for an unfortunate gap of four days, an uninterrupted run of eighty-three days of data was accumulated from September 9 to November 30.

Large scale changes take place quite rapidly on this section of coast and the process data tends to be quite "noisy". By trial and error, three-day moving averages were found to suppress this just sufficiently to make trends in the data recognizable. Curves for breaker height, wave period, and wave direction at each of the four stations are given in Figures 3:16 and 3:17. Interpolation was resorted to to fill the four day gap in October.

No attempt has been made to mathematically

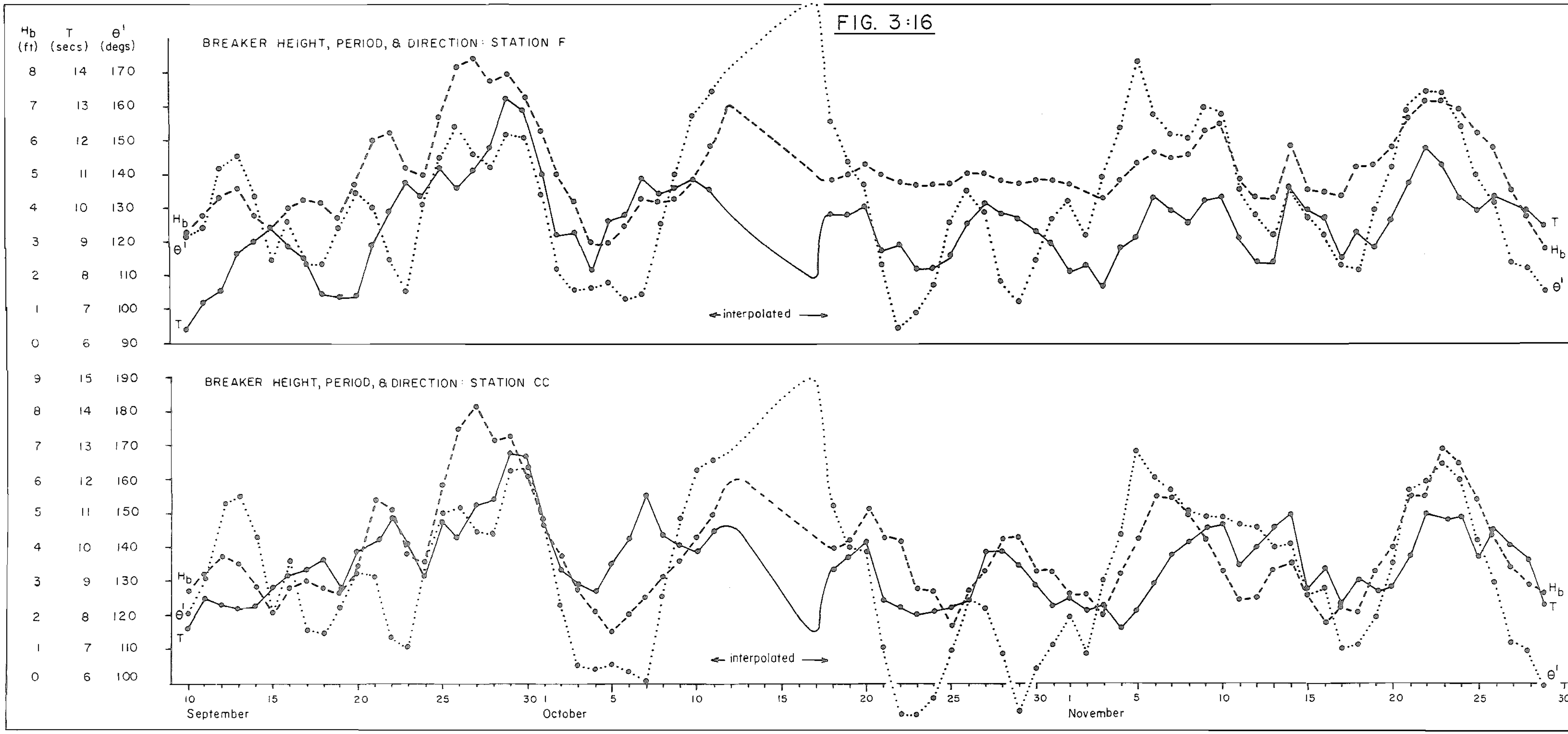
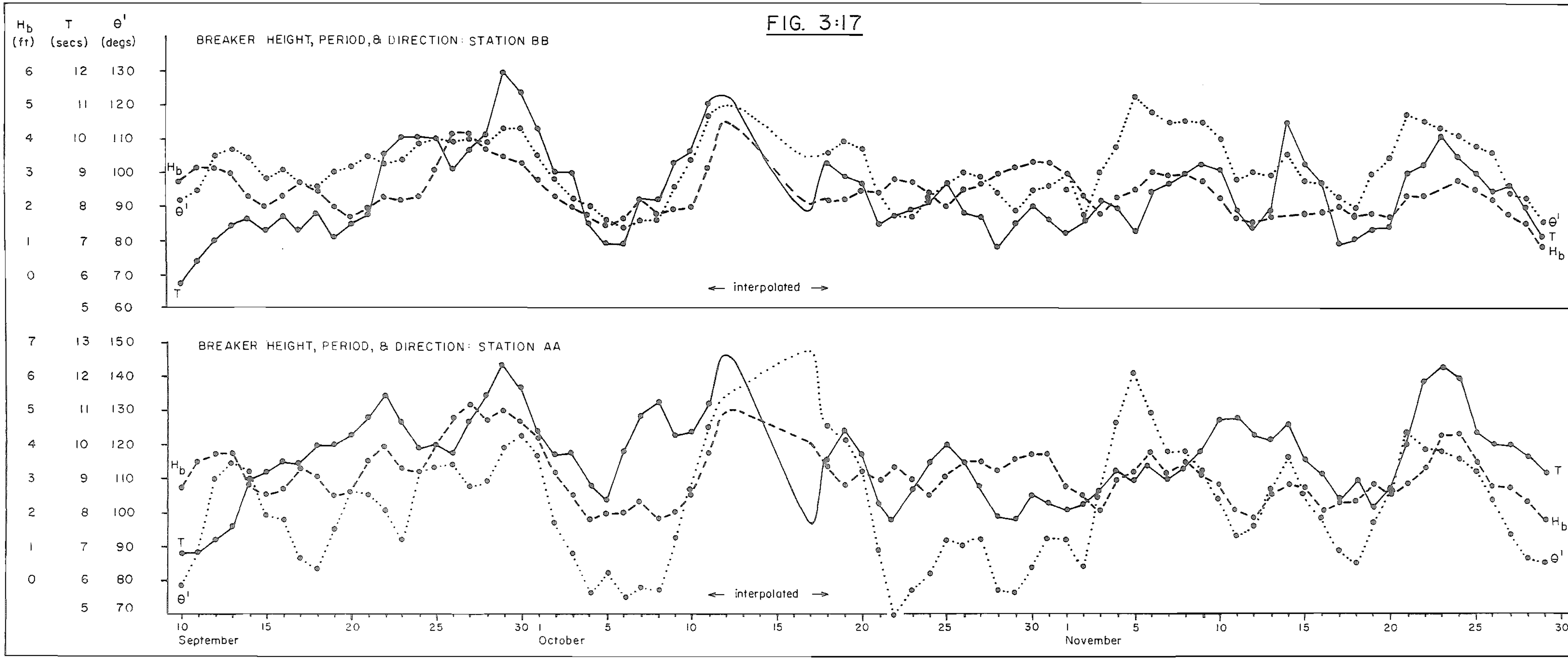


FIG. 3:16
BREAKER HEIGHT, PERIOD, & DIRECTION: STATION F
BREAKER HEIGHT, PERIOD, & DIRECTION: STATION CC
H_b (ft)
T (secs)
θ' (degs)
interpolated
September
October
November

FIG. 3:17


BREAKER HEIGHT, PERIOD, & DIRECTION: STATION BB
BREAKER HEIGHT, PERIOD, & DIRECTION: STATION AA
H_b (ft)
T (secs)
θ' (degs)
← interpolated →
September
October
November

separate the curves into their component frequencies. They are presented for qualitative assessment only. The first noticeable characteristic is a primary cycle having a wave-length of about seventeen days. Figures 3:16 and 3:17 show at least four major peaks in process intensity at all stations on September 28, October 13, November 5, and November 23. This periodicity is especially noticeable at the two southern stations but the amplitude of the cycle appears to become attenuated towards the north, especially at BB. Superimposed on the seventeen day cycle are minor variations lasting two to three days. These shorter cycles have about the same amplitude at all of the stations. It is suggested that had the remaining six process variables been plotted in the same way, the same cycles described above would also be evident.

Three-day moving averages of two of the derived variables have also been plotted for each station. Daily variation in wave steepness (Figure 3:18), and wave energy per square foot of sea surface (Figure 3:19), show the same primary and secondary cycles as do breaker height, period, and direction, and additionally, because the curves for each station are shown together, it is easy to see individual differences in process activity between the stations. Figures 3:16 and 3:17 show

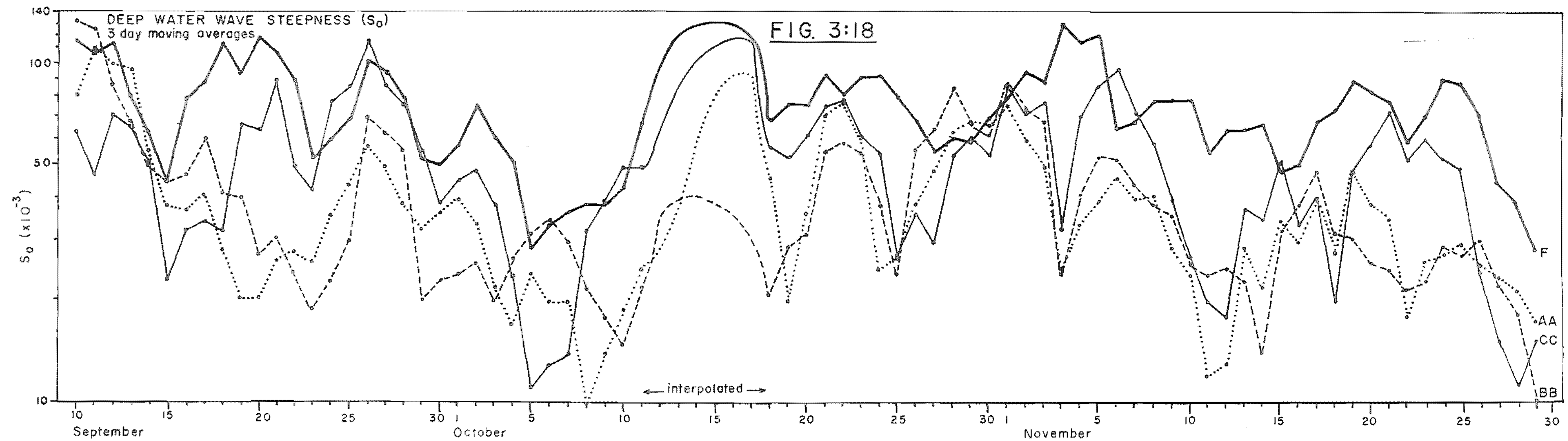


FIG. 3:18

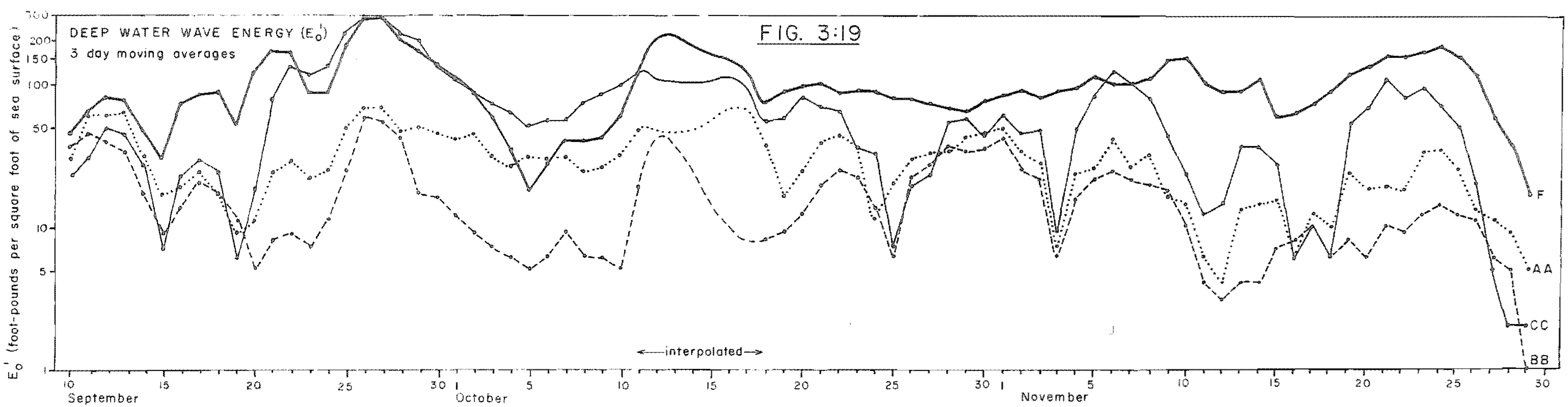


FIG. 3:19

that the processes at any one station tend to change more or less in phase. It is also of some interest to discover whether single process variables also change synchronously at all stations. Figures 3:18 and 3:19 show that this is not always the case. The individualistic behaviour of steepness and wave energy at F is often at variance with conditions elsewhere. Figure 3:19 shows that not only is wave energy consistently higher at F but also that it is less affected than the other stations by periods of relative quiescence. On October 25, November 3, and November 17, the energy values were low at all other stations. On these dates at F, wave energy either increased or remained steady. Figure 3:18 shows that the steepness values tell the same story.

Process Characteristics in the Context of Other Coastal Studies

Both the processes and the responses of this study constitute a selection of dynamic variables that appertain to the physiographic changes taking place on the Hapuku Delta. The responses however, are more closely bound by the unique sedimentological features of the study beaches. This is not true of the marine environment which has more global uniformity, and where parameters similar to the ones used in this thesis on the Hapuku coast, have also been examined elsewhere. It is therefore apposite to briefly consider the wave processes of this study in the perspective of other relevant coastal research.

McLean (1971) took a series of measurements of breaker heights along the Kaikoura coast. Although only twelve observations on an average of one per month were made at each station, for the stretch of coastline around the Hapuku Delta, his results are broadly similar to those of this study. The only difference of note is that the present study has a higher mean value and a greater range in the values of breaker height near the mouth of the Hapuku River.[1] However this is not unusual in view of the large difference in the sampled observations of the two studies.

Not surprisingly, there are also a number of similarities in the characteristics of the waves off the Hapuku Delta and waves that have been studied elsewhere on the east coast. Pickrill (1973) notes that wave directions in the north-east of South Island are bimodally distributed and have a north-

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[1]McLean found a mean of 3.1 feet, and his observations ranged from a minimum of 1.8 feet to a maximum of 5.0 feet. The corresponding values for this study are 4.4 feet, 1.0 and 10.0 feet.

west or north component, and another south or south-east component. Kirk (1969) also found that bi-modality was a feature of the waves in Canterbury Bight. The breaker heights had a primary mode of 4.3 feet and a surprisingly high secondary mode, associated with southerly storm waves, of 10.0 feet. Nearer to the area which is the concern of this study, Kirk (1970) showed that the two modal wave directions (southerlies and north-easterlies) were strongly correlated with wave period, being associated with periods of 11.0, and 7.0 to 8.0 seconds, respectively.

The wave steepness values of this study are low compared with those usually quoted in the literature. Although it is difficult to make direct comparisons with the physical conditions obtaining in other studies, the steepness of the Hapuku waves is such that they would be considered almost overwhelmingly constructional on the foreshore. Only at CC and F, where So occasionally exceeds 0.02, is the value high enough to be regarded as destructional on the beach. It will be shown later however, that wave steepness is a rather feeble predictor of whether the study profiles are in an erosional or a depositional phase.

As regards the steepness values at other locations in New Zealand with comparable open sea exposures to those of this study, Kirk (1967) notes a range of So from 0.0012 to 0.0300 in Canterbury Bight, and Burgess (1968) calculated mean monthly steepness values in Pegasus Bay that ranged from a low of 0.005 in May, to 0.015 in January. Both these examples are comparable to the values found for the Hapuku region.

The seasonal variations in the wave characteristics are also in substantial agreement with those of other New Zealand studies. Hodgson (1966) noted that in summer off the Otago Peninsula, breaker heights were lower and wave periods shorter than they were in the winter. Kirk (1967) found a similar seasonal distribution in Canterbury Bight, and noted as well the predominance of north-easterly wave conditions in summer, and south-easterlies in winter. Similarly, Burgess (1968) testified to the flatter, north-easterly waves in summer in Pegasus Bay.[1]

Summary

Nine process variables have been defined for the study. They are: breaker height, wave period, wave direction, angle of wave approach,

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[1]Although he detected no seasonality in breaker height.

deep water wave height, deep water wave-length, wave steepness, total energy per wave, and total energy per square foot of sea surface.

The wave climate in the study area has been described for the year. Distribution-free statistical methods were shown to be superior to parametric techniques for representing the process features. The following distributional characteristics are the most notable at each station. CC receives waves from a wider directional range than the other stations. Most of them arrive from directions other than the shore-normal direction. F has the highest, steepest, and most powerful waves of all the stations. Both AA and BB receive waves of less height, and energy than either CC or F in spite of the fact that AA is the most exposed station on the coast. BB is very sheltered and only receives the lower, less powerful waves. Waves at BB are also unusual in that they have very short periods and wave-lengths.

Along shore, the most prominent feature is that the waves break more and more shore-normally from the south to the north.

In general, breaker height, wave period, and wave direction can be said to show a high degree of functional inter-relationship, and higher breakers are inter-related with longer period waves.

Higher breaker heights are also interdependent with southerly waves, but the southerlies do not necessarily have significantly longer periods than other waves.

Although both wave period and wave-length showed appreciable variation from month to month throughout the year during the study, waves at all stations tended to be higher, steeper, and have longer periods and greater energy during the winter months. During the summer months, the reverse was true.

Day to day variation of the three variables measured in the field revealed two periodic cycles in process intensity. The major cycle was approximately seventeen days long. A minor cycle having a period of about three days also occurred. Both cycles could be seen at all stations, but the seventeen day cycle was less prominent at the two northern stations. Steepness and wave energy also showed a similar periodicity. Daily process variation tended to increase and decrease in phase at all stations, except at F where wave action seldom dropped in intensity to the low levels occasionally reached at the other three profile locations.

In the context of other coastal research, the wave characteristics of this study are similar both distributionally, and in terms of seasonal variation, to those described by previous workers on the east coast of South Island. On a global scale, the most distinguishing feature of the waves is that they appear to be flatter than those of most other studies overseas.

CHAPTER IV

THE RESPONSES

In the same way that the previous chapter described the processes, this chapter is concerned with a description of the spatial and temporal characteristics of selected response variables. In the interests of organizational uniformity and ease of comparison, the treatment of response description parallels as much as possible, that of the processes. However, a thorough treatment of the responses and their interaction with one another merits considerably more attention than do the processes. There are several reasons for this. Beach responses are less well understood both theoretically and empirically than is wave motion. Also, as has already been pointed out, the responses operate within a sedimentological framework that is not only unique to the study area but is also extremely diverse in physical character. The basic principles of shallow water wave theory on the other hand, are more universally applicable and while complex, are nevertheless better understood in terms of physical laws. Finally, of essential importance in this work, is the question of how the waves affect the beach, not how nearshore topography affects the shallow water wave characteristics. In consequence, this chapter at times delves into specific aspects of response behaviour in rather more detail than has been done with the processes.

First, the main features of the responses at each station are described for the year, and the similarities and differences between stations are compared. This is followed by a discussion of the sweep zones or "envelope curves" at each station and their textural attributes. An investigation of the functional relationships between the response variables follows this. Next, attention is directed to examining the temporal variation of the responses. This is done at three scales; day to day changes, month to month changes, and variation in the responses over a long term (thirty year) period. A program of nearshore sounding and sampling is described and finally the descriptive evidence from all the responses is used to present an explanation of how and why sediment is transported around the delta. The chapter ends with a summary.

The Response Variables

Five response variables are used in this study, and as for the processes, the methods used for measuring each of them have been described in detail in Chapter II. The response variables are:

(1) Gains (and losses) of sediments to the beach face

(2) Foreshore texture

(3) Foreshore slope

(4) Shoreline position

(5) Degree of cusp development.

Characteristics of the Responses at Each Station

Figure 4:1 shows the important features of foreshore slope, foreshore texture, and shoreline position at each station for the entire year. Histograms for gains and cusps are not shown. No consistent year-long sample of cusps exists, and a gains histogram is not shown because the shoreline position is considered to be a better measure of addition and removal of beach sediment, than absolute differences in volume between the profiles. For one thing, the shoreline position is less influenced by cusp migration across the section at the top of the foreshore, and for another, its use avoids the inaccuracies involved in extrapolating the volumetric change of some of the profiled sections down to the twenty-one foot elevation, something that occasionally had to be done when the surf was high. Additionally, as Burgess[1] points out, net volumetric

[1]Burgess, J.S., 1968; p.32.

change on the beach is a rather poor indicator of topographic change, because when material is eroded from high on the profile and then redeposited lower down, the net volumetric change often does not reveal this.

The sample from which the histograms are constructed is a six day stratified random sample, similar to that of the processes, and was taken from the data set of all days on which profiles were measured (Appendix 2:1). The sample size at each of the stations is as follows: for CC, n = 32; for F, n = 33; for AA, n = 24; and for BB, n = 32. The mean, median, standard deviation and coefficient of variation[1] are also given with each of the histograms in Figure 4:1, and Figure 4:2 shows how these sample statistics change from station to station.

CC has a relatively fine textured foreshore with particle sizes ranging from -4.0 phi to -1.5 phi. The mean size is -2.5 phi, on the small end of the pebble category in Wentworth's classifica-

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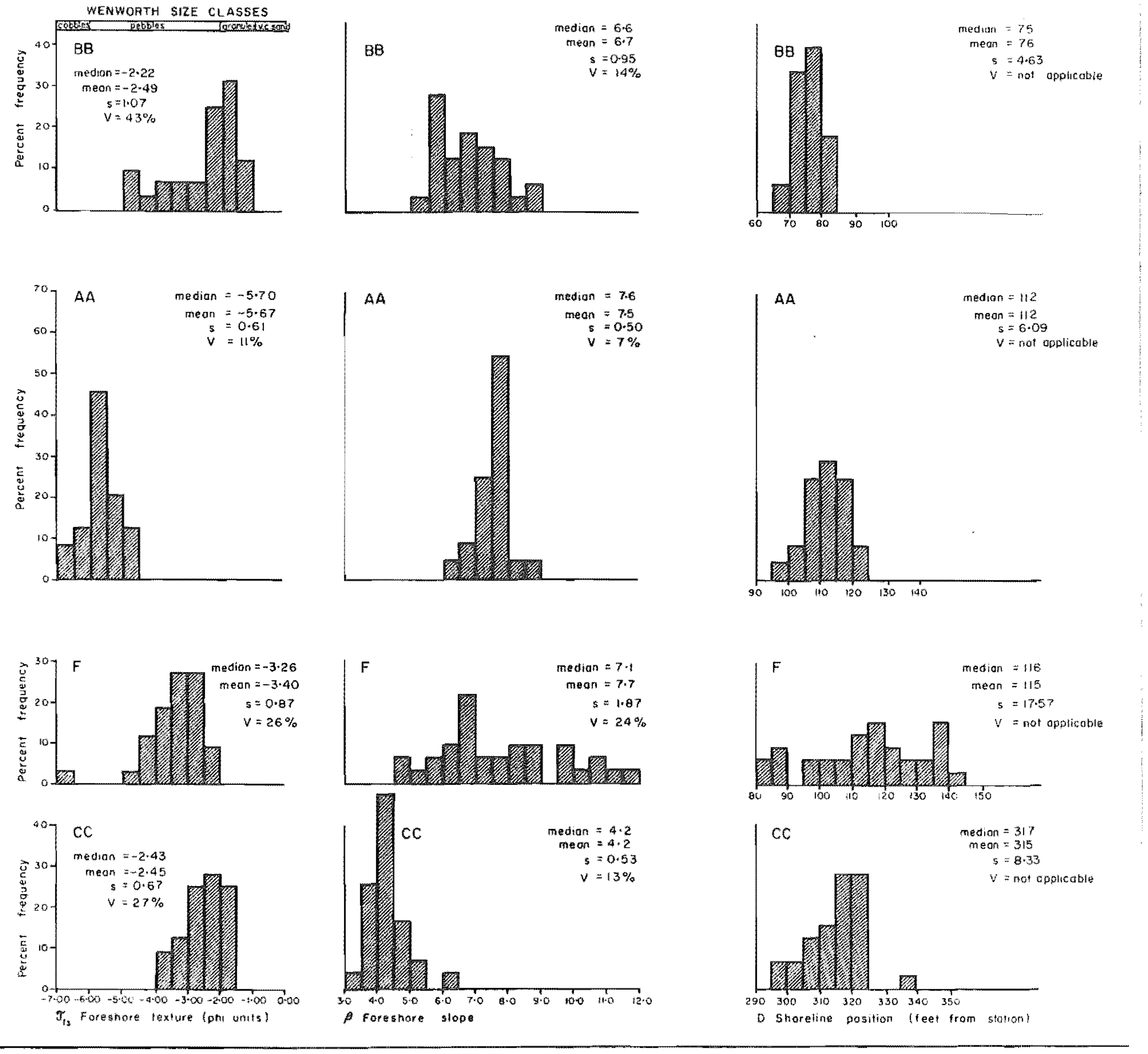
[1]Since the distance from the station hub to the shoreline varies from profile to profile, the calculated coefficients of variation are meaningless for the four histograms showing shoreline position. In these cases, the standard deviations can be used both as absolute and relative measures of variation about the mean.

FIG. 4:1


WENWORTH SIZE CLASSES
cobbles
pebbles
granules v.c. sand
BB
median = -2·22
mean = -2·49
s = 1·07
V = 43%
BB
median = 6·6
mean = 6·7
s = 0·95
V = 14%
BB
median = 75
mean = 76
s = 4·63
V = not applicable
AA
median = -5·70
mean = -5·67
s = 0·61
V = 11%
AA
median = 7·6
mean = 7·5
s = 0·50
V = 7%
AA
median = 112
mean = 112
s = 6·09
V = not applicable
F
median = -3·26
mean = -3·40
s = 0·87
V = 26%
F
median = 7·1
mean = 7·7
s = 1·87
V = 24%
F
median = 116
mean = 115
s = 17·57
V = not applicable
CC
median = -2·43
mean = -2·45
s = 0·67
V = 27%
CC
median = 4·2
mean = 4·2
s = 0·53
V = 13%
CC
median = 317
mean = 315
s = 8·33
V = not applicable
Percent frequency
Foreshore texture (phi units)
β Foreshore slope
D Shoreline position (feet from station)

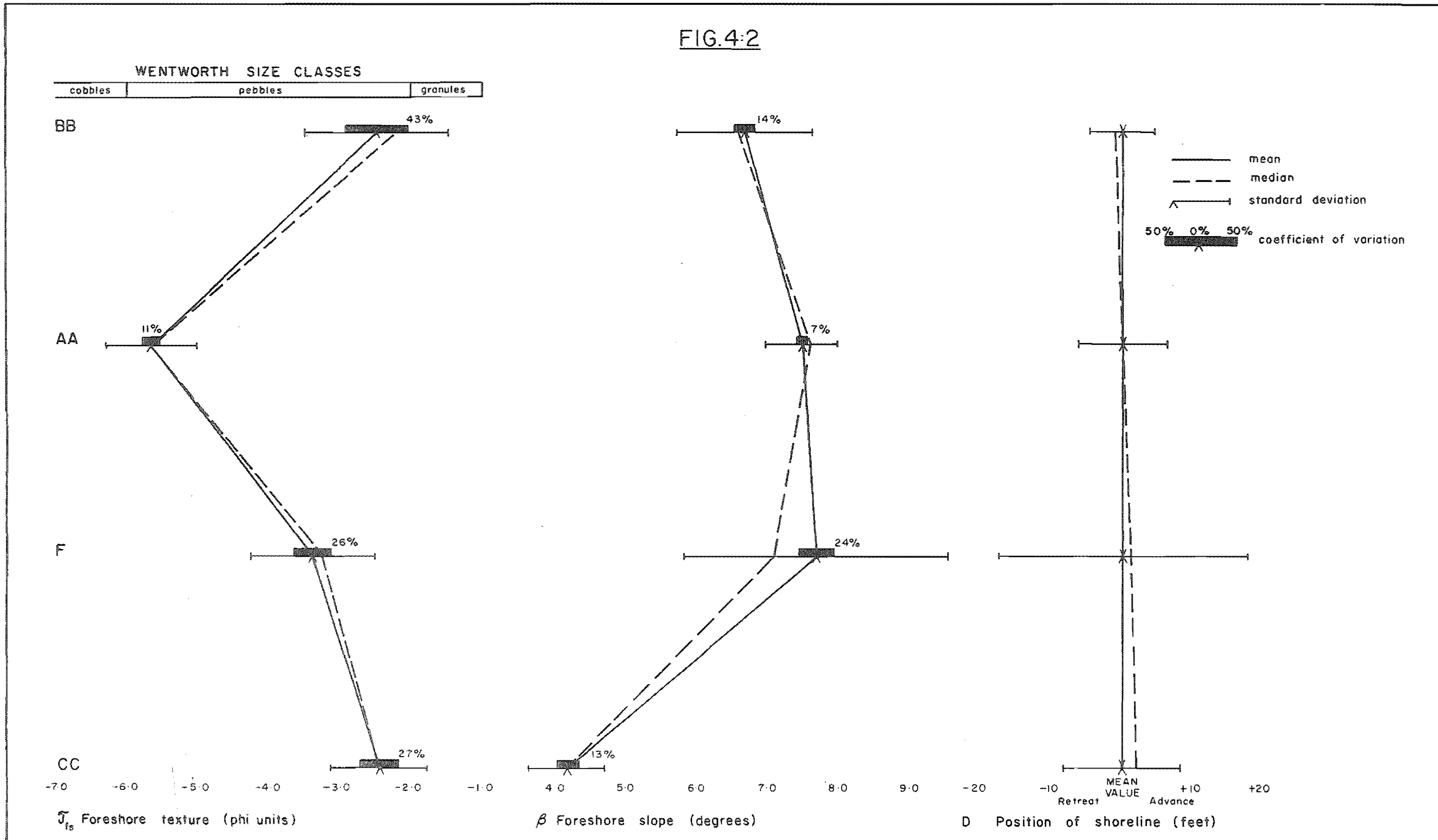


FIG. 4:2
WENTWORTH SIZE CLASSES
cobbles
pebbles
granules
BB
AA
F
CC
43%
11%
26%
27%
14%
7%
24%
13%
mean
median
standard deviation
50% 0% 50%
coefficient of variation
-7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0
4.0 5.0 6.0 7.0 8.0 9.0
-20 -10 MEAN VALUE +10 +20
Retreat
Advance
$\mathcal{T}_{fs}$ Foreshore texture (phi units)
β Foreshore slope (degrees)
D Position of shoreline (feet)

tion. The foreshore slopes at CC are flat, ranging from 3.0 to 6.5 degrees, and close to fifty per cent of the time the slopes are within a half of a degree or so of the mean value of 4.2 degrees. The mean position of the shoreline is three hundred and fifteen feet from the base station, and is skewed left,[1] showing that most of the time, the shoreline position is seaward of its mean value for the year. The standard deviation from this position is about eight feet.

The foreshore texture at F has a mean value of -3.4 phi in Wentworth's pebble class, but occasionally the texture is much coarser than this, ranging up to a size of -7.0 phi in the cobble category. Foreshore slopes range all the way from 4.5 degrees, up to 12.0 degrees with a mean value of 7.7 degrees. There is a prominent positive skew to the slope histogram at F, showing that for most of the year foreshore slopes are flatter than their mean value. Also of note, is the wide variability of slope values about the mean at this station (Figure 4:2). The mean shoreline position is one hundred and fifteen feet from the base sta-

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[1]Skewness, as already mentioned with reference to the processes, can be inferred from the relative positions of the median and mean (Figure 4:2).

tion and there are two modes to the distribution, one from one hundred and ten feet to one hundred and twenty feet from the station, and the other from one hundred and thirty-five to one hundred and forty feet. The bimodality of this distribution is the main reason that the shoreline positions are much more widely dispersed about the mean than those of other stations.

AA has a coarse textured foreshore, with a mean grain size of -5.7 phi, towards the coarse end of Wentworth's pebble classification. Figure 4:2 shows that it is also texturally anomalous in that it has much the coarsest sediment of all the profiles. The small standard deviation and coefficient of variation show that it is also more consistently coarse, both in absolute and in relative terms, compared to the other stations. Slightly more than twenty per cent of the time the foreshore texture falls within the cobble category. The slope of the foreshore at AA has a mean value of 7.5 degrees and this is quite flat compared with the other profiles. Over fifty per cent of the time, slopes are within half a degree of this value, a very small variation compared with the other stations. The mean position of the shoreline is one hundred and twelve feet from the station with a standard deviation of only six feet from this point.

The foreshore at BB has a mean particle size of -2.5 phi in the small pebble class, but the distribution is strongly skewed to the left with a proportionately higher number of occurrences in the fine granule category. It is also of interest to note that the range of grain sizes on the foreshore at BB, is greater than anywhere else (Figure 4:2). The foreshore slope angles have a mean of 6.7 degrees, and here too the distribution is skewed, with foreshore slopes flatter than the mean occurring more frequently than those steeper than the mean. The mean shoreline position is seventy-six feet from the station, and varies less shore-normally than those at other profile sites.

Alongshore Variation in the Response Variables

Figure 4:2 shows that both the mean and median foreshore textures get progressively coarser from station CC in the extreme south to station AA. Further north, towards BB, the foreshore once again becomes finer.

Mean foreshore slope increases rapidly with distance from 4.2 degrees at CC in the south, to F, the next station to the north, and, with a mean foreshore slope of 7.7 degrees, the one with the steepest foreshore on the delta (Figure 4:2). Further north, from F to AA, and from AA to BB, it decreases more slowly, with the mean value at BB of 6.7 degrees being still about one and a half times as steep as the foreshore at CC in the extreme south.

As pointed out in an earlier footnote, shoreline positions cannot be directly compared between stations, but one trend that is noticeable in Figure 4:2 is that of skewness. It can be seen that the shorelines at CC and F are usually seaward of their mean position, implying that only occasionally does severe erosion take place. At BB on the other hand, the distribution is positively skewed, indicating a shoreline position that frequently lies landward of its mean position. This situation suggests that BB is in a state of erosional equilibrium with its environment, and over the long term is probably retreating. The lack of skewness at AA is indicative of long term dynamic stability.

At this point, it is worth digressing from a description of the responses to mention briefly two apparent anomalies in the relationship of the texture and slope curves of Figure 4:2.

The first is that AA, with much the coarsest foreshore textures, does not have correspondingly steeper slopes than the other stations. In view of the well documented association of coarser textures with steeper slopes, this is unusual. Later in this chapter, when the textural attributes of the sweep zone at this station can be considered, the reasons for this will be discussed.

The second anomaly has to do with the size-sorting and foreshore slope relationships at BB and CC. McLean and Kirk (1969) made a study of the relationships between texture, sorting, and foreshore slope on the Canterbury Bight and Kaikoura beaches. To the extent that their findings relate to the investigations of the present study, some worth-while comparisons can be made. They found that over and above the primary control that sediment size has on foreshore slope, poorly sorted material occurs on flatter slopes than does well sorted material of the same mean grain size. Although their data was compiled from individual samples of beach sediment, and the data of the present study represents four composite samples for the year, it is reasonable to expect the same corresponding relationships to exist. Figure 4:1 shows that both CC and BB have essentially the same mean grain size; at CC it is -2.45 phi, and at BB, -2.49 phi. The standard deviations provide a measure of sorting for these two beaches; in the case of BB, the standard deviation is 1.07 phi units, indicating a poorly sorted deposit relative to CC where it is 0.67 phi units. Figure 4:2 shows that the poorly sorted deposits at BB occur on considerably steeper slopes having a mean value of 6.7 degrees, than do the well sorted deposits at CC, which occur on flatter slopes, having a mean of 4.2 degrees. This is not what would be expected, and it is clear that the beach at BB is unusually steep for its grain size and sorting. The probable explanation for this is that in comparison to CC, it is also more protected. McLean and Kirk[1] have noted Wiegel's (1964) observation that protected beaches have steeper slopes than exposed ones, and the over-steepened beach at BB may be one good example of the extent to which exposure influences beach slope.

The final graph in Figure 4:2 shows the standard deviations of the shoreline positions from their mean value for each station. The median values are also shown. The standard deviations can be used as indicators of how mobile each profile is in terms of advance and retreat, relative to the other stations. The least active station is AA, not surprising in view of the extreme coarseness of its foreshore, a feature to be examined in greater detail later. The most active is F,

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[1]McLean, R.F., and Kirk, R.M., 1969; p.138.

and CC and BB advance and retreat about equal amounts during the year.

With respect to the beaches of the Canterbury Bight, Kirk (1967) argues that the flatter foreshore slopes (relative to grain size) are indicative of a state of erosional equilibrium over much of the Bight. Although the grain size/beach slope relationship of the present study will be defined functionally later in this chapter, it would be unwise to use this relationship as an indicator of contemporary conditions of dynamic equilibrium for the Hapuku Delta beaches, because for sediment sizes ranging into Wentworth's pebble, cobble, and boulder categories, there is no accepted documented evidence on beach slope for what constitutes the norm. Moreover, such a universal standard is unlikely to be established, because for the larger grain sizes, the effects of shape and packing become important.[1]

On the other hand, the mean and median shoreline position curves of Figure 4:2 do provide a measure of distributional skewness, independent of both foreshore slope and grain size, and directly related to shoreline advance and retreat, that

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[1]See for example, Bluck, B.J., 1967.

is eminently acceptable as an indicator of conditions of long term dynamic equilibrium at the profile sites.[1] Using skewness as a criterion, Figure 4:2 suggests that profiles CC and F are advancing seawards, profile AA is stationary, and profile BB is being eroded.

Sweep Zones and Textural Variation with Depth

Another way of measuring profile mobility is to plot the "sweep zones" or "envelope curves" at each site. These define the absolute elevation and distance limits within which all of the profiles fall during a particular time period. Because all elevations and distances are represented, the sweep zones have the added advantage of showing what parts of the profile change most and which change least.

Figure 4:3 shows the sweep zones for the year at each station.[2] The figure shows that in

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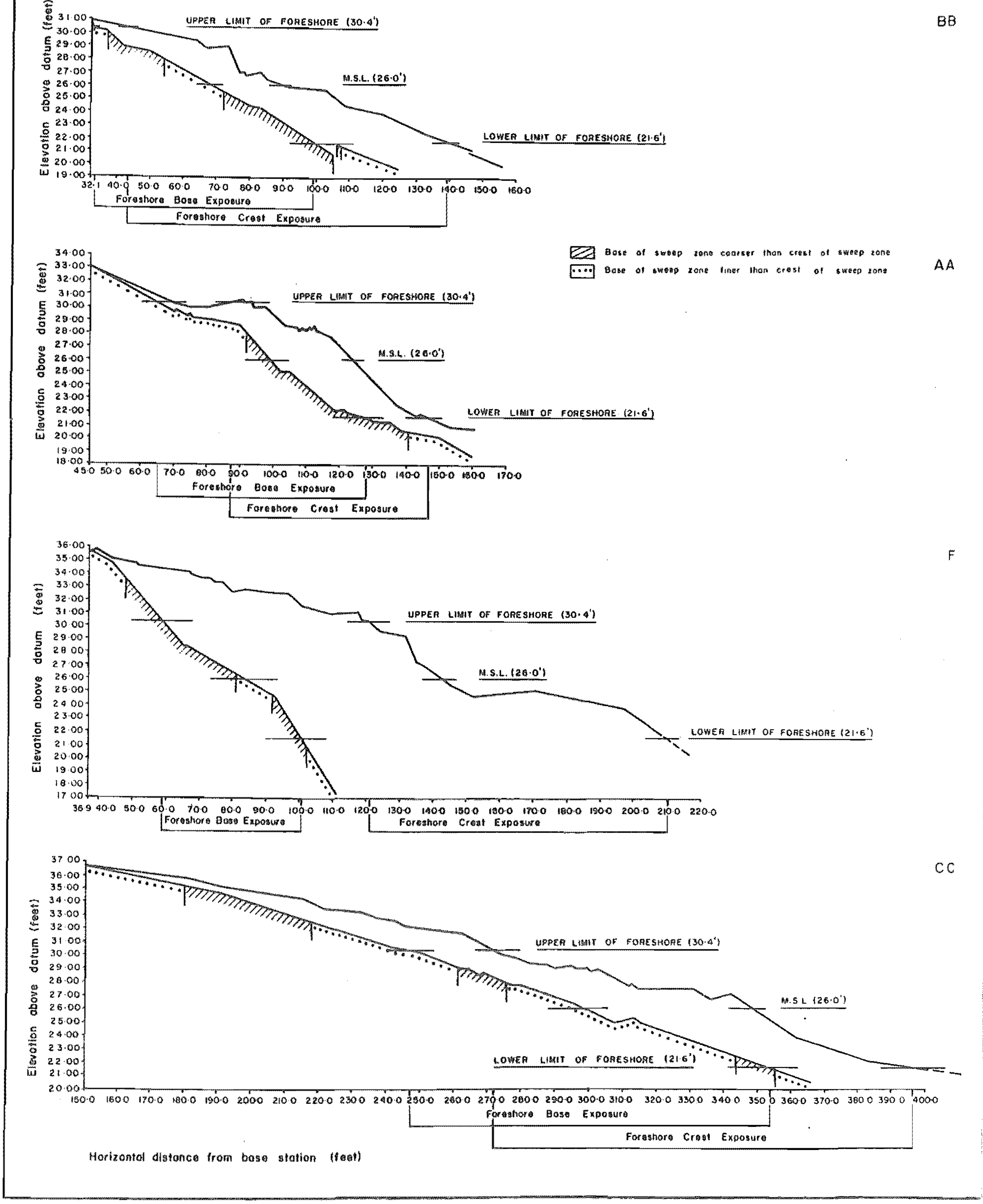
[1]Although proposed here as a superior criterion of long term conditions of shoreline progradation and retrogradation, it is not the only one. Further evidence from air photographs will be introduced later in the chapter.

[2]For this, as for the subsequent analysis in this chapter, the sample consists of all of the days on which profiles were measured, not the observations making up the six day stratified random sample referred to earlier. The sample size at CC is 85, at F, 92, at AA, 28, and at BB, 78.

FIG. 4:3



BB
UPPER LIMIT OF FORESHORE (30·4')
M.S.L. (26·0')
LOWER LIMIT OF FORESHORE (21·6')
Foreshore Base Exposure
Foreshore Crest Exposure
AA
Base of sweep zone coarser than crest of sweep zone
Base of sweep zone finer than crest of sweep zone
F
CC
Elevation above datum (feet)
Horizontal distance from base station (feet)

terms of volume of material moved shore-normally over the period of the year, profile F is by far the most active. This substantiates a similar conclusion reached earlier in this chapter with reference to the standard deviation of the shoreline position at F, shown in Figure 4:2. The reason that F is more active than the other profiles is not entirely due to sediment supply from the Hapuku and subsequent dispersal by waves. The size of the material also plays a part in determining profile mobility, with coarse material being more mobile than fine (Shepard, 1950). For the very large sizes such as those found at AA however, this relationship probably does not hold.

A notable feature of the sweep zone curves is the lenticular bulge in the foreshore section of the zone at AA. Large imperfectly formed cusps are a feature of this region. They usually trend north-east, with their long axes lying obliquely to the shoreline, and the cusp configuration is shifted only by the largest southerly storm waves. At the time that the field data was being collected, it was noticed that there appeared to be a northward migration of the cuspate form. Some investigations were carried out to determine whether it was just the surface configuration that was changing, or whether beach material was actively being transported along shore. The results of these are inconclusive. Under some conditions, labelled cobbles and boulders in the foreshore zone did move a short distance northwards. The maximum distance moved was of the order of three feet during four days of protracted southerly storm waves. Under the influence of similar wave conditions, an injection of 1,800 blocks disappeared to the north overnight. Shingle deposits on the beach were never observed to move southwards. Yet there is little evidence, either from the aerial photography or from the sounding survey to suggest that transport of large amounts of sediment is a frequent enough occurrence at AA to produce major, long term changes in either the plan shape of the shoreline or in the submarine contours.

Whether or not a beach recedes, advances, or is stationary, under wave attack, depends ultimately upon how easily the individual particles are moved. This in turn, is largely a function of size, although shape and density are also important. The analysis of the profile data has so far focused only on the vertical range of profile positions. Textural measures were also included in the profiling method though, and have been quantified (Chapter II). It is possible to use the textural indices in conjunction with the sweep zones in a way which will permit textural change with depth to be described. This line of inquiry has particular relevance to answering the question of whether the surficial foreshore sediments are homogeneous with depth or whether they represent a depositional veneer of fine material in motion over a coarser structural foundation, as suggested by McLean (1970). If the latter is true, then it is possible that the coarser substructure is potentially effective in preventing shoreline retreat.

It should be remembered, of course, that many other factors, including hydraulic forces and the orientations of the individual grains are also involved, and the existence of large boulders alone may not prevent coastline erosion. For example, the slope of the foreshore will have an effect. Under given conditions of incident wave attack and foreshore grain size, a steeper slope will restrict the shore-normal distance over which the swash can operate. Not only does this mean that wave energy will be more powerful per unit area because it is concentrated in a narrower zone, but also that since the foreshore percolation rate remains fixed, the greater volume of water per unit area on the beach can easily overtax the percolation capacity of the foreshore so that the bed material becomes saturated. P.H. Kemp has demonstrated both from model studies (Kemp, 1961) and on natural shingle beaches (Kemp, 1963) that such a condition also results from significant increases of the swash period relative to the prevailing wave period, and Kirk (1970) found a similar result when he analyzed the flow structures in the swash-backwash zone of sand-shingle beaches similar to some of the ones in the present study. Both found that a highly saturated bed was one of the characteristics conducive to rapid erosion.

In the same way that the individual profiles were super-imposed to define the limits of the sweep zones, a record of the textural composition of each profile segment contributing to the upper and lower sweep zone curves was compiled. Using the values given in Table 2:3, mean textural indices were calculated at intervals along the crest and base of each sweep zone. The general relationship of base and crest texture along each profile is shown in Figure 4:4 for mean textures calculated every five feet horizontally. The intersections of the upper and lower elevation limits of the foreshore with the sweep zones (Figure 4:3) are also shown in Figure 4:4. The foreshore exposures of all of the profiles at any station can only begin in the range defined by the upper limits of the foreshore, and must end in the range defined by the lower

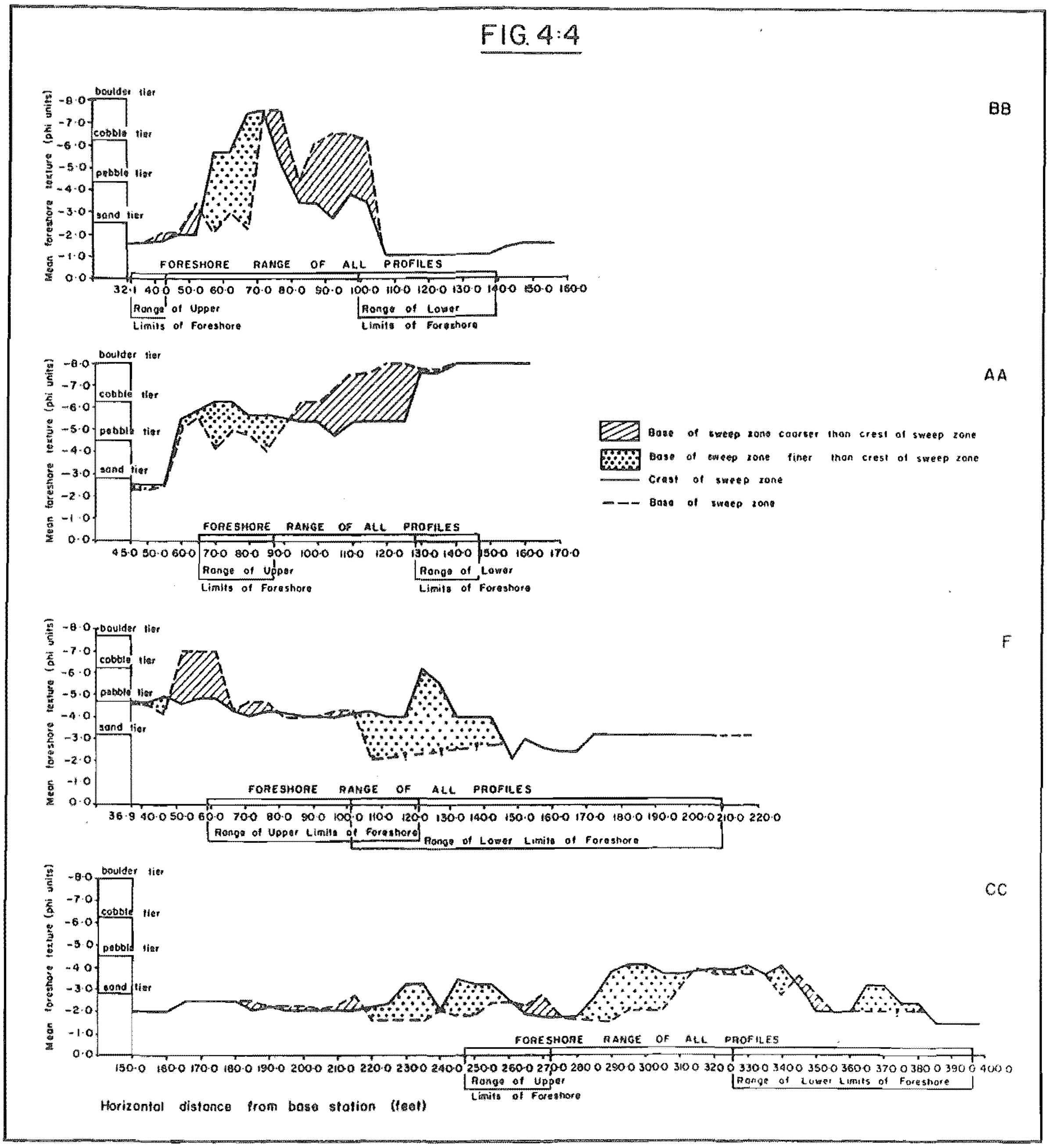


FIG. 4:4
BB
AA
F
CC
boulder tier
cobble tier
pebble tier
sand tier
Mean foreshore texture (phi units)
FORESHORE RANGE OF ALL PROFILES
Range of Upper Limits of Foreshore
Range of Lower Limits of Foreshore
Base of sweep zone coarser than crest of sweep zone
Base of sweep zone finer than crest of sweep zone
Crest of sweep zone
Base of sweep zone
Horizontal distance from base station (feet)

limits of the foreshore.

Figure 4:4 shows that there is considerable textural variation with depth, as well as along the lengths of the profiles. Within the foreshore horizons at both of the northern stations (AA and BB), there is an increase in the grain size of the sweep zone bases with increasing distance from the station. Only on the upper foreshores are the bases finer than the crests.[1] Further seaward than seventy-two feet at BB, and ninety-one feet from station AA, they are considerably coarser. This is interesting, because it implies in both cases that if a coarser substructure exists, it becomes progressively more exposed at increasing distances along the profile.

Even more interesting are the textural differences of the crest and the base at BB. Sediments along the sweep zone crest quickly increase in mean size out to seventy-two feet. Beyond this, there is an abrupt decrease to finer material. In

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[1]It is no coincidence that the stipled areas in Figure 4:4, on all profiles except CC, are where the noses of cusps frequently occur. The sediment composing these is a lag gravel formed when the backwash removes the fines. The smoother silouettes of the bases of the sweep zones (Figure 4:3), testify to minimal cusp development whenever the profiles are in a heavily eroded phase.

other words, with profiles close to their maximum elevation, there is likely to be a mobile zone of relatively fine sediment low on the foreshore, (seawards of seventy-two feet from the station), with the coarser grains lying shorewards of this point. In contrast to this situation, when profile BB is eroded, Figure 4:4 shows that the sediments high on the profile are fine compared to the coarser grains lying closer to the sea. It may not be too presumptuous to suggest at this point that when the beach is in an eroded phase, fine material exists high on the foreshore because it has been taken from the scarp which forms the landward margin of the beach. Because the beach is narrow though, it does not stay there long and the fines are easily moved to lower elevations where they are found after the wave intensity returns to less severe levels.

Something of the same pattern exists at AA. In this case however, Figure 4:4 shows that when the profile is built up, there is very little variation in grain size along its length. Also, there is no erosional scarp on the backshore at AA. It is likely that the finer grain sizes shorewards of ninety-one feet that are present when the profile is eroded, result from wave action cutting through the lag deposits of coarse gravel to expose the finer material beneath. At the same time, lower down on the foreshore it would be expected that some of the relatively fine interstitial grains among the boulders would be removed, and the lower foreshore would be coarsened as at BB.

Another point worth mentioning about AA relates to the width of the sweep zone. It has already been pointed out that all of the sweep zones except AA get progressively wider with increasing distance from the station. Figure 4:3 shows a constriction in the zone at AA beginning on the base at one hundred and nineteen feet from the station, and on the crest at one hundred and thirty-seven feet. Transposing these values to Figure 4:4 shows that for both crest and base, they occur mostly in the boulder tier of the textural classification, near the maximum coarseness values reached by each. For the crest, the mean foreshore texture at this point is -7.7 phi. For the base it is -7.9 phi. To the extent that the narrow sweep zone width is an indicator of lack of foreshore sediment mobility, it would appear that these represent the upper coarseness limits beyond which, even surf generated by the highest storm waves cannot move material at this station. The large boulders at AA are moved more by gravity than by direct wave action. The waves are able to undermine the boulders by removing the interstitial fines which support them, and the boulders then shift downwards to a lower elevation. The net result of this process is the production of a boulder-armoured platform low on the foreshore. This explains the anomalously low foreshore slopes mentioned earlier in connection with Figure 4:2. It will also later be shown that though AA is an example of a profile that is supplied with a very meagre amount of sediment from outside sources, the sheer size of foreshore material effectively prevents shoreline retreat under prevailing wave attack.

At the two southern stations (CC and F), the pattern of textural variation with depth is more obscure. The sweep zone at F is so thick that the foreshore exposure along the crest lies entirely seaward of the basal exposure (Figure 4:3). In consequence, textural comparisons of the profiles between the crest and the base are impossible to make beyond a distance of one hundred and one feet from the station. Between forty-eight, and one hundred and one feet from the station though, the base of the sweep zone is generally coarser than the crest (Figure 4:4) and Figure 4:3 shows that these footages are inclusive of foreshores that relate to the eroded phase of the beach. Textural variation along the sweep zone crest at F is small, though not as small as the variation at AA. Still, like AA, the size range of the surficial sediments of the profiles occurring near the crest of the sweep zone at F is small compared to the range at BB.

The textural changes along the crest and the base of the sweep zone at CC appear to be almost random. Unlike the other profiles there are no areas where a clear distinction can be drawn between the coarseness of the crest and base. The one characteristic that is discernible, is an irregular periodic coarsening of the crest at two hundred and thirty feet, two hundred and forty-five feet, from two hundred and ninety feet to three hundred and forty feet, and at three hundred and sixty-five feet. For the most part, the base of the sweep zone does not conform to this pattern, although there is one profile segment between three hundred and fifteen feet and three hundred and forty-five feet, that does conform to a correspondingly coarser segment on the crest. At CC, these examples of locally coarse irregularities in the profiles are small swash berms. They become size-sorted mainly due to changes in the inter-relationship of grain size (which affects percolation rate), wave action, and swash slope gradient.

The Detection of Statistically Significant Differences in Crest and Base Textures

On the basis of some of the textural variations discussed in the previous section, there seem to be grounds for suspecting that larger grain size is an important characteristic of the foreshore exposures along the sweep zone bases at all of the profile sites except CC. If this supposition can be confirmed it will lend substantial support to the viewpoint that there is indeed a coarse framework to the structure of the delta that may act as a bulwark to shore retreat by wave action.

To investigate this, a mean coarseness index for the foreshore crest exposure and for foreshore base exposure was calculated from crest and base textures sampled every two feet along each of the profiles.[1] To detect a significant difference between these sample means, Student's t-Test could have been used but it presupposes normally distributed samples with equal standard deviations. Figure 4:1 shows that texture is not normally distributed, and comparing the crest and slope curves of Figure 4:4, reveals marked differences in tex-

[1] In the field, textural variations occurring over less than two feet were not recorded.

tural variability, especially at AA. And so, because of the rather restrictive assumptions attending parametric statistical methods, the U-Test[1] was used to decide whether or not the sweep zone bases were significantly coarser than the crests. The results of this test showed that at the ninety-five per cent confidence level, the foreshore exposure of the sweep zone base is significantly coarser at F and BB. At AA there is no significant difference, and at CC, rather surprisingly, the base is significantly finer than the crest.

It can be concluded that at F and BB, a coarser basement does exist to the foreshore sediment structure. At F it is exposed whenever the shoreline retreats to within eighty-three feet of the station (Figure 4:3). Figure 4:1 shows that on a yearly basis, this happens infrequently, less than five per cent of the time, and although shoreline retreat to within ninety feet of the station is by no means unusual, it has already been shown that flatter slopes, associated with profiles close to the sweep zone crest, occur much more frequently at F, than the steeper slopes associated with the base configuration. At BB a coarser substructure also exists and is exposed whenever the shoreline

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[1]Freund, J.E., 1965; p.296.

is eroded to within sixty-eight feet of the station (Figure 4:3). Figure 4:1 shows that the shoreline is within this distance of the station also about five per cent of the time, but it was noted while recording the sweep zone textures, that the base of the zone seaward of the shoreline position was more commonly exposed at BB than at profile F. It will be shown later that this contributes to significant seasonal coarsening of the foreshore at BB.

At AA there is no significant textural difference between the crest and the base of the sweep zone. This may be a statistical consequence of the relatively small size range of the foreshore material, in comparison with the range at other profiles. This feature of the foreshore sediments has already been noted in a general sense in connection with the response characteristics at this station.[1] More specifically, Figure 4:4 shows that of the three northern profiles, over the foreshore exposures of the sweep zone, AA also has the smallest range of textures.[2] Nevertheless, it seems likely, for reasons already discussed, that the

---

[1]See Figure 4:2.

[2]6.6 phi units at BB, 5.0 at F, and 4.0 at AA.

region seaward of one hundred and nineteen feet from AA, is highly resistant to erosion by wave attack.

At CC a coarser base does not exist to the foreshore sweep zone. Indeed, the opposite appears to be true, with the crest having significantly coarser textures on the whole, than the base. The data resources of this study are not detailed enough to explain this abnormality.

Functional Relationships Between Pairs of Response Variables

In many studies there is an opportunity to choose the best units for expressing the variables. Frequently, however, in the absence of evidence to the contrary, one suspects that no attempt has been made to do so. If only the distributional characteristics of a variable are being studied, this is not serious, and in fact, a good case can be made for describing the variable in the units most commonly used. On the other hand, when equations are presented to describe the mathematical dependency of one or more variables upon another, failure to express the variables in forms that maximize the predictive strength of the independent variable is more serious and can produce misleading conclusions. At the very least, the researcher runs the risk of understating the strength of the relationship and in extreme cases this can lead him to the conclusion that no significant relationship exists when, in fact, a good association could be shown if one of the variables had been expressed in a different way.

In some research problems the choice is obvious because either the scatter of data points is reduced or the regression curve is much less complicated when the data is expressed one way than when it is expressed the other. Unfortunately this is not true of process and response measurements gathered from the beach environment where the scatter is considerable, and it is difficult to tell by mere inspection whether the regression is best described by a straight line, a simple curve, or some other function.

A large part of this problem is, of course, overcome by the use of polynomials. Their versatility is such that a reasonable fit to the data will often be obtained regardless of the units used. In most cases, however, this is likely to be a costly benefit, paid for with the superfluous complexity of a multi-term equation, when a simpler one of lower order could have been used, had a data transformation been applied to one of the variables.

This line of discussion has been pursued because it is topical to the consideration of response inter-action. Even a cursory examination of current published work reveals that unlike particle size, for which phi units have justifiably gained wide acceptance (Tanner, 1969), and shoreline position, for which horizontal distance from a datum is the obvious choice, there is no hard and fast rule for expressing foreshore slope. The three most common ways are by:

(a) the vertical angle

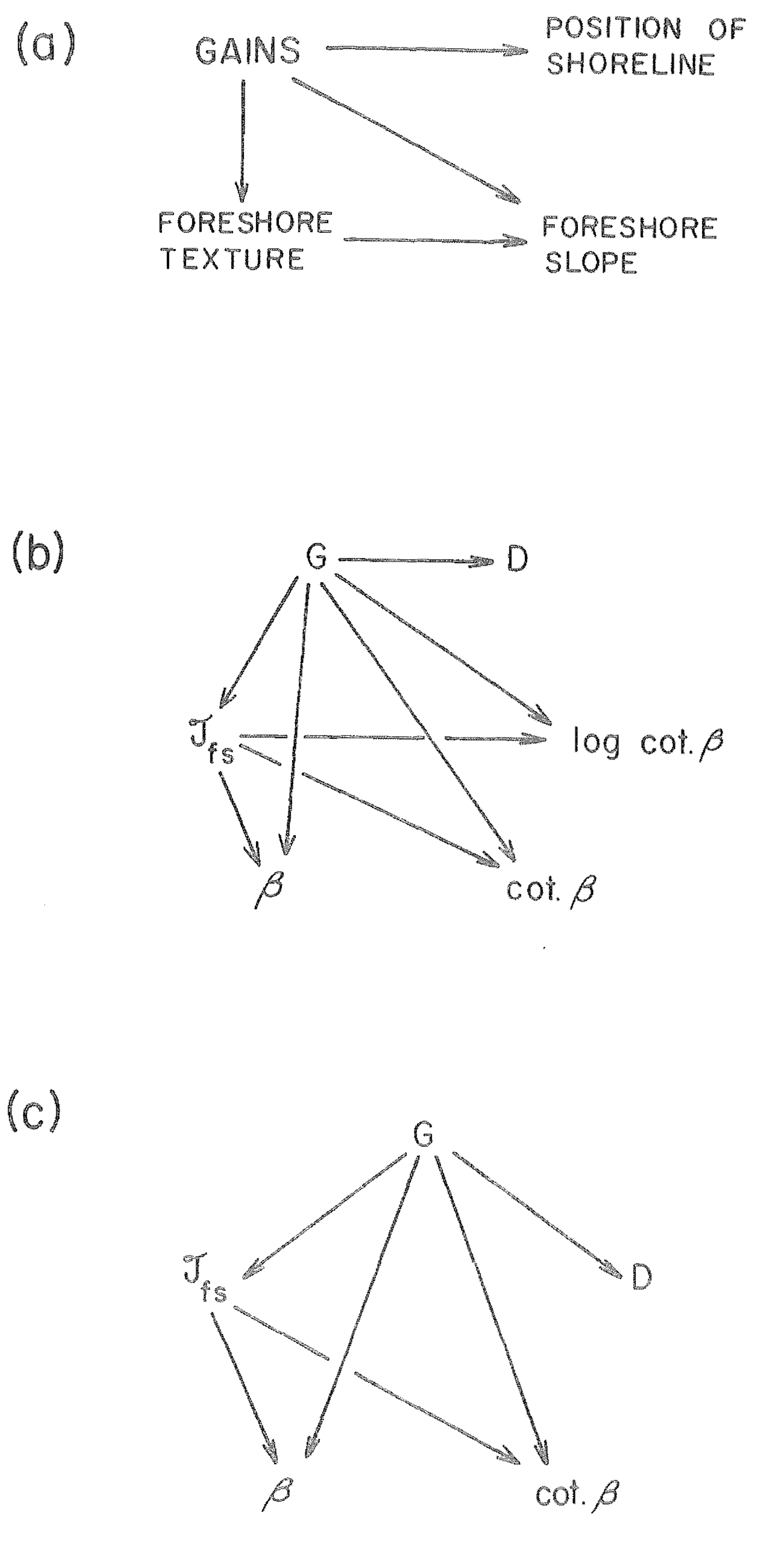
(b) the cotangent of the vertical angle

(c) the logarithm of the cotangent of the vertical angle.

It will soon become clear that the response inter-relations cannot be explained in terms of simple linear equations as were most of the processes. It was felt, therefore, that rather than guess at the most effective way of expressing foreshore slope, and perhaps by guessing wrong, end up with a set of predictor equations festooned with needless terms, it would be better to test each of (a), (b), and (c) above at each profile station so that the one(s) that was least suited to slope description could be eliminated.

Figure 4:5 shows schematically the response variables that were tested. Four inter-relationships seemed worthy of investigation and these

FIG. 4:5


(a)
GAINS
POSITION OF SHORELINE
FORESHORE TEXTURE
FORESHORE SLOPE
(b)
G
D
$\mathcal{T}_{fs}$
log cot. β
β
cot. β
(c)
G
$\mathcal{T}_{fs}$
D
β
cot. β

are depicted in Figure 4:5(a) with the arrows pointing in the direction of the dependent variables.[1] Figure 4:5(b) is identical to 4:5(a) except that foreshore slope has been expressed in the three forms referred to above.

The results of the screening procedure to find the best way of expressing foreshore slope showed that at all stations, either the vertical angle or its cotangent gave the best predictor equations with gains and texture. The logarithm of the cotangent was therefore excluded from further consideration. Figure 4:5(c) symbolizes the six response interactions that were studied.

These six were subjected to the same polynomial correlation and regression program as the three measured process variables. Appendix 4:1 is similar to Appendix 3:2 in the previous chapter, and lists the results of the computer printout from the first order equation to the best fit polynomial for all six response combinations at all

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[1]It is hard to imagine how shoreline position, slope, or texture can influence gains. On the other hand, it is reasonable to assume that the amount of material supplied to the foreshore may have a measurable influence on each of these three variables. Similarly, slope is thought to be affected by texture rather than the reverse. Cusps have not been included because they are considered to be primarily related to changes in the wave processes.

stations. As with the processes, the station, independent and dependent variables, sample size, orders of the polynomials, per cents explained variation, standard errors of the estimate, and F-ratios are given with each response pair. The significance levels and best predictor equations are also shown.

Figure 4:6 is analogous to Figure 3:7 and shows the fifteen best predictor equations along with the per cent variation explained by the independent variable.

Each of the six response combinations depicted in Figure 4:5(c) will be discussed in turn.

Gains versus Foreshore Texture

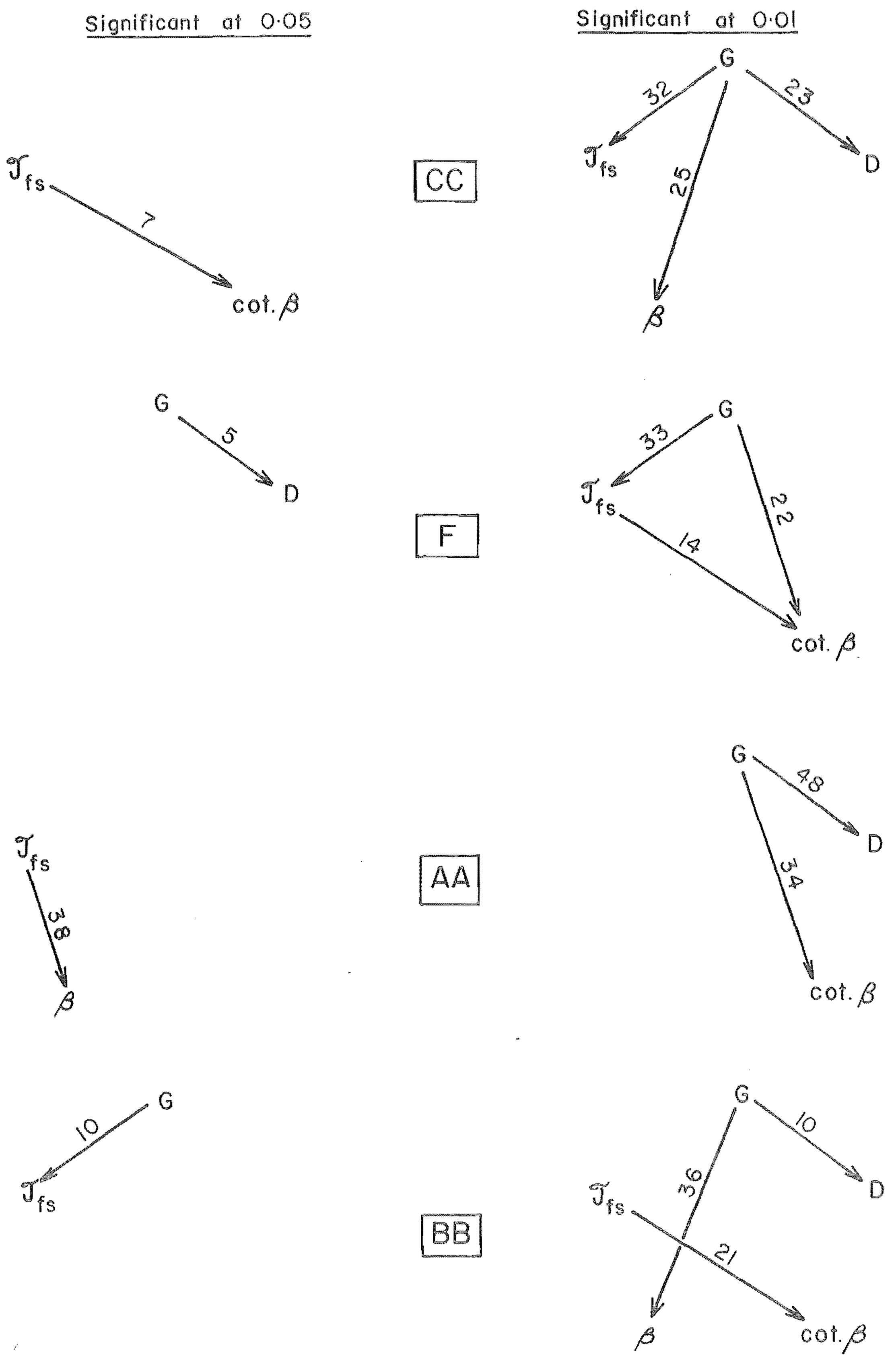
The three best predictor equations are given below.

At CC;

$$\begin{aligned}\mathcal{T}_{fs} = &-2.713 + 0.3189(10^{-3})G + 0.3463(10^{-3})G^2 \\ &- 0.1891(10^{-5})G^3 - 0.7654(10^{-7})G^4 \\ &+ 0.2066(10^{-9})G^5 + 0.5366(10^{-11})G^6 \\ &- 0.6390(10^{-14})G^7 - 0.1235(10^{-15})G^8 \\ &+ 0.6243(10^{-19})G^9 + 0.8189(10^{-21})G^{10}\end{aligned}$$

(explains 32% at .01)

FIG. 4:6



38 percent explained variation of best predictor equation

At F;

$$\mathcal{T}_{fs} = -3.710 - 0.1122(10^{-1})G + 0.4110(10^{-3})G^2 + 0.3148(10^{-5})G^3 - 0.9229(10^{-7})G^4 - 0.2013(10^{-9})G^5 + 0.6552(10^{-11})G^6 + 0.3757(10^{-14})G^7 - 0.1756(10^{-15})G^8 - 0.1291(10^{-19})G^9 + 0.1575(10^{-20})G^{10}$$

(explains 33% at .01)

At BB;

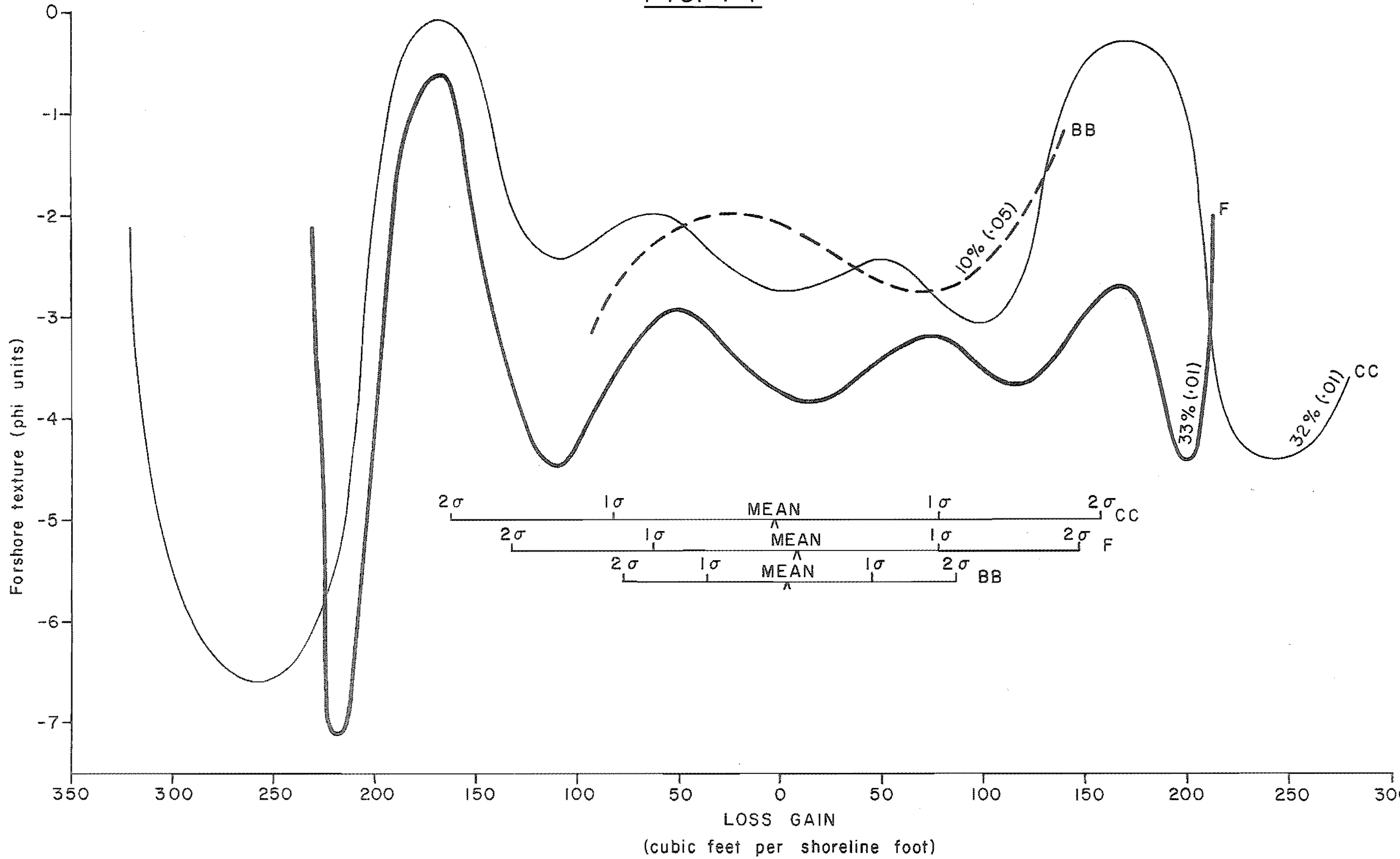
$$\mathcal{T}_{fs} = -2.127 - 0.9152(10^{-2})G - 0.8040(10^{-4})G^2 + 0.1406(10^{-5})G^3$$

(explains 10% at .05)

These three curves are graphed in Figure 4:7. There is no significant relationship between gains and foreshore texture at AA.

It has been demonstrated by an analysis of the textures of the upper and lower sweep zone profiles that in the foreshore region, the crest of the sweep zone is significantly coarser at CC than the base. Since the crest is associated with the addition of sediment and the base with the eroded state, it is to be expected that the gains/texture curve in Figure 4:7 would reflect this trend. That is, gains should be associated with coarser textures than losses, and the trend of the curve should have a negative slope. This is certainly true for gains and losses falling

FIG. 4:7


0
-1
-2
-3
-4
-5
-6
-7
Forshore texture (phi units)
BB
F
CC
10% (·05)
33% (·01)
32% (·01)
2σ
1σ
MEAN
1σ
2σ
CC
2σ
1σ
MEAN
1σ
2σ
F
2σ
1σ
MEAN
1σ
2σ
BB
350
300
250
200
150
100
50
0
50
100
150
200
250
300
LOSS GAIN
(cubic feet per shoreline foot)

within one standard deviation of the mean value (sixty-eight per cent of the cases), and also appears to be true out to about two standard deviations from the mean, which includes ninety-five per cent of the cases.

Similarly at F, the sweep zone analysis suggests that the base is significantly coarser than the crest, and accordingly when all of the gains and losses are related to texture, it is expected that the curve will slope positively in Figure 4:7. Once again, this is true within two standard deviations of the mean value at F.

At AA no significant difference was found between the texture of the base and crest of the sweep zone. Consistent with this result is the lack of any significant correlation at AA for the gains/texture combination.

At BB the sweep zone base was found to be significantly coarser than the crest. Figure 4:7 lends support to this conclusion. The gains at BB do show significantly finer textures than the losses, although both the per cent explained variation and the significance level are rather less than at CC and F.

These findings are important. The sweep zone analysis shows that at CC, F, and BB there are significant textural differences between profiles in a state of erosion and in the accreted state. But the evidence for coming to these conclusions is based on mean grain size measurements at only two positions, the crest and the base. The corroborative evidence provided by using all of the profile data as in the gains/texture curves of Figure 4:7, shows that not only is there a significant difference in texture between crest and base, but that there is a progressive increase in foreshore coarseness all the way through the sweep zone from crest to base at profiles F and BB, and a continuous decrease of particle size with depth through the sweep zone at CC.

There is one other rather perplexing feature of Figure 4:7 that deserves mention. In spite of the difference in particle size on the two beaches, there is a remarkable similarity between the CC curve and the curve at F. Thus, at both CC and F, for gains and losses of sediment within about twenty cubic feet of their respective means, the particle sizes are smaller than for either gains or losses of the order of sixty cubic feet on either side of the mean gains. Beyond the sixty cubic foot figure, particle sizes once again decrease at both stations. There is no obvious reason to suspect that these trends should be so similar, because the beach at F should be preferentially influenced by the discharge of riverine sediment. In the region of high volumetric gain, (in excess of two hundred cubic feet per shoreline foot), this is probably true, and the difference in the curves in this region may reflect textural modification to the foreshore at F by sediments supplied during high river discharge. If this is true, then Figure 4:7 suggests that over ninety-five per cent of the time, the effect of the river is undetectable.

Gains versus Foreshore Slope

There is a significant relationship between gains and foreshore slope at all four stations. The best predictor equations are:

At CC;

$$\beta = 4.072 - 0.1676(10^{-2})G + 0.1289(10^{-4})G^2$$

(explains 25% at .01)

At F;

$$\cot\beta = 7.644 - 0.7860(10^{-2})G + 0.7753(10^{-4})G^2 + 0.1998(10^{-5})G^3 - 0.1735(10^{-8})G^4 - 0.3852(10^{-10})G^5$$

(explains 22% at .01)

At AA;

$$\cot\beta = 7.534 - 0.1962(10^{-3})G + 0.4422(10^{-4})G^2$$

(explains 34% at .01)

At BB;

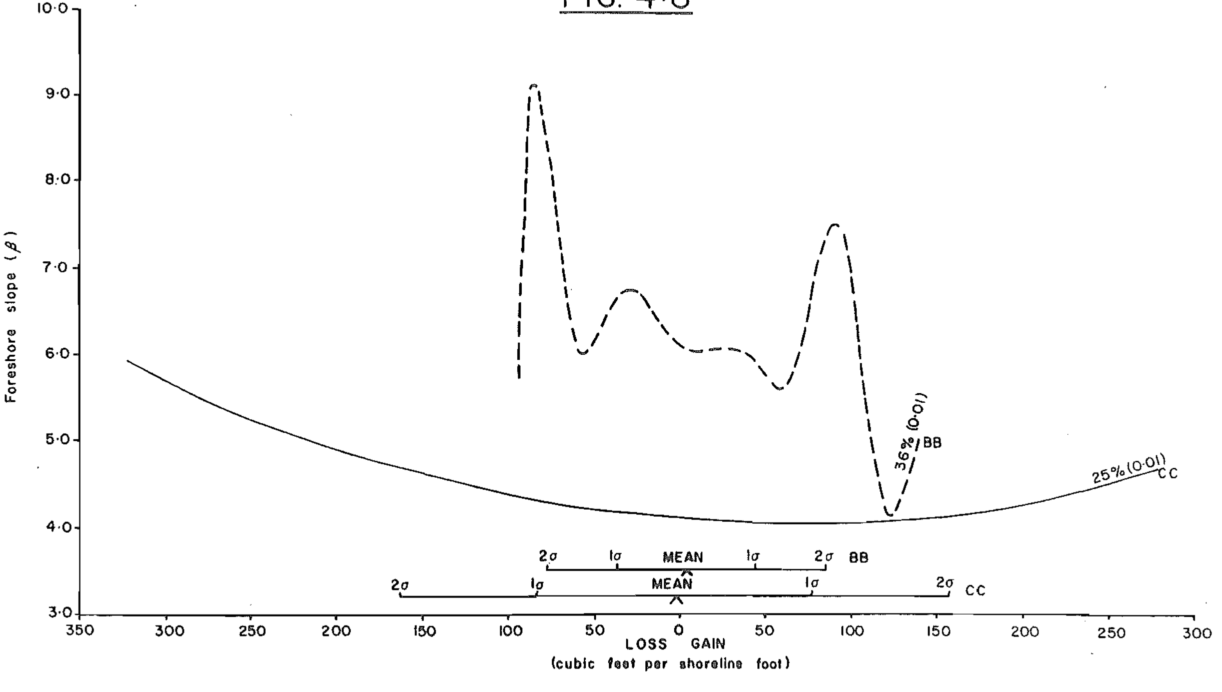
$$\beta = 6.107 - 0.1614(10^{-1})G + 0.9654(10^{-3})G^2 + 0.2679(10^{-5})G^3 - 0.8029(10^{-6})G^4 + 0.2717(10^{-8})G^5 + 0.1863(10^{-9})G^6 - 0.9640(10^{-12})G^7 - 0.1211(10^{-13})G^8 + 0.7460(10^{-16})G^9$$

(explains 36% at .01)

These four equations are graphed in Figures 4:8 and 4:9. They contain no surprises. They simply show that when there is a large amount of sediment on the beach, the slopes are flatter at all stations than when the beaches have been cut back. Thus, portions of the curves in the regions of maximum gain relate in general to the slopes of the crests of their respective sweep zones, and in the regions of maximum loss they relate to the slopes of the sweep zone bases.

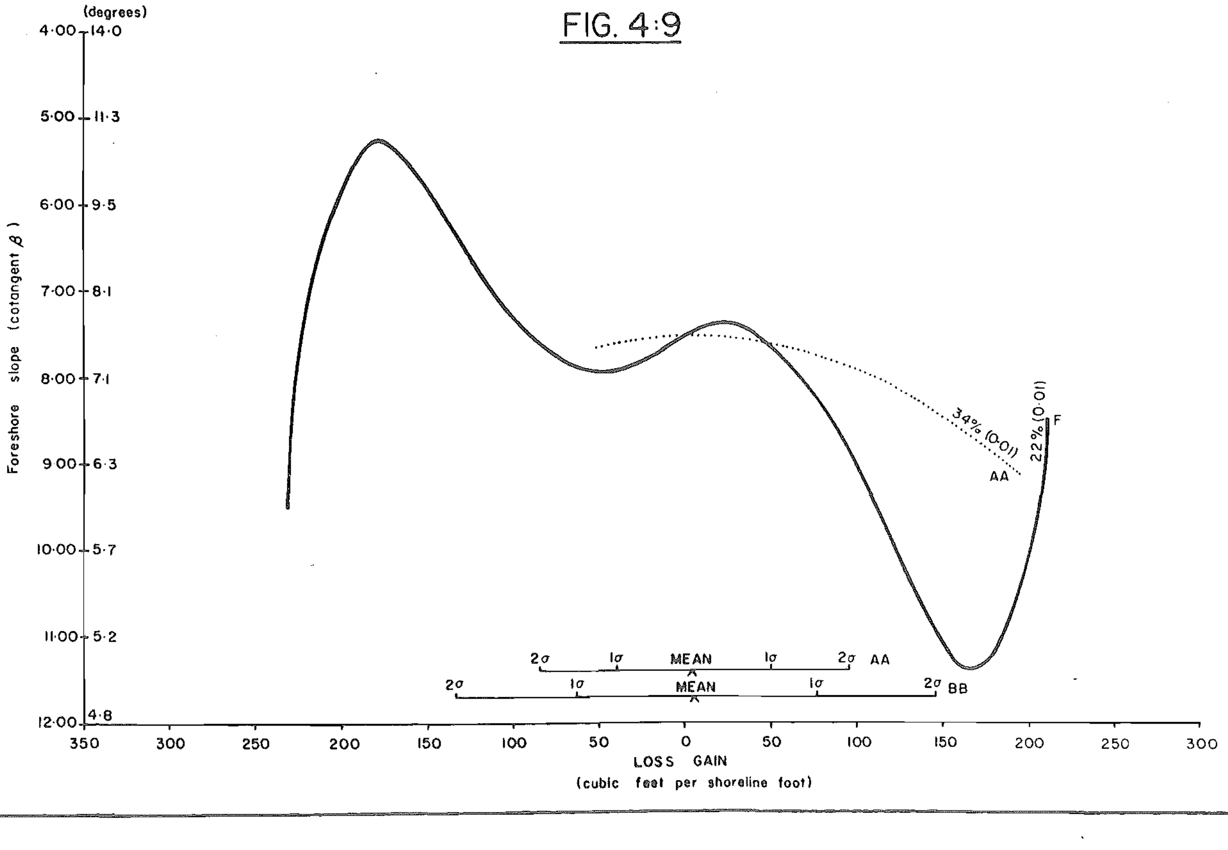
The maximum and minimum slopes at F and BB are more clearly defined than they are at CC and AA. For F, Figure 4:9 shows that maximum foreshore slopes occur for losses of about one hundred and eighty cubic feet, the minimum slopes, for gains of one hundred and seventy cubic feet. Figure 4:10 shows that these values correspond to shoreline positions one hundred and five feet and one hundred and twenty-one feet,

FIG. 4:8



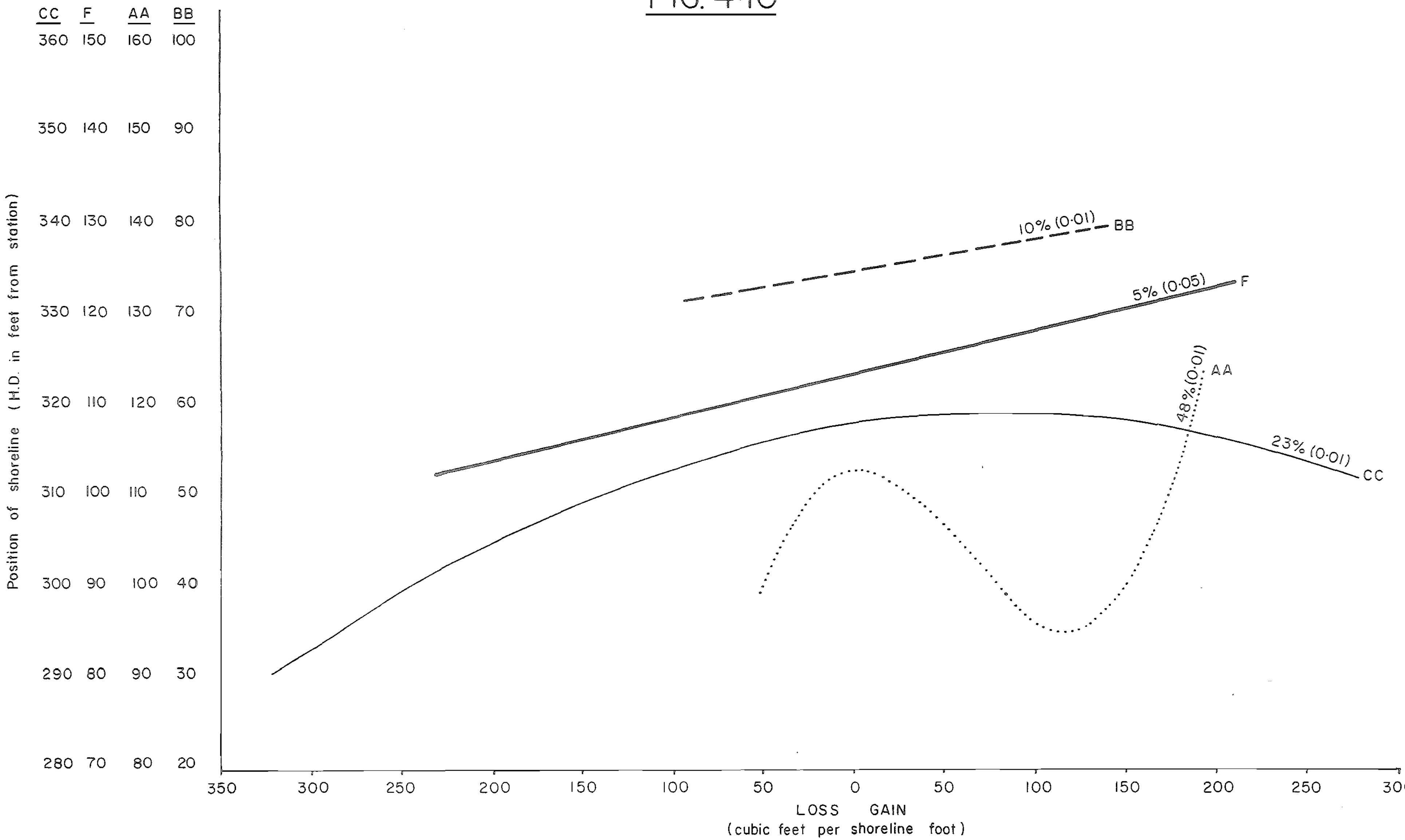
Foreshore slope (β)
10·0
9·0
8·0
7·0
6·0
5·0
4·0
3·0
36% (0·01) BB
25% (0·01) CC
2σ 1σ MEAN 1σ 2σ BB
2σ 1σ MEAN 1σ 2σ CC
350 300 250 200 150 100 50 0 50 100 150 200 250 300
LOSS GAIN
(cubic feet per shoreline foot)

FIG. 4:9



Foreshore slope (cotangent β)
(degrees)
4·00 14·0
5·00 11·3
6·00 9·5
7·00 8·1
8·00 7·1
9·00 6·3
10·00 5·7
11·00 5·2
12·00 4·8
34% (0·01) AA
22% (0·01) F
2σ 1σ MEAN 1σ 2σ AA
2σ 1σ MEAN 1σ 2σ BB
350 300 250 200 150 100 50 0 50 100 150 200 250 300
LOSS GAIN
(cubic feet per shoreline foot)

FIG. 4:10



CC F AA BB
360 150 160 100
350 140 150 90
340 130 140 80
330 120 130 70
320 110 120 60
310 100 110 50
300 90 100 40
290 80 90 30
280 70 80 20
Position of shoreline (H.D. in feet from station)
10% (0·01) BB
5% (0·05) F
48% (0·01) AA
23% (0·01) CC
350 300 250 200 150 100 50 0 50 100 150 200 250 300
LOSS GAIN
(cubic feet per shoreline foot)

respectively, from station F. Similarly, comparing Figure 4:8 with Figure 4:10 shows that the steepest slopes at BB occur about seventy-three feet from the station, and the flattest, about seventy-nine feet from the station.

Gains versus Shoreline Position

Figure 4:10 shows these relationships, and the equations describing them are as follows.

At CC;

$$D = 318.5 + 0.2909(10^{-1})G - 0.1811(10^{-3})G^2$$

(explains 23% at .01)

At F;

$$D = 114.0 + 0.4769(10^{-1})G$$

(explains 5% at .05)

At AA;

$$D = 112.92 + 0.3736(10^{-2})G - 0.3588(10^{-2})G^2 + 0.2003(10^{-4})G^3$$

(explains 48% at .01)

At BB;

$$D = 75.36 + 0.3383(10^{-1})G$$

(explains 10% at .01)

With the exception of the curve at profile F, these curves are all significant at the ninety-nine per cent level, and a relatively large proportion of the variation in shoreline position is explained by gains. The positive slope of the curves show that as expected, gains are usually associated with shoreline advance, and losses with shoreline retreat.

The case of F is interesting because the predictive power of the equation is not nearly as strong as that at the other stations. Large volumetric gains at F are related to infrequent river floods. When they occur, these deposits are nearly always found low on the foreshore, at distances one hundred and fifty feet or more from the station. Figure 4:3 shows that in this region, the crest of the sweep zone has a broad hump. Inasmuch as large gains at profile F are usually deposited seaward of mean sea level on the foreshore, and mean sea level is the index for shoreline position, it is not surprising that the correlation between gains and shoreline position is singularly low.

The curve at AA is also of interest. Although the correlation here is quite high, it is unclear why the shoreline position should lie so far landward for sediment gains of the order of one hundred cubic feet per shoreline foot. It is quite possible that the sinuosity of the curve in

Figure 4:10 has something to do with periodic episodes of longshore cusp migration rather than shore-normal addition and removal of material.

<u>Foreshore Texture versus Foreshore Slope</u>

This relationship is an important one, not only because many researchers have published data relating these two variables, but because the data of this study relate to much larger grain sizes than are usually found in the literature.

Figures 4:11 and 4:12 are graphs of the best predictor equations given below.

At CC;

$$\cot\beta = 15.66 + 0.7077\mathcal{T}_{fs}$$

(explains 7% at .05)

At F;

$$\cot\beta = 11.08 + 0.9317\mathcal{T}_{fs}$$

(explains 14% at .01)

At AA;

$$\beta = -132.1 - 76.07\mathcal{T}_{fs} - 13.67\mathcal{T}_{fs}^{2} - 0.8105\mathcal{T}_{fs}^{3}$$

(explains 38% at .05)

At BB;

$$\cot\beta = 10.53 + 0.6347\mathcal{T}_{fs}$$

(explains 21% at .01)

FIG. 4:11

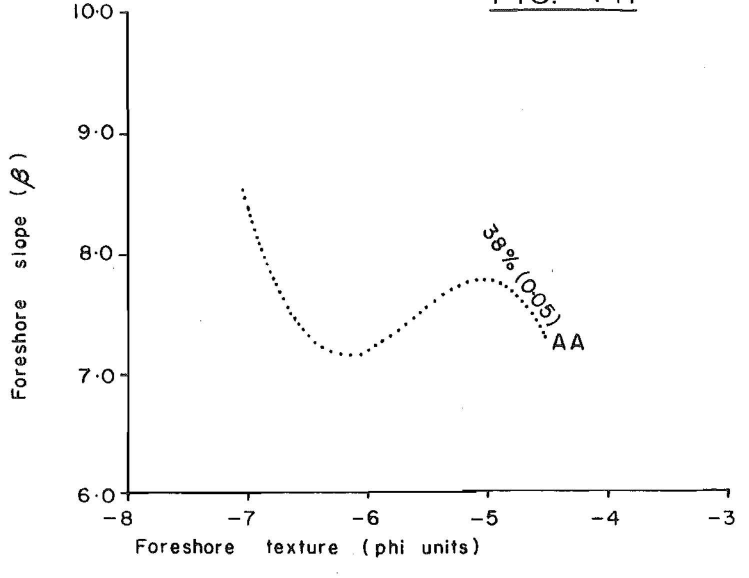
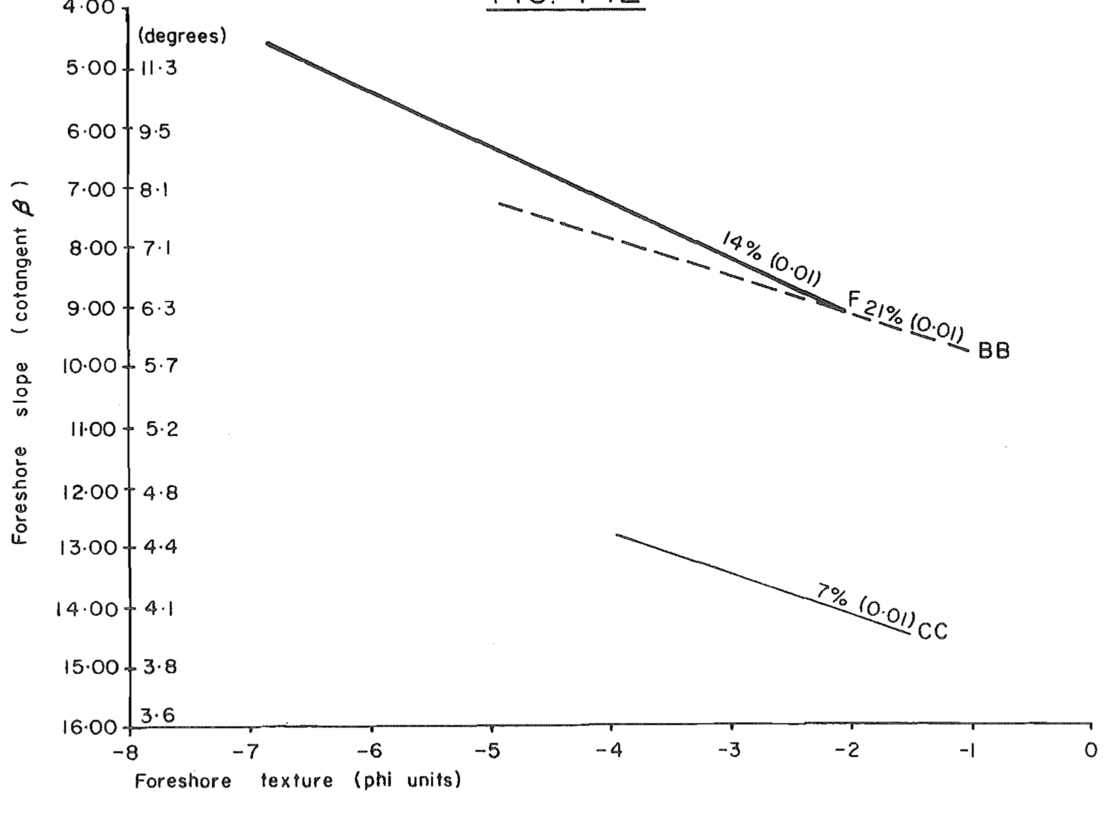


FIG. 4:12



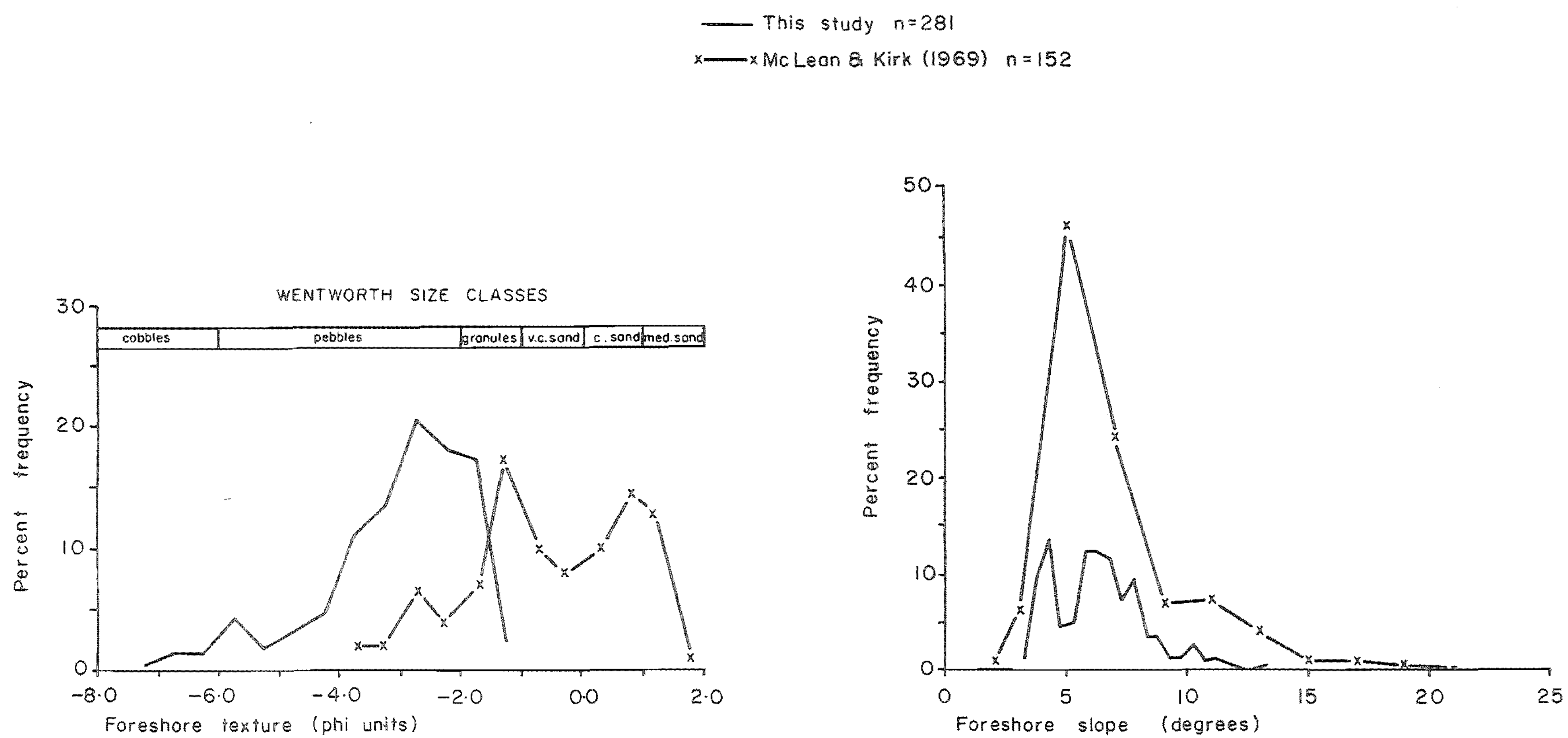
All of the curves show a general trend towards steeper foreshore slopes at larger grain sizes. This is in agreement with well-known model studies (Rector, 1954; Bagnold, 1940), and also from studies on natural beaches (King, 1972; Krumbein, 1961; and Bascom, 1951).

At CC, F, and BB, the relationship is linear (Figure 4:12), and at AA, it is a third degree polynomial curve (Figure 4:11). Mention has already been made of the anomalously low slopes at AA in respect of the sizes of the grains on the foreshore, and some of the physical reasons for this have been suggested. Figure 4:11 shows that although the over-all trend of foreshore slope is toward steeper values with coarser material, that in detail, specifically between minus five phi and minus six phi, the opposite is true. Reference to Figure 4:2 will show that more than two-thirds of the yearly sample falls within this size range, and Figure 4:4 shows that these sizes are characteristic of the upper foreshore landward of one hundred and twenty-five feet from the station. They do not occur seaward of this point. Mention has also been made of the low energy levels of the waves at AA (Figure 3:6) and much of what energy is available is dissipated by turbulence on the extremely coarse and permeable lower foreshore. Furthermore, field observations have shown that the upper foreshore at AA is an area immune from wave attack except by the highest storm southerlies, the deposits here representing an irregular and intermittent storm berm. The implication is that the foreshore slopes for grains in the minus five phi to minus six phi size range, may be abnormal compared to what they would be if waves were continually reworking the grains. It should also be noted that for grains larger than minus six phi, the curve shows an adjustment to steeper angles of repose.

Figure 4:12 shows the size/slope associations at CC, F, and BB. The rate of slope increase with size is equal at CC and BB. For F the overall increase in slope is slightly more rapid, an effect, no doubt, of the greater incidence of larger grains at this station.

The recent paper of McLean and Kirk (1969) also studied the size/slope relationship of the mixed sand and shingle beaches around Kaikoura. The sample sizes and the range of textures and slopes and their percentage frequency occurrence for McLean and Kirk's Kaikoura data, is shown in Figure 4:13 along with the data of this study. The frequency polygon for slope indicates that there is close correspondence in the slope values

FIG. 4:13


This study n=281
McLean & Kirk (1969) n=152
WENTWORTH SIZE CLASSES
cobbles
pebbles
granules
v.c.sand
c.sand
med.sand
Percent frequency
30
20
10
0
-8·0
-6·0
-4·0
-2·0
0·0
2·0
Foreshore texture (phi units)
50
40
30
20
10
0
0
5
10
15
20
25
Percent frequency
Foreshore slope (degrees)

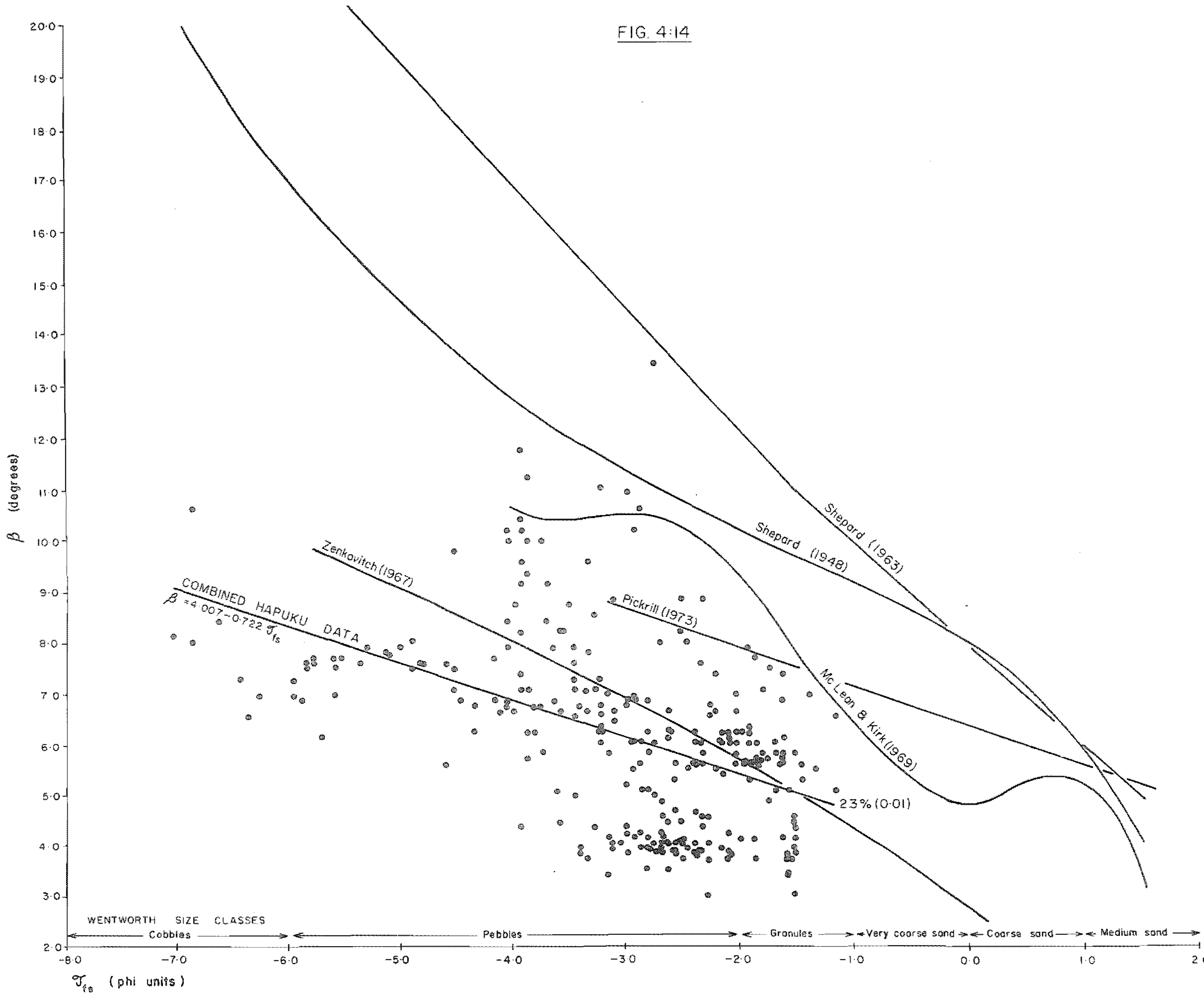
of the two studies, with a higher proportion of slopes in the four to seven degree range, than for values either greater or less than this.

The per cent frequency textural polygons however, show that the ranges of textures studied are quite different, and herein lies a source of considerable interest. Because the textures of the present study are coarser on the whole, than those of McLean and Kirk, an opportunity exists to see how effectively their findings can be extrapolated to the larger sizes of this study.

Direct evidence of the size/slope relationships on natural beaches is scanty for larger grain sizes, a reflection of the relative rarity on a world scale, of coarse-grained beaches. Besides the data of the two studies under discussion, only four other sources could be found relating any sort of slope continuum to grain size, for large grains. The relevant curves are shown in Figure 4:14.

It should be emphasized that there are some intrinsic differences among the curves. Unlike the others, Zenkovich's (1967) curve is meant to represent the equilibrium slope, not of the subaerial beach but of the stable slope that would result in the zone below low water. He considers that the zone landward of this is often over-

FIG. 4:14



20·0
19·0
18·0
17·0
16·0
15·0
14·0
13·0
12·0
11·0
10·0
9·0
8·0
7·0
6·0
5·0
4·0
3·0
2·0
β (degrees)
Shepard (1963)
Shepard (1948)
Mc Lean & Kirk (1969)
Zenkovitch (1967)
Pickrill (1973)
COMBINED HAPUKU DATA
β = 4·007 − 0·722 σ_{fs}
23% (0·01)
WENTWORTH SIZE CLASSES
Cobbles
Pebbles
Granules
Very coarse sand
Coarse sand
Medium sand
-8·0
-7·0
-6·0
-5·0
-4·0
-3·0
-2·0
-1·0
0·0
1·0
2·0
σ_{fs} (phi units)

steepened by erosion, and so the slopes are a-typical of the equilibrium form.[1] McLean and Kirk[2] suggest that the relationship described by Shepard's 1963 curve may relate to pure textural members rather than to slopes developed from admixtures of different size grades. It is also interesting that Shepard's 1963 curve has been modified slightly from his earlier 1948 values. Of all the curves shown in Figure 4:14, the 1969 and combined Hapuku curves should be expected to agree most closely, especially in the region describing similar size grades. On the whole they do not.[3] For equivalent grain sizes, McLean and Kirk found steeper slopes than those of the present study. One possible explanation for this is that because the methods of measuring foreshore slope were not the same for each study, an element of systematic bias exists in the data sets. For the 1969 work, Bascom's "reference point" (Bascom, 1951), was used, and the

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[1]Zenkovich, V.P., 1967; p.268.

[2]McLean, R.F., and Kirk, R.M., 1969; p.151.

[3]Pickrill's 1973 curve however, at the larger grain sizes, is in better agreement with the 1970 Hapuku data.

foreshore slope was measured with an Abney Level. For the 1970 work, because of the concavity of the slopes in the foreshore region of the study beaches, the location of Bascom's reference point was thought to involve an unacceptable level of subjective judgment, and so as described in Chapter II, foreshore slope was measured inter-tidally from the beach profiles. It is quite possible therefore, that the two studies are measuring different things. Unfortunately, the degree to which bias of this sort affects the final curves cannot be known.

It can be seen from the curves in Figure 4:14 that the variation in foreshore slope becomes greater for larger grain sizes. The curves tend to converge, and for material in the medium sand range, they are in close agreement. Other researchers have also noted a greater variability in beach gradient with increasing size. It would seem that coarse grains can become adjusted over a wider range of slopes than fine grains, and that their angle of repose depends to great extent on particular site characteristics such as exposure. Kuenen, for example, cites instances where cobble slopes can attain angles of anywhere from twenty to fifty degrees,[1] and King also notes the greater

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[1]Kuenen, Ph.H., 1957; p.273.

slope variability of coarse-grained beaches.[1]

One final point of comparison between McLean and Kirk's 1969 work and the findings of this study, relates directly to the morphology of the Kaikoura sand-shingle beaches. They found that there was a wider range of slope values in the range from minus one phi to minus three phi than for sizes either larger or smaller than these. Their data, however, does not extend beyond minus four phi, and there are only six values between minus three and minus four phi. The data of the present study suggest that for Kaikoura beaches at least, the wide slope variability can be extended out to, but not beyond, minus four phi. Figure 4:14 shows that sizes larger than this occur over a much more restricted slope range.

Response Variation with Time

In discussing the process changes through time (Chapter III), the long term changes were treated first, and the details of day to day process variation were filled in later. It seems wiser to discuss the responses in the reverse order. In this way a comprehensive account can

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[1] King, C.A.M., 1972; p.346.

be given at the end of this chapter that will describe the relatively long term effects related to shore morphology. It is, after all, the cumulative effect of short term changes on the profiles that determine major topographic changes that take place over a longer period.

Response Change from Day to Day

Figures 4:15, 4:16, 4:17, and 4:18 show at CC, F, AA, and BB, respectively, the short term, day to day variation of gains, cusp development, foreshore texture, shoreline position, and foreshore slope. For each of these responses measurement was done on a daily basis from early September to the end of November at all stations except AA.[1] At AA, daily records were not kept because the day to day changes were negligible. Instead, readings were made every week so that at least the total response change at AA could be related to the total changes at the more frequently sampled stations. When first plotted, the magnitude of the short term variability of gains was noticed to be much greater than that

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[1]A reliable and consistent record of cusp development was taken during this period and, accordingly, it is now included with the other responses.

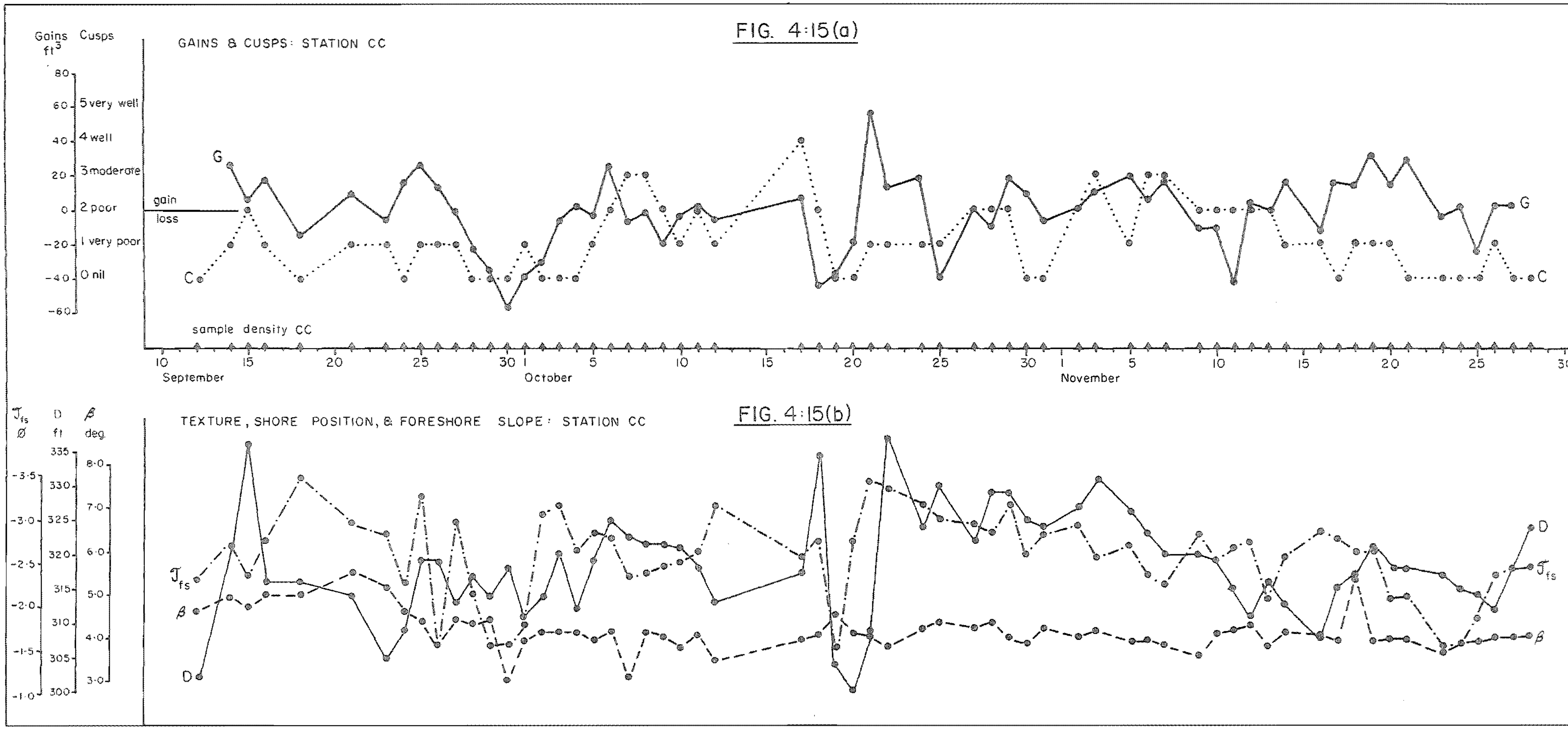


FIG. 4:15(a)

FIG. 4:15(b)

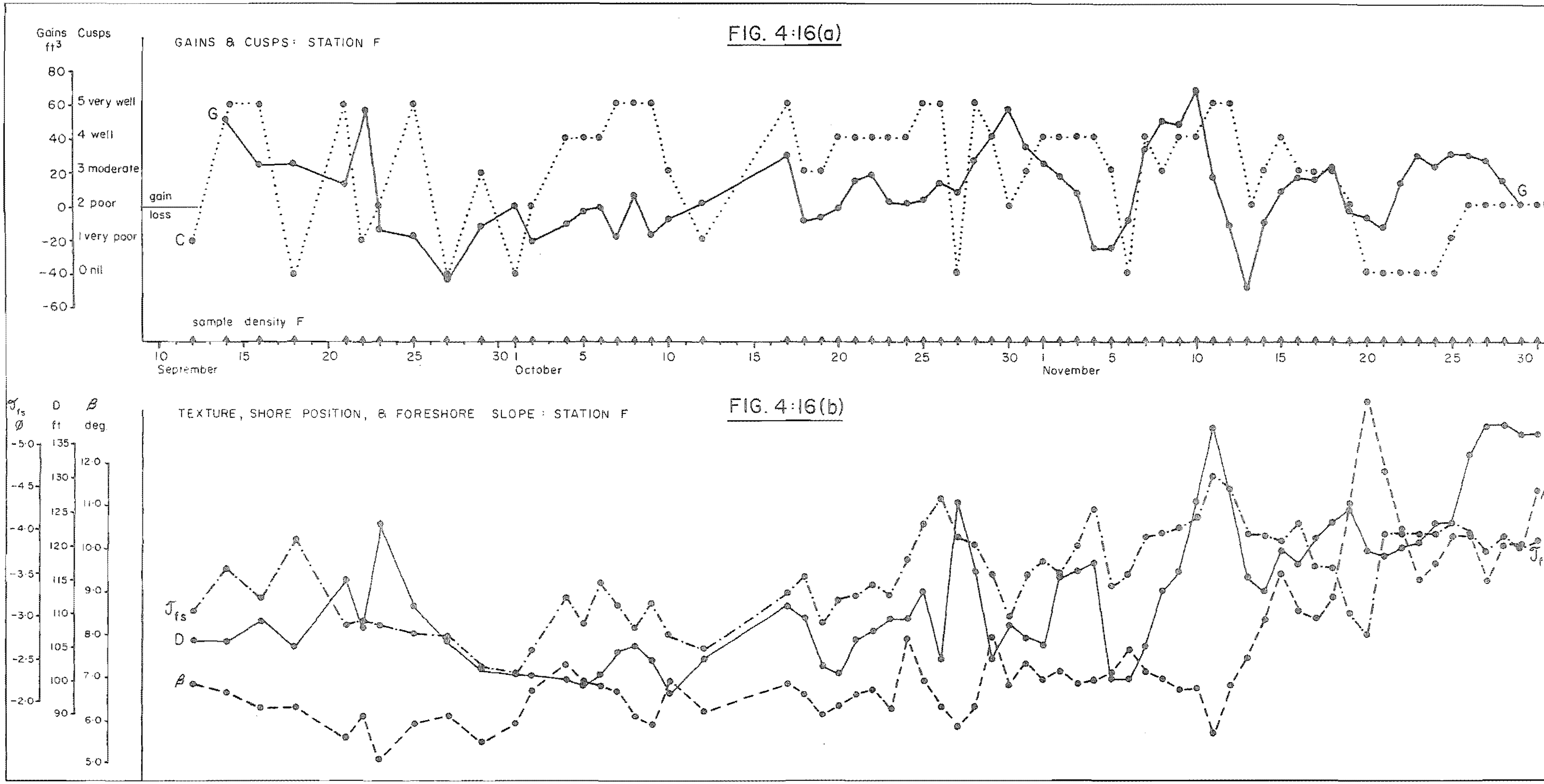
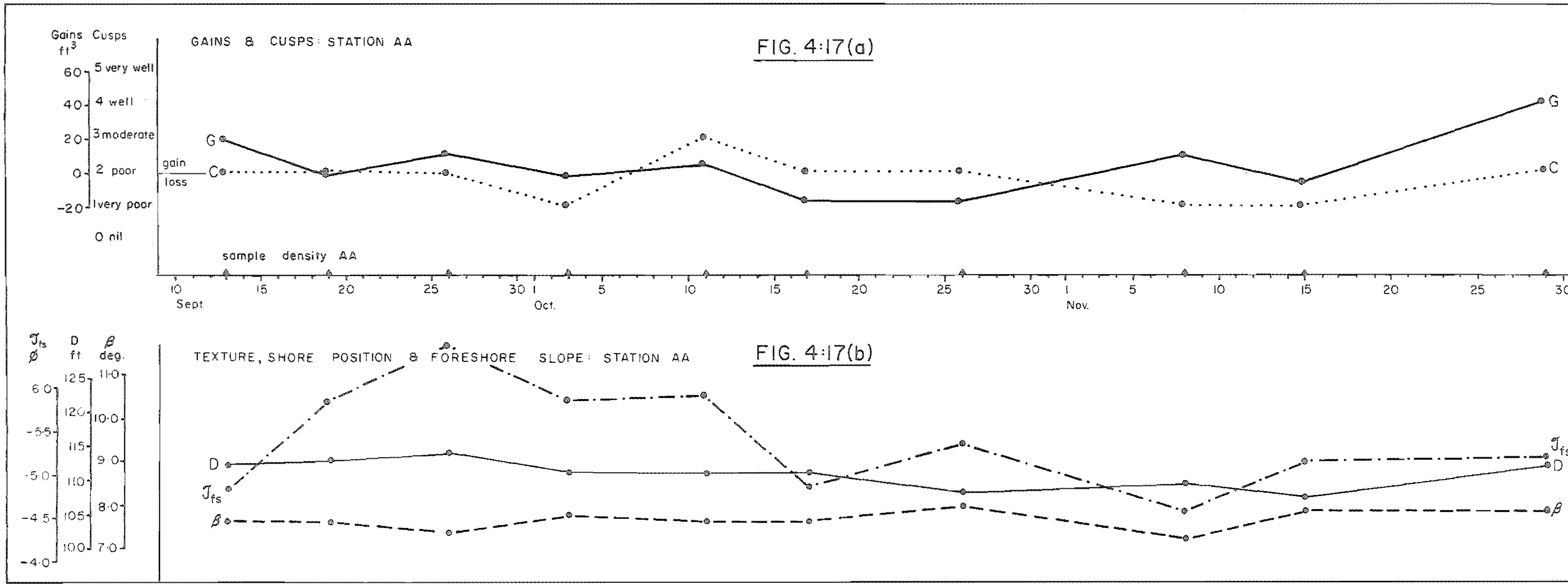


FIG. 4:16(a)
GAINS & CUSPS: STATION F
Gains ft³
Cusps
5 very well
4 well
3 moderate
2 poor
1 very poor
0 nil
gain
loss
sample density F
September
October
November
FIG. 4:16(b)
TEXTURE, SHORE POSITION, & FOREFSHORE SLOPE: STATION F
D ft
β deg



Gains ft³
Cusps
60
40
20
0
-20
5 very well
4 well
3 moderate
2 poor
1 very poor
0 nil
gain
loss
GAINS & CUSPS: STATION AA
FIG. 4:17(a)
G
C
sample density AA
10 Sept
15
20
25
30
1 Oct.
5
10
15
20
25
30
1 Nov.
5
10
15
20
25
30
$\mathcal{T}_{fs}$ ø
D ft
β deg.
6·0
-5·5
-5·0
-4·5
-4·0
125
120
115
110
105
100
11·0
10·0
9·0
8·0
7·0
TEXTURE, SHORE POSITION & FORESHORE SLOPE: STATION AA
FIG. 4:17(b)
D
$\mathcal{T}_{fs}$
β

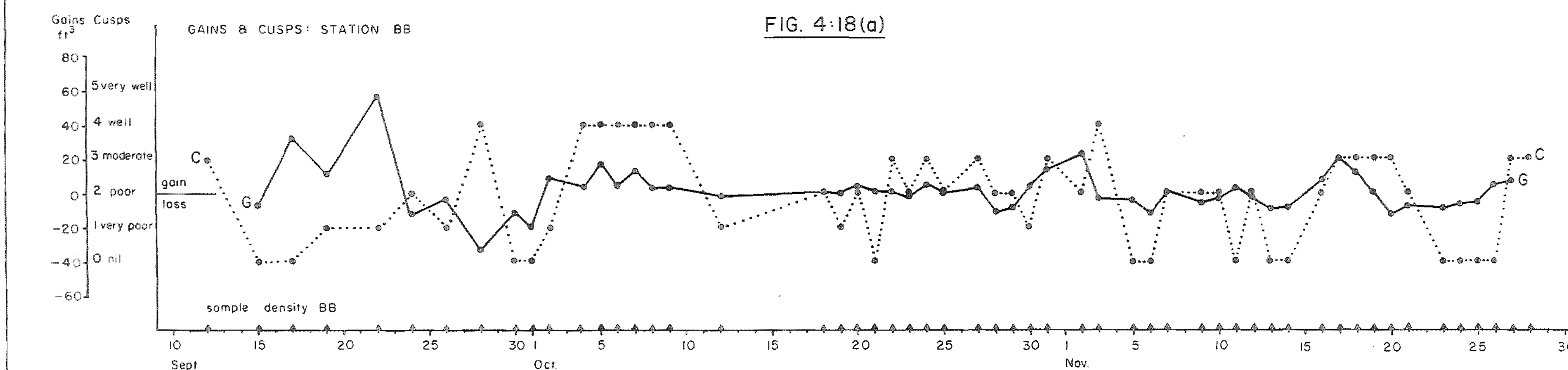


FIG. 4:18(a)

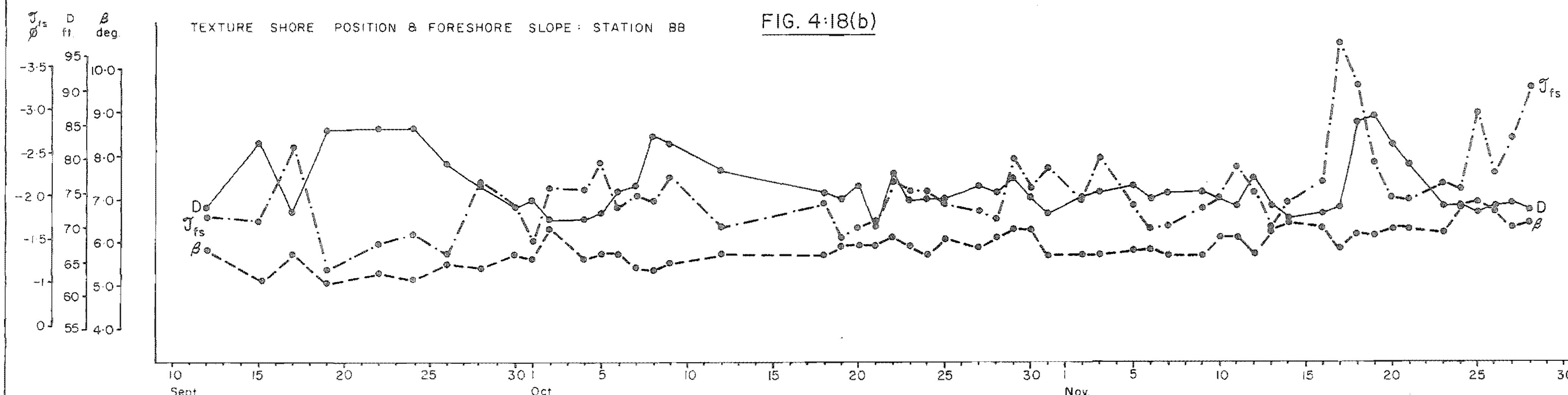


FIG. 4:18(b)

of any of the other responses. This showed that substantial volumes of sand and shingle are moved very rapidly on the study beaches, but the high variability made it difficult to tell if there were any longer term cycles in the data. Accordingly, two, three, and four-day moving averages were used to smooth the gains curves. The three-day averages were found to be the best compromise between reducing the "noise" caused by the short-term variations and retaining sufficient detail to show longer term variations, and these are the ones that have been plotted in Figures 4:15(a), 4:16(a), and 4:18(a).[1] The data for cusps, foreshore slope, texture, and shoreline position is depicted in its original form.

If one characteristic is obvious in the daily response curves, it is their almost total lack of any identifiably regular periodicity. The only exceptions to this are the gains curve at F, where Figure 4:16(a) shows what appears to be an eight to ten day cycle of gains and losses from mid-October to the end of November, and the cusp curves at F (Figure 4:16(a)) and BB (Figure 4:18(a))

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[1]For obvious reasons, no moving averages were calculated at station AA.

which show a lack of cusp development every eight to ten days during the same period. It is something of an understatement to say that neither of these is particularly well defined however, and their real existence as "cycles" is in doubt. This irregularity emphasizes the complex nature of the beach responses and stands in contrast to the crude but more clearly defined periodicity of process variation with time, discussed in the previous chapter. An important distinction can thus be drawn between the processes and the responses of this study. Wave attack on the beaches grows and diminishes more or less regularly with time. But there is little evidence to show that there are correspondingly regular alterations in any of the beach responses.

p 131 Fig

[illegible]

wave period or direction graph

It will be remembered that net volumetric gain (or loss) was cited as being a poor indicator of topographic change on the beach. Even though the total sediment budget from one day to the next may show no net change, it is usual, even probable, that measurable erosion and deposition has taken place somewhere along the section. Along with this, of course, the profile will have changed shape. The daily gross volumetric change shows neither of these effects. In order to observe their magnitude and location, it is necessary to subdivide the vertical range of each profile section into smaller units. This has been done for all the profiles, and daily changes in the plan position of the contour lines have been mapped at one foot intervals for the latter half of October and all of November. These are shown in Figures 4:19, 4:21, 4:23, and 4:25, at stations CC, F, AA, and BB, respectively.[1] Figures 4:20, 4:22, 4:24, and 4:26, which should be considered along with the Figures just mentioned, show the corresponding changes in volume for every vertical foot of section between 21.00 and 33.00 feet. Total daily volumetric changes and the cumulative curve for each of the sections between elevations of 21.00 feet and 33.00 feet are also shown. Also pertinent to this discussion are the daily precipitation values recorded at the Kaikoura Meteorological Station, for the same period. These bear a close relationship to changes at profile F, and are therefore shown as part of Figure 4:22.

It has already been pointed out that the flooding of the Hapuku River, and the amount of entrained sediment that it carries, is most dif-

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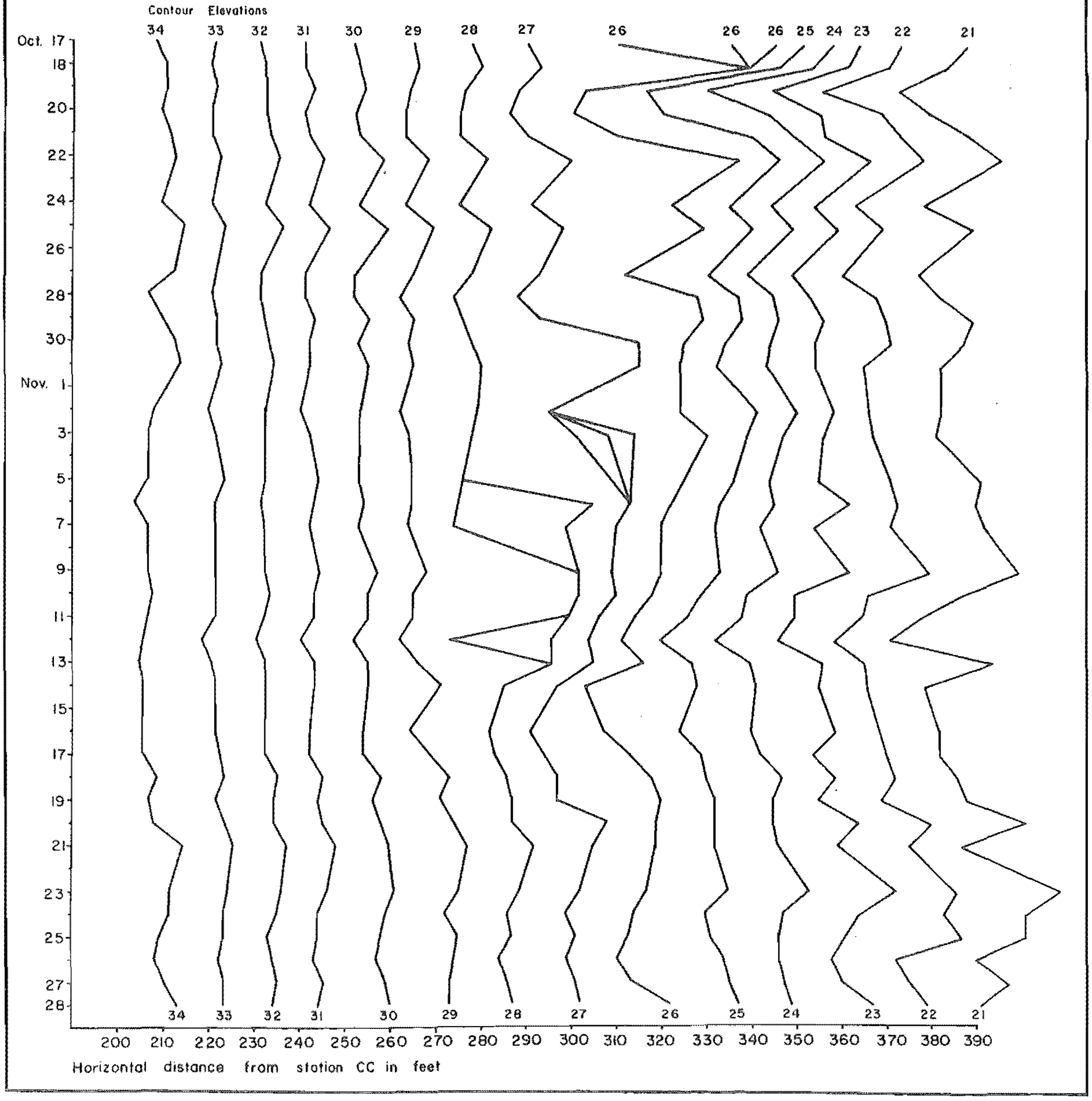
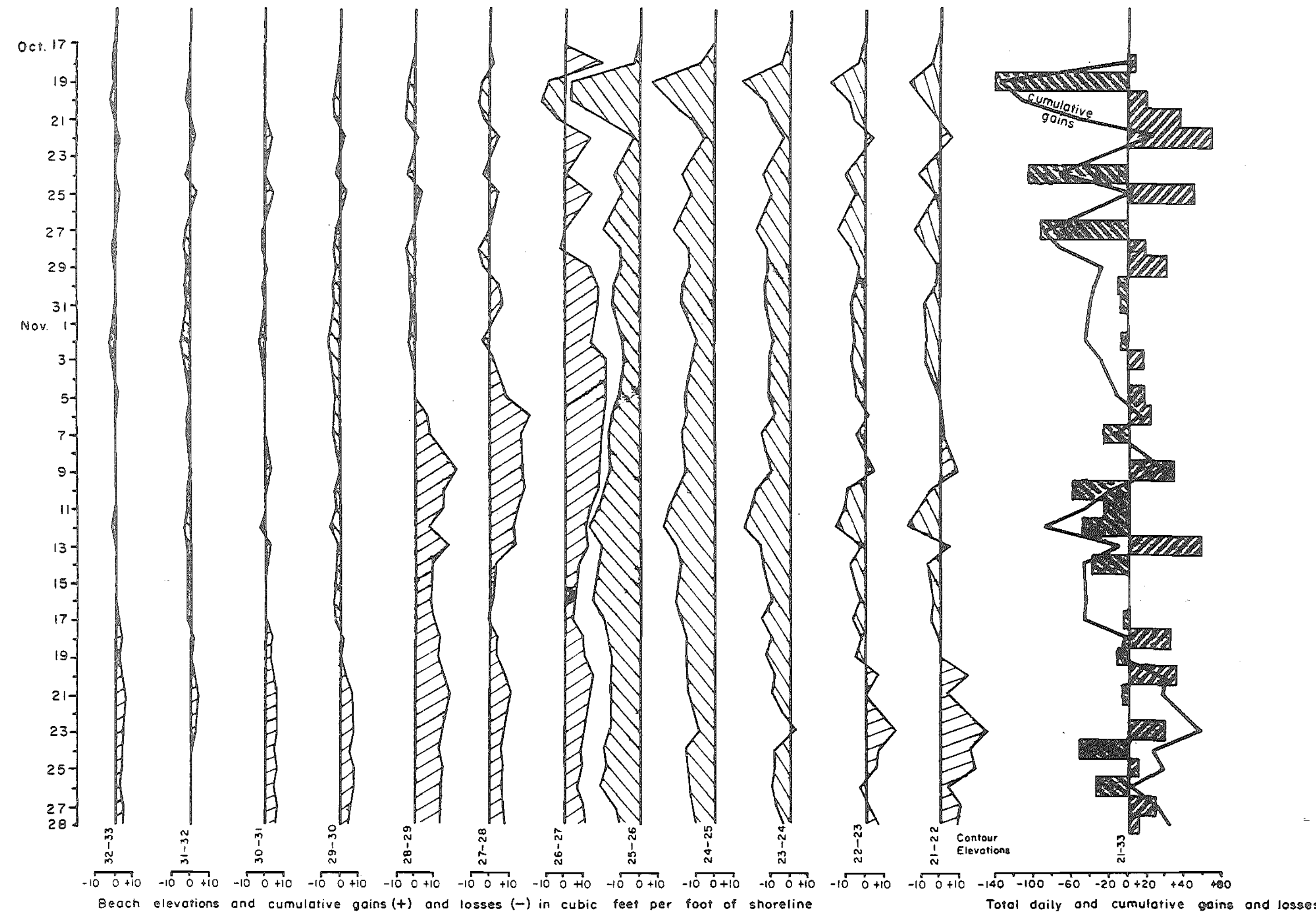
[1] It can be seen from the diagrams which map the daily changes in profile shape that most of the variation takes place below an elevation of 30.00 feet on all profiles. This figure corresponds well, with the upper limit of the foreshore, defined earlier as 30.40 feet.

FIG. 4.19



Contour Elevations
34
33
32
31
30
29
28
27
26
26
26
25
24
23
22
21
Oct. 17
18
20
22
24
26
28
30
Nov. 1
3
5
7
9
11
13
15
17
19
21
23
25
27
28
34
33
32
31
30
29
28
27
26
25
24
23
22
21
200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390
Horizontal distance from station CC in feet

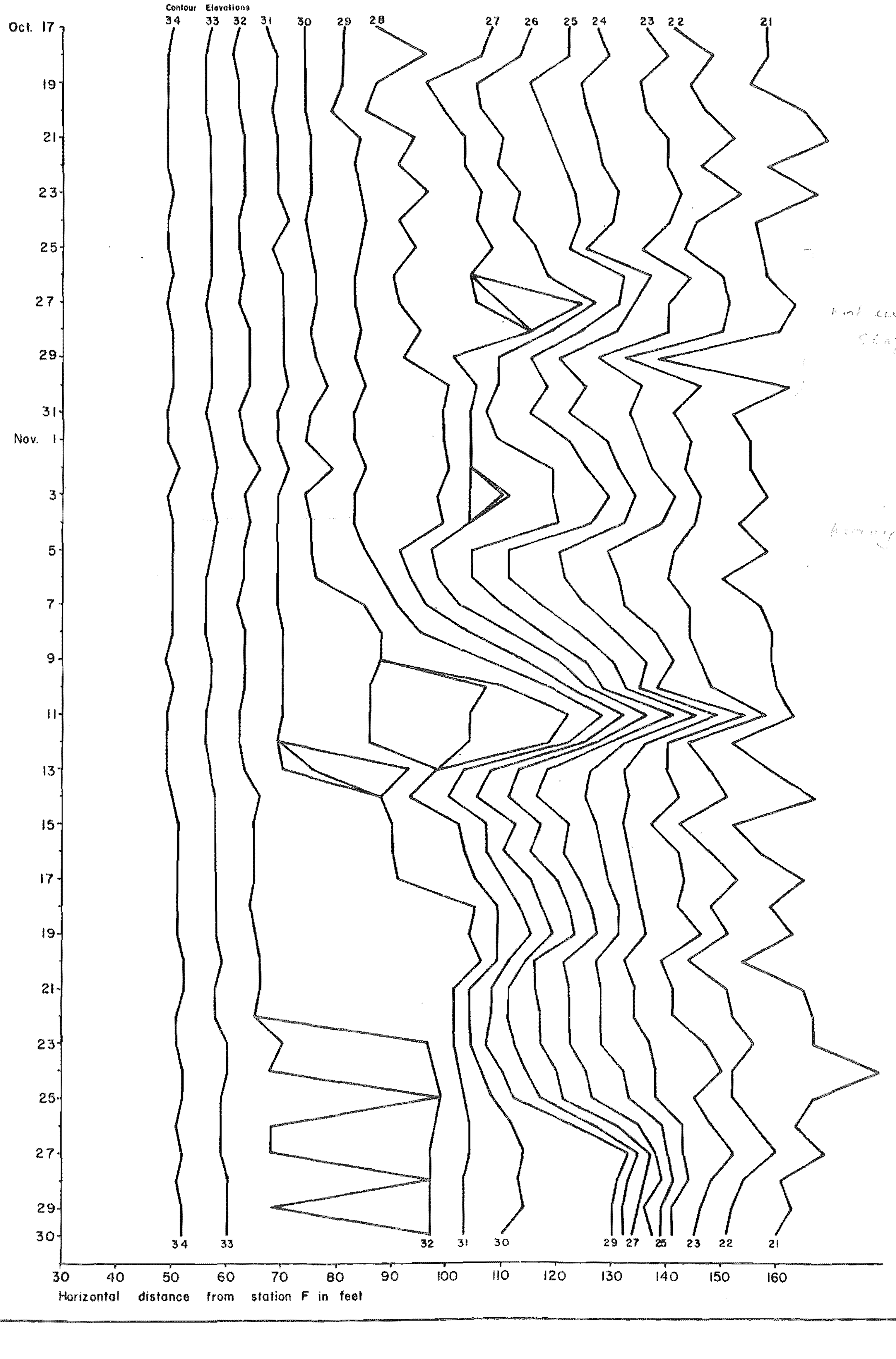
FIG. 4:20



PROFILE CC

volumetric gain relative to Oct. 17
volumetric loss relative to Oct. 17
total daily gain
total daily loss

FIG. 4:21



Contour Elevations
34 33 32 31 30 29 28 27 26 25 24 23 22 21
Oct. 17
19
21
23
25
27
29
31
Nov. 1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
30
34 33 32 31 30 29 27 25 23 22 21
30 40 50 60 70 80 90 100 110 120 130 140 150 160
Horizontal distance from station F in feet

FIG. 4:22

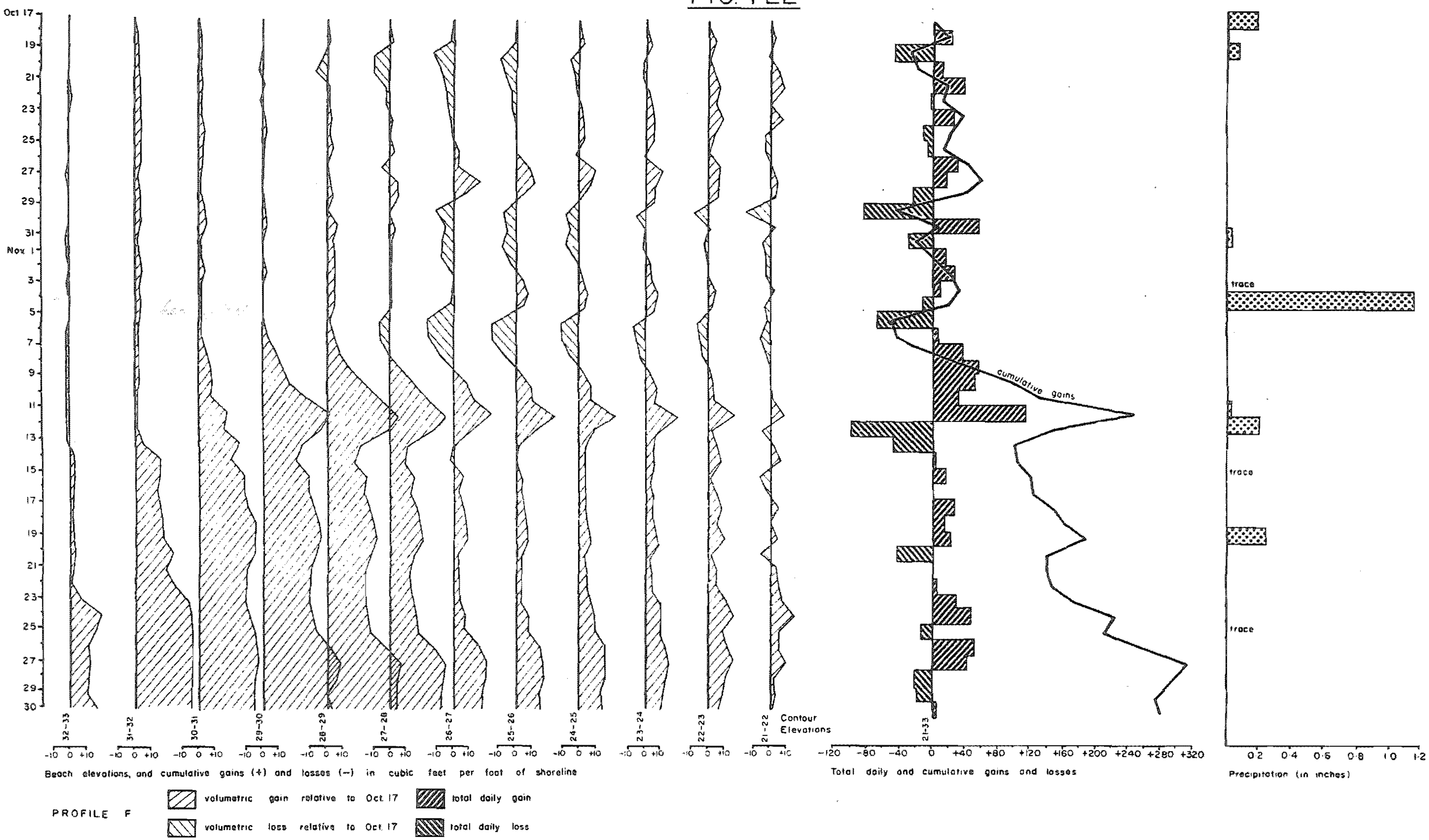
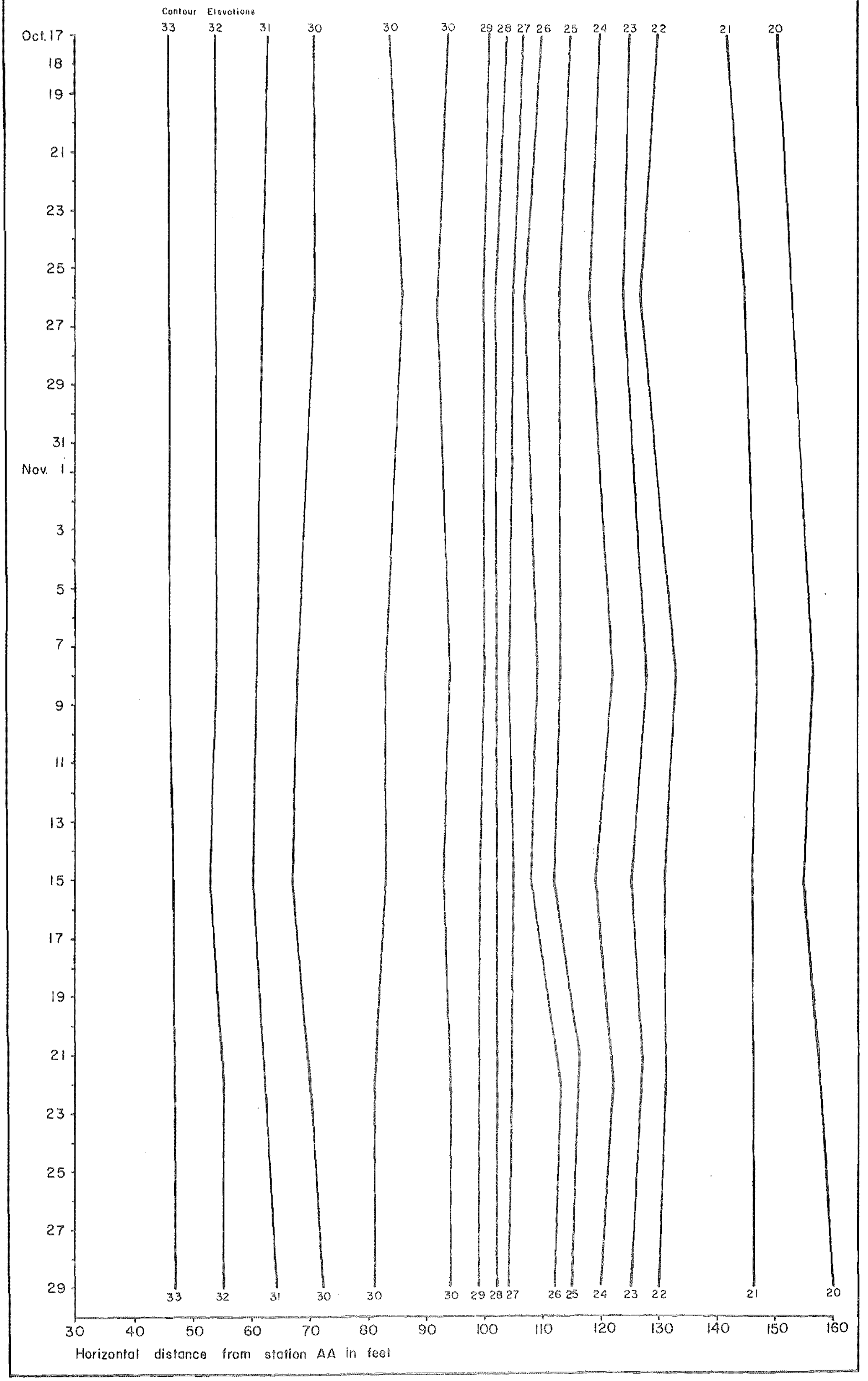

Oct 17
19
21
23
25
27
29
31
Nov 1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
30
32-33
31-32
30-31
29-30
28-29
27-28
26-27
25-26
24-25
23-24
22-23
21-22
Contour Elevations
-10 0 +10
Beach elevations, and cumulative gains (+) and losses (−) in cubic feet per foot of shoreline
cumulative gains
21-33
−120 −80 −40 0 +40 +80 +120 +160 +200 +240 +280 +320
Total daily and cumulative gains and losses
trace
trace
trace
0·2 0·4 0·6 0·8 1·0 1·2
Precipitation (in inches)
PROFILE F
volumetric gain relative to Oct. 17
volumetric loss relative to Oct. 17
total daily gain
total daily loss

FIG. 4:23



Contour Elevations
33 32 31 30 30 30 29 28 27 26 25 24 23 22 21 20
Oct. 17
18
19
21
23
25
27
29
31
Nov. 1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
33 32 31 30 30 30 29 28 27 26 25 24 23 22 21 20
30 40 50 60 70 80 90 100 110 120 130 140 150 160
Horizontal distance from station AA in feet

FIG. 4:24

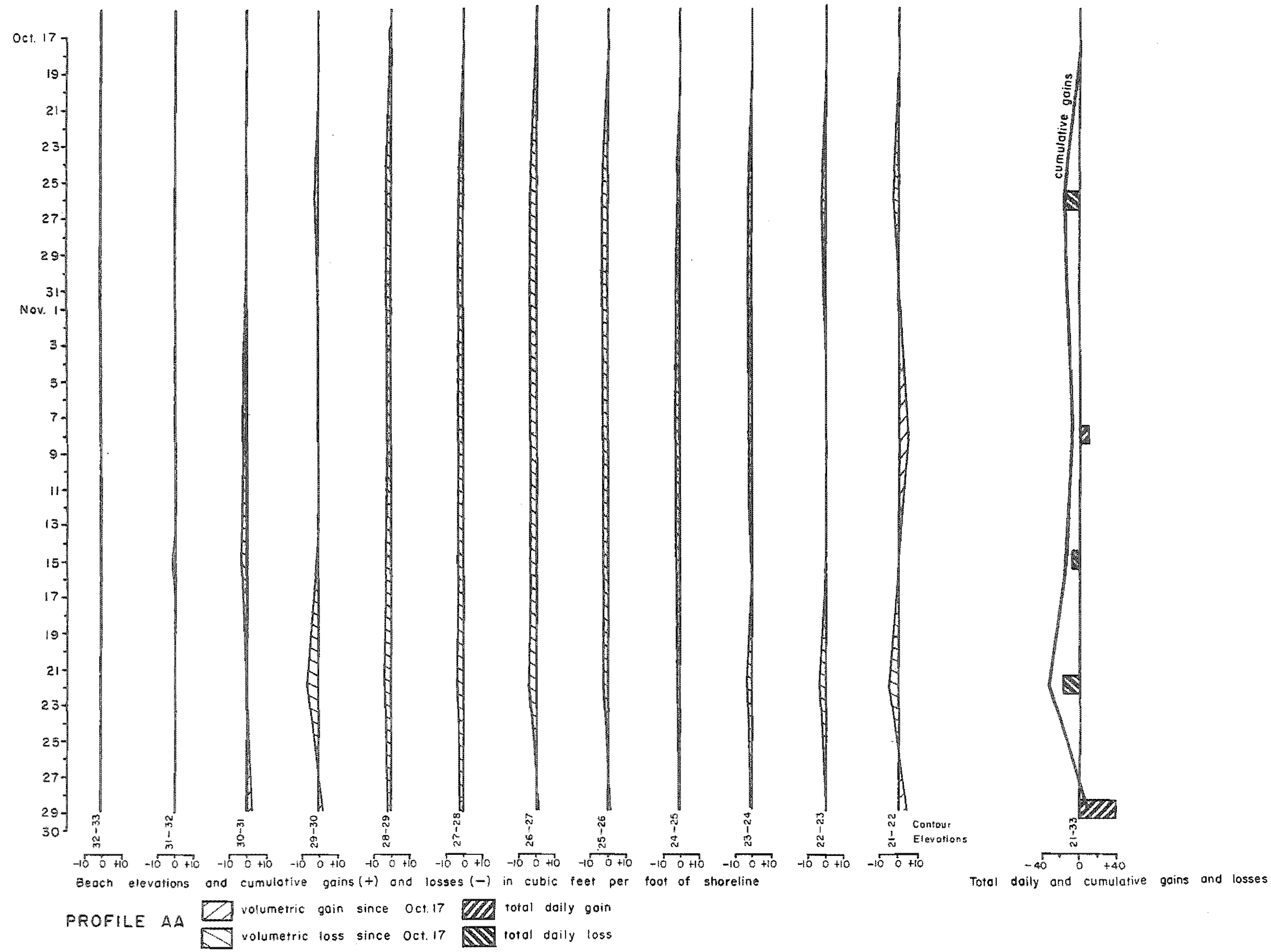

Oct. 17
19
21
23
25
27
29
31
Nov. 1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
30
cumulative gains
32-33
31-32
30-31
29-30
28-29
27-28
26-27
25-26
24-25
23-24
22-23
21-22
Contour Elevations
21-33
-10 0 +10
-40 0 +40
Beach elevations and cumulative gains (+) and losses (−) in cubic feet per foot of shoreline
Total daily and cumulative gains and losses
PROFILE AA
volumetric gain since Oct. 17
volumetric loss since Oct. 17
total daily gain
total daily loss

FIG. 4:25

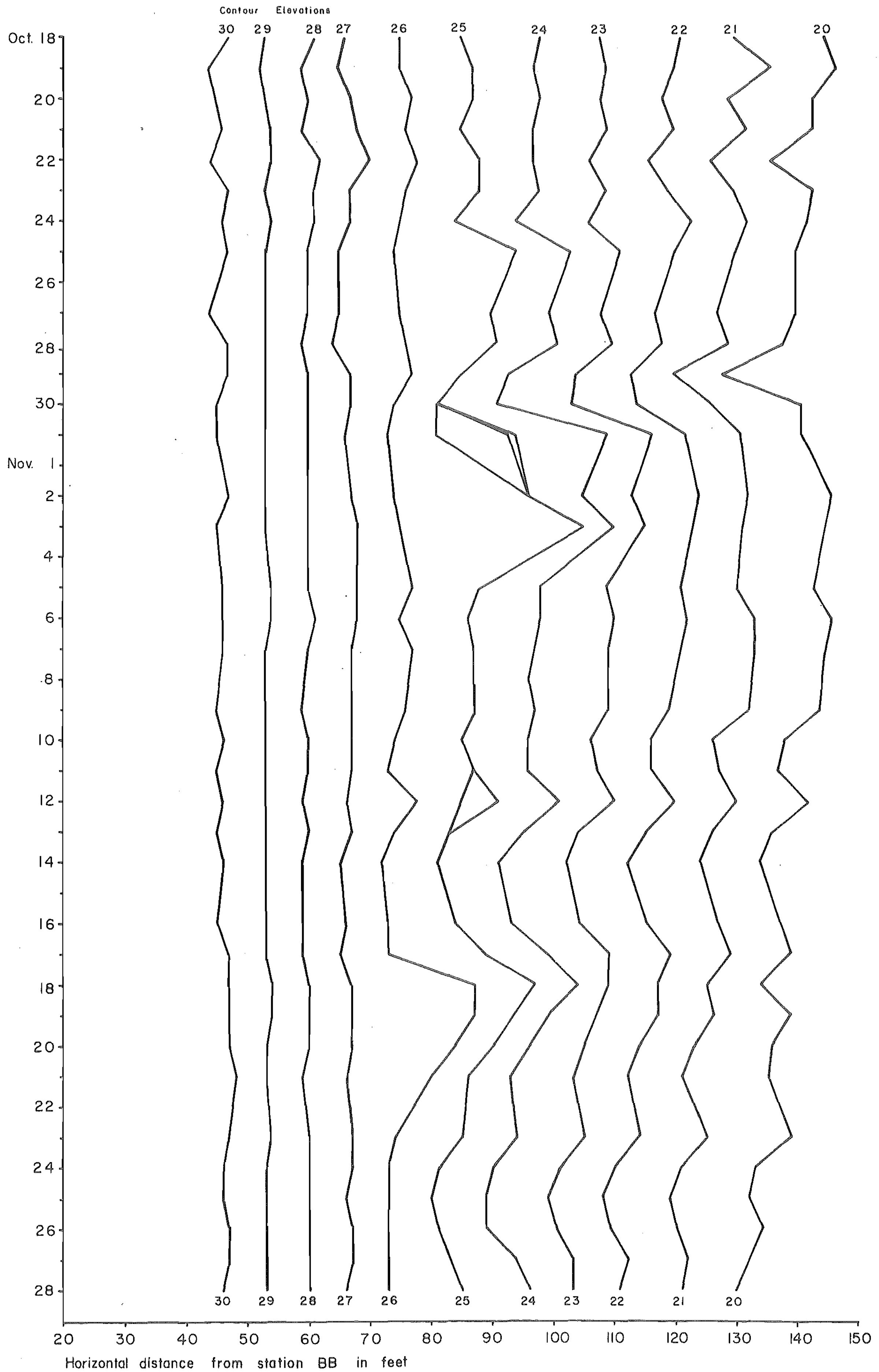
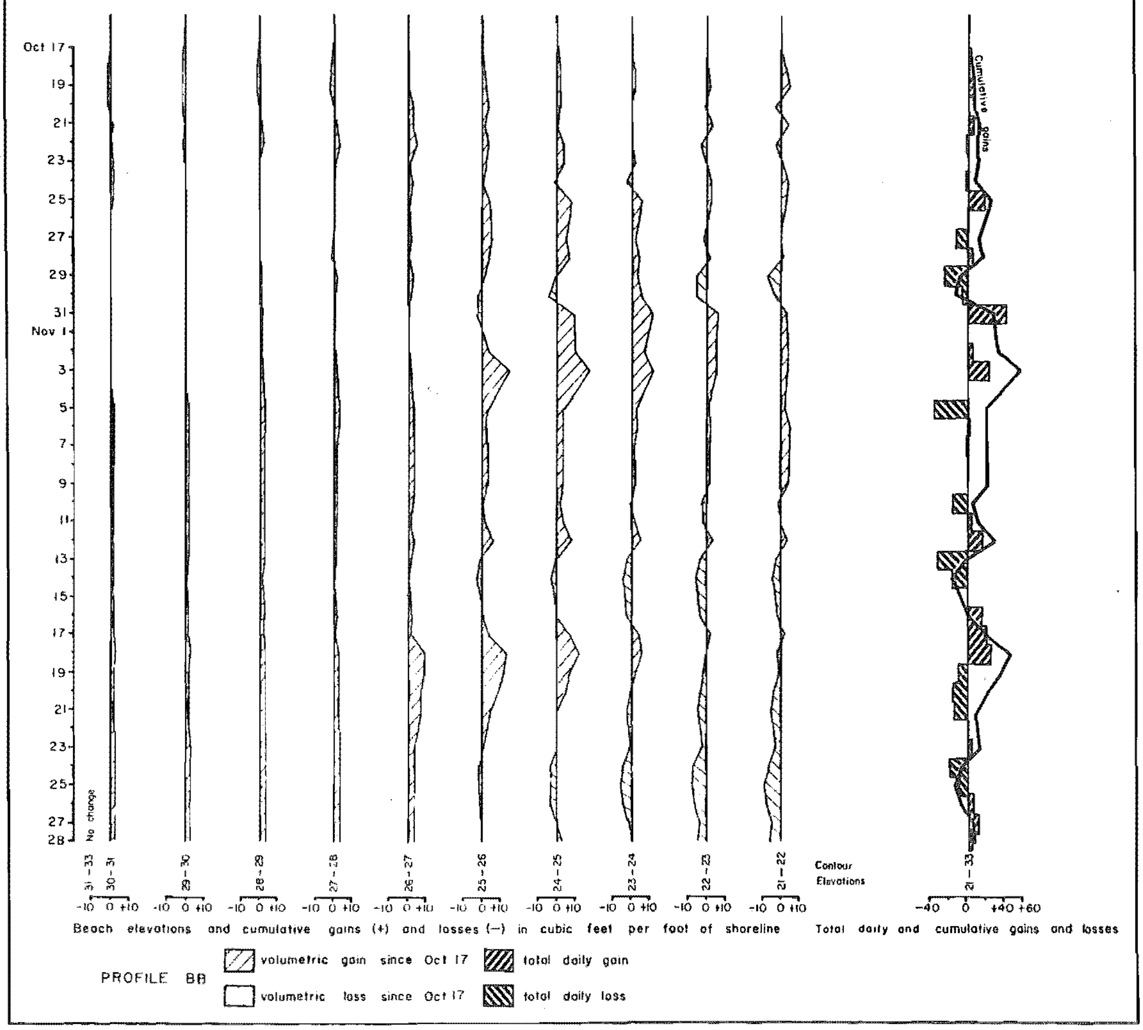

Contour Elevations
30 29 28 27 26 25 24 23 22 21 20
Oct. 18
20
22
24
26
28
30
Nov. 1
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30 29 28 27 26 25 24 23 22 21 20
20 30 40 50 60 70 80 90 100 110 120 130 140 150
Horizontal distance from station BB in feet

FIG. 4:26


Oct 17
19
21
23
25
27
29
31
Nov 1
3
5
7
9
11
13
15
17
19
21
23
25
27
28
No change
31 - 33
30 - 31
29 - 30
28 - 29
27 - 28
26 - 27
25 - 26
24 - 25
23 - 24
22 - 23
21 - 22
Contour Elevations
21 - 33
Cumulative gains
-10 0 +10
-40 0 +40 +60
Beach elevations and cumulative gains (+) and losses (—) in cubic feet per foot of shoreline
Total daily and cumulative gains and losses
PROFILE BB
volumetric gain since Oct 17
volumetric loss since Oct 17
total daily gain
total daily loss

ficult to measure in the field. Fortunately the effects of a large flood on nearby profiles are easily seen. During the month and a half of intensive data collection such a flood occurred, and so not only does the following discussion relate to non-flood conditions, but perhaps most importantly, the effect to the profiles of large inputs of sediment can be seen, and subsequent profile modifications can also be traced.

Figures 4:22 and 4:21 clearly show both the effects of the flood and the more usual conditions prior to the flood peak at profile F. From October 17 to November 5 the profile was characterized by a uniform foreshore slope (Figure 4:21), and about equal amounts of erosion and deposition took place, confined mainly to elevations below 29.00 feet. Daily gains and losses to the beach were of the order of twenty to thirty cubic feet per shoreline foot.

not Oct 25-30

On November 6, a phase of increasing foreshore deposition began, and continued for six days. During this time, three hundred and four cubic feet of sediment were deposited on the beach. The source of this material was the river which had gone into flood as a result of the heavy rainfall of November 4. Enough additional rain fell on the 11th, 12th, and 19th to maintain river discharge at a reasonably high level for the rest of the month. The slopes of the cumulative curves of Figure 4:22, as well as the large seaward movement of the twenty-seven to thirty foot contours of Figure 4:21, show that most of the initial material supplied to the beach from November 6 to 11 was deposited between these elevations. On November 10 a berm developed on the upper foreshore (Figure 4:21).

The period of deposition was followed by two days of erosion (November 12 and 13), concentrated between elevations of twenty-six and thirty feet. The steep slope of the foreshore was moderated and the berm was reduced in size and moved shoreward. The berm crest also flattened, producing a broad depositional bench between sixty-five and one hundred feet from the station.

Another depositional phase was initiated on November 22. Foreshore slopes steepened once more, and a second order berm formed lower down on the shore between one hundred and ten and one hundred and thirty feet from the station.

Although obvious at profile F, the effect of large sediment discharge from the river is not as easily seen at the other stations. At none of the other profile sites is the flood discharge/ profile modification relationship as obviously demonstrated as it is at F.

Profile AA (Figures 4:23, 4:24) was essentially stable throughout the period, and the figures show that there was little change either in beach volumes or in profile shape. Figure 4:23 shows that changes in volume at AA were small compared to those at other profiles. Values of only eight or nine cubic feet per foot of shoreline were usual over a period of about a week. Figure 4:24 shows that the shape of the profile was also fairly stable. The low slopes of the lower foreshore, and the steeper slopes of the upper foreshore changed their positions very little during October and November.

Similarly at BB (Figures 4:25, 4:26) the day to day changes in profile volume and shape disclose no obvious link either with the daily precipitation values in Kaikoura, or with the large volumes of sediment added to profile F. At BB, Figure 4:25 reveals that larger volumes of sediment were in transit on the beach than at AA, but less than at either CC or F. On a daily basis, about fifteen cubic feet appears to be about average. The profile shape variability was also less here than at either CC or F, but greater than at AA (Figure 4:26).

In contrast to conditions at the two northern profiles, it is suggested that profile CC, at least to some extent, reflects the same changes as those already shown to have taken place at F. In general the trend of the cumulative volume curve in Figure 4:20 is positive. More material was present on the beach at the end of November than at the middle of October. Moreover, although this curve does not show the transient peaks observable at F, the onset of a major positive increase in volume at CC occurred on the lower foreshore on November 16. It is suggested that this is related to the major addition at profile F which peaked five days earlier. Consistent with this suggestion, is the fact that the wave records show that for the whole of this period the waves were from north of shore-normal at F. A corresponding progressive seaward migration of the foreshore contour lines at both CC and F can also be seen in Figures 4:19 and 4:21.

Although there are other similarities between CC and F, such as the formation of a wide berm on the upper foreshore following the steepening of the lower foreshore, it should be emphasized that the present discussion of changes at CC and F has to do specifically with very large inputs of sediment from the river to the beach. It is only during these times that sediment contributions by the Hapuku can dominate topographic changes on the beach. At other times of the year, sediment input is so small as to be unmeasurable, and wave action is the chief determinant of the profile characteristics. Nevertheless, as these figures demonstrate, high fluvial discharge, when it occurs, is a major, though ephemeral, cause of beach profile modification at F, and to a lesser extent, at CC as well. It is linked to the intensity of local precipitation, and when the river is in flood, alteration to both the shapes and to the sediment volumes of the local profiles is very clear, and can be associated directly with concomitant changes in the volume of material brought down on the flood stage.

Seasonal Response Change

Figures 4:27 to 4:30 depict the changes in the mean monthly response values for the year. The mean values for gains, foreshore texture, foreshore slope, and shoreline position are listed in Appendix 4:2.

Figure 4:27, which shows month to month changes in volumetric gains at each of the four stations differs from the other graphs just mentioned in that it shows the net cumulative gain/ loss value at the end of each month rather than the mean value for the month.[1]

Monthly Variation in Sediment Gain

The relative irregularity of daily response changes, already noted, is also characteristic of the month to month changes in the responses. The gain/loss graphs of Figure 4:27 show this particularly well. There are wide fluctuations in the amount of sediment on the beach at the end of each month, and over the year, the curves show none of the smooth trends, either at one station, or between stations, that characterize the monthly process curves (Figures 3:13, 3:14, 3:15). As expected, Figure 4:27 shows that the two southern stations vary more than the two northern ones.

Monthly Variation in Foreshore Texture

Figure 4:28 shows these trends. The interstation agreement is closer than for sediment gain, and all of the curves except AA show that foreshore texture coarsens during the winter months. The most prominent textural coarsening is at BB, where textures are coarser than the yearly mean

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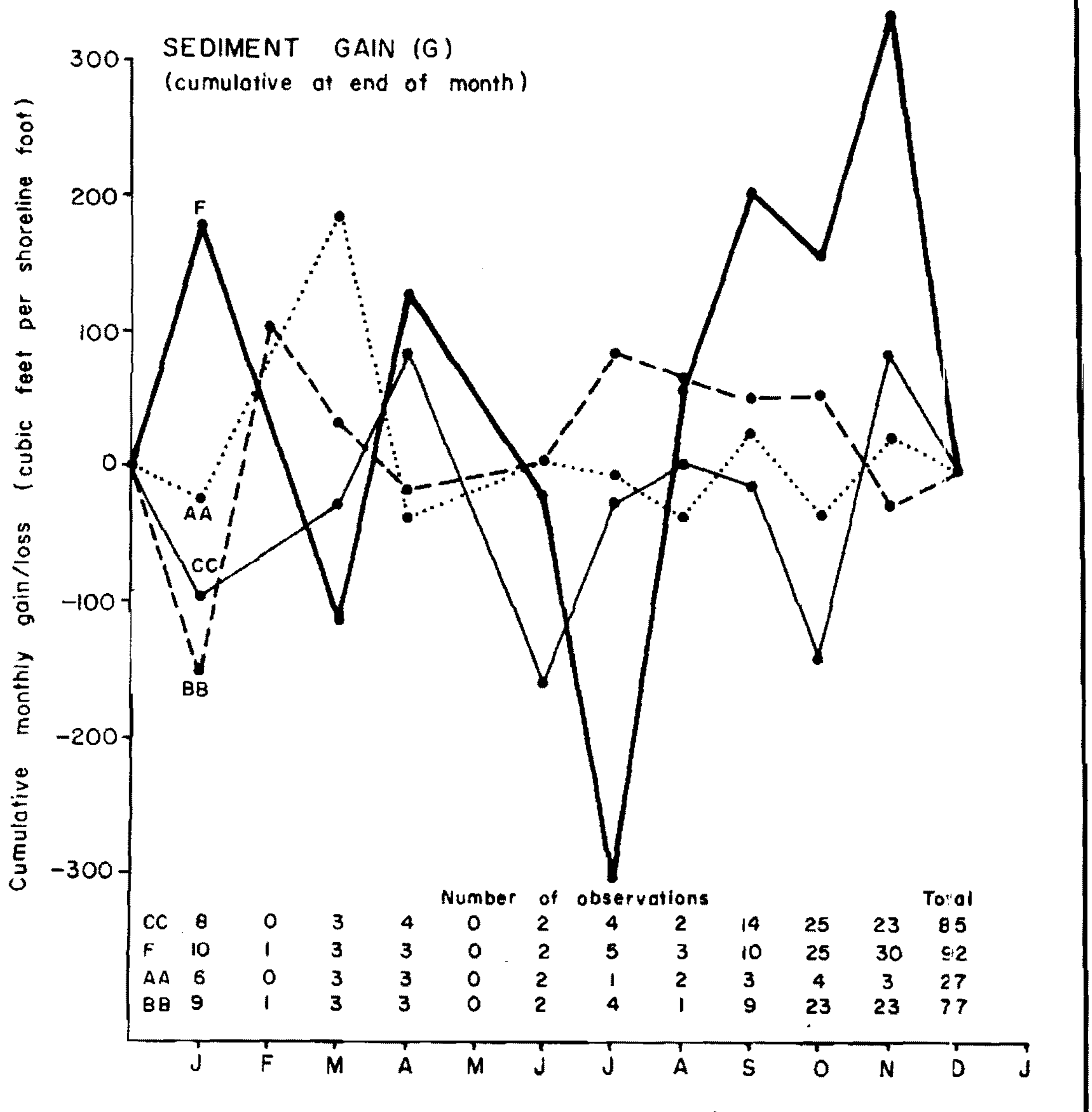
[1]Because volumetric change is essentially a difference in sediment volume from one sample period to the next, quoting mean monthly gains and losses to the beach is pointless unless the same number of samples are taken concurrently at each station for each month.

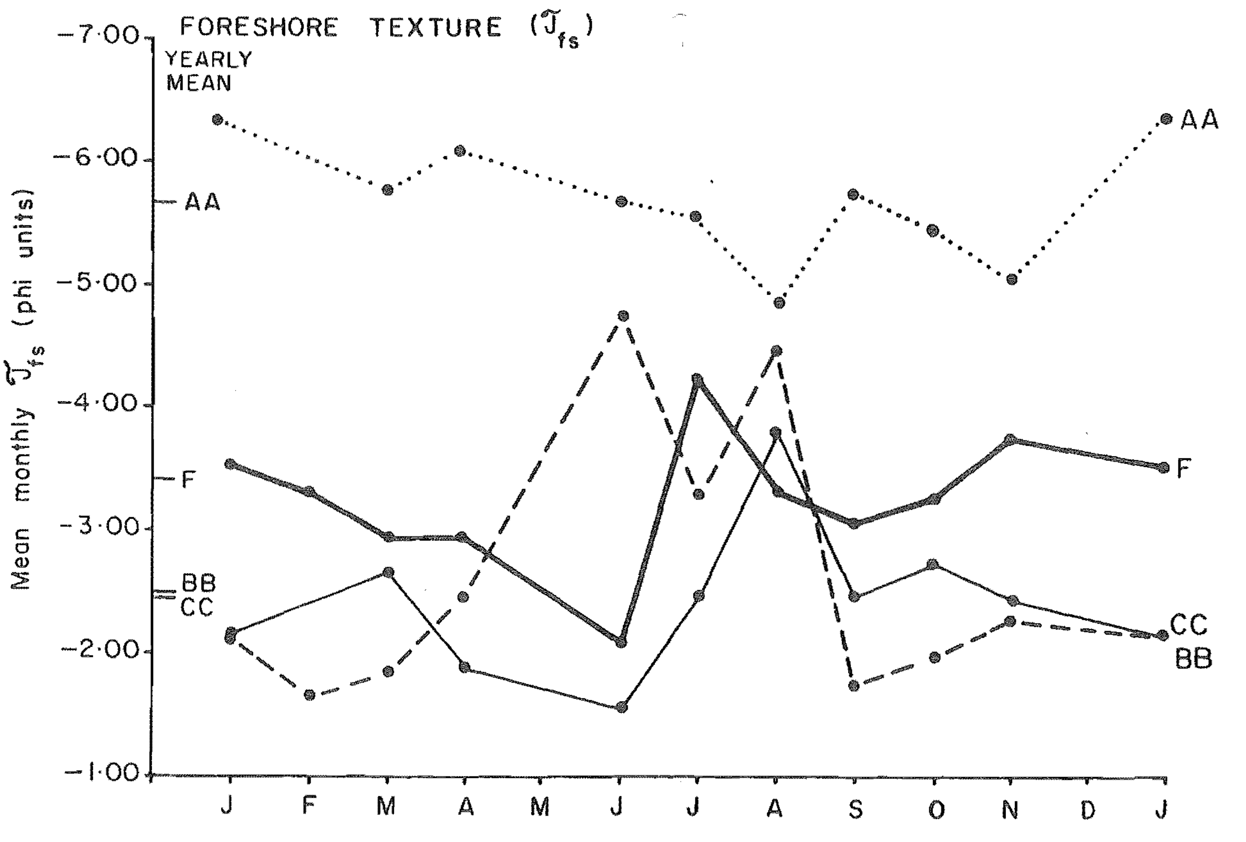
FIG. 4:27



Number of observations

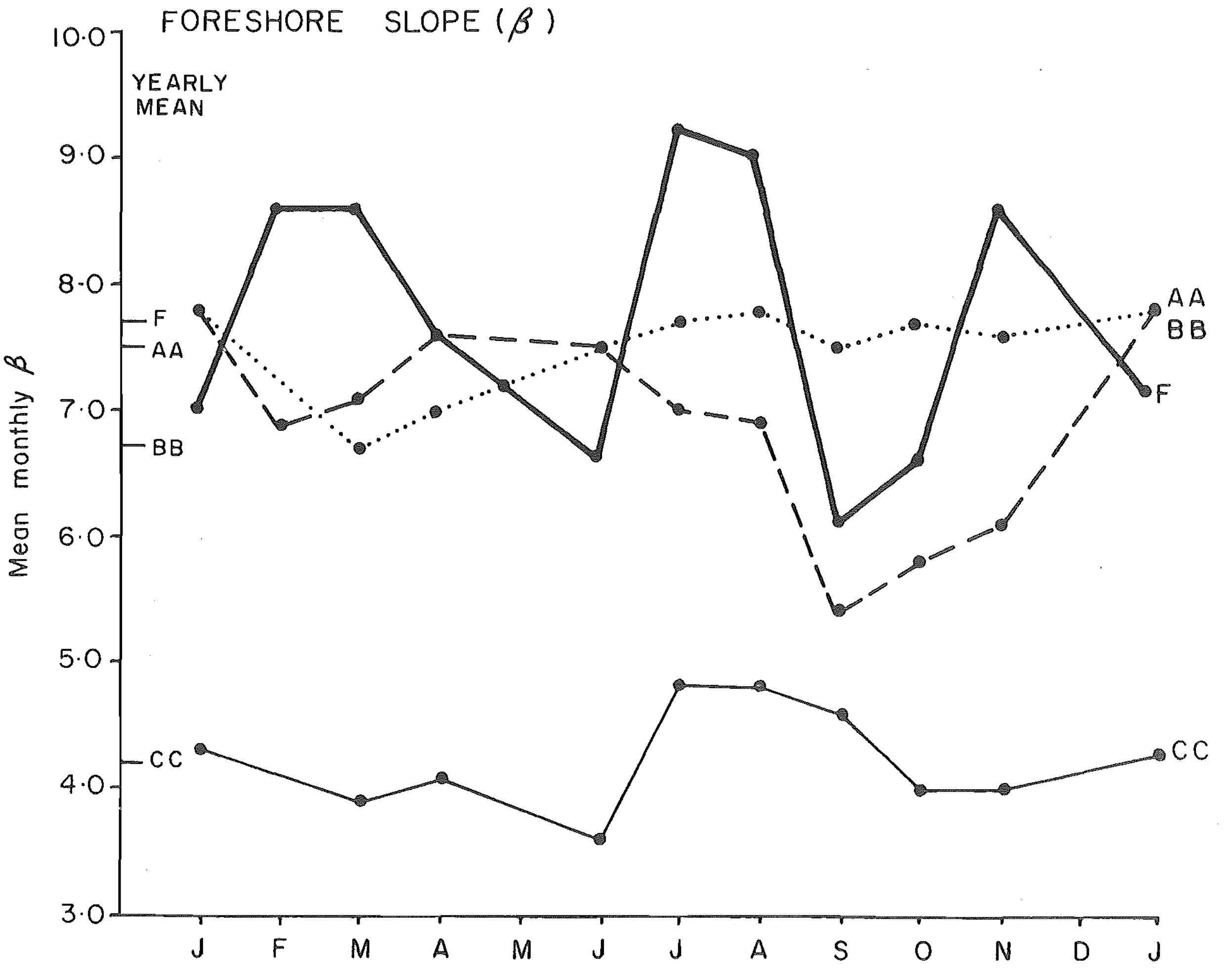
	J	F	M	A	M	J	J	A	S	O	N	Total
CC	8	0	3	4	0	2	4	2	14	25	23	85
F	10	1	3	3	0	2	5	3	10	25	30	92
AA	6	0	3	3	0	2	1	2	3	4	3	27
BB	9	1	3	3	0	2	4	1	9	23	23	77

FIG. 4:28



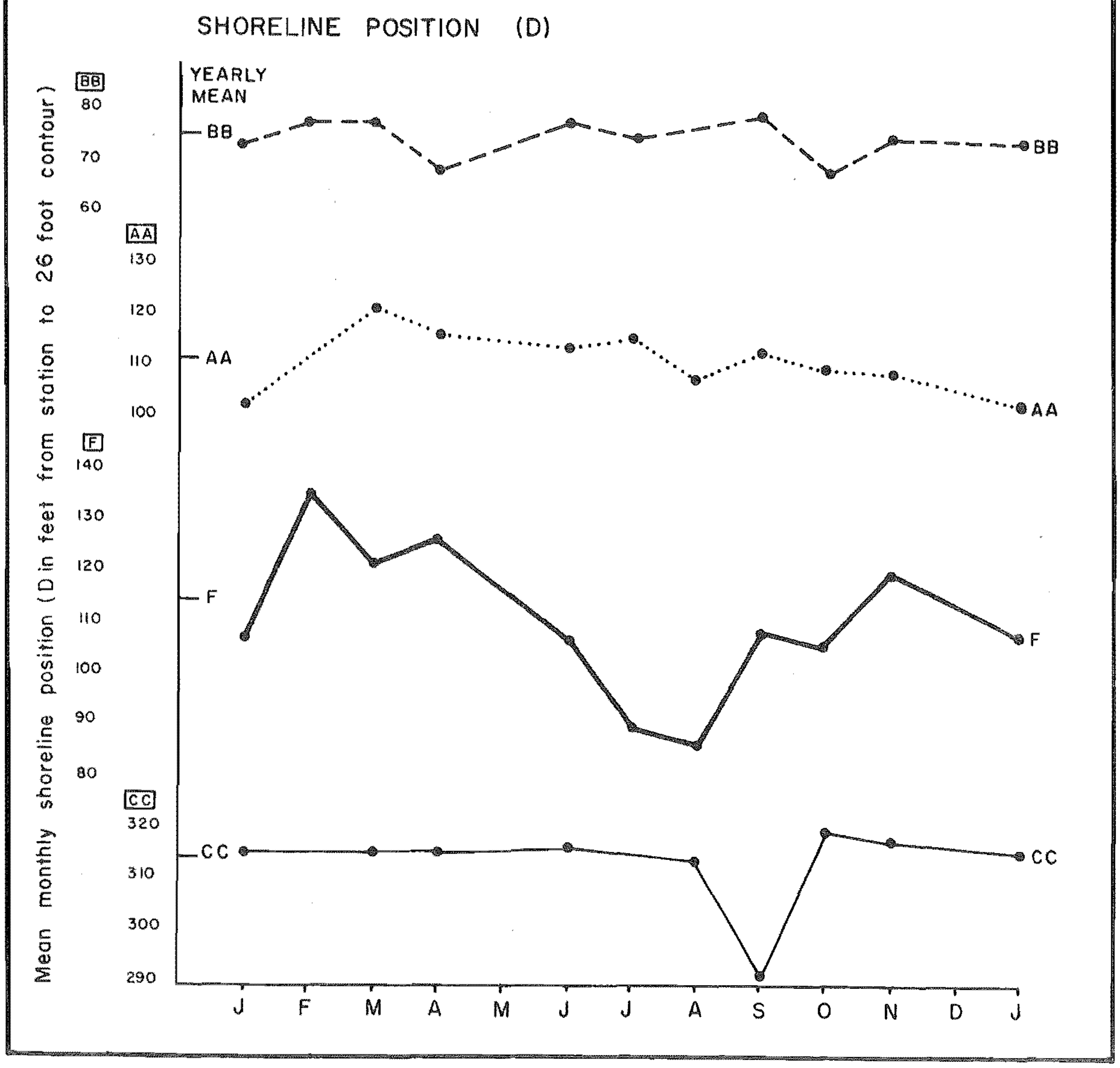
FORESHORE TEXTURE ($\mathcal{T}_{fs}$)
YEARLY MEAN
-7·00
-6·00
-5·00
-4·00
-3·00
-2·00
-1·00
AA
F
BB
CC
Mean monthly $\mathcal{T}_{fs}$ (phi units)
J
F
M
A
M
J
J
A
S
O
N
D
J

FIG. 4:29



FORESHORE SLOPE (β)
YEARLY MEAN
10·0
9·0
8·0
7·0
6·0
5·0
4·0
3·0
Mean monthly β
F
AA
BB
CC
J
F
M
A
M
J
J
A
S
O
N
D
J
AA
BB
F
CC

FIG. 4:30


SHORELINE POSITION (D)
YEARLY MEAN
Mean monthly shoreline position (D in feet from station to 26 foot contour)
BB
80
70
60
AA
130
120
110
100
F
140
130
120
110
100
90
80
CC
320
310
300
290
J
F
M
A
M
J
J
A
S
O
N
D
J

from April to late August. Thereafter, they are finer. This compares to only slightly coarser textures than usual between January and November at CC. The curve showing variation at F indicates that textures tend to be finer than their yearly mean value between February and June. From July to January, they tend to be coarser. There is comparatively little textural variation at AA.

Monthly Variation in Foreshore Slope

This is shown in Figure 4:29. Like the gains curves of Figure 4:27, the agreement in seasonal variation between the four stations is not overwhelming. This comes as no great surprise because as noted by many authors, slope values depend not only upon textural differences at different sites, but on a whole complex of interlocked variables including coastline exposure, size and shape sorting, and intensity of wave attack. However, some distinguishing features of slope variation at each station can be seen. At CC, foreshore slopes get steeper during July, August, and September. This corresponds to a time at CC when textures are coarser (Figure 4:28) and waves are also higher and steeper than usual (Figures 3:13, 3:15). At F, there are no major seasonal trends, and steep and flat foreshores occur at all times of the year. Likewise, at AA major trends are difficult to pick, although during March and April, slopes are flatter than usual. At BB, the foreshore slopes, like those at CC, steepen and flatten more or less in phase with increasing and decreasing coarseness (Figure 4:28). During the study year, they were slightly above their mean value for much of the early part of the year, and decreased to a minimum value in September.

Monthly Variation in Shoreline Position

Figure 4:30 shows that the maximum seaward advance of the shoreline occurs during the late summer in February and March at F and AA, and in October at CC. The most obvious trend though, is the retreat during the winter of the shoreline at CC and F. From its position of maximum advance, F retreats to a much greater extent than does CC. Seasonal advance and retreat at AA and BB are absent. Both profiles appear to be immune from the period of winter retreat present at the two southern stations. It can thus be concluded that unless special local conditions prevail, the beaches of this study conform to the summer fill, winter cut sequence noted on the east coast of South Island by other writers (Kirk, 1969, 1967; Dingwall, 1966; Blake, 1964). At AA, no seasonal cycle exists because most of the sediment is immobile under the prevailing wave energy conditions. BB lacks a seasonal cut and fill sequence partly because wave energy is low and partly because it is more protected than the other stations.

Long Term (thirty year) Changes Along the Coast

In recent years, a number of studies have been done on the east coast of South Island which use evidence related to both wave records and present-day sediment properties to help explain, among other things, the advance or retreat of the coastline over a period of years. In addition, historical material in the form of old maps and charts has also contributed to an understanding of the movement of the shoreline. Three of these larger scale studies are those of Pickrill (1973), Kirk (1967), and Blake (1964). Pickrill found that coastal progradation was taking place along the northern portion of Cloudy Bay due to longshore drifting of cliff debris. Kirk established that Canterbury Bight was eroding over much of its length at rates of up to three feet per year. Blake concluded that the coastline of Pegasus Bay is prograding, especially in the vicinity of the river-mouths. In addition, a good deal of attention has also been directed towards more detailed work on smaller sections of the coast. Numbered among these, are studies by Armon (1970), McLean (1970), Dickson (1969), McLean and Kirk (1969), Martin (1969), and Burgess (1968).

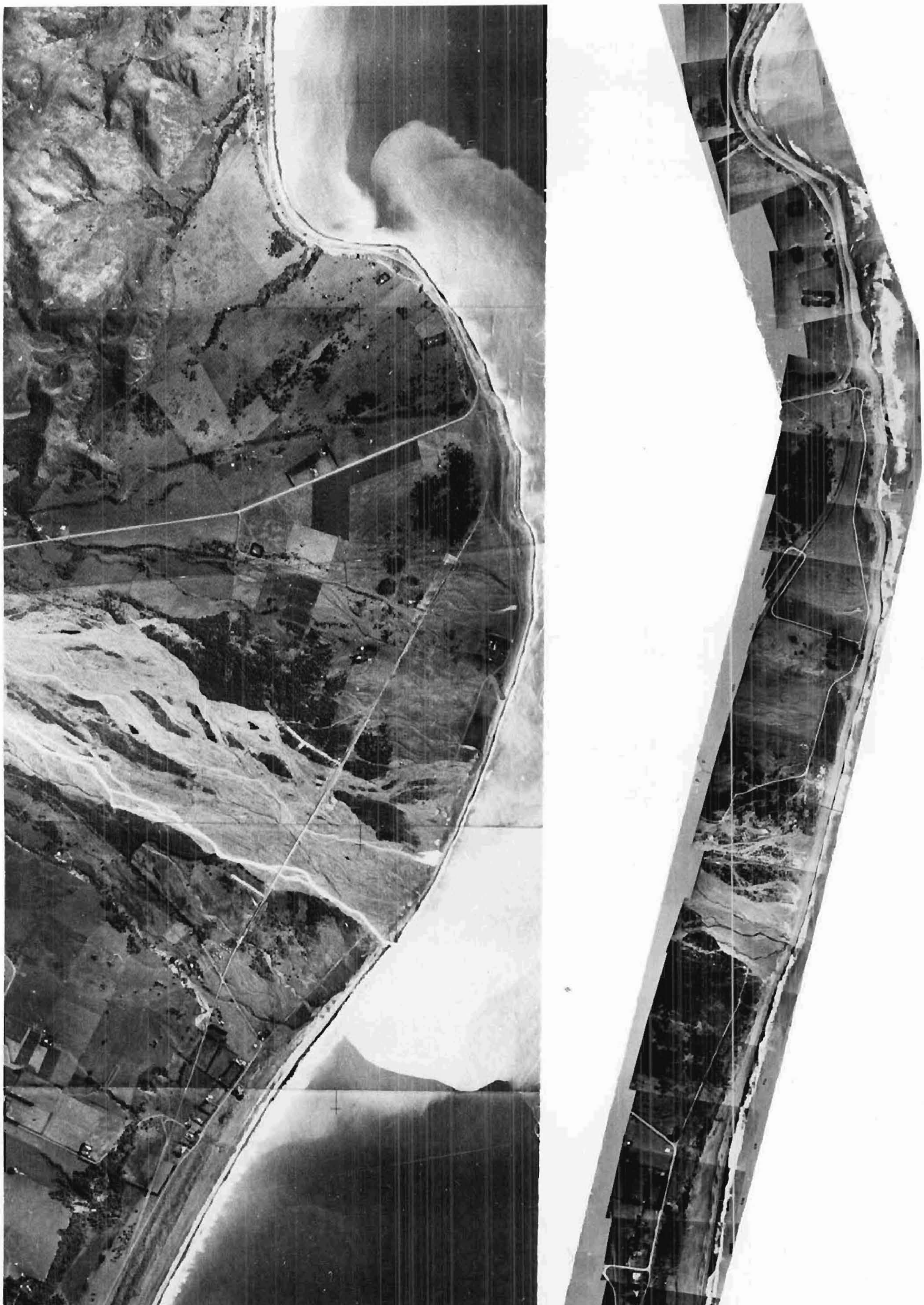
For many of these studies, repeated measurements of beach profiles served as one of the major data sources from which long term beach conditions could be inferred. It is felt by the present writer that long term conclusions such as these, which are based on extrapolation from short term observations, should be considered as being notoriously risky. One way of verifying the conclusions is by the use of airphotos. It will be demonstrated that insofar as coastline advance and retreat is concerned, their use provides valuable corroborative evidence to data gathered from beach profiles.

The New Zealand Government Photos, flown in December, 1942, provide photo coverage of the study area at a scale large enough (one inch to 1,256 feet) to permit major shore features to be identified. For comparison with these, a set of vertical airphotos was taken by the author in February of 1973 from an altitude of 3,000 feet. These were later enlarged to scales of one inch to three hundred and forty-seven feet, and one inch to one hundred and fifty-five feet. From the first of these enlarged sets, a photomosaic was constructed for use with the 1942 photos. The second set has been used to illustrate specific features in the text of this thesis.

At a 1.18 reduction for the 1942 photos, and a 4.44 reduction for the working mosaic of the 1973 photos, Plate 4:1 shows the coastline in 1942 (left) and 1973 (right) at a scale of about one inch to 1,475 feet.

Seventeen transects were located along the length of the coast from south of CC to north of BB. Four points were marked on each transect for the 1942 photos, and the same four points located on the 1973 photos. The first and most important of these was a base point, situated as close to the shoreline as possible to minimize the cumulative effect of shore-normal scale distortion, and clearly identifiable on both photographs. The second, third, and fourth points, respectively, were the limit of vegetative growth on the backshore, the crest of the winter berm, and the shoreline position (mean sea level). Of these last three, each has certain advantages and disadvantages both as regards ease of location on the photos, and as suitable indexes of coastal re-

PLATE 4:1



treat or advance.[1]

The vegetation limit is the easiest to locate, but it is perhaps the least satisfactory as an index of long term shore-normal coastal movement not only because it is apt to vary seasonally, but also because the vegetation may be periodically decimated by local residents or governments.

The crest of the winter berm usually has the disadvantage that it is not always particularly easy to see on air photographs, but since the 1942 photos were flown at 8:25 A.M., and the 1973 photos were flown at only three thousand feet, the combination of flat lighting for one set of photos, and large scale for the other made identification easier. Its main advantage is that its position is less influenced by short term events than other coastal features, but on most beaches, (which are flatter than the ones of this study), it is ill-defined and therefore difficult to locate with precision.

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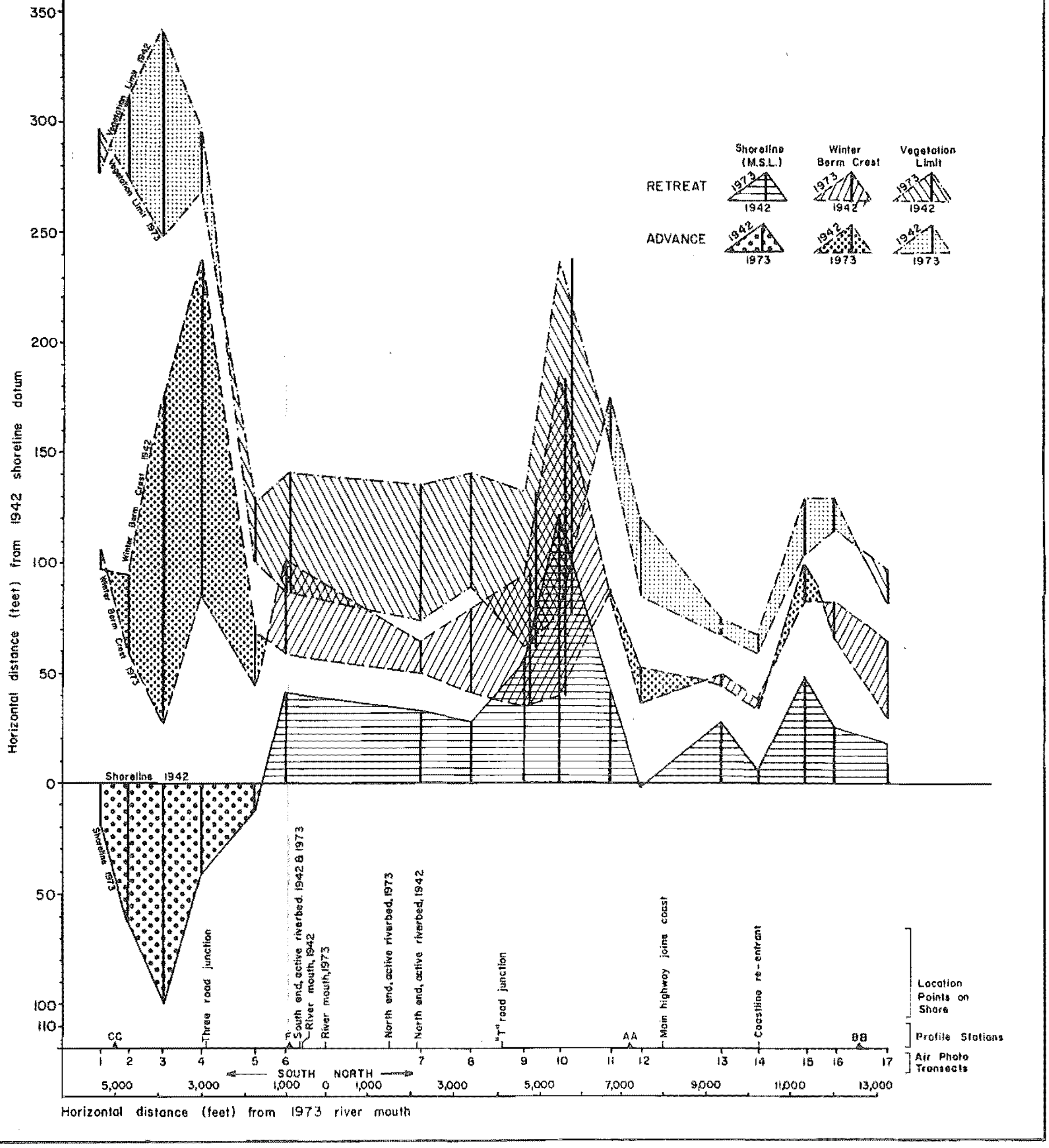
[1]Weber (1970) discusses in some detail the problems involved in selecting a meaningful shoreline index. Stafford (1971), and Moffitt (1969) are additional sources. He concludes that the water line, though not ideal, is the most practical and reliable index even though its location depends upon the extent of wave runup.

The last point located on the photos was the position of mean sea level. This was estimated using the water line, as recommended by Weber, as a guide. A certain amount of judgment was necessary because the 1942 photos were taken between times of high and low water, while the 1973 photos were flown during low tide. It was largely because of this that the berm crest and vegetation limit were also included in the interpretative procedures. In this way, a total of three points were plotted, all related to long term shoreline movement, the berm crests and vegetation limits providing independent checks on the reliability of the advance and retreat of the mean sea level positions.

The distance in feet from the base point of each transect to each of these three locations was measured both for 1942 and for 1973. Figure 4:31 shows the transects, the profile sites, identifiable shore features, the positions of all the plotted points, and their shore normal movement from 1942 to 1973. Since the zero footage datum at the base points on the photos bears no relationship to shoreline movement, the locations and distances on this figure have been adjusted to the 1942 shoreline datum.

Figure 4:31 emphasizes the value of using

FIG. 4:31


Shoreline (M.S.L.)
Winter Berm Crest
Vegetation Limit
RETREAT
ADVANCE
1973
1942
Vegetation Limit 1942
Vegetation Limit 1973
Winter Berm Crest 1942
Winter Berm Crest 1973
Shoreline 1942
Shoreline 1973
Horizontal distance (feet) from 1942 shoreline datum
360
350
300
250
200
150
100
50
0
50
100
110
Three road junction
South end, active riverbed, 1942 & 1973
River mouth, 1942
River mouth, 1973
North end, active riverbed, 1973
North end, active riverbed, 1942
"T" road junction
Main highway joins coast
Coastline re-entrant
Location Points on Shore
CC
AA
BB
Profile Stations
Air Photo Transects
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
SOUTH
NORTH
5,000 3,000 1,000 0 1,000 3,000 5,000 7,000 9,000 11,000 13,000
Horizontal distance (feet) from 1973 river mouth

more than one line of inquiry in attempting to understand the extent and rate of contemporary geomorphic changes. Regardless of the care and forethought used in choosing the profile sites to be representative of their particular stretch of coast, their initial location involves intuitive assumptions about coastal dynamics. The data gathered from them are still only representative of conditions at each particular profile. If, however, additional, independent information can also be included which focuses on the same variables being measured, then it can be used to confirm or discredit the conclusions reached by alternative methods.

Some explanations based on beach profile data (in particular, the skewness values of the yearly shoreline distributions), have already been tentatively put forward to describe the relative state of long term coastal advance and retreat at each profile site. Figure 4:31 is a valuable addition to these interpretations. It is also clear that a good deal of confidence can be put in these results because as the figure shows, there is a high degree of internal agreement in the interpretation, both alongshore and shore-normally.

Furthermore, both spatially and temporally, the figure is more representative of contemporary shoreline changes than the data so far presented. Spatially, seventeen transects give a more continuous record along the whole length of the shoreline than do four profiles. Temporally, a thirty year record is more representative of present day conditions than a one year record because it is less subject to unusually large or small variations in any particular year.

Figure 4:31 shows that in general, the shoreline south of 1,500 feet south of the present day river-mouth, is advancing. The amount of advance for the five transects totals forty-six feet for the thirty year period and the average rate of advance is therefore about 1.5 feet per year in this region. North of this, the shoreline is retreating an average of about 1.3 feet per year. Locally however, as the figure shows, there are departures from these values. The zone of maximum advance is three quarters of a mile south of the 1973 river-mouth where the shoreline is prograding at a rate of about 3.3 feet per year. The maximum rate of retreat is even more rapid, reaching levels of 4.0 feet per year a mile north of the river-mouth.

It can be seen that these conclusions are substantially the same as those reached earlier in this chapter from an examination of profile-derived data. There are two points that need to be mentioned however. The first is that it was suggested earlier on the basis of the negative skewness of the yearly shoreline distribution, that profile F was advancing seaward. This is a good example of how the data for one year may be unrepresentative of long term conditions. Figure 4:31 shows that over the long term, the change from shoreline retreat in the north to shoreline advance in the south, takes place not at F, but five hundred feet further south. The second point revealed by Figure 4:31 is that profile AA is uncharacteristic of the shoreline either to the north towards BB, or to the south, towards F. Both these areas are undergoing shoreline retreat. The shoreline at AA is atypical in that it shows neither retreat nor advance. The figure also shows that the shore at the coastline re-entrant also appears to be fairly stable (or at least retreating less than the areas either immediately to the north or immediately to the south), and grains finer than cobbles and boulders may over a long period, collect here rather than at the adjacent coastline sites (Plate 4:2).

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In keeping with the viewpoint expressed in Chapter II that sources of error should be considered, the tolerance limits for the measure-

PLATE 4:2

ments taken from the air photos, and depicted in Figure 4:31, are specified. They are given for each transect in Appendix 4:3 along with a short explanation of the sources of error, and how they were measured. It can be seen that in no case is the probable error large enough to invalidate the general conclusions expressed above.

Measurement in the Nearshore Zone

It has often been pointed out that changes to the subaerial beach depend to some extent on the nature of the nearshore submarine topography, and it is almost common knowledge that the slope and relief of the zone seaward of the breakers chiefly determines the breaker characteristics. Some researchers have been able to incorporate data from this zone into their studies. Nearly always, the physical symbol of their good fortune is a pier or jetty from which measurements can be made. The delta of the Hapuku is not so blessed. Even if it were, a pier would be of only limited use because the aims of this study are to describe, interpret, and inter-relate coastal changes over a fairly wide area of coastline, not just at one site.

In recognition that the nearshore zone is no less important because of these objectives, a local fishing vessel was hired, and a sounding and sampling survey undertaken. Water depths below the keel were continuously recorded by echo sounder on a chart recorder, and later converted to feet below mean sea level. They are considered to be accurate to within plus or minus two feet. Sample locations were determined primarily by resection from shore features, using the compass equivalent of the clinometer described in Chapter II, and visual checks were also made. Attainment of high levels of accuracy in locating the sample positions was not considered particularly critical in view of the method of sampling which involved dragging a steel tube, open at one end, over the bottom and waiting for it to collect a "representative" sediment sample. The sample positions are probably accurate to within about one hundred feet normal to the shore, and two hundred feet parallel to it. Figure 4:32 shows the nearshore bathymetry and the sample locations.

Nearshore Bathymetry

The figure shows that there is some interesting nearshore topography surrounding the delta. The most noticeable feature is the reef, about 1,000 feet offshore, which begins about 3,400 feet north of the river-mouth and extends for more than

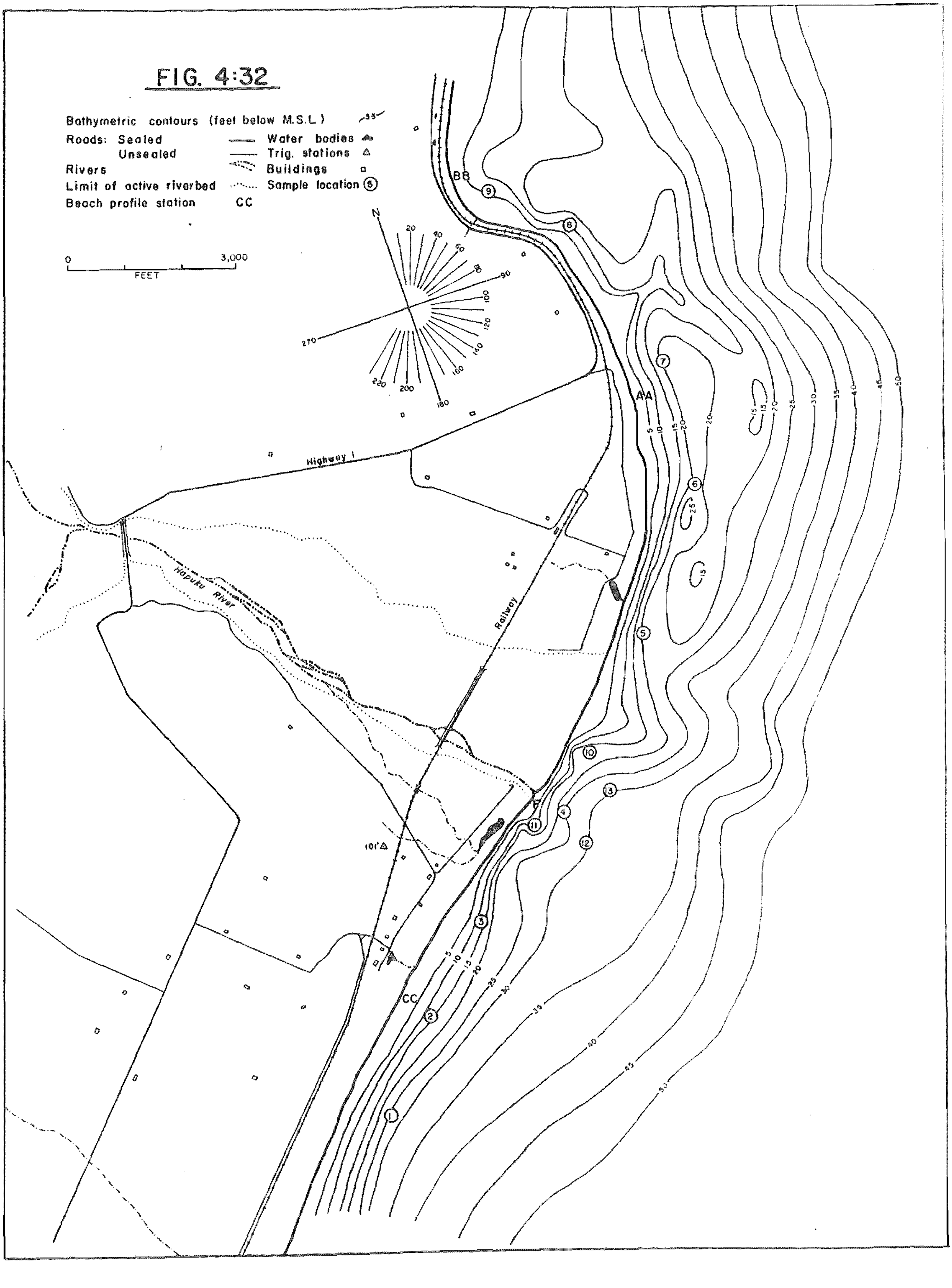
FIG. 4:32
Bathymetric contours (feet below M.S.L.)
Roads: Sealed
Unsealed
Rivers
Limit of active riverbed
Beach profile station CC
Water bodies
Trig. stations
Buildings
Sample location
0 3,000
FEET
N
Highway 1
Hapuku River
Railway
AA
BB
CC
101'

a mile to the north. In places, it is less than fifteen feet from mean sea level, and landwards of it, for three quarters of its length, it is bordered by a trough with depths of more than twenty-five feet.

The reef has special significance because it is the dominant influence on incoming waves at AA. Much of the deep water wave energy is lost both by bottom friction and sometimes by breaking on the reef, with the result that waves arriving at the shore at AA are uncommonly weak compared with those arriving at CC and F to the south.

The reef has some effects esteemed by the surfing community too. Waves arriving from the south-east quarter are diffracted. The lateral transfer of wave energy along the crest, and the re-entrant of the coastline north of AA combine to prolong the stability of the wave form. As would be expected, this effect is maximized during periods of south-easterly swell rather than more locally generated storm seas.

One effect that was noted during the collection of field data, was the complication the reef introduced in obtaining daily measurements of the wave parameters. Wave periods and breaker heights were generally measured close to shore, as described in Chapter II. At AA, though, long period waves often first break on the reef (thereby losing energy), then reform and break once more closer to shore. Short period waves on the other hand, are able to maintain their stability over the reef and only break as they approach the beach. The reef thus filters out the higher, more powerful waves. Since the wave period of a shoaling wave remains essentially unchanged, this has the effect of drastically reducing not only the wave height, but also the wave steepness values at AA. Attention has been drawn to both these points in the previous chapter.

Another feature of the wave climate at AA, also noted in Chapter II, is that in spite of being more exposed than either CC or F, waves approach AA from a relatively narrow sector. It would appear, therefore, that the reef also attenuates the directional range of incoming waves. Figure 4:32 shows that the reef parallels the shore. Both are convex seaward. It is suggested that waves approaching AA, unlike those approaching any other station, undergo two major episodes of refraction; first as they approach the reef, and second as they approach the beach. In effect, before they ever arrive at AA, the waves are pre-aligned to a more shore-normal approach direction than they otherwise would be, thus reducing the directional range of waves arriving at the shoreline.

These modifications to wave height and direction also explain why the process interrelationships at AA, described in Chapter III, are unusual compared to the other exposed stations.

It will be recalled that longer period waves at all stations except AA, showed significantly higher breaker heights (Figure 3:11). That this relationship does not hold at AA is the result of the tendency of long period waves to break first on the reef, then to reform and break at lower heights closer inshore (where the breaker height was measured).[1]

The statistical dependency of wave direction upon period was also noted at stations CC and F, but not at station AA, which is as exposed as the other two (Figure 3:12). The reason, already noted, is that at AA the reef provides an additional opportunity for refraction not present at the other two exposed stations, and all of the waves, but especially the shorter period ones, (which are refracted less under given conditions

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[1]It should probably be noted that this and the following point, concerning the effects of the reef, do not conflict in any way with the observations made earlier in Chapter III that at AA, as elsewhere, high waves have longer periods (Figure 3:10) and come from the south (Figure 3:9), and that southerly waves are higher (Figure 3:8).

than longer period waves) have a better chance of adopting a shore parallel alignment.

Nearshore Sediment Samples

The thirteen sediment samples collected from the nearshore bottom, were washed, oven-dried, and sieved at half-phi intervals by standard laboratory techniques (Krumbein and Pettijohn, 1938). Each sieve fraction was weighed, and mean phi diameter ($M\phi$) and sorting ($\sigma\phi$) values calculated by the method of moments.[1] Mean grain sizes range from a maximum of -1.70 phi (coarse granules) for sample eight, to 3.21 phi (very fine sand) for sample two, and the size and sorting values are listed in the first part of Appendix 4:4.

Figure 4:33 shows that the most noticeable longshore trend in grain size is a decrease south of the mouth of the river. Compared to the samples taken very close to the river-mouth, grain size also decreases to the north, but not to the same extent. Shore-normally, as would be expected, fine sediment (samples twelve and thirteen) is deposited seaward of the coarse sediment (samples eleven, four, and ten). In most cases, the worst

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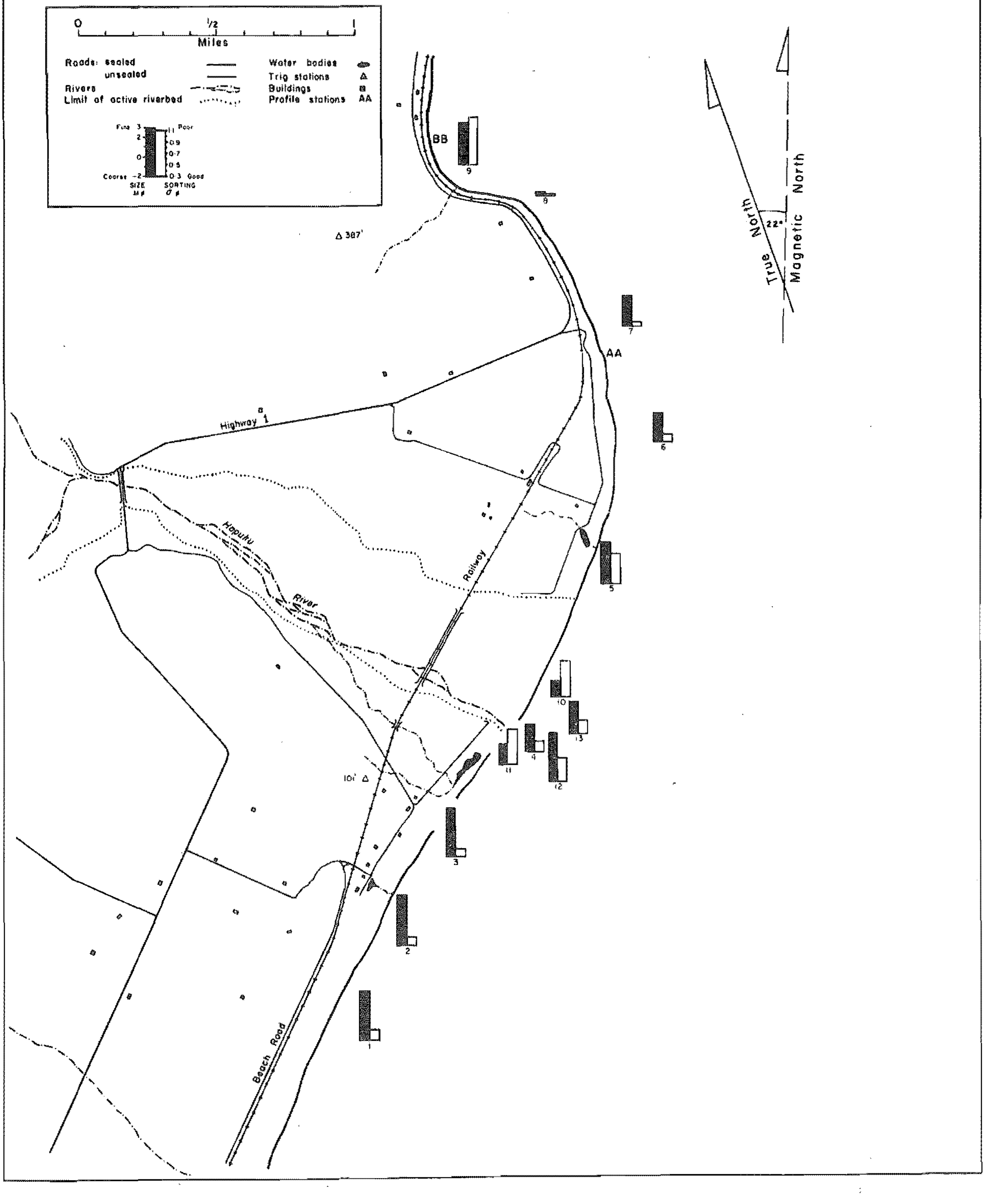
[1] Folk, R.L., 1968; p.49.

FIG. 4:33



0
1/2
1
Miles
Roads: sealed
unsealed
Rivers
Limit of active riverbed
Water bodies
Trig stations
Buildings
Profile stations AA
Fine 3
2
0
Coarse -2
Poor
0.9
0.7
0.5
0.3 Good
SIZE
SORTING
BB
AA
Δ 387'
101' Δ
Highway 1
Hapuku
River
Railway
Beach Road
True North
Magnetic North
22°
1
2
3
4
5
6
7
8
9
10
11
12
13

sorted samples occur around the river-mouth with better sorting values being characteristic of samples six, seven, and eight to the north, and samples one, two, and three, to the south.[1]

There are two interesting features of the sampled sediment that deserve passing mention. The first is that samples four and ten were composed almost entirely of mussels. By far the largest proportion consisted of the small ribbed mussel, Aulacomya maoriana, but the green mussel, Perna canaliculus was also present. The community did not appear to have been established very long. The oldest shells were only four years old (Fenwick, pers. comm.).

The other point of interest is that native gold was easily identifiable by naked eye in the finer fractions of several of the samples, around the river-mouth.[2] Although the wide occurrence of alluvial gold has been known for some time in New Zealand,[3] its presence on the east coast of South Island as far north as the Hapuku has, so far as this writer knows, not been reported. (See for example, Williams, 1965.)

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[1]The anomalously poor sorting values of sample nine suggests that these sediments may come from a different source than those further south, a possibility to be investigated in the next section.

[2]It does not exist in payable quantities.

[3]Park, J., 1910; p.335 ff. McKay, A., 1902.

The sediment sampling survey is meant to give only an approximate idea of the nature of the nearshore bottom. Although the survey results do give some impression of the kind of submarine sediment that borders the delta, almost certainly, coarser material than what was sampled occurs there. The sampling drag was sometimes felt to bounce over either bedrock, or pebbles and cobbles, and upon retrieval was found to be empty. The inability of the drag to sample these coarser sizes obviously biases the results.

The Movement of Sediment Around the Delta

So far, the sediment, profile, and wave characteristics have been described and interrelated, the contemporary conditions of shoreline advance and retreat have been discussed, and some consideration has been directed toward the dynamics of the sweep zones. But no attempt has been made yet, to explain how and where sediment is moved on the delta as a whole. This omission has been intentional. In some studies, the direct labelling and tracing of sediment grains has been used, and has met with some success, although it is generally conceded that effective tracing programs are often expensive and time consuming. In the present study, no large-scale tracing program was attempted, and the conclusions regarding the movement of sand, pebbles, cobbles, and boulders will be deduced primarily from inferential rather than direct evidence.

King identifies four major sources of beach material. They are: the cliffs behind the beach, river or glacier sources, offshore sources, and sources from along shore.[1] In respect of the present study, the only logical choice for the origin of the beach sediments is the Hapuku River. Except for Lyell Creek, five miles to the south of the study area, there is no major drainage to the sea either to the south or to the north for a distance of more than twelve miles from the mouth of the Hapuku. Furthermore, the Kaikoura Peninsula to the south, and a long stretch of rocky coastline to the north effectively inhibit the potential for large scale alongshore supply from beyond the immediate region. Eroding cliff faces are not a feature of the backshore, and there are no glaciers in the area.

It is equally hard to imagine an offshore source. The continental shelf off Kaikoura is extremely narrow, between one and two miles in width,[2] and although sand can be sporadically

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[1]King, C.A.M., 1972; p.224.

[2]Brodie, J.W., 1964; p.48.

moved onshore, there are no unequivocal examples in the coastal literature where material of most of the sizes present on the Hapuku beaches has been observed to come from submarine sources.[1]

On the other hand, the Hapuku has been observed in flood, and a documented example of the supply of river-borne sediment to the beach has already been described. It is therefore considered that the beach deposits owe their existence to infrequent but large scale sediment inputs from the flooding of the Hapuku.

As already stated, an understanding of the movement of the material brought down by the river after it reaches the sea, depends on descriptive conclusions reached from several different sources of data. There are five main sources of information from which sediment movement can be inferred. They are:

(1) the physical appearance of the profiles

(2) the sweep zone characteristics

(3) daily changes in the positions of contour lines

(4) long term conditions of shoreline advance and retreat measured from air photographs

(5) evidence derived from sediment parameters.

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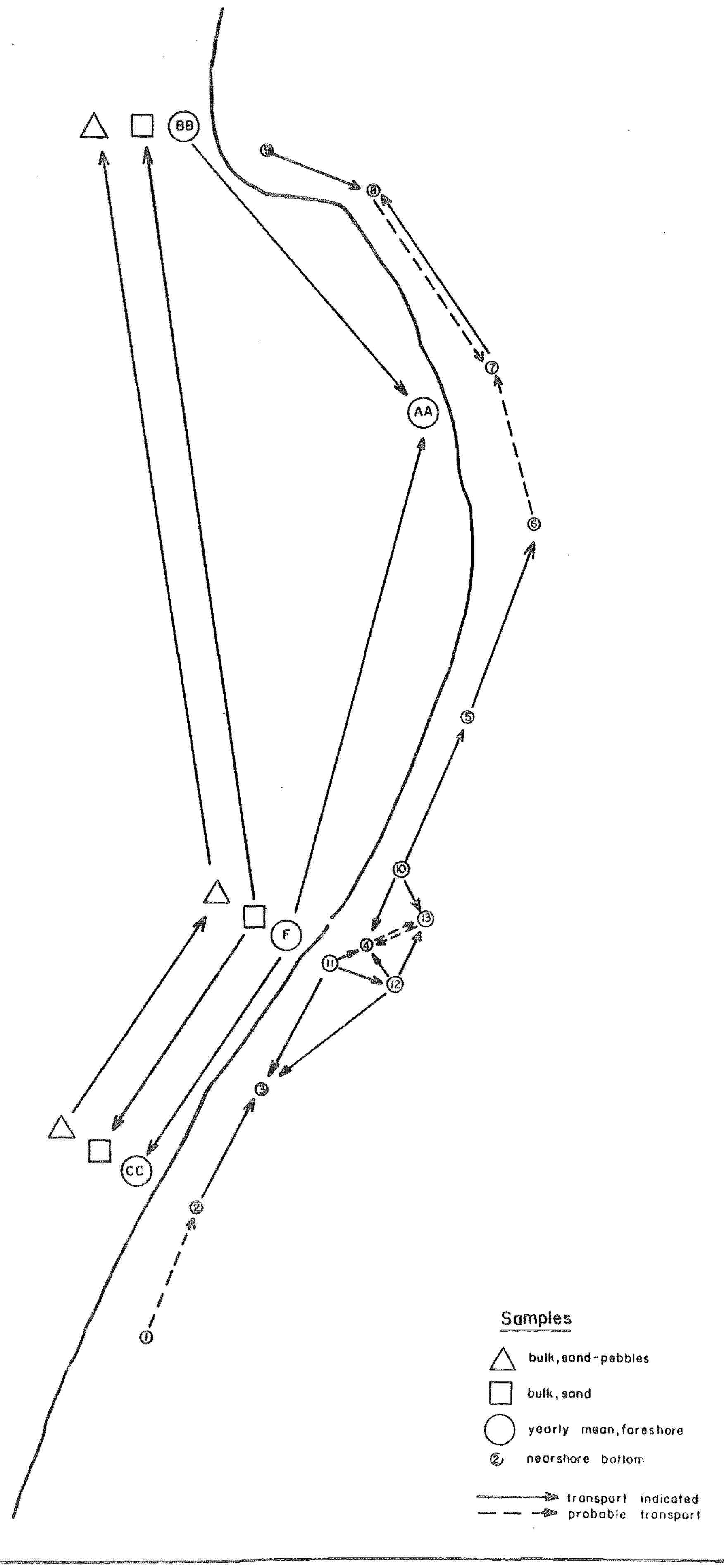
[1]Hardy, J.R., 1964; p.55.

Of these, the main features of all except (5) have already been described.

Many studies have been done which use sediment parameters to trace movement away from the sediment source as well as to discriminate among specific depositional environments. One of the classic studies of this kind is the 1957 work of Folk and Ward on the sediments of the Brazos River Bar. More recent investigations include those of Friedman (1961) and Greenwood (1969). In Japan, Sunamura and Horikawa (1972) have studied predominant littoral drift directions in relation to changes in grain size and size sorting. They conclude that transport directions can be inferred from size and sorting changes alongshore. In particular, they contend that transport away from the source is indicated, regardless of changes in grain size, if sorting improves. If sorting values stay the same, then transport is only indicated if grain size decreases.

Using these methods, Figure 4:34 shows the hypothetical transport directions that result for three sets of Hapuku samples, namely, the nearshore bottom samples, already referred to, yearly mean foreshore "samples" taken from the year's record of profile textures at all stations, and bulk samples of sand-pebbles and sand, channel-sampled

FIG. 4:34


BB
AA
F
CC
Samples
bulk, sand-pebbles
bulk, sand
yearly mean, foreshore
nearshore bottom
transport indicated
probable transport

from the foreshore at CC, F, and BB. Appendices 4:4, 4:5, and 4:6 list, respectively, the relevant size and sorting values. The directions indicated on Figure 4:34 will now be taken into account, along with the other four informational sources listed above, in describing how the sand, pebbles, cobbles, and boulders become distributed on the study beaches.

Probably the single most easily seen result of the processes controlling the distribution of material brought down by the river, is the rapid size segregation of the heterogeneous mixture of sand, pebbles, cobbles, and boulders into either fine or coarse deposits on the beaches. South of profile F, material coarser than pebbles is rare; north of the profile, cobbles and boulders predominate. The size sorting begins as soon as the river delivers its load to the sea. Heavier particles in the river move as bedload, and the lighter, smaller particles, as suspended load.

The competence of the river to carry both sizes cannot be doubted. Surface velocities of eighteen feet per second have been measured by the author during floods, and at such times, large boulders can be heard and occasionally seen, crashing down the channel bed. Upon reaching the sea, velocity drops drastically, and the larger particles are deposited close to the river-mouth. The less dense fresh water, carrying the suspended sand and silt, overrides the heavier sea water, causing a broad surface stain around the mouth. Because the wave-energy environment around the mouth is high, silt remains in suspension, where it is carried out to sea and is thereby effectively removed from the nearshore system. Sand sized grains are deposited in the nearshore zone seawards of the river-mouth. Thus, from the moment the sediment reaches the sea, silt is moved offshore, and the sand and small pebbles are separated from the coarser grains.

The intensive sampling around the river-mouth shows this clearly. Grains finer than four phi are almost absent from the nearshore bottom samples, and samples eleven, four, and ten, close to the mouth are coarser than twelve, and thirteen, further out.

Once deposited on the bottom, wave action is the predominant mechanism by which the grains are transported. Because of the steep "steps" which are characteristic of the seaward limit of the foreshore, it is difficult for the pebbles and smaller cobbles to return to the beach face. Large cobbles and boulders, on the other hand, may be deposited landwards of the surf zone and if the waves are powerful enough, they may from time to time be moved a short distance alongshore.

The closest station to the river-mouth is F, and the wave climate at this station is essentially the same as that at the mouth. It has been pointed out in Chapter II that waves from north of shore-normal, which are primarily north-easterlies, are more frequent in this area, than waves from south of shore-normal, which are primarily southerlies. But since the north-easterlies have lower breaker heights, and wave energy is mainly a function of wave height, they are also less powerful. It is suggested that it is only the southerlies that are capable of moving the large cobbles and boulders, and therefore the predominant direction of transport for these large sizes is to the north.

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Sand, of course, can also be moved by the waves, and potential for both northward and southward transport away from the river-mouth exists. The energy requirements to move sand and pebbles are not as high as those required to move cobbles and boulders, and so both north-easterlies and southerly waves are able to transport these finer sizes. Again, because north-easterlies are more frequent than southerlies at the river-mouth, most of the sand and pebbles are transported south towards CC, where they constitute the main supply to the beaches at the south of the study area. In this area, Figure 4:31 shows that accretion of the foreshore is taking place as a result of these sediment inputs. The beach at CC is very wide, and this also is consistent with a situation where sediment supply to the foreshore exceeds removal.

A smaller amount of sand-pebbles is moved north, but it is not deposited on the beaches because the energy levels there are too high, and so transport takes place primarily seaward of the breaker zone. The amount of sand and pebbles moving north becomes progressively less partly because some of it is periodically removed south again. The reef around AA, further inhibits the easy passage of this sediment by forcing it to move further offshore, so that it is likely that both profiles AA and BB are virtually starved of a supply of sediment from the south.

The foreshore region from the river-mouth north to AA is, except for the sheltering effect of the reef, one of consistently high wave energy. The high energy southerlies that slowly move the cobbles and boulders northwards, are also able to remove material to the offshore zone. In these cases however, it is the smaller, more easily transported grains in this size range that are most easily removed. Since the smaller sizes make up the volumetric bulk of the deposits, large boulders being relatively rarely supplied by the river, the preferential loss of cobbles from the beach along this stretch of coast results in a high rate of shore erosion (Figure 4:31). It is probable that there is a limiting size beyond which prevailing wave energy levels are incapable of moving boulders, and unlike the stretch of coast to the south, the lower, less powerful southerlies at AA are not able to move the large boulders on the lower foreshore, and as already demonstrated, the shoreline is highly resistant to erosion.

Profile BB has no protective reef to sap the energy of oncoming waves, but it is sheltered, and the wave energy levels here are comparable to those at AA. With little or no longshore supply of sediment from the south, the waves are able to erode the foreshore. The source of the sediments on the beach at BB is almost entirely the glacio-fluvial deposits of the backshore, and the existence of a four foot high erosional scarp landwards of the high tide elevation, and the narrow beach, testify to coastal erosion and net shoreline retreat at this station.

Figure 4:35 is a schematic synopsis of the

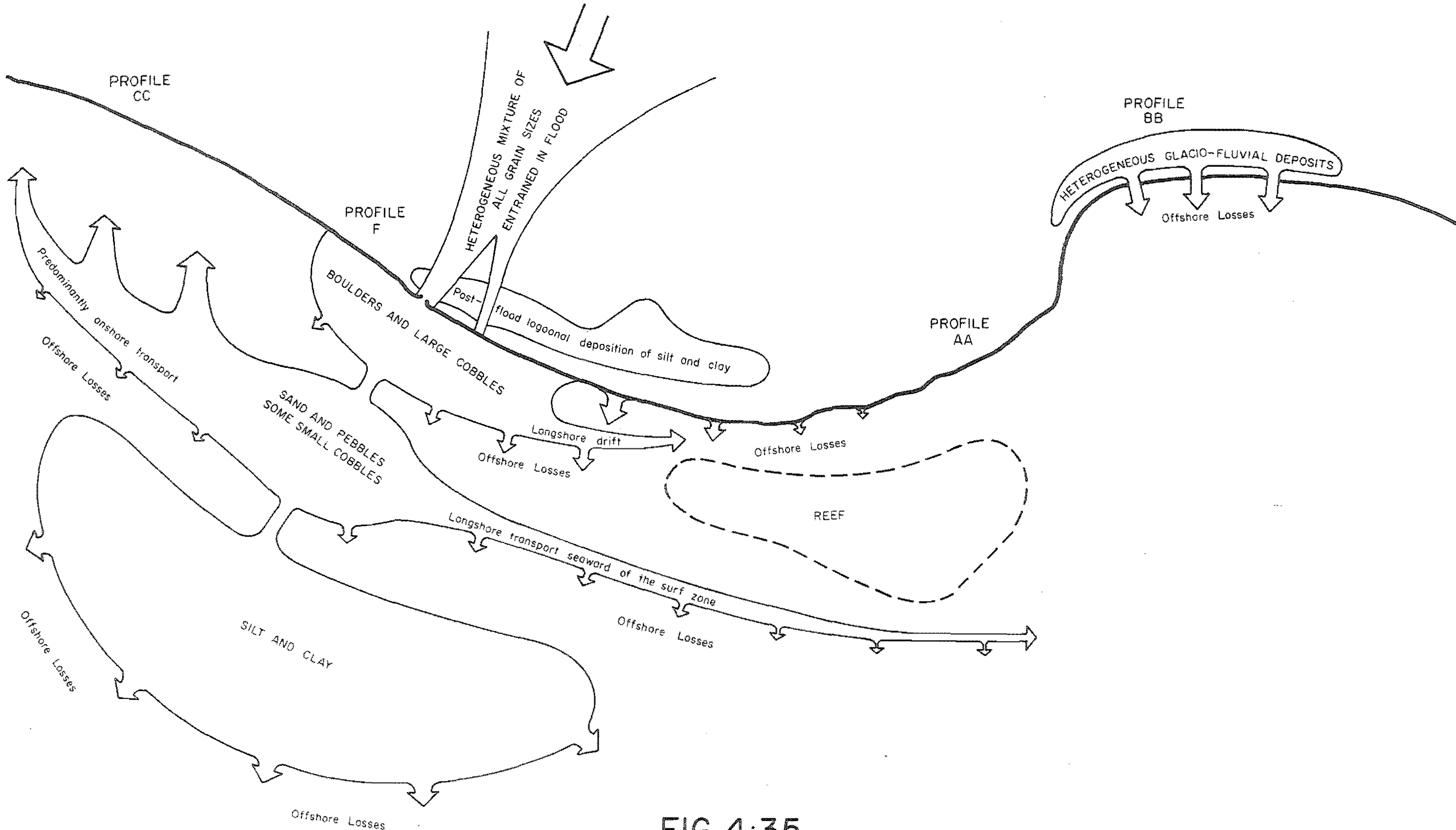
PROFILE CC
PROFILE F
HETEROGENEOUS MIXTURE OF ALL GRAIN SIZES ENTRAINED IN FLOOD
PROFILE BB
HETEROGENEOUS GLACIO-FLUVIAL DEPOSITS
Offshore Losses
Predominantly onshore transport
Offshore Losses
BOULDERS AND LARGE COBBLES
Post-flood lagoonal deposition of silt and clay
PROFILE AA
SAND AND PEBBLES SOME SMALL COBBLES
Longshore drift
Offshore Losses
Offshore Losses
REEF
Longshore transport seaward of the surf zone
Offshore Losses
SILT AND CLAY
Offshore Losses
Offshore Losses

FIG 4:35

foregoing discussion, and shows the movement of all sizes of sediment around the delta.

Summary

Although the organization of this chapter follows to some extent that of the processes in the previous chapter, strict adherence to such an outline would yield a superficial descriptive understanding of the response changes taking place on the beach. Accordingly, the responses have been explored and discussed in greater depth so as to more fully grasp the complex dynamics of the coastal zone. The discursive thrust of this chapter has thus converged from a comprehensive description of the response characteristics, to a detailed explanation of beach and sediment mobility. Where necessary, reference has also been made to the influence of specific wave characteristics on individual profiles.

The characteristics of the five response variables have been described at each of the four profile sites. The most active profile in terms of sediment mobility, is F, and it has been shown that it owes much of its activity to large but infrequent inputs of riverine sediment brought down when the Hapuku is in flood. The least active profile is AA. The extremely large boulders composing the lower foreshore at this station move so little that shoreline movement is all but undetectable by the measurement methods used in this study.

The steepest slopes on the delta are at F, and mean foreshore slopes are progressively less at AA and BB, with profile CC having much the flattest mean slope of all the sites.

The relationship between foreshore slope and grain size has been investigated by many authors, but in the main, their observations relate almost exclusively to sizes much finer than the sand to boulder assemblages found on the Hapuku beaches. It has been shown however, that in common with other studies, the general trend toward steeper slopes with increasing grain size is also true of the study beaches. Two size/slope anomalies are evident however, one at AA and the other at BB. Both are explainable in terms of the peculiar sediment dynamics of this stretch of coast. The very coarse foreshore at AA does not have correspondingly steep slopes because the prevailing waves cannot move the large boulders except by undermining them. Longshore input of boulders to the station is extremely small, and those that are undermined slip down-slope producing a relatively flat boulder platform low on the foreshore which extends seawards and is resistant to further movement. At BB, the foreshore slope is anomalously steep for its mean grain size because its restricted exposure protects it from the long erosive backwash of the southerly storms.

One indication of long term coastal ~~ag~~retrogradation or progradation is the skewness of the shore position distribution. A distribution that is negatively skewed (distributional tail landwards) indicates that most of the time the position of the shoreline is seaward of its mean, and therefore the long term trend is progradational. If the skewness is positive, ~~ag~~retrogradation is indicated. It is suggested that this measure of profile equilibrium is better (especially where sizes larger than pebbles are common), than one which relies on assumptions, however well founded, about the "standard" grain size/foreshore slope relationship.

Using the skewness criterion, the year's data indicates that the shorelines at CC and F are in long term phases of progradation, AA is stationary, and BB is eroding. In three out of four cases, these conclusions are confirmed over a thirty year period by independent evidence gathered from air photos. The one exception is profile F. Though it prograded during the study year, it is located on a section of coast that retreated over the past thirty years.

It should also be noted that the inferred transport directions based on the grain size and size sorting values of selected sediment samples are also consistent with the above conclusions regarding long term shoreline stability.

The sweep zones of the study beaches were also examined in detail. The shapes of the envelope curves confirm much of what has already been described with regard to profile mobility; that is, F was shown to be very mobile, and the other three profiles, less so. In addition, however, the sweep zone textures were also described, and the foreshore crest and base exposures of the sweep zones were used in conjunction with the field classification of sediment size to investigate a suggestion of McLean's (1970) that a coarse boulder basement exists over much of the delta which may inhibit shore erosion. A significantly coarser basement was found to exist at F and BB, at AA there was no significant difference between the crest and the base, and at CC, somewhat surprisingly, the base was found to be finer than the crest.

As with the processes, statistical methods were used to discover and describe the functional relationships between pairs of response variables.

In all, fifteen equations were found that expressed a significant dependency between the response variables. Significant relationships exist between volumetric gains and texture[1] at CC, F, and BB; and between gains and foreshore slope, gains and shoreline position, and texture and foreshore slope, at all stations. The regression equations show that at F and BB, large volumetric gains tend to be associated with a finer textured foreshore than do losses. At CC, the opposite is true, and large gains relate to a coarser foreshore than do losses. These findings agree well with those from the sweep zone analysis, and confirm that in general there is a progressive coarsening with depth at profiles F and BB, while at CC, progressively finer sizes are encountered at increasing depths through the sweep zone.

The gains/foreshore slope curves at all stations show that gains are associated with flatter slopes than losses.

The gains/shoreline position relationships are also what would be expected, with gains relating to advance, and losses to retreat of the shoreline.

Foreshore texture as a control of foreshore

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[1]In each case, the independent variable is quoted first, the dependent, last.

slope was explored in greater detail than some of the other response inter-relations, and the findings of this study were compared to those of Pickrill (1973), McLean and Kirk (1969), Zenkovich, (1967), and Shepard (1963, 1948). The slopes of the present study were found to be flatter for equivalent grain sizes than those of previous studies, and on the Hapuku beaches, the scatter of foreshore slope values was found to be very much smaller for grain sizes larger than medium pebbles (-4.0 phi), than for sizes finer than this.

Response variation with time was studied at three scales, daily, monthly, and over a thirty year period. The distinguishing feature of the daily changes on the beach, when compared with daily process variation, is a lack of any cyclical regularity in the response values. A close correspondence however, was shown to exist between local precipitation in Kaikoura, the flooding of the Hapuku, and additions of the sediment brought down by the flood to profile F, and to a lesser extent, to profile CC as well.

Seasonal trends in some of the responses are noticeable. The two most prominent ones are a textural coarsening of the foreshore during the winter at all profiles except AA, and shoreline retreat at CC and F, again, during the winter months.

The long term (thirty year) changes in the coast were studied with the use of air photographs. The methods of measurement were specified and the reliability of these was also taken into account by calculating and stating the tolerance limits. The results of the air photo interpretation showed that south of the river-mouth, during the last thirty years, aggradation has taken place, while north of it, the shoreline has retreated. At profile AA very little shore-normal movement has taken place. These findings are in good accord with those suggested by the sweep zones and beach profiles, and are especially valuable because they fill in a number of spatial gaps in the profile data.

The nearshore sounding and sampling program was described, and the importance of the reef in modifying incoming waves at AA was also stressed.

Finally, all of the profile, air photo, and sediment sampling information was integrated into an explanation of how and why sediment is moved around the delta. The chapter concludes with a schematic representation of this, which shows that of the wide range of sizes supplied to the delta by the Hapuku, silt and clay move offshore, sand and pebbles are deposited south of the river, and an ever-dwindling supply of cobbles and boulders moves slowly north from the mouth toward AA. Profile BB receives very little supply from the Hapuku, and the beach material on this profile is derived from the erosion of the terriginous glacio-fluvial deposits on the backshore.

CHAPTER V

PROCESS-RESPONSE INTER-RELATIONSHIPS

This chapter combines the processes and responses statistically, in order to disclose and examine significant inter-relationships between specified wave process variables and particular beach responses.

Process lag is taken into account and multivariate equations, as well as polynomials are included in the analysis. Each of: gains, foreshore texture, foreshore slope, shoreline position, and degree of cusp development, is discussed at each station with respect to the wave process variables.

The predictor equations which are developed and discussed in this chapter represent relationships that are thought to be important on the study beaches. In all, fifty-eight equations are given which relate wave processes to selected beach responses. Although a prodigious number, it is not considered excessive in view of the variety of beach types represented, and the fact that fifteen variables, nine of which have been lagged up to two days, have been considered at each site. Although some equations have more predictive power than others in terms of explained variation, discussion has been restricted in this chapter to those equations that are significant at the relatively high (for beach studies) .01 confidence level.

Ten polynomial equations, as well as being significant at .01 also explain more than fifty per cent of the variation in the dependent variable; equivalent to a correlation coefficient in excess of 0.71. These are regarded as being exceptionally representative of the beaches they describe, and they have been graphed. In addition, four multivariate equations are also felt to be important, and these, along with the ten polynomials, receive special attention in the text. The chapter ends with a summary.

Process Lag and the Correlation Matrix

It has already been pointed out that the development of predictor equations for beach processes and responses has been attempted before (Harrison, 1970; Harrison, Pore, and Tuck, 1965; Dolan, 1965; Harrison and Krumbein, 1964; Kemp, 1961; Krumbein, 1959). In recognition that time scale differences occur in the response of the beach to different processes (Schwartz, 1968), most of these studies incorporate some measure of process lag into their analysis. In the present study lagged processes are also used, and it will be shown that foreshore geometry, more often than not, relates best to pre-existing process intensity, rather than to processes operating at the same time that the responses are measured. A preliminary correlation analysis of the study data indicated that after two days, the significance of the relationships between processes and responses dropped to low levels, and so, as well as correlating process and response contemporaneously, the processes were lagged for both one, and then two days.

The correlation matrix is large. With nine processes and six responses, fifty-four process-response pairs exist, and as mentioned above, the processes were lagged at three periods, giving a total of one hundred and sixty-two polynomial screening runs to find the best predictor equations. The unprepossessing bulk of computer printout has therefore not been transformed into an appendix and included, as has been done in the previous two chapters. Instead, the best predictor equations at the .01 level, as well as their per cents explained variation and standard errors, have been abstracted from the computer output and appear in the text of this chapter.

As with the equations which treat the processes and responses separately, the emphasis here is placed on the polynomials. That including curvilinear functions in the analysis adds substantially to the degree of statistical predictivity derived using only linear methods, is as easily demonstrated too. A typical case in point is the relationship between deep water wave height and cusp development at profile CC. The best predictor equation is a sixth degree polynomial, and it explains fifty-four per cent of the variation in cusps at the .01 level. The linear equivalent explains less than one per cent of the variation and is not significant even at the .05 level.

The inclusion of process lags in the screening runs necessitated the use of a data set of daily observations of process and response at all stations. For reasons already given, beach changes at AA were usually unmeasurable, and daily profiling was considered a waste of time at this site. At the other sites however, daily records do exist, and the data set used for analysis in this chapter is the month and a half record of daily observations from September 17 to November 30.

Multivariate Correlation and Regression

In common with the studies just mentioned, one of the procedures used in this chapter is that of multiple regression analysis. With one dependent variable and twenty-seven independent variables,[1] the general form of the multivariate equation is:

$$Y = b_0 + b_1X_1(t) + b_2X_1(t-1) + b_3X_1(t-2)\ldots\ldots + b_{25}X_9(t) + b_{26}X_9(t-1) + b_{27}X_9(t-2)$$

where: Y is the response variable

b_0 is the y intercept

b_1, b_2, etc. are regression coefficients

X_1, X_2, etc. are process variables

(t), (t-1), etc. refer to the daily lags of the individual process measurements.

A stepwise regression program[2] was used, and admission of independent variables to the equation was limited at each stage of the regression, to those that contributed significantly at the .01 level to a reduction in the sum of squares of the dependent variable. Because the significance

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[1]Three lag periods for each of the nine processes.

[2]I.B.M. Scientific Subroutine "STEPR".

level is relatively high, most of the independent variables are eliminated from the regression so that the final equation contains correspondingly few terms.

Krumbein (1964, 1961) used a sequential multiple regression technique which tested all possible combinations of the independent variables taken one at a time, two at a time, three at a time, etc., with each dependent variable. Although comprehensive, this method suffers from the serious disadvantage that the cost in computer time, and the time necessary to examine the output becomes enormous when more than a few variables are used.

Harrison, Pore, and Tuck (1965) used a more efficient stepwise multiple regression technique, and were able to test eleven process variables with six lag periods each, on each of five beach responses, but they drew attention to the fact that the equations were based on linear assumptions, and they concluded that ultimately non-linear interactions would have to be taken into account.[1]

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[1]In a later paper (Harrison, 1970) it was shown that predictivity of the linear regression equations was improved by expressing the independent variables in dimensionless form.

The best predictor polynomial and multiple linear regression equations have been arranged in five tables; one for each of: gains (G), foreshore texture (σ_{fs}), foreshore slope (β or cot β), shoreline position (D), and degree of cusp development (C). Each will be discussed in turn.

Predictor Equations for Gains

Table 5:1 shows these, and the eleven equations are self-explanatory. At CC, gains and losses to the beach are most closely associated with breaker height at a process lag of one day. A cubic equation explains thirty-two per cent of the variation in gains with a standard error of forty-four cubic feet per shoreline foot (fairly large in comparison with the daily fluctuations shown on Figure 4:15(a)).

At profile F, gains are also associated with the previous day's wave heights, but they are also predicted as well by the previous day's wave steepness and wave energy values. Of these, the best predictor is deep water wave height (Equation (3)) which explains fifty per cent of the variation in gains. Restricting the statistical model to the linear assumptions implicit in the multivariate case, yields deep water wave energy (Equation (10))

TABLE 5:1

BEST PREDICTOR EQUATIONS SIGNIFICANT AT THE .01 LEVEL
FOR GAINS

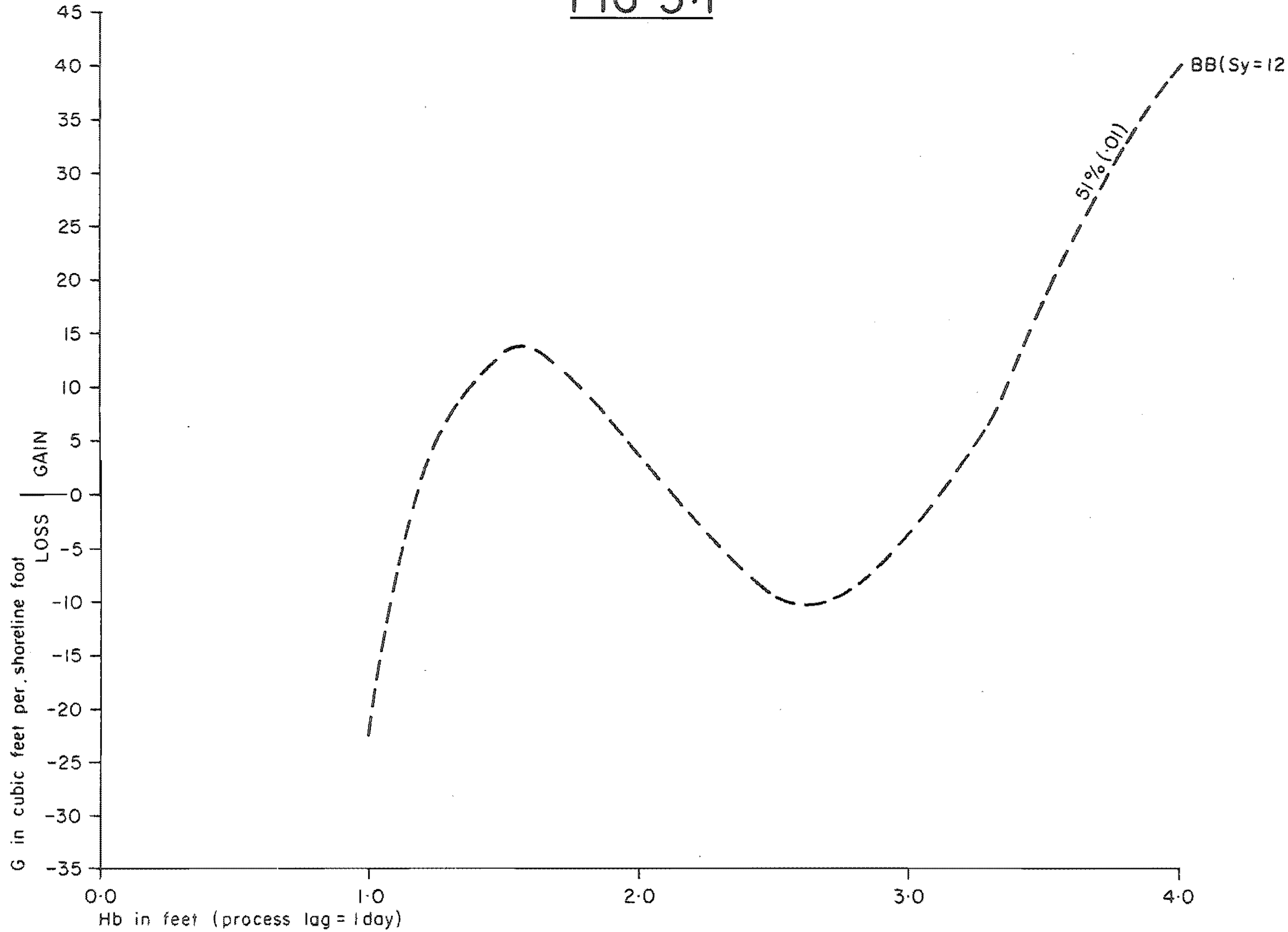
	REGRESSION EQUATION	PROF.	PROC. LAG	EXPL. VAR.	Sy
	2-VARIATE POLYNOMIAL				
(1)	$G = 332.7 - 330.4Hb + 91.71Hb^2 - 7.640Hb^3$	CC	t-1	32%	44
(2)	$G = -57.66 + 12.41Hb$	F	t-1	16%	38
(3)	$G = -1287 + 5266Ho - 8554Ho^2 + 7415Ho^3 - 3873Ho^4 + 1261Ho^5 - 249.8Ho^6 + 27.41Ho^7 - 1.272Ho^8$	F	t-1	50%	32
(4)	$G = -59.85 + 1431(10)So - 5938(10^2)So^2$	F	t-1	21%	37
(5)	$G = -21.29 + 0.5963(10^{-3})Eo$	F	t-1	19%	37
(6)	$G = -26.29 + 0.3436(Eo')$	F	t-1	16%	37
(7)	$G = -492.9 + 908.1Hb - 572.3Hb^2 + 148.0Hb^3 - 13.33Hb^4$	BB	t-1	51%	12
(8)	$G = -54.33 + 133.0Eo - 84.48Eo^2 + 21.99Eo^3 - 2.695Eo^4 + 0.1530Eo^5 - 0.3209(10^{-2})Eo^6$	BB	t-1	56%	12
(9)	$G = -15.38 + 2.029(Eo') - 0.3732(10^{-1})(Eo')^2$	BB	t-2	27%	15
	MULTIVARIATE LINEAR				
(10)	$G = -22.01 + 0.6020(10^{-3})Eo(t-1)$	F	—	19%	37
(11)	$G = -49.21 + 33.72Hb(t-2) - 4.838(10^{-3})Eo(t-2) - 1.503(10^{-3})Eo(t)$	BB	—	27%	15

as the sole predictor at the .01 level.

At BB, gains are predicted exclusively by the wave energy values and breaker height (Equations (7), (8), and (9)). Of these, the instantaneous energy contained per foot of wave crest (Equation (8)) relates best to the volumetric beach changes, with breaker height (Equation (7)) being almost as predictive. This relationship is reflected in the multiple regression equation as well (Equation (11)). The association is not nearly as strong though, as for the polynomial cases, and this shows up in the much lower explained variations, and higher standard errors.

Equation (7) and Equation (8) are shown graphically in Figures 5:1 and 5:2. Figure 5:1 suggests that the day following the occurrence of breaker heights of 3.5 feet or lower, may show either net gains or net losses to the beach, but for breakers greater than 3.5 feet high, the tendency is for net accretion to take place on the foreshore the following day. This may have some relation to the longshore distribution of sediment depicted schematically in Figure 4:34. Waves greater than 3.5 feet high are rare at BB (Figure 3:1), and when they do occur, they come from southerly directions (Figure 3:9). It is possible that such waves, infrequent though they are, transport a small amount

FIG 5:1

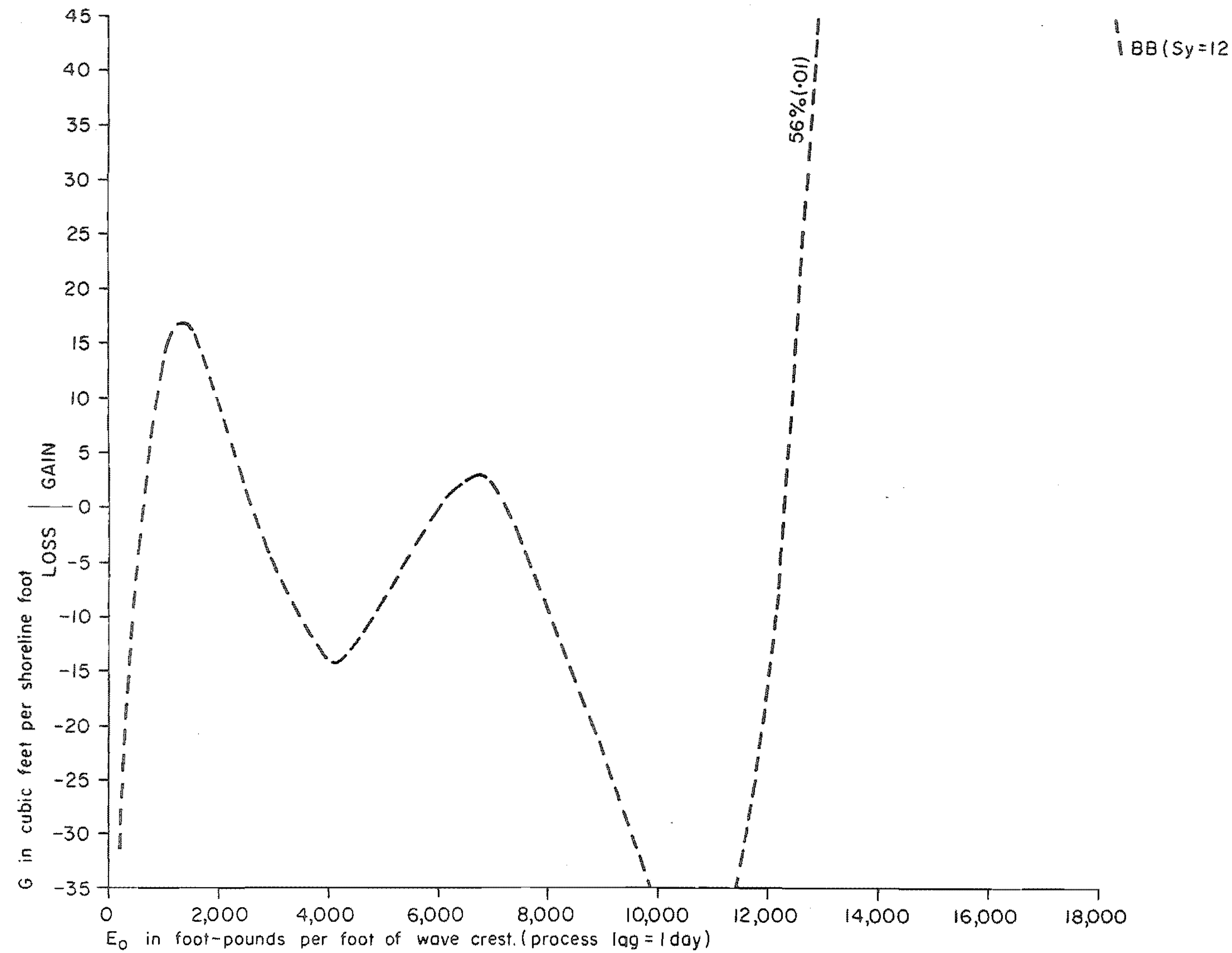

45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
GAIN
LOSS
G in cubic feet per, shoreline foot
0·0
1·0
2·0
3·0
4·0
Hb in feet (process lag = 1 day)
BB(Sy=12)
51%(·01)

of sand-sized sediment northwards into the shallow water offshore from BB, whence it is capable of being moved landwards as the southerly wave height and energy conditions decay.

Other researchers have found important relationships between wave heights and net erosion and deposition on the foreshore. Harrison and Krumbein (1964), found that wave height was one of the variables significantly associated with foreshore deposition, but not with foreshore erosion. However, using an enlarged data set from this earlier study, Harrison, Pore, and Tuck (1965) showed that higher waves were significant in promoting both erosion and deposition.

Figure 5:2 shows the strong relationship between wave energy and gains at profile BB. Again the process lag is one day, and in general the higher wave energy values tend to be associated with net volumetric losses to the beach. However, very high wave energy values, in excess of 12.5 thousand foot pounds per foot of wave crest are related to net gains on the foreshore, and though rare, may be associated with the same kind of longshore transport conditions as just discussed with relation to Figure 5:1.

FIG 5:2



45
40
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30
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15
10
5
0
-5
-10
-15
-20
-25
-30
-35
GAIN
LOSS
G in cubic feet per shoreline foot
56%(·01)
BB (Sy=12)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
E$_0$ in foot-pounds per foot of wave crest. (process lag = 1 day)

Wave Steepness as a Predictor of Beach Changes

One of the enigmas of this study is the lack of a strong correlation between wave steepness and gains. Much has been made in the literature of the ability of steep waves to erode and flat waves to build beaches. King, for example, flatly states that "Wave steepness has been shown to be the most significant factor on the foreshore.",[1] and Thompson and Harlett (1068), Ippen and Eagleson (1955), and Saville (1950) all found that higher wave steepness values significantly increased cut, and lower steepness values increased fill.[2] Iwagaki and Sawaragi (1958), working with a laboratory model of a sand beach, found that for Ho/Lo values in the range 0.0092 to 0.0093, accretion of the foreshore resulted, but when Ho/Lo reached values of 0.0574 to 0.0594, erosion became dominant. In field experiments, Patrick and Wiegel (1955), Bruun (1954), and King (1953), had similar results, but found that the measured steepness values in the field were lower than those measured in laboratory models.

Kirk (1970), on the other hand, suggested

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[1]King, C.A.M., 1972; p.419.

[2]Ingle (1966), on the other hand, found that breaker height seemed to be the best predictor of beach cut and fill.

that Ho/Lo ratios were poor predictors of morphologic change on mixed sand-shingle beaches. The results of the present study tend to support this view, and for the wide range of sediment sizes present on the study beaches, Table 5:1 shows that a strong wave steepness/gains relationship is clearly non-existent.

Predictor Equations for Foreshore Texture

The equations showing foreshore texture as predicted by the process variables, are given in Table 5:2. This variable is not predicted as well by the wave processes as some of the other responses are. Part of the reason for this is that texture is more closely associated with the slope of the foreshore, as discussed in the previous chapter, than it is with wave variables.[1] Another, more important reason is that the beach texture depends on the sizes of grains that are available for reworking by waves. Although it is possible to describe the study beaches in a general way by saying that all sizes from sand to boulders are widely represented, if storm conditions remove sand from the beach through the breaker zone, the fore-

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[1]In the multivariate case, slope should have been included as one of the independent variables.

TABLE 5:2

BEST PREDICTOR EQUATIONS SIGNIFICANT AT THE .01 LEVEL
FOR FORESHORE TEXTURE

	REGRESSION EQUATION	PROF.	PROC. LAG	EXPL. VAR.	Sy
	2-VARIATE POLYNOMIAL				
(12)	$\sigma_{fs} = -2.435 - 0.2963Hb + 0.0614Hb^2$	CC	t	27%	0.40
(13)	$\sigma_{fs} = -3.790 + 0.1309T$	CC	t	21%	0.41
(14)	$\sigma_{fs} = -3.775 + 0.0094(\theta')$	CC	t	37%	0.37
(15)	$\sigma_{fs} = -5.169 + 0.8320(10^{-1})\theta - 0.6008(10^{-3})\theta^2$	CC	t	33%	0.38
(16)	$\sigma_{fs} = -3.208 + 0.1396(10^{-2})Lo$	CC	t	23%	0.41
(17)	$\sigma_{fs} = -2.809 + 0.1223(10^{-4})Eo$	CC	t	27%	0.40
(18)	$\sigma_{fs} = 5645 - 274.6(\theta') + 5.463(\theta')^2 - 0.5692(10^{-1})(\theta')^3 + 0.3278(10^{-3})(\theta')^4 - 0.9899(10^{-6})(\theta')^5 + 0.1226(10^{-8})(\theta')^6$	CC	t-1	47%	0.37
(19)	$\sigma_{fs} = -4.151 + 0.3343Hb - 0.4621(10^{-1})Hb^2$	F	t-1	21%	0.37
(20)	$\sigma_{fs} = -2.992 - 0.1129(10^{-1})\theta$	F	t-1	17%	0.38
(21)	$\sigma_{fs} = -3.471 - 0.5651(10^{-5})Eo$	F	t-1	17%	0.37
	MULTIVARIATE LINEAR				
(22)	$\sigma_{fs} = -3.951 + 0.1088(10^{-1})\theta'(t)$	CC	—	43%	0.36
(23)	$\sigma_{fs} = -3.539 - 0.1365(10^{4})Eo(t-1) - 0.1206(10^{-1})\theta(t-1) + 0.2395Hb(t-1)$	F	—	30%	0.36
(24)	$\sigma_{fs} = -3.314 + 0.0115\theta'(t)$	BB	—	10%	0.48

shore will remain coarse grained, regardless of wave conditions, until a finer fraction is once again available.

The table shows that at CC, for both the polynomials and the multiple regression equation, the association between process and response is strongest when there is no process lag. This suggests that there is a relatively rapid adjustment of the surface texture at CC to prevailing wave conditions. At F, the polynomials and the multiple regression equation show that the best correlations relate to process lags of one day, suggesting that surface texture adjusts rather more slowly to process change. The slower adjustment at profile F may reflect the additional time required for the waves to come to equilibrium with the infrequent but large inputs of riverine sediment to the beach.[1]

Of all the processes, wave direction (θ') at CC shows the highest correlation with foreshore texture (Equation (18)). Although the equation is not included in the graphed figures because it does not explain more than fifty per cent of the response variation, it comes very close to this figure, and compared to the correlations of the other polynomial

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[1]In early November, the river went into flood. (See Figure 4:22.)

equations in Table 5:2, it is pre-eminent. Its standard error is also only 0.37 phi units which is small compared to the daily textural fluctuations at this profile as shown in Figure 4:15(b). For these reasons and because the equation is interesting as regards longshore sediment transport, it was plotted and examined. It showed that though there is considerable variation of σ_{fs} with θ', there are, as a rule, coarser textured foreshores associated with waves approaching obliquely towards the shore, than with waves approaching shore-normally.

The main point to note in Table 5:2 however, is that in contrast to most of the multiple regression equations relating process and response, Equations (22) and (23) are as predictive as the polynomials. In fact, these two equations are to be preferred to any of them. Equation (22) explains almost as much of the variation in texture, as does Equation (18), and Equation (23) by including three independent variables, eclipses the predictive power of all of the polynomials at profile F. Wave direction is most closely related to the texture of the foreshore at CC, while at F, energy, wave approach angle, and breaker height are the most important variables.

Predictor Equations for Foreshore Slope

Eight polynomial, and two multivariate equations express the ten significant relationships at the .01 level between foreshore slope and the wave processes (Table 5:3). Of these, three at CC (Equations (25), (26), and (27)), and one at BB (Equation (32)), explain more than fifty per cent of the variation in slope on their respective profiles, and are shown graphically in Figures 5:3, 5:4, 5:5, and 5:6.

The best slope correlations at CC are achieved by lagging the processes by two days, those at F by using no process lags. This is a reversal at these profiles of the temporal relationships of texture with process, discussed in the last section, and the situation seems to be that whereas there is a relatively rapid accommodation of foreshore slope to wave action at F, and a slower adjustment of textural changes, the opposite is true of profile CC, where surface texture adjusts rapidly, but foreshore slope responds more slowly to prevailing wave action. The foreshore slope at BB, like CC, shows the highest correlation with a process lag of two days (Equation (32)). Table 5:3 also shows that Equation (33) is another example of a multivariate function that compares reasonably well in predictivity with the bivariate associations.

TABLE 5:3

BEST PREDICTOR EQUATIONS SIGNIFICANT AT THE .01 LEVEL
FOR FORESHORE SLOPE

	REGRESSION EQUATION	PROF.	PROC. LAG	EXPL. VAR.	Sy
	2-VARIATE POLYNOMIAL				
(25)	$\beta = 20.98 - 5.106T + 0.5038T^2 - 0.1634(10^{-1})T^3$	CC	t-2	66%	0.19
(26)	$\cot\beta = 41.14 - 208.3Ho + 590.1Ho^2 - 814.8Ho^3 + 615.5Ho^4 - 267.7Ho^5 + 66.87Ho^6 - 8.918Ho^7 + 0.4919Ho^8$	CC	t-2	59%	0.68
(27)	$\beta = 7.690 - 0.2167(10^{-1})Lo + 0.3963(10^{-4})Lo^2 - 0.2283(10^{-7})Lo^3$	CC	t-2	62%	0.20
(28)	$\cot\beta = 14.00 + 0.2297(Eo') - 0.4130(10^{-1})(Eo')^2 + 0.2124(10^{-2})(Eo')^3 - 0.4784(10^{-4})(Eo')^4 + 0.5340(10^{-6})(Eo')^5 - 0.2902(10^{-8})(Eo')^6 + 0.6127(10^{-11})(Eo')^7$	CC	t-2	49%	0.74
(29)	$\cot\beta = -95.70 + 310.1Hb - 363.9Hb^2 + 222.1Hb^3 - 78.53Hb^4 + 16.68Hb^5 - 2.096Hb^6 + 0.1434Hb^7 - 0.0041Hb^8$	F	t	50%	1.2
(30)	$\beta = 8.432 + 0.2578(10^{-3})Eo - 0.2100(10^{-7})Eo^2 + 0.4841(10^{-12})Eo^3 - 0.4196(10^{-17})Eo^4 + 0.1221(10^{-22})Eo^5$	F	t	44%	1.4
(31)	$\cot\beta = 7.302 - 0.1951(10^{-3})Eo + 0.1546(10^{-7})Eo^2 - 0.3646(10^{-12})Eo^3 + 0.3265(10^{-17})Eo^4 - 0.9806(10^{-23})Eo^5$	F	t-1	35%	1.3
(32)	$\cot\beta = 133.6 - 971.7Ho + 3077Ho^2 - 5207Ho^3 + 5187Ho^4 - 3136Ho^5 + 1130Ho^6 - 223.1Ho^7 + 18.55Ho^8$	BB	t-2	70%	0.30
	MULTIVARIATE LINEAR				
(33)	$\beta = 8.977 - 0.9669T(t-2) + 0.0920(10^{-1})Lo(t-2) - 0.0345(10^{-1})Eo'(t-1)$	CC	—	65%	0.19
(34)	$\cot\beta = 8.999 + 0.3090Ho(t-2)$	BB	—	13%	0.46

Numerous studies have indicated that for any given grain size, flat foreshores are associated with waves that are steep and have long periods and long wave-lengths, while steep foreshores are associated with low values of these parameters (King;[1] Harrison, 1969; Rector, 1954; Iverson, 1952). It has also been observed that high waves usually tend to flatten beach slopes while low waves tend to build them to steeper angles.[2] The data of the present study indicate that except for profile F, these relationships are also true of the study beaches.

Figure 5:3 shows that at CC, short period waves relate to steeper foreshore slopes than do long period waves. In particular, the steepest slopes at CC are associated exclusively with wave periods of less than seven seconds.[3] The relationship between beach slope and wave height at CC is less clear (Figure 5:4). There is considerable variation of slope with increasing wave height at CC, but slightly flatter foreshore slopes do occur

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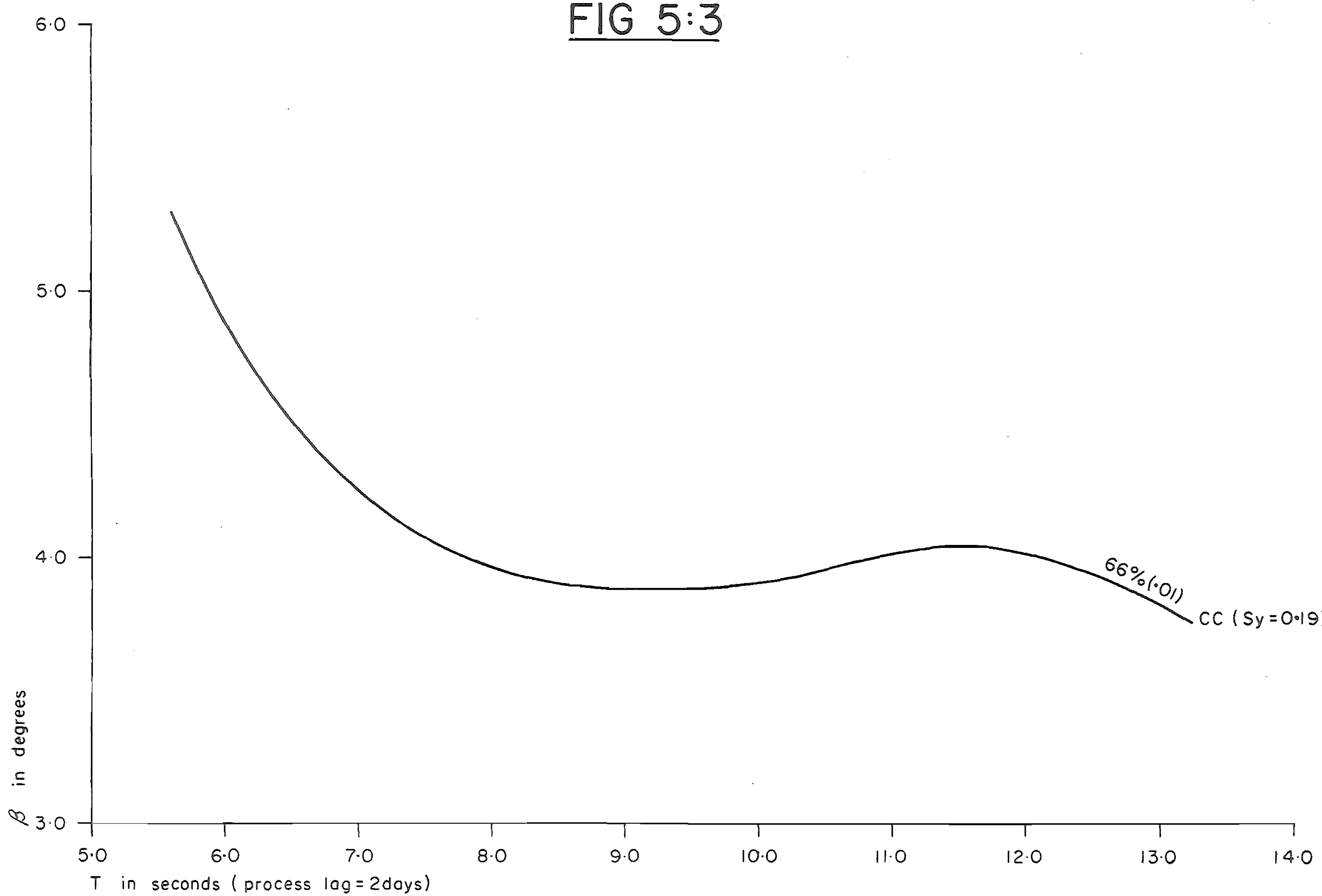
[1]King, C.A.M., 1972; p.325 ff.

[2]Although the effect of wave height depends to a great extent upon its relationship with steepness and wave-length.

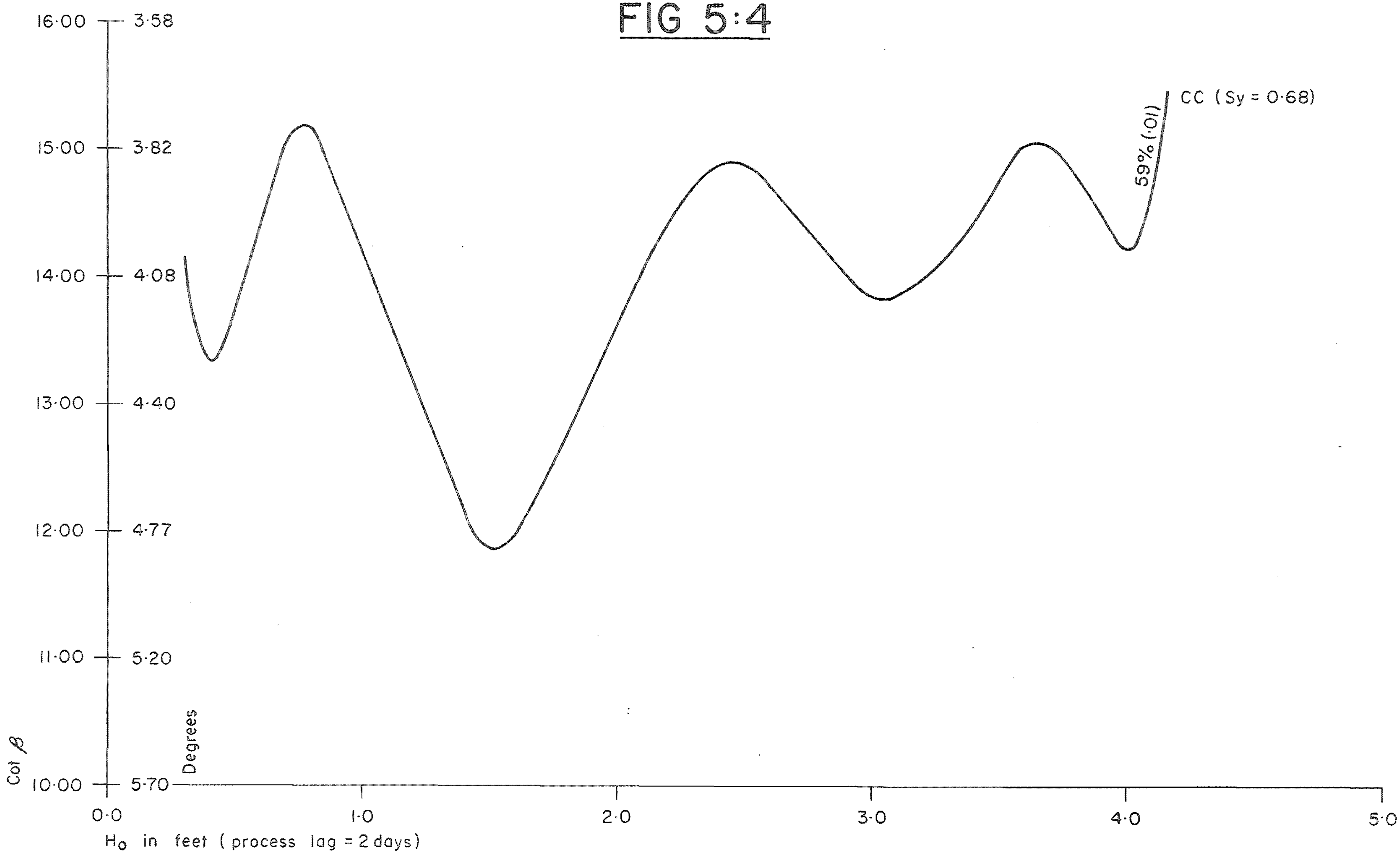
[3]This corresponds to a wave-length of 251 feet (Figure 5:5).

FIG 5:3



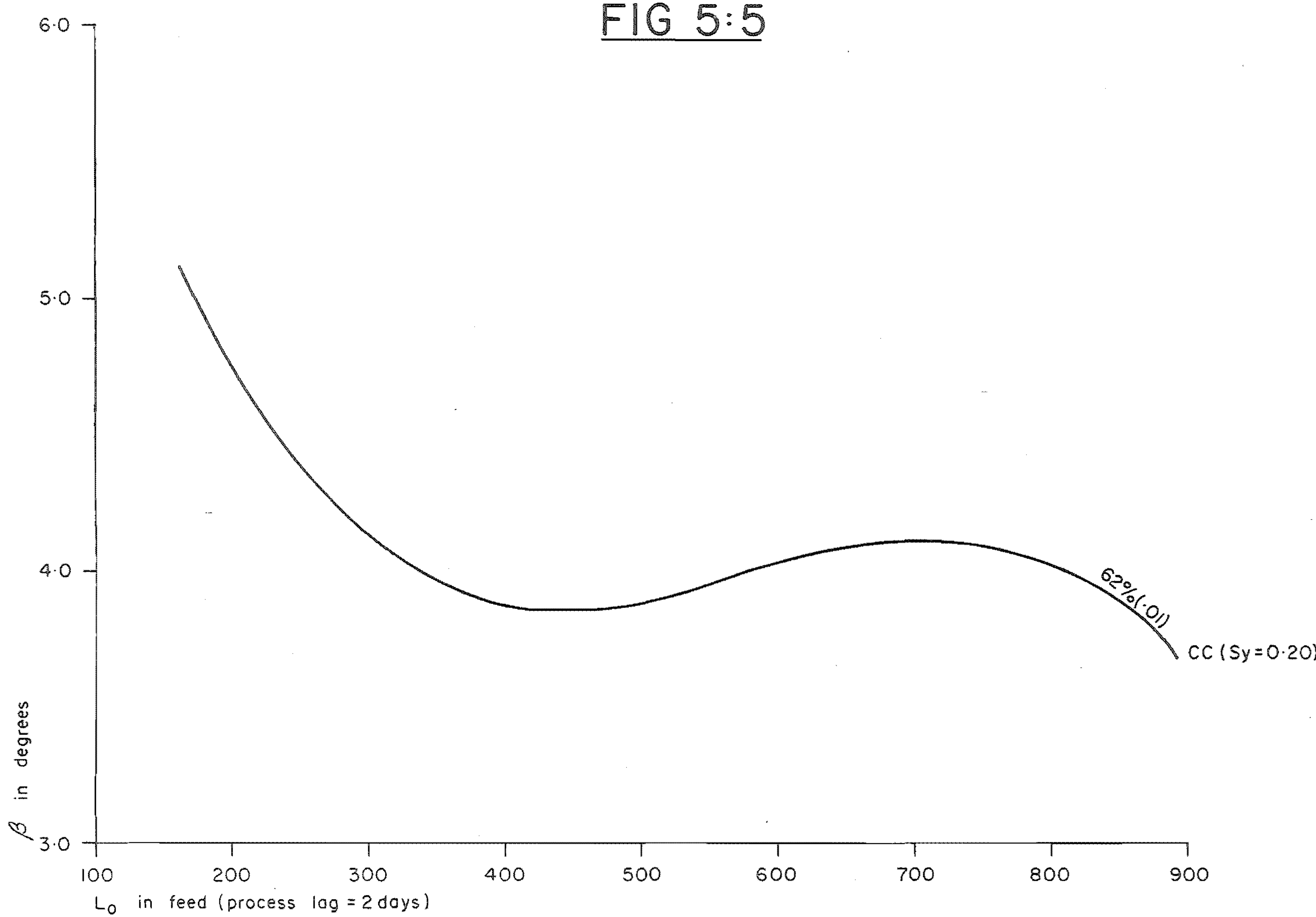
6·0
5·0
4·0
3·0
β in degrees
66%(·01)
CC (Sy=0·19)
5·0
6·0
7·0
8·0
9·0
10·0
11·0
12·0
13·0
14·0
T in seconds (process lag = 2days)

FIG 5:4



16·00
15·00
14·00
13·00
12·00
11·00
10·00
3·58
3·82
4·08
4·40
4·77
5·20
5·70
Cot β
Degrees
CC (Sy = 0·68)
59% (·01)
0·0
1·0
2·0
3·0
4·0
5·0
H_o in feet (process lag = 2 days)

FIG 5:5

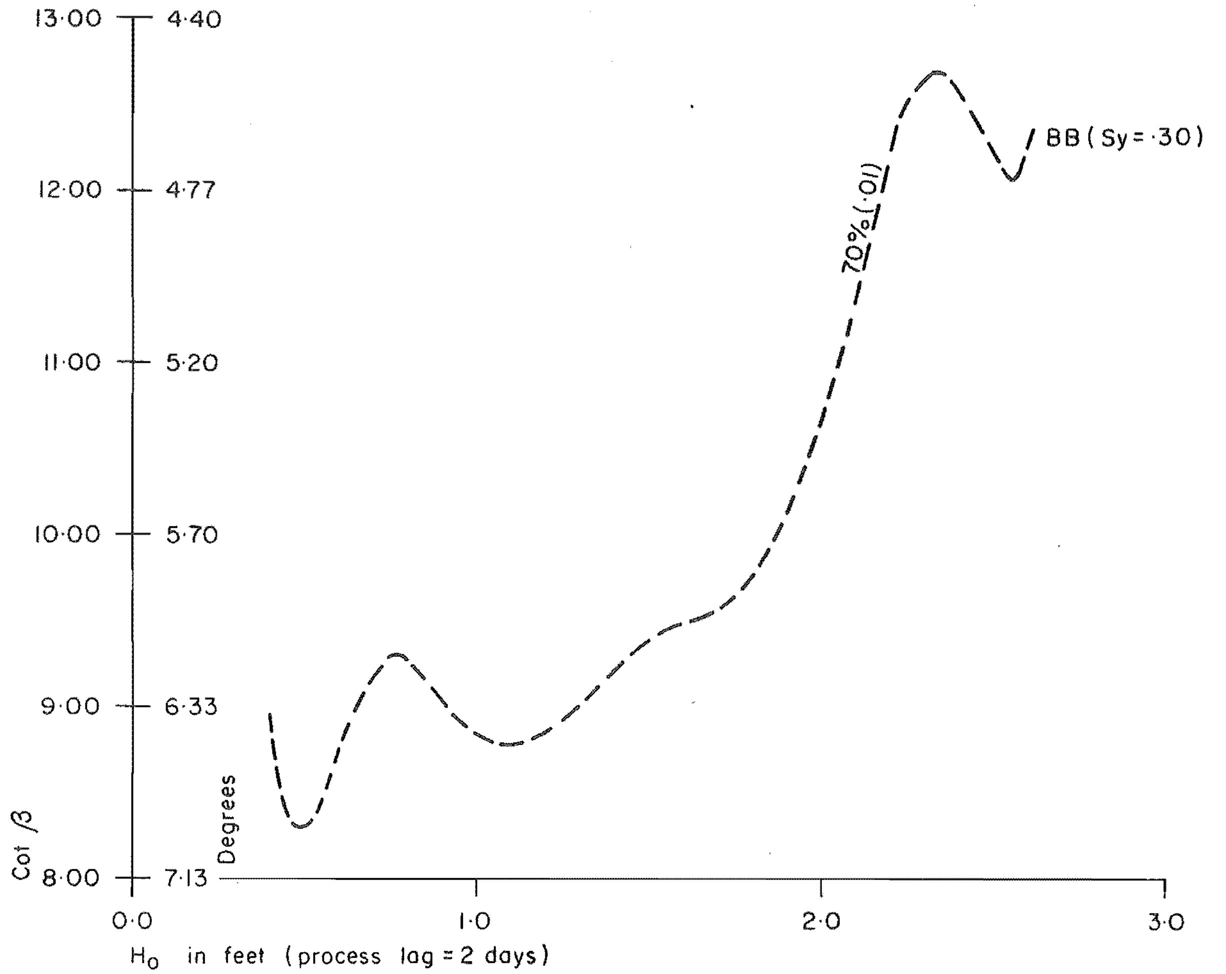

6·0
5·0
4·0
3·0
β in degrees
100
200
300
400
500
600
700
800
900
L_o in feed (process lag = 2 days)
62%(·01)
CC (Sy=0·20)

with higher waves than with lower ones.

At profile F, Equations (29) and (30) have high explained variations and low standard errors. Although not included in the graphed figures, a plot of these equations shows that the slope of Equation (29) has a negative trend over the range of wave heights measured, with higher waves associated with steeper slopes. Pebbles are a very common constituent of the foreshore at F, and the foreshore is sometimes composed exclusively of them. The negative rather than the more usual positive trend of the slope of the equation, probably reflects the ability of high waves to fling the pebbles up slope, over-steepening the profile. Equation (30), also having high significance, has no overall positive or negative slope. Its most notable feature is that very high or very low energy waves tend to be associated with steeper slopes than those whose energy levels approximate mean values.

At profile BB there is also a significant correlation between wave height and beach face slope. Figure 5:6 shows that this is especially noticeable whenever the deep water wave height exceeds 1.5 feet. Waves higher than this are strongly associated with flat slopes at BB, which lie between 4.5 and 6.0 degrees.

FIG 5:6



13·00
12·00
11·00
10·00
9·00
8·00
Cot β
4·40
4·77
5·20
5·70
6·33
7·13
Degrees
0·0
1·0
2·0
3·0
Ho in feet (process lag = 2 days)
70% (·01)
BB (Sy = ·30)

Predictor Equations for Shoreline Position

There is only one outstandingly predictive polynomial equation between the processes and shoreline position (Table 5:4). This is Equation (40), shown graphically in Figure 5:7. Wave period lagged two days "explains" eighty-two per cent of the variation (equivalent to a correlation coefficient of 0.91) in shoreline position at BB, with long period waves related to landward positions of the shoreline, and short period waves related to seaward positions of the shoreline.[1] The multivariate Equation (43) also shows that wave period is the only "controlling" variable of D at station BB.

Although it is known that long period waves, because of the long corrosive swashes associated with them, are often responsible for erosive action on the foreshore, laboratory studies have shown that it is only in conjunction with known values of wave height and wave steepness that their effect can be known. Rector, in a study done under the auspices of the Beach Erosion Board (1954), found that changes in wave period were manifested in pronounced beach

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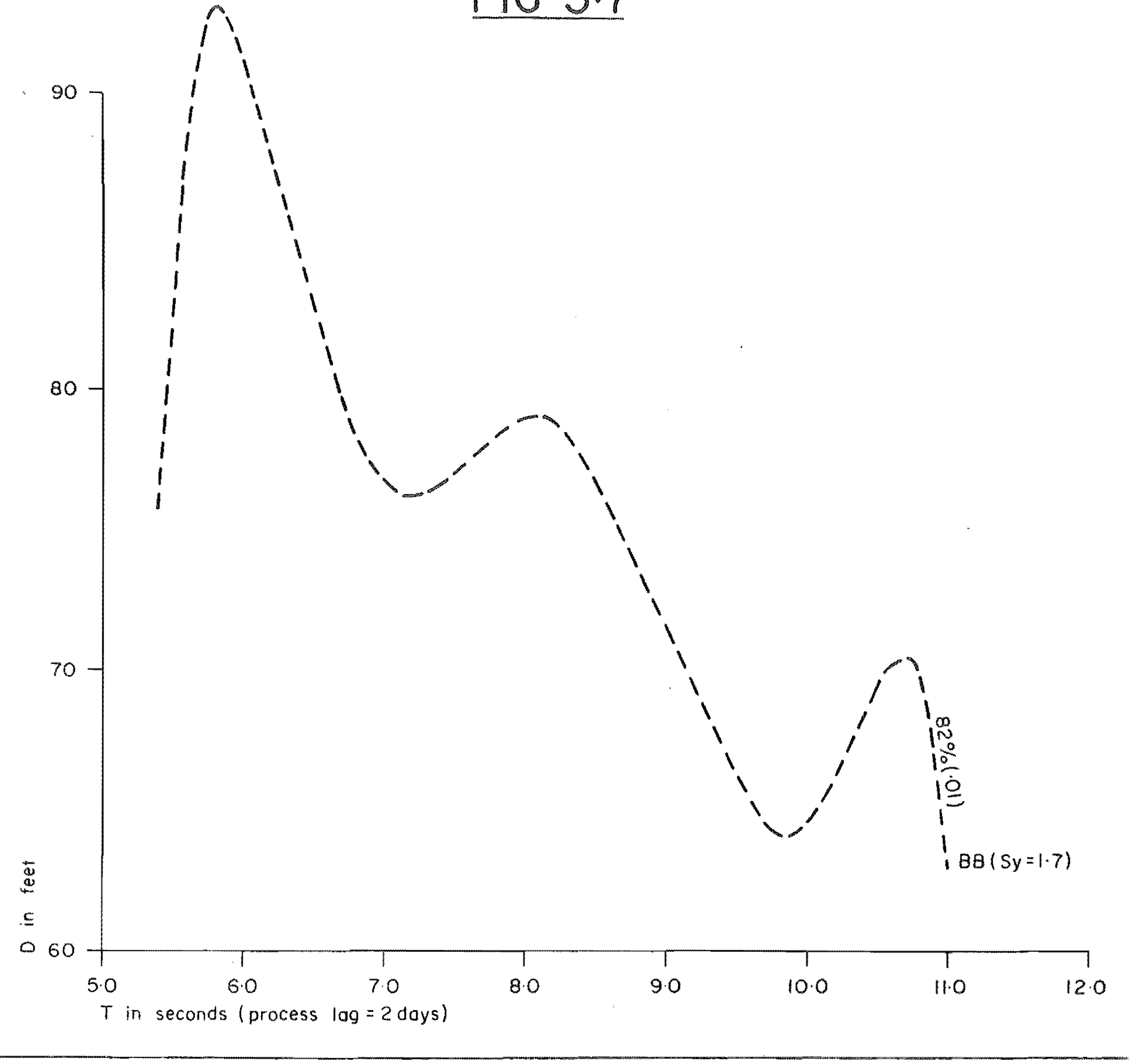
[1]This equation is the most strongly predictive of all the process-response pairs. The statistical association of these variables would have been lost in the welter of less significant equations if only linear regression methods had been used. The simple linear form "explains" but twelve per cent of the variation in D, and is just barely significant at .05.

TABLE 5:4

BEST PREDICTOR EQUATIONS SIGNIFICANT AT THE .01 LEVEL
FOR SHORELINE POSITION

	REGRESSION EQUATION	PROF.	PROC. LAG	EXPL. VAR.	Sy
	2-VARIATE POLYNOMIAL				
(35)	$D = 336.7 - 0.1325(\theta')$	CC	t	22%	7.5
(36)	$D = 332.1 - 0.1983\theta$	CC	t	24%	7.5
(37)	$D = 143.8 - 18.09Ho + 2.712Ho^2$	F	t	20%	9.9
(38)	$D = 131.1 - 0.3433(Eo') + 0.1568(10^{-2})(Eo')^2$	F	t	21%	9.8
(39)	$D = 51.85 + 97.37Hb - 42.23Hb^2 + 6.931Hb^3 - 0.3799Hb^4$	F	t-2	31%	9.5
(40)	$D = -8547(10) + 6521(10)T - 2045(10)T^2 + 3378T^3 - 310.2T^4 + 15.01T^5 - 0.2995T^6$	BB	t-2	82%	1.7
	MULTIVARIATE LINEAR				
(41)	$D = 340.6 - 0.1574\theta(t) - 0.8812(10^{-1})\theta'(t-2)$	CC	—	32%	6.8
(42)	$D = 110.5 + 0.1316Eo(t-2)$	F	—	13%	10.0
(43)	$D = 92.89 - 1.176T(t) - 1.018T(t-2)$	BB	—	29%	3.1

FIG 5:7



90
80
70
60
D in feet
5·0
6·0
7·0
8·0
9·0
10·0
11·0
12·0
T in seconds (process lag = 2 days)
82% (·01)
BB (Sy = 1·7)

profile changes only insofar as they altered the wave steepness. Watts, in a later study (Watts, 1954) confirmed this, and showed that it was also true even when variations in wave period about a mean value, rather than fixed wave periods, were used.

Of the statistical interdependency of the processes and shoreline position at the other stations Table 5:4 shows that the angle of wave approach (and wave direction) is most important at CC, and breaker height and wave energy are most influential at profile F. With relation to Equation (36), it is worth noting that Harrison (1970) also found that the angle of wave approach was an important predictor of shoreline position. Although his variables differed from the ones of this study, he showed that with the measurement of wave approach angle unlagged, shore-normal waves were associated with shoreline retreat; essentially the same relationship as shown here by Equation (36).[1] For the multivariate cases, Equation (41) is a good predictor. It is able to explain a relatively high proportion

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[1]Harrison's studies were conducted on sand sized foreshore deposits. It is perhaps also important that this equation applies to the closest approximation in the study area to a sand beach.

of the variation in shoreline position because both Equations (35) and (36) are linear. In contrast to this, Equation (43) suffers badly in comparison to the predictive strength of Equation (40). Even though wave period is singled out as being the most significant independent variable, the explained variation is much lower, and the standard error of the estimate much higher for the multiple regression equation than for the sixth degree polynomial.

Predictor Equations for Cusps

The fifteen equations of Table 5:5 show that the process variables are more statistically influential in predicting the degree of cusp development than they are for any of the other responses. This is encouraging, and it suggests that a process-response study specifically focused on cusp formation might be worth-while. The way in which cusps are formed has long been a subject of interest, but despite this widespread attention, there is still no universally accepted theory of cusp formation. Johnson (1919) concluded that waves approaching the beach shore-normally were responsible for cusp formation. Shepard (1963) also feels that their formation is favoured by the shore-normal approach of waves, and is related to the height of the waves

TABLE 5:5

BEST PREDICTOR EQUATIONS SIGNIFICANT AT THE .01 LEVEL FOR CUSP DEVELOPMENT

	REGRESSION EQUATION	PROF.	PROC. LAG	EXPL. VAR.	Sy
	2-VARIATE POLYNOMIAL				
(44)	$C = -2.474 + 27.42Ho - 60.86Ho^2 + 57.00Ho^3 - 25.52Ho^4 + 5.399Ho^5 - 0.4329Ho^6$	CC	t-1	54%	0.73
(45)	$C = 2.052 - 0.3084(Eo') + 0.2255(10^{-1})(Eo')^2 - 0.6295(10^{-3})(Eo')^3 + 0.7848(10^{-5})(Eo')^4 - 0.4407(10^{-7})(Eo')^5 + 0.9060(10^{-10})(Eo')^6$	CC	t-1	48%	0.77
(46)	$C = 15.28 - 15.50Hb + 6.259Hb^2 - 0.9894Hb^3 + 0.0527Hb^4$	F	t	38%	1.3
(47)	$C = 6.801 - 0.4118T$	F	t	18%	1.5
(48)	$C = 4.905 - 0.4238(10^{-2})Lo$	F	t	17%	1.5
(49)	$C = 4.063 - 0.2585(10^{-4})Eo$	F	t	23%	1.4
(50)	$C = 2083(10) - 1481(10)T + 4312T^2 - 658.8T^3 + 55.75T^4 - 2.479T^5 + 0.4531(10^{-1})T^6$	F	t-1	52%	1.2
(51)	$C = 1.904 + 0.2658(10^{-3})Eo - 0.2099(10^{-7})Eo^2 + 0.7394(10^{-12})Eo^3 - 0.1208(10^{-16})Eo^4 + 0.8837(10^{-22})Eo^5 - 0.2339(10^{-27})Eo^6$	F	t-1	41%	1.3
(52)	$C = 3.474 - 0.4033(10^{-3})Eo + 0.2536(10^{-7})Eo^2 - 0.5333(10^{-12})Eo^3 + 0.4448(10^{-17})Eo^4 - 0.1273(10^{-22})Eo^5$	F	t-2	35%	1.4
(53)	$C = 5.547 - 0.0382(\theta')$	BB	t	19%	1.1
(54)	$C = -5317 + 367.0\theta - 9.060\theta^2 + 0.8246(10^{-1})\theta^3 + 0.9734(10^{-4})\theta^4 - 0.3997(10^{-5})\theta^5 - 0.1356(10^{-8})\theta^6 - 0.2951(10^{-9})\theta^7 + 0.6852(10^{-11})\theta^8 - 0.3067(10^{-3})\theta^9$	BB	t	80%	0.64
(55)	$C = -229.2 + 6.976(\theta') - 0.6910(10^{-1})(\theta')^2 + 0.2246(10^{-3})(\theta')^3$	BB	t-1	37%	1.0
(56)	$C = -26.37 + 0.8302\theta - 0.5962(10^{-2})\theta^2$	BB	t-1	39%	1.0
	MULTIVARIATE LINEAR				
(57)	$C = 4.030 - 0.2577(10^{-4})Eo(t)$	F	—	24%	1.4
(58)	$C = 5.659 - 0.5284(10-1)\theta'(t)$	BB	—	22%	1.1

at the time they were produced. He states that conditions which favour longshore transport do not favour the formation of cusps. Russell and McIntyre also concur with this view.[1] Kemp (1961) considers that obliquely approaching waves inhibit cusp formation but argues that the significant factor is the local lateral circulation set up due to the lack of coincidence between the completion of the backwash of one wave and the succeeding plunge. Komar (1971) associates giant cusps with rip currents. Vladmirov (1950), on the other hand, has observed the transfer of shingle laterally from one cusp to another and in contrast to most currently held opinion, suggests that cusps may be stable under conditions of longshore transport.

The present study does not disclose the specific way in which cusps form, even with particular reference to the study beaches. Table 5:5 shows that virtually all process variables play a significant role in local cusp development. At CC wave height and energy appear to be most closely tied to cusp formation (Equations (44) and (45)), while at BB, the angle of wave approach is the most affiliated process (Equation (54)). The process lags that give the best predictor equation are also more

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[1]Russell, R.J., and McIntyre, W.G., 1965; p.308.

variable at each station for cusp development than they are for the other responses. Profile CC is the only exception to this, having two equations ((44) and (45)) whose optimum process lag is one day.

Three equations have been graphed. Figure 5:8 is of Equation (44), and shows a roughly cyclical relationship between deep water wave height and cusp development at profile CC. During the study, the poorest developed cusps here, were consistent with deep water heights (lagged by one day) of one and three feet, the best developed with two and four foot waves. Wave energy, expressed per square foot of sea surface, is another good predictor of cusp development (Equation (45)), and the curve for this equation, which is not shown, exhibits a periodicity similar to that of Figure 5:8. The poorest cusps at CC are associated with energy fluxes of ten and seventy-three foot-pounds per square foot, and the best developed cusps with thirty-five and one hundred and seventeen foot-pounds per square foot.

Figure 5:9 depicts Equation (50). It shows that the association between well developed cusps and wave period is best at wave periods of about 7.0 to 8.0 seconds, measured the previous day. Very long period waves (12.0 seconds), or very short period waves (6.0 seconds), tend to relate to a

FIG 5:8

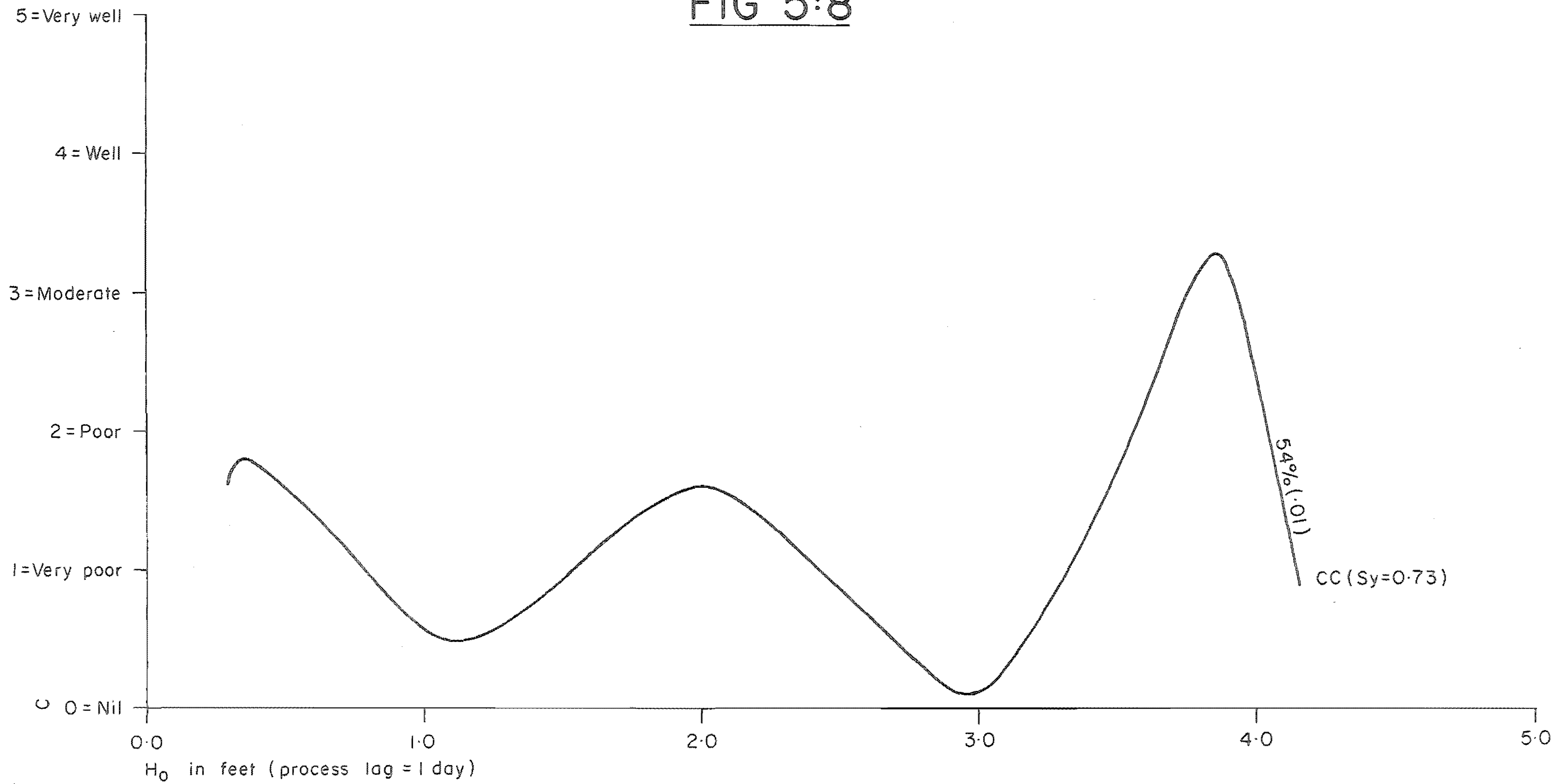
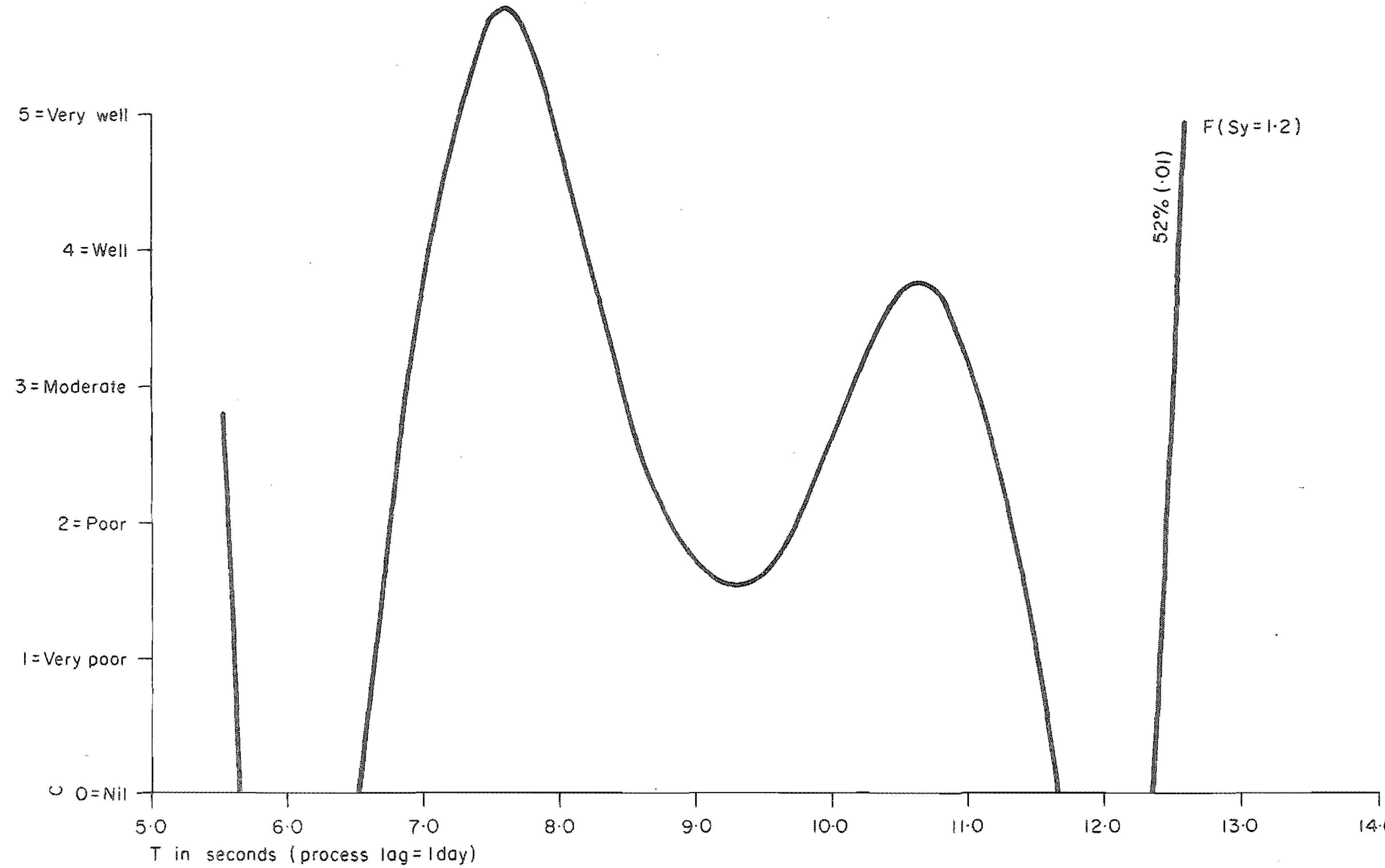

5 = Very well
4 = Well
3 = Moderate
2 = Poor
1 = Very poor
C
0 = Nil
0·0
1·0
2·0
3·0
4·0
5·0
H_o in feet (process lag = 1 day)
54% (·01)
CC (Sy = 0·73)

FIG 5:9



5 = Very well
4 = Well
3 = Moderate
2 = Poor
1 = Very poor
C 0 = Nil
5·0
6·0
7·0
8·0
9·0
10·0
11·0
12·0
13·0
14·0
T in seconds (process lag = 1 day)
F (Sy = 1·2)
52% (·01)

lack of cusp development.

Figure 5:10, which shows the form of Equation (54), is particularly interesting since it emphatically suggests that at profile BB, well developed cusps relate not to the shore-normal approach of waves, but to waves approaching from oblique angles. This observation is unusual, and at odds with most published accounts having to do with cusp stability. It tends to lend some weight to arguments that do not find the co-existence of obliquely approaching waves with well developed cusps a contradiction.[1]

Summary

The statistical dependence of sediment gains, foreshore texture, foreshore slope, shoreline position, and degree of cusp development have been assessed in relation to nine process variables. Process lag has been taken into account, and fifty-eight equations, all significant at the .01 level, have been given to describe specific interactions with the wave characteristics at each of three profile sites. Ten of these equations, in addition to being signi-

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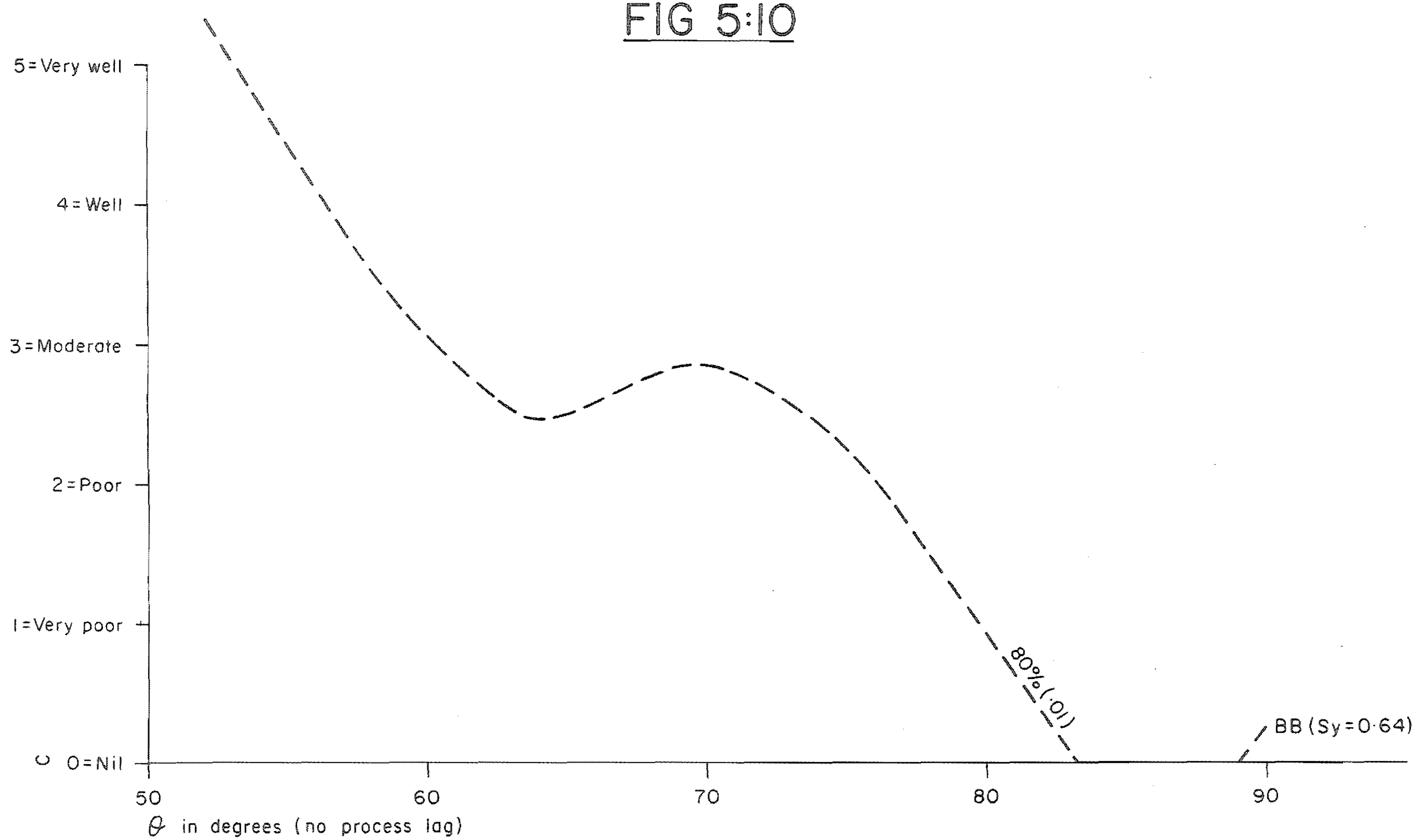
[1]It is interesting to note that Pickrill (1973; p.45) also found that oblique waves were not inimical to cusp stability.

FIG 5:10


5 = Very well
4 = Well
3 = Moderate
2 = Poor
1 = Very poor
c 0 = Nil
50
60
70
80
90
θ in degrees (no process lag)
80% (·01)
BB (Sy = 0·64)

ficant at .01, "explain" more than fifty per cent of the variation in the dependent variable. They have been graphed and discussed. Statistical analysis of the study data based upon the linear model has been shown to be inadequate in most cases, to describe significant associations among the variables. In four cases, however, multiple regression equations were shown to be as good, or better predictors of particular beach responses, as the best predictor polynomials. Not surprisingly, the independent variables in each of these four equations were found to conform closely to linear relationships with their respective dependent variables.

The most prominent process variables associated with daily gains and losses on the beach were shown to be wave height and wave energy. Progressively higher wave heights though, were not invariably related to more and more volumetric losses, even though the highest waves with the most energy, did tend to be associated with erosion rather than deposition. Wave steepness, in the literature one of the most popular indices of process intensity, proved to be a very poor predictor of the responses in this study.

Textural changes related best to wave height, wave direction, and energy, except at profile BB, where there was a lack of any obvious connection between surface texture and process change.

The mean slope of the foreshore related best to breaker height, with wave energy playing a secondary role. High, long period, long wave-length waves were generally related to flatter foreshore slopes than their shorter counterparts. However, at profile F, high waves related to steep foreshores. This is most likely due to the prevalence of pebbles at this profile, and the ability of the high breakers and powerful swash to over-steepen the foreshore by flinging them up the swash slope.

In respect of shoreline advance and retreat, it was shown that profile CC was most closely associated with wave direction and the wave approach angle, while at F and BB, wave height and energy, and wave period, respectively, were the most important process variables. At profile BB a very strong association between long period waves and landward positions of the shoreline, and short period waves and more seaward shoreline positions prevailed.

A wide variety of process variables related to the degree of cusp development on the profiles, with wave height and energy being most important at CC, wave height, energy, and wave period at F, and wave direction and wave approach angle, the most important predictors at profile BB. BB in particular is interesting because in contrast to most currently held opinion regarding cusp formation, it was shown that oblique, rather than shore-normal waves were related best to a condition of well developed cusps on the foreshore.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A description of the study area, the distinguishing features of the four beach profiles, and the wave characteristics at each profile have been given. The configuration of the nearshore contours have also been mapped.

Nine wave process parameters, and six beach response parameters have been defined, their temporal and spatial variation described, and their degree of inter-relationship measured. As part of this, a description of the way in which various sized sediment is first supplied by the Hapuku River, and later dispersed by wave action, has been postulated. The functional relationships between process and response variables have also been treated in some detail, and a number of predictor equations have been advanced, and in the more important cases, graphed, to mathematically describe these relationships.

Field and laboratory methods have been described and techniques suggested to overcome some of the practical problems of dealing with large sediment sizes. A method whereby profiles can be quickly surveyed by one man, with a minimum loss in accuracy was also developed and the errors of the method have been discussed.

Statistical methods have also been described, and wherever the nature of the data contravened the underlying assumptions of parametric statistics, non-parametric methods have been used.

As stated at the outset, one of the main objectives of the study was to mathematically specify the functional relationships between the process and response variables and it was pointed out that there is no uniquely best way of doing this. The primary method used in this study examines successive orders of polynomial equations, and consistently results in the selection of the equation that explains the greatest proportion of variation in the dependent variable at the highest significance level possible.

The possibilities of stepwise multivariate correlation and regression were also explored, and have also been used for inter-relating process with response, but it was found that in most cases they gave both less predictive and less significant results than the curvilinear methods.

The Wave Processes

Probably the most important feature of

the wave processes is their areal variability. The beach profile that receives the highest, steepest, and most powerful waves is F. To the south towards CC, the wave attack is slightly less vigorous, and the two northern profiles, AA and BB, receive waves of low energy. The reasons for the less vigorous wave attack in the north are the reef at AA which saps the energy of approaching waves, and the relatively well protected aspect of the beach at BB.

The process variables show a significant degree of functional inter-relation, with southerly waves, on the whole, having higher breaker heights, but not necessarily longer wave periods than waves approaching from other directions.

A seasonal variation is also obvious in breaker height, with higher wave heights occurring in winter than in summer. The corresponding seasonal trend in wave period and wave direction is less obvious, however.

Day to day change in the process variables appear to follow two cycles; one of about seventeen days with a shorter cycle of about three days superimposed upon it.

The Responses

Like the wave climate around the delta, areal variability is also a feature of the beach characteristics. The coarsest beach is AA, composed largely of boulders, and the finest is CC, which is composed mostly of coarse sand. Profiles F and BB are intermediate in texture to these two.

There is also considerable variability in the shore-normal mobility of the foreshore sediment. The most active, is profile F, which is not surprising since it is located closest to the source of sediment for the delta, the mouth of the Hapuku River. The least active profile is that at AA where movement of the boulders, especially on the lower foreshore, hardly ever takes place.

Unlike the wave processes however, the periodicity of response variation with time is lacking.

The functional inter-relationships between the response variables are more complex than those of the processes, and this is reflected in the higher degree polynomials needed to express them. In most cases the equations confirm expected associations between the variables, such as the positive correlation between sediment gains and shoreline position. They also show however, that there is a significant progressive increase in foreshore coarseness with depth through the sweep zone at profiles F and BB, but not at profile CC or AA. Thus the possibility that a coarser "basement" may inhibit shoreline retreat exists only at profiles F and BB.

The inter-relationship between foreshore slope and grain size shows, in common with other studies, that steeper foreshores are associated with larger grains, but on the study beaches, the slopes are generally flatter for given grain sizes than those documented by other authors. Also, there is considerably more variability in slope, for grains smaller than minus four phi. At larger sizes than this, foreshore slopes occur over a more restricted range.

The pattern of sediment movement around the delta is interesting. As mentioned earlier, the sediment source for the delta is the Hapuku River, but for most of the year it supplies very little material to the beaches. The inputs to the beach come mainly from a few large, but infrequent floods which are capable of transporting a whole range of sizes from boulders down to clay. During such floods, nearly all of this material is delivered to the sea and size-sorting begins immediately. The silt and clay are retained in suspension and carried offshore on the surface in the less dense fresh water. Coarser sand and pebbles are deposited nearer shore where, if the volume of material is large enough, they may considerably advance the shoreline in the region of the river-mouth. Boulders and large cobbles settle out as soon as they reach the sea.

From the mouth, sediment is transported both north and south along the coast as well as offshore. Medium and coarse sand and pebbles move mainly southwards under the influence of the more frequent north-easterly waves, and constitute the main supply to the beaches south of the river mouth. The long term trend of the shoreline in this region is towards seaward advance.

Cobbles and boulders move north by longshore drift under the influence of intermittent storm southerlies, but the amount of this material is progressively reduced and only the very largest sizes remain on the beach. There is a net volumetric loss of beach material in this region, and the long term trend of the shoreline here is towards pronounced retreat.

At profile BB, in the north, the beach sediment is supplied by the erosion of the glaciofluvial deposits of the backshore. Although the long term trend of the shoreline is towards retreat, there is some evidence to show that minor amounts of sediment may occasionally be supplied to the beach at BB from offshore after storm southerlies have transported material past the reef further south.

Based on the net advance and retreat of the shoreline over a thirty year period, the shoreline south of the present day mouth is advancing at an average rate of about 1.5 feet per year, and north of the river-mouth, it is retreating at a rate of about 1.3 feet per year. The shoreline in the vicinity of profile AA is stable, and in the vicinity of BB it is retreating at a mean rate of about 0.7 feet per year.

Processes and Responses

A large number of equations were shown to be statistically significant in predicting responses of the beach from measured wave variables. Four of these, as well as being ninety-nine per cent significant, show outstandingly high explained variation in the beach response. They are:

(a) the association of flatter foreshore slopes at CC with long period waves, and steep foreshore slopes with short period waves.

(b) the relationship of flatter foreshore slopes with higher waves, and steeper slopes with lower waves at BB.

(c) the association of shoreline retreat with long period waves, and shoreline advance with short period waves at BB.

(d) the high correlation between well developed cusps and obliquely approaching waves at BB, and poorly developed cusps with shore-normal waves.

For all of these inter-relationships, the process lag is two days, except for (d) where there is no process lag. The evidence thus suggests that for the beaches in the extreme north and the extreme south of the area, there appears to be a considerable lag in the morphological response of the foreshore deposits to changes in the wave parameters. The exception to this generality is cusp development, which tends to respond rapidly to wave action. It has already been shown that at profile F the optimum process lag is less consistent because of the periodic influence of river floods, while at AA, direct process-response effects defy practical measurement.

Of the four relationships shown above, the first two are in accord with established theoretical and practical studies. The third one, namely the relationship of shoreline retreat with long period waves, and its converse, appears to be true of the coastline represented by profile BB in this study, but because of particular site characteristics, it should not be considered, nor is it intended, to be invariably typical of beaches in general.[1] The last inter-relationship between cusps and the

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[1]Although there may be some connection here between this result and that of Harrison, Pore, and Tuck (1965) who also found that net foreshore erosion was promoted by long period waves.

angle of wave approach is interesting because it runs contrary to some currently held opinions regarding cusp formation. It suggests that the best developed cusps occur with obliquely approaching waves.

Finally, there is a conspicuous absence of wave steepness as a significant predictor of beach changes. In spite of its wide spread notoriety as an effective index of beach erosion and deposition, it is considered that on coarse-grained beaches such as those of this study, its usefulness is questionable.

Suggestions for Further Research

There are a number of questions raised by the present study that relate both to beaches as a whole and to process-response studies in general, as well as to particular aspects of the coarse gravel beaches of the Hapuku Delta.

A number of attempts have been made to effectively define the functional relationship between wave processes and beach responses, but a comprehensive statement is yet to be formulated. Indeed, the proliferation of statistical screening techniques to isolate the most meaningful variables attests to the widespread acceptance that the best way of expressing them is still unknown.

Studies such as the present one, while not attempting to formulate a definitive statement on beach morphology in general, make important contributions to a better understanding of the behaviour of particular beach systems. In this way, the boundary conditions within which mathematical parameters either become accepted or rejected as influential on different kinds of foreshores are clarified. Thus, wave steepness, a parameter considered in the literature to be of fundamental importance in influencing beach changes, was shown to be a very ineffective predictor on the coarse beaches of this study. Well developed cusps too, are often regarded as being, if not initiated, then at least sustained, by shore parallel waves. This study has shown that on some foreshores exactly the opposite case can be supported.

It has been argued that the interplay between process and response is usually described better by curvilinear equations rather than by equations of the linear type, and indeed, some of the regression equations have been shown to be statistically rewarding as far as they go. It is concluded however, that although these equations can prove useful in a predictive sense for specific beaches, a comprehensive understanding of the beach system can only be achieved by considering the processes and responses as operating collectively along a time continuum. In this way the response of the whole system can be assessed in terms of subtle changes in the inter-relations between a number of process variables operating simultaneously. One of the major advantages of this approach is the ability to detect time-dependent trends in the beach responses even though they do not progress to completion.

The swing towards treating beach and near-shore phenomena as continuous time series is only recently being explored,[1] and it is likely that if a general process-response model for the beach environment is to be successfully formulated, this approach is one that will be used.

Another problem which has plagued coastal researchers is that of feedback between dependent and independent variables, and inter-correlation effects between various independent variables. Most traditional statistical methods are incapable of dealing with these problems because they treat the variables as being mutually exclusive, but there are becoming available procedures for reducing or negating feedback and inter-correlation. Jones (1972) has published a dimensionless analysis of

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[1] See for example, King and Mather, 1972.

beach slope from five independent variables from which inter-correlation effects have been removed. He also discusses the extension of the multiple regression model to trend-surface analysis. The direction that future research lies is undoubtedly in testing techniques such as these on data from natural beaches.

Some of the results of the present work also raise intriguing questions that are rather less cosmic in scope, and are amenable to study on a more detailed scale.

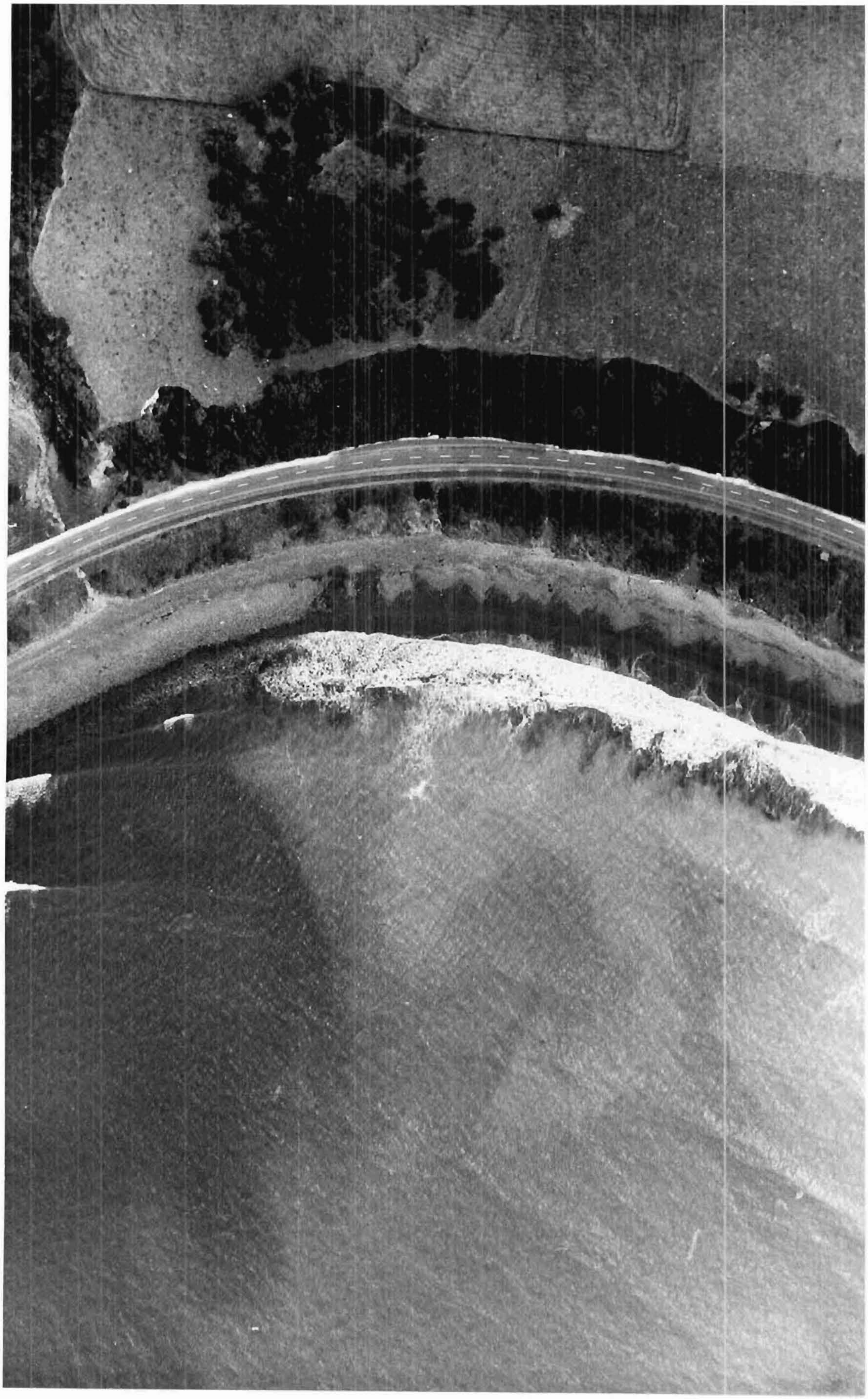
Some recent work has been published (Novak, 1972) which suggests that large grains, having intermediate diameters in the -6.2 phi to -6.7 phi range are mobile in the swash zone under the influence of waves less than 1.0 foot high. Results of the present study show that many of the foreshore grains at profile AA fall within this range, and some exceed it. In view of the suggestion put forth earlier, that the large boulders of the lower foreshore at this profile promote shoreline stability, it would be interesting to examine the mobility of specific grains at this station and on the stretches of coast immediately to the north and south, (see Plate 4:2), to determine if movement on the foreshore was limited to grains below a specific size, or whether some other factor such as position on the foreshore was more important.

Another small scale study could be directed at the relationship between the slow longshore movement of sediment suggested by this study, and the apparent relative stability of the wave-like shoreline features shown in Plate 6:1. Dolan (1970) made a study of similar features on the sand beaches of Cape Hatteras, and found that longshore migration rates of up to 600 feet per month occurred, and Phillips (1964) measured average rates of longshore movement of the order of four hundred and forty feet per month, on the sand and shingle beaches of the Holderness Coast.

Finally, the mechanics of cusp formation in relation to prevailing wave action could be profitably studied on the beaches of the Hapuku Delta. It has already been mentioned that at BB well developed cusps are associated with obliquely approaching waves. Mention has not been made of the fact that the transition alongshore from profile BB, between a cuspate foreshore and a non-cuspate foreshore is often very abrupt and probably closely related to corresponding changes in the characteristics of the breaking wave (Plate 6:2). Moreover, the place on the foreshore at which cusps begin to form, moves alongshore from day to day. Attention could be focussed on this in a small scale

PLATE 6:1

PLATE 6:2



project which could reasonably be expected to show more of the specific details of cusp formation on these beaches than has been able to be done in the present study.

Some Final Considerations

In Chapter I, it was stated that description and analysis were the two main aims of this study. In practice, however, the two are mutually interrelated. Mere description, whether mathematical or verbal, often suggests analytically remunerative procedures, while analysis itself, because it examines and enunciates the relationships among phenomena, can be considered a specialized form of exposition.

The aims of the study have been fulfilled, and the methodological emphasis has been put on the use of a polynomial screening technique rather than a multivariate one, to decipher the interplay among various process and response variables. The rationale for this approach is based on the contention that *a priori* assumptions about functional inter-relationships should be avoided in scientific inquiry. This is not to denigrate the desirability of being able to express response variability in terms of a number of significant controlling processes. However, this thesis has demonstrated that multivariate equations are better predictors only as long as it can be established that the linear model is an acceptably close approximation of the functional relationship. Thus, foreshore texture at profile F was shown to be predicted best by a multiple regression equation that included three process variables, rather than by one of the polynomials (Table 5:2). This was only shown to be true though, after the best polynomial functions were known. In this sense, the best predictor polynomial equations can be used as a criterion for either accepting or rejecting the excellence of the multivariate model.

Besides providing a comprehensive description of wave and beach behaviour in a particular geographic setting, the research has yielded some supplementary rewards. Attention has already been drawn to some of the unusual natural features of the area that at first impeded data collection by conventional means. Chiefly by trial and error, most of these difficulties were overcome and it is submitted that the various practical methods devised to deal with them can be confidently applied elsewhere.

The best tactical approach to comprehending the beach system is yet to be found. New and more powerful statistical techniques are being applied which are geared to handle the spatial and temporal multidimensionality which characterizes the coastal environment. Some show promise of being successful, and some have been shown to be inferior. Nevertheless, it is by variously trying new approaches, or variations of old ones, that a more enlightened comprehension of the coastal zone will ensue. It is submitted that by focusing on some of the fundamental inter-actions among specific wave and beach variables, this study has made more intelligible some important aspects of the foreshore behaviour of coarse beach deposits.

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APPENDICES

APPENDIX 2:1

HORIZONTAL EXPOSURES OF EACH SEDIMENT CATEGORY ON THE FORESHORE, AND DAILY, AND MEAN MONTHLY FORESHORE SLOPE AND TEXTURAL INDICES

KEY

A	Total horizontal exposure of foreshore (feet)
B	Foreshore slope (cot β)
C	Foreshore slope, β (degrees)
D	Textural index, σ_{fs} (phi units)
E	Mean monthly textural index $\overline{\sigma_{fs}}$
F	Mean monthly foreshore slope (degrees)

PROFILE CC

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Jan 4										37		4		11		54	106	12.05	4.7	-2.57	-2.15	4.3
8																110	110	12.50	4.6	-1.52		
10										30	77					21	128	14.55	3.9	-3.42		
14											23				70	34	127	14.43	4.0	-2.15		
17															13	129	142	16.14	3.6	-1.56		
20															39	80	119	13.52	4.2	-1.66		
24															60	42	102	11.59	4.9	-1.77		
27										19	9	13			44	26	111	12.61	4.5	-2.51		
Mar 16												No textures measured					141	16.02	3.6		-2.65	3.9
22										52		19			58		129	14.66	3.9	-3.01		
27										12	13	14			23	61	123	13.98	4.1	-2.28		
Apr 4										15	34	9			31	34	123	13.98	4.1	-2.66	-1.89	4.1
11																127	127	14.43	4.0	-1.52		

PROFILE CC (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Apr 14																128	128	14.45	4.0	-1.52		
25												5			76	39	120	13.52	4.2	-1.86		
Jun 20																168	168	19.09	3.0	-1.52	-1.52	3.6
26																119	119	13.52	4.2	-1.52		
July 1											33				47	34	114	12.95	4.4	-2.32	-2.49	4.8
5										12	31	16				60	119	13.52	4.2	-1.98		
22												7			75		82	9.32	6.1	-2.09		
30										63	31					17	111	12.61	4.5	-3.58		
Aug 2										17	60	22					99	11.25	5.1	-3.65	-3.80	4.8
8										74	40						114	12.95	4.4	-3.95		
Sep 12										25					50	33	108	12.27	4.7	-2.32	-2.48	4.6
14										10	32				59		101	11.48	4.9	-2.71		
15										5	31				26	44	106	12.05	4.7	-2.38		
16										9	35				57		101	11.48	4.9	-2.74		

PROFILE CC (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Sep 18										9	59	25			8		101	11.48	4.9	-3.47		
21										10	41				40		91	10.34	5.5	-2.96		
23											38	7		24	30		99	11.25	5.1	-2.81		
24											31				41	37	109	12.39	4.6	-2.29		
25										23		79			12		114	12.95	4.4	-3.28		
26												3				128	131	14.89	3.9	-1.56		
27							21			32					11	51	115	13.07	4.4	-2.99		
28										15	12				14	77	118	13.41	4.3	-2.12		
29																114	114	12.95	4.4	-1.52		
30																165	165	18.75	3.1	-1.52		
Oct 1															18	111	129	14.66	3.9	-1.58	-2.74	4.0
2							9				20	44		40		8	121	13.75	4.2	-3.07		
3										13	61			41		8	123	13.98	4.1	-3.15		
4										12	29			39	20	22	122	13.86	4.1	-2.63		
5										10	46			44		24	124	14.09	4.1	-2.83		

PROFILE CC (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Oct 6										7	36	9		38	25	7	122	13.88	4.1	-2.79		
7										5	38			37		81	161	18.30	3.1	-2.31		
8										8	25			40		50	123	13.98	4.1	-2.40		
9										5	34			41		46	126	14.32	4.0	-2.48		
10										5	39			40		50	134	15.23	3.7	-2.50		
11										5	41			39		38	123	13.98	4.1	-2.61		
12											84	11		31	14	2	142	16.14	3.6	-3.16		
17										35	7	9			36	41	128	14.55	3.9	-2.58		
18										41	13				34	38	126	14.32	4.0	-2.70		
19																113	113	12.84	4.5	-1.52		
20											45	28			4	45	122	13.86	4.1	-2.72		
21										52	50					25	127	14.43	4.0	-3.42		
22							5			35	45	21			4	22	132	15.00	3.8	-3.37		
24										32	53				5	29	119	13.52	4.2	-3.19		

PROFILE CC (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Oct 25											66	16			12	24	118	13.41	4.3	-3.00		
27										36	33				12	39	120	13.64	4.2	-2.93		
28										40	24				9	44	117	13.30	4.3	-2.88		
29										24	64				9	28	125	14.20	4.0	-3.15		
30										20	31				48	30	129	14.66	3.9	-2.60		
31										25	36				29	30	120	13.64	4.0	-2.81		
Nov 2										34	35				28	29	126	14.32	4.0	-2.91	-2.41	4.0
3											57				11	55	123	13.98	4.1	-2.55		
5							6			39					62	22	129	14.66	3.9	-2.69		
6											49				5	75	129	14.66	3.9	-2.35		
7										8	35				5	83	131	14.89	3.8	-2.27		
9										19	52				45	21	137	15.57	3.7	-2.84		
10										35	14					72	121	13.75	4.2	-2.52		
11										45		9			19	47	120	13.64	4.2	-2.68		

<u>PROFILE CC</u> (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 12										38	10	9			18	43	118	13.41	4.3	-2.73		
13										12	7	18				96	133	15.11	3.8	-2.10		
14										7	34	4			53	24	122	13.86	4.1	-2.51		
16										7	32	43			13	32	127	14.43	4.0	-2.83		
17										8	54	6			30	30	128	14.55	4.0	-2.77		
18										6	29	8			27	25	95	10.80	5.3	-2.61		
19										30	14	13			24	48	129	14.66	3.9	-2.61		
20										19	6				30	73	128	14.55	4.0	-2.10		
21										20	8				20	80	128	14.55	4.0	-2.12		
23														9		135	144	16.25	3.5	-1.58		
24														11		120	131	14.89	3.8	-1.59		
25											16			12		105	133	15.11	3.8	-1.86		
26										15	9	8		14	57	25	128	14.55	4.0	-2.37		
27										32		6		11	26	53	128	14.55	4.0	-2.41		

PROFILE CC (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 28										20	9	14		10	33	43	129	14.66	3.9	-2.43		

Class	Total Horizontal Exposure	Per Cent Exposure
cp	41	.4
pc	1273	12.4
p	2020	19.7
ps	499	4.9
sc	532	5.2
sp	1653	16.1
s	4223	41.2
		99.9

PROFILE F

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Jan 3										9		5		55		39	108	12.27	4.7	-2.71	-3.51	7.0
8										1					16	66	83	9.43	6.1	-2.16		
9											33					47	80*	9.09	6.3	-2.84		
10										26	47						73*	8.30	6.9	-4.10		
15											64				10		74*	8.41	6.8	-3.75		
17											70						70	7.95	7.2	-3.96		
20										37	28						65	7.39	7.7	-4.18		
21										30	24	9					63	7.16	8.0	-4.09		
24										24	23					12	59	6.70	8.4	-3.73		
27										18	24				13	5	60	6.82	8.3	-3.59		
Feb 7											35	4				19	58	6.59	8.6	-3.31	-3.31	8.6
Mar 16													No textures measured				49	5.57	10.2		-2.95	8.6

*In cases where the top of a cusp projects above 30.4 feet elevation, the horizontal distance of the foreshore is taken from the mean of the points of intersection of 30.4 feet elevation with the cusp.

PROFILE F (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Mar 21										10	18			7	15	62	112	12.73	4.5	-2.67		
27											26				7	12	45	5.11	11.1	-3.22		
Apr 4										22		8		31	15	21	97	11.02	5.2	-3.00	-2.94	7.6
11												11			21	30	62	7.05	8.1	-2.46		
25										12	20				5	15	52	5.91	9.6	-3.35		
Jun 20																71	71	8.07	7.1	-2.06	-2.06	6.6
27																83	83	9.43	6.1	-2.06		
July 1										16			40		14		70	7.95	7.2	-3.31	-4.21	9.2
5										19			31		14		64	7.27	7.8	-3.37		
8													29		18		47	5.34	10.6	-2.91		
22			31	16													47	5.34	10.6	-6.87		
30			7						13		31						51	5.80	9.8	-4.57		
Aug 2			3								16		13			24	56	6.36	8.9	-3.13	-3.30	9.0
3			9						1		16		19		5		50	5.68	10.0	-4.08		

<u>PROFILE F</u> (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Aug 8			2						6				8		12	34	62	7.05	8.1	-2.70		
Sep 12										16	13		4		11	28	72	8.18	7.0	-3.03	-3.05	6.1
14										15	41		1			18	75	8.52	6.7	-3.57		
16										25	17		2			35	79	8.98	6.4	-3.22		
18										14	61		1			4	80	9.09	6.3	-3.92		
21											39		2			49	90	10.23	5.6	-2.91		
22											38		3			42	83	9.43	6.1	-2.97		
23											43		1			55	99	11.25	5.1	-2.90		
25											32		1			51	84	9.55	6.0	-2.80		
27										4	26					53	83	9.43	6.1	-2.77		
29											18					73	91	10.34	5.5	-2.44		
Oct 1											12					73	85	9.66	5.9	-2.33	-3.26	6.7
2											15	9				51	75	8.52	6.7	-2.62		
4										16	22				9	22	69	7.84	7.3	-3.24		

PROFILE F (cont.)

Date	Boulder Dominant b	bc	bp	bs	Cobble Dominant cb	c	cp	cs	Pebble Dominant pb	pc	p	ps	Sand Dominant sb	sc	sp	s	A	B	C	D	E	F
Oct 5										5	17	9			16	25	72	8.18	7.0	-2.94		
6										22	26					26	74	8.41	6.8	-3.41		
7										25	9				12	29	75	8.52	6.7	-3.11		
8										14	5	17				47	83	9.43	6.1	-2.87		
9							13			15	6				7	43	84	9.55	6.0	-3.16		
10										4	9	16			9	35	73	8.30	6.9	-2.80		
12											12	15				54	81	9.20	6.2	-2.62		
17										13	31					30	74	8.41	6.8	-3.26		
18										10	45					21	76	8.64	6.6	-3.49		
19											38					45	83	9.43	6.1	-2.93		
20										20	14	8			12	25	79	8.98	6.4	-3.19		
21										22	20					34	76	8.64	6.6	-3.22		
22							6			15	22					32	75	8.52	6.7	-3.35		
23							4			20	15				20	21	80	9.09	6.3	-3.25		

PROFILE F (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Oct 24							6			16	23					18	63	7.16	8.0	-3.66		
25							18			32	5				5	12	72	8.18	7.0	-4.09		
26							14			38	19	9					80	9.09	6.3	-4.36		
27					5		7			45		6			6	17	86	9.77	5.8	-3.91		
28							19			28	5				6	21	79	8.98	6.4	-3.84		
29										35	5				2	21	63	7.16	8.0	-3.49		
30							6			20					8	40	74	8.41	6.8	-2.99		
31							8			20	6				35		69	7.84	7.3	-3.48		
Nov 1							6			37	2			3	10	15	73	8.30	6.9	-3.63	-3.74	8.7
2							10			17	10				22	11	70	7.95	7.2	-3.49		
3							11			36	4				6	17	74	8.41	6.8	-3.81		
4							17			32	14					10	73	8.30	6.9	-4.22		
5							9			17		13				31	70	7.95	7.2	-3.34		
6							15			6	7	10				28	66	7.50	7.6	-3.48		

PROFILE F (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 7										5	50	15					70	7.95	7.2	-3.91		
8										3	70						73	8.30	6.9	-3.98		
9							1			20	54						75	8.52	6.7	-4.01		
10										37	38						75	8.52	6.7	-4.15		
11					18		8			13	49						88	10.00	5.7	-4.62		
12					14		7			14	29		3			7	74	8.41	6.8	-4.40		
13											68						68*	7.73	7.4	-3.96		
14											60						60	6.82	8.3	-3.96		
15										4	35	14					53	6.02	9.4	-3.89		
16										17	42						59	6.70	8.4	-4.07		
17										14	28				18		60	6.82	8.3	-3.59		
18							4			14	17	4				18	57	6.48	8.8	-3.53		
19											23					22	45	5.11	11.1	-3.03		
20											14					23	37	4.20	13.4	-2.78		

PROFILE F (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 21											42						42	4.77	11.8	-3.96		
22											48						48	5.45	10.4	-3.96		
23											54						54	6.14	9.3	-3.96		
24											52						52	5.91	9.6	-3.96		
25										14	35						49	5.57	10.2	-4.07		
26										1	48						49	5.57	10.2	-3.97		
27							6			9	23				16		54	6.14	9.3	-3.74		
28										22	21				7		50	5.68	10.0	-3.91		
29										22	18					10	50	5.68	10.0	-3.75		
30										10	29				5		44	5.00	11.3	-3.87		

PROFILE F (cont.)

Class	Total Horizontal Exposure	Per Cent Exposure
bp	21	.3
cb	37	.6
cp	195	3.1
pb	20	.3
pc	1097	17.5
p	2168	34.6
ps	182	2.9
sb	158	2.5
sc	96	1.5
sp	407	6.5
s	1882	30.0
		99.8

PROFILE AA

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Jan 4		29			33												62	7.05	8.1	-6.86	-6.33	7.9
8	13				46												59	6.70	8.5	-6.64		
10		36			25												61	6.93	8.2	-7.02		
15	12	15								38							65	7.39	7.7	-5.62		
17	7	13			21					26							67	7.61	7.5	-5.86		
24	18				29					24							71	8.07	7.1	-5.97		
Mar 16													No textures measured				81	9.20	6.2		-5.77	6.8
22					19		52										71	8.07	7.1	-5.63		
28		9			19		44										72	8.18	7.0	-5.90		
Apr 5	4	12	24				36										76	8.64	6.6	-6.42	-6.09	7.1
11	3	21			25		11			11							71	8.07	7.1	-6.25		
26					16		51										67	7.61	7.5	-5.61		
Jun 20	15						54										69	7.84	7.3	-5.96	5.68	7.5

PROFILE AA (cont.)

Date	Boulder Dominant b	bc	bp	bs	Cobble Dominant cb	c	cp	cs	Pebble Dominant pb	pc	p	ps	Sand Dominant sb	sc	sp	s	A	B	C	D	E	F
Jun 27							66										66	7.50	7.6	-5.40		
Jul 26		6			27		11			21							65	7.39	7.7	-5.54	-5.54	7.7
Aug 1		7					27			29							63	7.16	7.9	-5.05	-4.83	7.8
8					3		20			43							66	7.50	7.6	-4.60		
Sep 13	1				21					44							66	7.50	7.6	-4.85	-5.71	7.5
19	10				17		28			11							66	7.50	7.6	-5.80		
26	11	16			16		24			2							69	7.84	7.3	-6.47		
Oct 3	3	9					53										65	7.39	7.7	-5.82	-5.46	7.7
11		9			10	9	38										66	7.50	7.6	-5.88		
17			5				31		4	5	21						66	7.50	7.6	-4.83		
26		5	6		4		25			23							63	7.16	7.9	-5.32		
Nov 8					9	13	12	5			16	8				7	70	7.95	7.2	-4.53	-5.01	7.6
15						18	17		29								64	7.27	7.8	-5.13		
22		5			12	9	10			29							65	7.39	7.7	-5.21		

PROFILE AA (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 29			4		12		23			25							64	7.27	7.8	-5.16		

Class	Total Horizontal Exposure	Per Cent Exposure
b	97	5.4
bc	192	10.7
bp	39	2.2
cb	364	20.3
c	49	2.7
cp	633	35.3
cs	5	.3
pb	33	1.8
pc	331	18.4
p	37	2.1
ps	8	.4
s	7	.4
		100.0

PPOFILE BB

Date	Boulder Dominant b	bc	bp	bs	Cobble Dominant cb	c	cp	cs	Pebble Dominant pb	pc	p	ps	Sand Dominant sb	sc	sp	s	A	B	C	D	E	F
Jan 4									6	45					14	12	77	8.75	6.5	-3.10	-2.12	7.8
8												7	22		15	21	65	7.39	7.7	-1.90		
10												5		12		54	71	8.07	7.1	-1.40		
15													14		33	21	68	7.73	7.4	-1.63		
17													20	12	5	30	67	7.61	7.5	-1.73		
20													41	10	5		56	6.36	8.9	-2.35		
21										11			21	20	8		60	6.82	8.3	-2.50		
24									5	6			13	27	5		56	6.36	8.9	-2.53		
28												6	13	21	6	17	63	7.16	7.9	-1.94		
Feb 7													17	14	5	37	73	8.30	6.9	-1.65	-1.65	6.9
Mar 16												No textures measured					70	7.95	7.2		-1.82	7.1
22											17	8	22		11	18	76	8.64	6.6	-2.31		
28										19			12		20	15	66	7.50	7.6	-2.32		

PROFILE BB (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Apr 4		20										11			26		57	6.48	8.8	-4.00	-2.45	7.6
11															4	72	76	8.64	6.6	-1.13		
26										23		4			7	34	68	7.73	7.4	-2.22		
Jun 20		26			4					16			6	10		5	67	7.61	7.5	-4.91	-4.75	7.5
28		14		17									15	21			67	7.61	7.5	-4.58		
Jul 2									13	22			25		11		71	8.07	7.1	-3.16	-3.26	7.1
7					9					11			4		8	42	74	8.41	6.8	-2.29		
22										42					13	25	80	9.09	6.3	-2.67		
31					26				20	12					4		62	7.05	8.1	-4.92		
Aug 8		14			22					12			3		5	17	73	8.30	6.9	-4.48	-4.48	6.9
Sep 12										13				8	25	40	86	9.77	5.8	-1.76	-1.73	5.4
15										10	3		8		24	53	98	11.14	5.1	-1.70		
17					11					14				7	56		88	10.00	5.7	-2.58		
19										10			6		16	67	99	11.25	5.1	-1.16		

PROFILE BB (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Sep 22					4									8	9	74	95	10.80	5.3	-1.45		
24					4									18	13	63	98	11.14	5.1	-1.56		
26														14	16	61	91	10.34	5.5	-1.34		
28					11							8	7		29	37	92	10.45	5.5	-2.15		
30								11					15		12	51	89	10.11	5.6	-1.88		
Oct 1													11	11	13	55	90	10.23	5.6	-1.47	-1.95	6.1
2								14						6	39	20	79	8.98	6.3	-2.08		
4										7	9		16	13	22	23	90	10.23	5.6	-2.07		
5					4					6	9		17	9	41		86	9.77	5.8	-2.39		
6							2			1			20	26	6	34	89	10.11	5.6	-1.86		
7										10	3		18	8	20	33	92	10.45	5.5	-1.95		
8										10			18	8	32	26	94	10.68	5.3	-1.92		
9							4			11	7		16	7	14	32	91	10.34	5.5	-2.21		
10													No textures measured				87	9.89	5.8			

<u>PROFILE BB</u> (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Oct 12										3			12	6	34	34	89	10.11	5.6	-1.64		
18											4		17	13	55		89	10.11	5.6	-1.91		
19										4			13		12	56	85	9.66	5.9	-1.52		
20										4			14	12		55	85	9.66	5.9	-1.61		
21										5			17	12		50	84	9.55	6.0	-1.70		
22							5				8		15	13	27	15	83	9.43	6.1	-2.15		
23							5			5			14	13	21	26	84	9.55	6.0	-2.03		
24										4	6		14	10	52	2	88	10.00	5.7	-2.01		
25										9			13	11	24	26	83	9.43	6.1	-1.90		
27										6		6	12	8	17	35	84	9.55	6.0	-1.83		
28										6			12	12	11	42	83	9.43	6.1	-1.72		
29										6	16	5	15	11	18	9	80	9.09	6.3	-2.41		
30										5	13			10	50	1	79	8.98	6.3	-2.09		
31										5	22		13	10	30	9	89	10.11	5.6	-2.32		

PROFILE BB (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 2										8	4		11	9	35	20	87	9.89	5.8	-1.94	-2.26	6.1
3										13	14	6	13	12	11	20	89	10.11	5.6	-2.41		
5										5			11	11	58	1	86	9.77	5.8	-1.89		
6										6			12	11		58	87	9.89	5.8	-1.62		
7										4			13	11	13	47	88	10.00	5.7	-1.63		
9							4						24	11	9	40	88	10.00	5.7	-1.85		
10							6						12	12	33	20	83	9.43	6.1	-1.94		
11							5			12			20	12	13	20	82	9.32	6.1	-2.34		
12							4						27	27		30	88	10.00	5.7	-2.02		
13							4							28		49	81	9.20	6.2	-1.64		
14							4						25	11		38	78	8.86	6.4	-1.91		
16							6			11			15		11	36	79	8.98	6.3	-2.16		
17							30			22		5	20			8	85	9.66	5.9	-3.78		
18							26			3	5	5	19	11		13	82	9.32	6.1	-3.27		

PROFILE BB (cont.)

Date	Boulder Dominant				Cobble Dominant				Pebble Dominant				Sand Dominant				A	B	C	D	E	F
	b	bc	bp	bs	cb	c	cp	cs	pb	pc	p	ps	sb	sc	sp	s						
Nov 19							4			18			28	12		21	83	9.43	6.1	-2.39		
20							3					7	20	12	5	32	79	8.98	6.3	-1.97		
21							3						24	17	8	27	79	8.98	6.3	-1.95		
23							6						34	11		30	81	9.20	6.2	-2.14		
24							17									58	75	8.52	6.7	-2.07		
25							5	11					51			6	73	8.30	6.9	-2.95		
26							4	11					34		5	21	75	8.52	6.7	-2.25		
27							5	12				11	19		18	14	79	8.98	6.3	-2.66		
28							7	17		11			25		10	8	78	8.86	6.4	-3.22		

PROFILE BB (cont.)

Class	Total Horizontal Exposure	Per Cent Exposure
bc	74	1.2
bs	17	.3
cb	95	1.6
cp	157	2.6
cs	76	1.3
pb	44	.7
pc	476	7.9
p	137	2.3
ps	87	1.5
sb	1008	16.8
sc	649	10.8
sp	1133	18.9
s	2042	34.1
		100.0

APPENDIX 3:1

DATA SET OF NINE WAVE PROCESSES AND SIX BEACH RESPONSES, JANUARY 3, 1970 TO NOVEMBER 30, 1970.

KEY

HB	=	Breaker Height (feet)
T	=	Wave Period (seconds)
THET'	=	Wave Direction (degrees of azimuth)
THET	=	Angle of Wave Approach (degrees of arc)
HO	=	Deep Water Wave Height (feet)
LO	=	Deep Water Wave-Length (feet)
SO	=	Deep Water Wave Steepness (x 10^{-3}) (dimensionless)
EO	=	Wave Energy (x 10^{3}) (foot-pounds per foot of crest per wave)
EO'	=	Wave Energy (foot-pounds per square foot of sea surface)
G	=	Sediment Gain to Beach since Previous Survey (cubic feet per shoreline foot)
TAUFS	=	Foreshore Texture (phi units)
BETA	=	Foreshore Slope (degrees)
COTBET	=	Foreshore Slope (cotangent of slope angle)
D	=	Position of Shoreline (horizontal feet from station to 26 foot contour)
C	=	Cusp Development (0 = nil; 1 = very poor; 2 = poor; 3 = moderate; 4 = well; 5 = very well)

PROCESS VARIABLES — RESPONSE VARIABLES

DATE	STN	MH	T	THET'	THET	HO	LO	SO	EO	EO'	G	TAUFS	BET	COTRET	O	C
4/1	CC	0.5	7.5	134.	78.	0.1	288.	0.4	0.036	0.1	-56.	-2.57	4.7	12.05	320.	0.
8/1	CC	2.5	10.3	136.	80.	1.0	543.	1.9	4.495	8.0	-77.	-1.52	4.6	12.50	312.	0.
9/1	CC	2.0	8.7	150.	86.	0.9	388.	2.2	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
10/1	CC	2.5	10.8	117.	61.	1.0	597.	1.6	4.495	8.0	23.	-3.42	3.9	14.55	318.	0.
11/1	CC	1.5	12.0	139.	83.	0.4	737.	0.6	0.971	1.3	0.	0.00	0.0	0.00	0.	0.
14/1	CC	1.0	7.1	165.	71.	0.4	258.	1.4	0.288	1.3	42.	-2.15	4.0	14.43	317.	0.
17/1	CC	5.0	9.6	157.	79.	3.1	472.	6.5	35.963	76.9	65.	-1.56	3.5	16.14	322.	0.
20/1	CC	1.0	8.6	130.	74.	0.3	379.	0.8	0.288	0.7	-65.	-1.66	4.2	13.52	318.	0.
21/1	CC	1.5	9.6	130.	74.	0.5	472.	1.1	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
22/1	CC	0.5	9.8	154.	82.	0.1	492.	0.2	0.036	0.1	0.	0.00	0.0	0.00	0.	0.
24/1	CC	2.0	11.0	92.	36.	0.7	620.	1.1	2.302	3.9	-104.	-1.77	4.9	11.59	307.	0.
25/1	CC	2.0	10.1	104.	48.	0.7	522.	1.4	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
26/1	CC	3.0	8.7	102.	46.	1.6	380.	4.1	7.768	20.5	0.	0.00	0.0	0.00	0.	0.
27/1	CC	1.0	8.8	118.	62.	0.3	396.	0.8	0.288	0.7	75.	-2.51	4.5	12.61	315.	0.
28/1	CC	0.5	9.7	124.	68.	0.1	482.	0.2	0.036	0.1	0.	0.00	0.0	0.00	0.	0.
29/1	CC	3.0	8.1	167.	69.	1.7	336.	5.1	7.768	23.1	0.	0.00	0.0	0.00	0.	0.
30/1	CC	2.5	10.5	155.	81.	1.0	564.	1.8	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
14/3	CC	2.5	10.3	131.	75.	1.0	543.	1.9	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
18/3	CC	7.0	10.6	162.	76.	4.6	575.	8.0	98.683	169.3	-93.	-2.65	3.6	16.02	311.	0.
21/3	CC	2.0	9.4	157.	79.	0.8	452.	1.8	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
22/3	CC	4.0	8.4	162.	74.	2.5	361.	7.0	18.413	50.0	112.	-3.01	3.9	14.46	322.	0.
23/3	CC	4.0	9.2	146.	90.	2.3	433.	5.3	18.413	42.3	0.	0.00	0.0	0.00	0.	0.
27/3	CC	1.0	11.0	162.	74.	0.2	620.	0.4	0.288	0.3	-47.	-2.28	4.1	13.98	314.	0.
28/3	CC	2.5	10.8	114.	58.	1.0	597.	1.6	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
30/3	CC	1.0	10.5	108.	52.	0.3	564.	0.4	0.288	0.7	0.	0.00	0.0	0.00	0.	0.
31/3	CC	2.5	8.0	108.	68.	1.3	328.	4.0	4.495	13.5	0.	0.00	0.0	0.00	0.	0.
4/4	CC	4.0	9.0	105.	49.	2.4	415.	5.7	18.413	46.1	18.	-2.66	4.1	13.98	319.	0.
5/4	CC	2.0	8.4	120.	64.	0.9	361.	2.5	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
6/4	CC	1.5	9.9	102.	46.	0.5	502.	1.0	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
7/4	CC	0.5	8.4	110.	54.	0.1	361.	0.3	0.036	0.1	0.	0.00	0.0	0.00	0.	0.
11/4	CC	4.0	12.6	165.	71.	1.7	813.	2.1	18.413	23.1	-97.	-1.52	4.0	14.43	308.	0.
12/4	CC	6.0	11.5	142.	86.	3.4	677.	5.0	62.144	92.5	0.	0.00	0.0	0.00	0.	0.
13/4	CC	3.0	11.5	142.	86.	1.2	677.	1.8	7.768	11.5	0.	0.00	0.0	0.00	0.	0.
14/4	CC	3.0	11.4	154.	82.	1.2	665.	1.8	7.768	11.5	206.	-1.52	3.9	14.45	320.	0.
24/4	CC	2.0	10.5	120.	64.	0.7	564.	1.3	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
25/4	CC	1.0	9.0	123.	67.	0.3	415.	0.7	0.288	0.7	-41.	-1.86	4.2	13.68	318.	0.
26/4	CC	2.5	4.5	169.	67.	2.3	104.	22.4	4.495	42.3	0.	0.00	0.0	0.00	0.	0.
10/6	CC	4.0	13.4	152.	84.	1.6	919.	1.7	18.413	20.5	0.	0.00	0.0	0.00	0.	0.
11/6	CC	3.5	11.1	156.	80.	1.6	631.	2.5	12.335	20.5	0.	0.00	0.0	0.00	0.	0.
12/6	CC	4.5	11.9	153.	83.	2.1	725.	2.9	20.217	35.3	0.	0.00	0.0	0.00	0.	0.
13/6	CC	3.0	9.6	142.	86.	1.4	472.	3.0	7.768	15.7	0.	0.00	0.0	0.00	0.	0.
14/6	CC	4.5	12.0	154.	82.	2.1	737.	2.9	26.217	35.3	0.	0.00	0.0	0.00	0.	0.
15/6	CC	3.5	12.0	115.	59.	1.4	737.	2.0	12.335	15.7	0.	0.00	0.0	0.00	0.	0.
20/6	CC	7.0	12.0	132.	76.	4.1	737.	5.5	98.683	134.5	-42.	-1.57	3.0	14.09	323.	0.
21/6	CC	4.5	10.6	131.	75.	2.4	575.	4.1	26.217	46.1	0.	0.00	0.0	0.00	0.	0.
22/6	CC	4.5	9.0	149.	87.	2.8	415.	6.8	26.217	62.7	0.	0.00	0.0	0.00	0.	0.
23/6	CC	3.0	11.0	154.	82.	1.3	620.	2.0	7.768	13.5	0.	0.00	0.0	0.00	0.	0.
24/6	CC	4.5	13.1	150.	86.	1.9	879.	2.2	26.217	28.9	0.	0.00	0.0	0.00	0.	0.
25/6	CC	3.0	12.2	100.	44.	1.1	762.	1.5	7.768	9.7	0.	0.00	0.0	0.00	0.	0.
26/6	CC	6.0	15.2	167.	69.	2.6	1183.	2.2	62.144	54.1	-116.	-1.52	4.2	13.92	311.	0.
27/6	CC	5.5	11.6	103.	47.	2.9	689.	4.3	47.867	67.3	0.	0.00	0.0	0.00	0.	0.
28/6	CC	4.0	10.0	105.	49.	2.1	512.	4.1	18.413	35.3	0.	0.00	0.0	0.00	0.	0.
29/6	CC	4.0	11.8	90.	34.	1.8	713.	2.5	18.413	25.9	0.	0.00	0.0	0.00	0.	0.
30/6	CC	4.0	12.2	172.	84.	1.7	762.	2.3	18.413	23.1	0.	0.00	0.0	0.00	0.	0.
1/7	CC	4.0	10.5	163.	73.	2.0	564.	3.6	18.413	32.0	-45.	-2.37	4.4	12.95	301.	0.
2/7	CC	1.0	8.8	92.	36.	0.3	396.	0.8	0.288	0.7	0.	0.00	0.0	0.00	0.	0.
4/7	CC	4.5	7.8	94.	38.	3.2	312.	10.4	26.217	81.9	0.	0.00	0.0	0.00	0.	0.
5/7	CC	2.0	8.2	109.	53.	0.9	344.	2.7	2.302	6.5	62.	-1.98	4.2	13.92	320.	0.
6/7	CC	2.0	10.8	111.	55.	0.7	597.	1.2	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
7/7	CC	6.0	10.9	112.	56.	3.6	608.	5.9	62.144	103.7	0.	0.00	0.0	0.00	0.	0.
8/7	CC	6.5	12.4	99.	43.	3.5	787.	4.5	79.011	98.0	0.	0.00	0.0	0.00	0.	0.
22/7	CC	6.0	14.1	152.	84.	2.8	1018.	2.7	62.144	62.7	-320.	-2.09	6.1	9.12	297.	0.
23/7	CC	7.5	12.4	148.	88.	4.4	787.	5.6	121.375	154.9	0.	0.00	0.0	0.00	0.	0.
25/7	CC	2.5	8.0	115.	59.	1.3	328.	4.0	4.495	13.5	0.	0.00	0.0	0.00	0.	0.
26/7	CC	2.0	9.4	104.	48.	0.8	452.	1.8	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
29/7	CC	5.0	10.5	151.	85.	2.8	564.	5.0	35.963	62.7	0.	0.00	0.0	0.00	0.	0.
30/7	CC	4.0	8.7	167.	69.	2.4	388.	6.3	18.413	46.1	278.	-3.58	4.5	12.61	299.	0.
31/7	CC	5.0	11.5	146.	90.	2.6	677.	3.8	35.963	54.1	0.	0.00	0.0	0.00	0.	0.
1/8	CC	4.5	10.2	94.	38.	2.5	533.	4.7	26.217	50.0	0.	0.00	0.0	0.00	0.	0.
2/8	CC	3.0	10.0	92.	36.	1.4	512.	2.7	7.768	15.7	-204.	-3.65	5.1	11.25	306.	0.
3/8	CC	2.5	9.3	87.	31.	1.1	443.	2.5	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
4/8	CC	1.5	9.8	96.	40.	0.5	492.	1.0	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
5/8	CC	2.0	7.0	181.	55.	1.1	251.	4.3	2.302	9.7	0.	0.00	0.0	0.00	0.	0.
6/8	CC	4.5	6.0	182.	54.	4.2	184.	22.9	26.217	141.1	0.	0.00	0.0	0.00	0.	0.
8/8	CC	5.0	6.1	172.	64.	4.9	191.	25.5	35.963	192.1	207.	-3.95	4.4	12.95	321.	0.
9/9	CC	3.0	6.1	161.	75.	2.3	191.	11.8	7.768	42.3	0.	0.00	0.0	0.00	0.	0.
10/9	CC	2.0	8.1	107.	51.	0.9	336.	2.8	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
11/9	CC	3.0	8.6	91.	35.	1.6	379.	4.2	7.768	20.5	0.	0.00	0.0	0.00	0.	0.
12/9	CC	4.5	8.9	196.	40.	2.8	406.	7.0	26.217	62.7	-24.	-2.32	4.6	12.77	303.	0.
13/9	CC	4.0	7.5	170.	66.	2.8	288.	9.8	18.413	62.7	0.	0.00	0.0	0.00	0.	0.
14/9	CC	2.0	8.2	100.	44.	0.9	384.	2.7	2.302	6.5	42.	-2.71	4.9	11.48	321.	1.
15/9	CC	2.5	8.9	159.	77.	1.2	406.	2.9	4.495	11.5	62.	-2.38	4.7	12.05	336.	2.
16/9	CC	1.5	9.2	98.	42.	0.5	433.	1.2	0.971	2.0	-87.	-2.74	5.0	11.48	316.	1.
17/9	CC	4.5	9.6	150.	86.	2.6	472.	5.6	26.217	54.1	0.	0.00	0.0	0.00	0.	0.
18/9	CC	3.0	9.2	97.	41.	1.5	433.	3.5	7.768	18.0	80.	-3.47	5.0	11.48	316.	0.
19/9	CC	1.0	10.0	95.	39.	0.3	512.	0.5	0.288	0.7	0.	0.00	0.0	0.00	0.	0.
20/9	CC	4.0	6.4	174.	62.	3.3	210.	15.8	18.413	87.1	0.	0.00	0.0	0.00	0.	0.
21/9	CC	5.5	13.3	129.	73.	2.6	906.	2.8	47.867	54.1	-37.	-2.96	5.5	10.34	314.	1.
22/9	CC	7.0	10.5	91.	35.	4.7	564.	8.3	98.683	176.7	0.	0.00	0.0	0.00	0.	1.
23/9	CC	3.0	8.9	120.	64.	1.5	406.	3.8	7.768	18.0	-16.	-2.81	5.1	11.25	305.	1.
24/9	CC	1.5	11.0	94.	38.	0.4	620.	0.7	0.971	1.3	35.	-2.29	4.6	12.19	309.	0.
25/9	CC	6.0	7.4	176.	60.	5.3	280.	18.8	62.144	224.7	26.	-3.28	4.4	12.95	319.	1.
26/9	CC	10.0	13.7	155.	81.	6.1	961.	6.4	287.705	297.7	19.	-1.56	3.8	14.89	319.	1.
27/9	CC	6.5	9.5	99.	43.	4.6	462.	10.0	79.011	169.3	-2.	-2.99	4.6	13.07	313.	1.
28/9	CC	8.0	10.7	154.	82.	5.6	586.	9.6	147.305	250.9	-14.	-2.12	4.3	13.41	317.	0.
29/9	CC	7.0	14.0	152.	84.	3.5	1004.	3.5	98.683	98.0	-53.	-1.52	4.4	12.05	314.	0.
30/9	CC	7.0	13.6	157.	79.	3.6	947.	3.8	98.683	103.7	-38.	-1.57	3.0	18.75	318.	0.
1/10	CC	4.5	10.5	157.	79.	2.4	564.	4.3	26.217	46.1	-80.	-1.58	3.9	14.46	311.	1.
2/10	CC	3.0	7.8	96.	40.	1.8	312.	5.7	7.768	25.9	1.	-3.07	4.1	13.75	314.	0.
3/10	CC	4.0	9.5	90.	34.	2.2	462.	4.8	18.413	38.7	-12.	-3.15	4.1	13.08	320.	0.
4/10	CC	1.5	9.5	102.	46.	0.5	462.	1.1	0.971	2.0	-7.	-2.63	4.1	13.86	312.	0.
5/10	CC	1.0	7.1	95.	39.	0.4	258.	1.4	0.288	1.3	22.	-2.83	4.0	14.09	319.	1.
6/10	CC	2.0	12.0	91.	35.	0.6	737.	0.8	2.302	2.9	-25.	-2.79	4.1	13.86	325.	2.
7/10	CC	3.0	11.5	98.	42.	1.2	677.	1.8	7.768	11.5	77.	-2.31	3.1	18.30	323.	3.
8/10	CC	2.5	11.2	85.	29.	0.9	642.	1.5	4.495	6.5	-80.	-2.40	4.1	13.98	322.	3.
9/10	CC	4.0	8.6	165.	71.	2.5	379.	6.5	18.413	50.0	0.	-2.48	4.0	14.32	322.	2.
10/10	CC	4.5	10.6	170.	66.	2.4	575.	4.1	26.217	46.1	20.	-2.50	3.8	15.23	321.	1.
11/10	CC	4.5	10.4	157.	79.	2.4	554.	4.4	26.217	46.1	-31.	-2.61	4.1	13.98	318.	2.
12/10	CC	6.0	10.5	172.	64.	3.7	564.	6.6	62.144	109.5	14.	-3.16	3.5	16.14	313.	1.
17/10	CC	4.5	7.5	189.	47.	3.4	288.	11.7	26.217	92.5	0.	-2.58	3.9	14.55	317.	4.
18/10	CC	2.0	8.5	100.	44.	0.9	370.	2.4	2.302	6.5	6.	-2.70	4.0	14.32	339.	2.
19/10	CC	5.5	12.2	170.	66.	2.8	762.	3.7	47.867	62.7	-141.	-1.57	4.5	12.84	304.	0.
20/10	CC	5.0	8.5	149.	87.	3.5	370.	9.4	35.963	98.0	23.	-2.72	4.1	13.86	300.	0.
21/10	CC	5.0	10.0	99.	43.	3.0	512.	5.8	35.963	72.0	57.	-3.42	4.0	14.43	309.	1.
22/10	CC	3.0	7.0	82.	26.	2.0	251.	7.8	7.768	32.0	89.	-3.37	3.8	15.00	337.	1.
23/10	CC	4.5	7.8	93.	37.	3.2	312.	10.4	26.217	81.9	0.	0.00	0.0	0.00	0.	0.
24/10	CC	1.0	9.2	97.	41.	0.3	433.	0.7	0.288	0.7	-104.	-3.19	4.2	13.92	324.	1.
25/10	CC	2.5	7.2	97.	41.	1.5	265.	5.5	4.495	18.0	73.	-3.00	4.3	13.41	330.	1.
26/10	CC	1.5	8.0	133.	77.	0.6	328.	1.9	0.971	2.9	0.	0.00	0.0	0.00	0.	2.
27/10	CC	4.0	10.3	142.	86.	2.1	543.	3.8	18.413	35.3	-90.	-2.93	4.2	13.68	322.	2.
28/10	CC	4.5	11.5	92.	36.	2.2	677.	3.2	26.217	38.7	19.	-2.88	4.3	13.10	329.	2.
29/10	CC	4.5	8.0	90.	34.	3.2	328.	9.6	26.217	81.9	42.	-3.15	4.0	14.20	329.	2.
30/10	CC	4.0	9.0	93.	37.	2.4	415.	5.7	18.413	46.1	-8.	-2.60	3.9	14.66	325.	0.
31/10	CC	1.5	9.6	128.	72.	0.5	472.	1.1	0.971	2.0	-6.	-2.81	4.2	13.44	324.	0.
1/11	CC	4.5	6.3	112.	56.	4.0	203.	19.8	26.217	128.0	0.	0.00	0.0	0.00	0.	1.
2/11	CC	1.5	10.0	116.	60.	0.5	512.	1.0	0.971	2.0	-4.	-2.91	4.0	14.32	327.	2.
3/11	CC	2.0	8.0	96.	40.	0.9	328.	2.9	2.302	6.5	17.	-2.55	4.1	13.98	331.	3.
4/11	CC	2.5	7.0	178.	58.	1.5	251.	6.0	4.495	18.0	0.	0.00	0.0	0.00	0.	3.
5/11	CC	5.0	7.7	159.	77.	3.8	304.	12.7	35.963	115.9	17.	-2.69	3.9	14.46	326.	1.
6/11	CC	5.5	9.5	171.	65.	3.6	462.	7.8	47.867	103.7	23.	-2.34	3.9	14.46	323.	3.
7/11	CC	6.0	9.4	153.	83.	4.1	452.	9.2	62.144	134.5	-24.	-2.27	3.8	14.89	320.	3.
8/11	CC	5.0	10.4	148.	88.	2.8	554.	5.1	35.963	62.7	0.	0.00	0.0	0.00	0.	2.
9/11	CC	4.0	10.7	152.	84.	2.0	586.	3.4	18.413	32.0	49.	-2.84	3.7	15.57	320.	2.
10/11	CC	4.0	10.5	147.	89.	2.0	564.	3.6	18.413	32.0	-58.	-2.52	4.1	13.75	319.	2.
11/11	CC	2.0	10.7	147.	89.	0.7	586.	1.2	2.302	3.9	-22.	-2.68	4.2	13.64	315.	2.
12/11	CC	1.0	7.3	140.	84.	0.4	273.	1.3	0.288	1.3	-47.	-2.73	4.3	13.41	311.	2.
13/11	CC	4.5	12.0	143.	87.	2.1	737.	2.9	26.217	35.3	80.	-2.10	3.8	15.11	316.	2.
14/11	CC	4.5	8.8	130.	74.	2.9	390.	7.2	26.217	67.3	-38.	-2.51	4.1	13.86	313.	1.
15/11	CC	1.5	12.2	151.	85.	0.4	762.	0.5	0.971	1.3	0.	0.00	0.0	0.00	0.	1.
16/11	CC	2.0	5.6	96.	40.	1.3	161.	8.3	2.302	13.5	2.	-2.83	4.0	14.43	308.	1.
17/11	CC	2.0	10.3	137.	81.	0.7	543.	1.3	2.302	3.9	-3.	-2.77	3.9	14.95	315.	0.
18/11	CC	2.5	9.0	97.	41.	1.2	415.	2.8	4.495	11.5	40.	-2.61	5.3	10.80	317.	1.
19/11	CC	1.5	7.8	99.	43.	0.6	312.	2.0	0.971	2.9	-0.	-2.61	3.9	14.66	321.	1.
20/11	CC	6.0	9.2	161.	75.	4.2	433.	9.8	62.144	141.1	52.	-2.10	3.9	14.55	318.	1.
21/11	CC	4.5	9.4	146.	90.	2.7	452.	5.9	26.217	58.3	-5.	-2.12	3.9	14.55	318.	0.
22/11	CC	6.0	10.5	165.	71.	3.7	564.	6.6	62.144	109.5	0.	0.00	0.0	0.00	0.	0.
23/11	CC	6.0	13.2	167.	69.	2.9	892.	3.3	62.144	67.3	40.	-1.58	3.5	16.25	317.	0.
24/11	CC	5.0	8.8	162.	74.	3.4	396.	8.5	35.963	92.5	-49.	-1.59	3.8	14.89	315.	0.
25/11	CC	4.5	10.7	151.	85.	2.4	586.	4.0	26.217	46.1	12.	-1.86	3.8	15.11	316.	0.
26/11	CC	2.5	9.7	113.	57.	1.1	482.	2.2	4.495	9.7	-34.	-2.37	3.9	14.95	312.	1.
27/11	CC	2.0	11.0	124.	68.	0.7	620.	1.1	2.302	3.9	29.	-2.41	3.9	14.95	318.	0.
28/11	CC	1.5	9.3	95.	39.	0.5	443.	1.2	0.971	2.0	11.	-2.63	3.9	14.66	324.	0.
29/11	CC	1.0	8.4	108.	52.	0.3	361.	0.9	0.288	0.7	0.	0.00	0.0	0.00	0.	0.
30/11	CC	1.5	7.4	94.	38.	0.7	280.	2.3	0.971	3.9	0.	0.00	0.0	0.00	0.	0.

DATE	STN	HH	T	THET'	THET	HO	LO	SO	EO	EO'	G	TAUFS	BET	COTAET	D	C
3/1	F	1.0	9.0	131.	80.	0.3	415.	0.7	0.208	0.7	0.	-2.71	4.6	12.27	139.	0.
8/1	F	5.0	11.0	151.	80.	2.7	620.	4.3	35.963	58.3	-59.	-2.16	6.1	9.43	120.	0.
9/1	F	5.5	9.9	155.	76.	3.5	502.	6.9	47.867	98.0	97.	-2.84	6.3	9.09	130.	0.
10/1	F	3.5	8.6	141.	90.	2.0	379.	5.3	12.335	32.0	45.	-4.10	6.8	8.10	138.	0.
11/1	F	2.5	9.7	155.	76.	1.1	482.	2.2	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
12/1	F	5.0	12.1	144.	87.	2.4	750.	3.3	35.963	46.1	0.	0.00	0.0	0.00	0.	0.
13/1	F	2.5	6.5	160.	71.	1.6	210.	7.4	4.495	20.5	46.	-3.75	6.8	8.41	139.	0.
16/1	F	5.0	9.1	151.	80.	3.3	424.	7.7	35.963	87.1	0.	0.00	0.0	0.00	0.	0.
17/1	F	5.5	8.3	143.	88.	4.1	353.	11.7	47.867	134.5	61.	-3.96	7.1	7.95	139.	0.
20/1	F	2.5	9.9	146.	85.	1.1	502.	2.1	4.495	9.7	-28.	-4.18	7.7	7.19	137.	0.
21/1	F	3.0	11.8	136.	85.	1.2	713.	1.6	7.768	11.5	17.	-4.09	7.9	7.16	138.	0.
22/1	F	2.0	11.6	158.	73.	0.6	689.	0.9	2.302	2.9	0.	0.00	0.0	0.00	0.	0.
24/1	F	3.5	10.0	112.	61.	1.7	512.	3.4	12.335	23.1	8.	-3.73	8.5	6.70	139.	0.
25/1	F	2.5	10.7	117.	66.	1.0	586.	1.7	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
26/1	F	3.5	8.8	112.	61.	2.0	396.	5.0	12.335	32.0	0.	0.00	0.0	0.00	0.	0.
27/1	F	3.0	9.9	119.	68.	1.4	502.	2.8	7.768	15.7	-8.	-3.59	8.3	6.82	140.	0.
28/1	F	2.0	9.9	127.	76.	0.8	502.	1.5	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
29/1	F	4.5	7.8	152.	79.	3.2	312.	10.4	26.217	81.9	0.	0.00	0.0	0.00	0.	0.
30/1	F	3.0	8.4	163.	68.	1.6	361.	4.5	7.768	20.5	0.	0.00	0.0	0.00	0.	0.
7/2	F	2.5	11.0	122.	71.	1.0	620.	1.5	4.495	8.0	33.	-3.31	8.6	6.59	136.	0.
14/3	F	3.5	10.5	137.	86.	1.7	564.	2.9	12.335	23.1	0.	0.00	0.0	0.00	0.	0.
16/3	F	9.0	10.5	152.	79.	6.8	564.	12.1	209.737	369.9	-196.	-2.95	10.2	5.57	118.	0.
21/3	F	4.0	9.9	137.	86.	2.1	502.	4.3	18.413	35.3	165.	-2.67	4.5	12.73	120.	0.
22/3	F	4.5	9.5	158.	73.	2.7	462.	5.8	26.217	58.3	0.	0.00	0.0	0.00	0.	0.
23/3	F	6.0	9.2	135.	84.	4.2	433.	9.8	62.144	141.1	0.	0.00	0.0	0.00	0.	0.
27/3	F	2.5	10.4	155.	76.	1.0	554.	1.8	4.495	8.0	-83.	-3.22	11.1	5.11	129.	0.
28/3	F	3.0	10.2	133.	82.	1.3	533.	2.5	7.768	13.5	0.	0.00	0.0	0.00	0.	0.
30/3	F	2.0	8.9	117.	66.	0.8	406.	2.1	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
31/3	F	2.5	10.0	173.	58.	1.0	512.	2.0	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
4/4	F	4.0	9.0	113.	62.	2.4	415.	5.7	18.413	46.1	146.	-3.00	5.2	11.02	124.	0.
5/4	F	4.0	9.8	126.	75.	2.2	492.	4.4	18.413	38.7	0.	0.00	0.0	0.00	0.	0.
6/4	F	2.5	10.5	117.	66.	1.0	564.	1.8	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
7/4	F	1.5	9.2	126.	75.	0.5	433.	1.2	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
11/4	F	6.0	12.6	156.	75.	3.1	813.	3.8	62.144	76.9	-104.	-2.46	8.0	7.05	125.	0.
12/4	F	7.0	12.6	140.	89.	3.9	813.	4.8	98.683	121.7	0.	0.00	0.0	0.00	0.	0.
13/4	F	6.5	12.0	136.	85.	3.7	737.	5.0	79.011	109.5	0.	0.00	0.0	0.00	0.	0.
14/4	F	3.5	9.6	157.	74.	1.8	472.	3.8	12.335	25.9	0.	0.00	0.0	0.00	0.	0.
20/4	F	2.5	9.4	162.	69.	1.1	452.	2.5	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
25/4	F	1.5	9.6	118.	67.	0.5	472.	1.1	0.971	2.0	87.	-3.35	9.6	5.01	132.	0.
26/4	F	3.5	5.2	172.	59.	3.3	130.	24.1	12.335	87.1	0.	0.00	0.0	0.00	0.	0.
10/6	F	5.0	11.1	141.	90.	2.7	631.	4.2	35.963	58.3	0.	0.00	0.0	0.00	0.	0.
11/6	F	5.5	10.4	146.	85.	3.3	554.	5.9	47.867	87.1	0.	0.00	0.0	0.00	0.	0.
12/6	F	4.5	10.5	132.	81.	2.4	564.	4.3	26.217	46.1	0.	0.00	0.0	0.00	0.	0.
13/6	F	5.0	10.4	142.	89.	2.8	554.	5.1	35.963	62.7	0.	0.00	0.0	0.00	0.	0.
14/6	F	4.0	10.7	146.	85.	2.0	586.	3.4	18.413	32.0	0.	0.00	0.0	0.00	0.	0.
15/6	F	4.0	12.0	122.	71.	1.8	737.	2.4	18.413	25.9	0.	0.00	0.0	0.00	0.	0.
20/6	F	8.0	12.2	131.	80.	4.9	762.	6.4	147.305	192.1	212.	-2.06	7.0	8.07	114.	0.
21/6	F	5.0	11.0	132.	81.	2.7	620.	4.3	35.963	58.3	0.	0.00	0.0	0.00	0.	0.
22/6	F	4.5	10.0	147.	84.	2.5	512.	4.9	26.217	50.0	0.	0.00	0.0	0.00	0.	0.
23/6	F	3.5	9.4	140.	89.	1.8	452.	4.1	12.335	25.9	0.	0.00	0.0	0.00	0.	0.
24/6	F	5.0	13.2	134.	83.	2.2	892.	2.5	35.963	38.7	0.	0.00	0.0	0.00	0.	0.
25/6	F	2.5	12.0	104.	53.	0.9	737.	1.2	4.495	6.5	0.	0.00	0.0	0.00	0.	0.
26/6	F	7.0	15.8	159.	72.	3.1	1278.	2.4	98.683	76.9	0.	0.00	0.0	0.00	0.	0.
27/6	F	6.0	13.1	122.	71.	3.0	879.	3.4	62.144	72.0	-232.	-2.06	6.1	9.43	99.	0.
28/6	F	5.0	10.4	108.	57.	2.8	554.	5.1	35.963	62.7	0.	0.00	0.0	0.00	0.	0.
29/6	F	4.5	10.3	100.	49.	2.5	543.	4.5	26.217	50.0	0.	0.00	0.0	0.00	0.	0.
30/6	F	4.5	8.4	170.	61.	3.0	361.	8.3	26.217	72.0	0.	0.00	0.0	0.00	0.	0.
1/7	F	4.5	10.0	167.	64.	2.5	512.	4.9	26.217	50.0	-25.	-3.31	7.1	7.95	102.	0.
2/7	F	2.5	10.2	122.	71.	1.0	533.	1.9	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
4/7	F	5.0	8.4	109.	58.	3.5	361.	9.8	35.963	98.0	0.	0.00	0.0	0.00	0.	0.
5/7	F	4.5	7.5	127.	76.	3.4	288.	11.7	26.217	92.5	-36.	-3.37	7.8	7.27	101.	0.
6/7	F	4.0	9.0	117.	66.	2.4	415.	5.7	18.413	46.1	0.	0.00	0.0	0.00	0.	0.
7/7	F	5.5	10.2	128.	77.	3.3	533.	6.3	47.867	87.1	0.	0.00	0.0	0.00	0.	0.
8/7	F	6.5	11.4	122.	71.	3.9	665.	5.8	79.011	121.7	-142.	-2.91	10.6	5.34	86.	0.
22/7	F	7.0	12.1	155.	76.	4.1	750.	5.4	98.683	134.5	-107.	-6.87	10.6	5.34	82.	0.
23/7	F	8.5	13.5	136.	85.	4.9	933.	5.2	176.687	192.1	0.	0.00	0.0	0.00	0.	0.
24/7	F	3.0	9.5	130.	79.	1.4	462.	3.1	7.768	15.7	0.	0.00	0.0	0.00	0.	0.
26/7	F	3.0	9.3	130.	79.	1.5	443.	3.3	7.768	18.0	0.	0.00	0.0	0.00	0.	0.
29/7	F	6.0	9.7	161.	70.	4.0	482.	8.3	62.144	128.0	0.	0.00	0.0	0.00	0.	0.
30/7	F	5.5	8.7	152.	79.	3.9	388.	10.1	47.867	121.7	7.	-4.57	9.8	5.80	80.	0.
31/7	F	6.0	10.3	132.	81.	3.8	543.	7.0	62.144	115.5	0.	0.00	0.0	0.00	0.	0.
1/8	F	4.5	9.1	116.	65.	2.8	424.	6.6	26.217	62.7	0.	0.00	0.0	0.00	0.	0.
2/8	F	3.5	12.0	102.	51.	1.4	737.	2.0	12.335	15.7	93.	-3.13	8.9	6.36	89.	0.
3/8	F	4.0	12.1	110.	59.	1.8	750.	2.3	18.413	25.9	-99.	-4.08	10.0	5.68	88.	0.
4/8	F	2.5	10.4	111.	60.	1.0	554.	1.8	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
5/8	F	2.0	6.1	174.	57.	1.2	191.	6.4	2.302	11.5	0.	0.00	0.0	0.00	0.	0.
6/8	F	5.0	8.2	150.	81.	3.6	344.	10.5	35.963	103.7	0.	0.00	0.0	0.00	0.	0.
8/8	F	5.5	7.0	179.	52.	4.9	251.	19.5	47.867	192.1	65.	-2.70	8.0	7.05	85.	0.
9/9	F	3.5	6.9	163.	68.	2.5	244.	10.3	12.335	50.0	0.	0.00	0.0	0.00	0.	4.
10/9	F	3.0	6.7	107.	56.	2.1	230.	8.9	7.768	35.3	0.	0.00	0.0	0.00	0.	4.
11/9	F	3.0	5.6	100.	49.	2.5	161.	15.3	7.768	50.0	0.	0.00	0.0	0.00	0.	1.
12/9	F	5.5	9.4	167.	64.	3.6	452.	8.0	47.867	103.7	85.	-3.03	6.9	8.18	106.	1.
13/9	F	4.5	7.9	160.	71.	3.2	320.	10.0	26.217	81.9	0.	0.00	0.0	0.00	0.	4.
14/9	F	4.0	8.8	110.	59.	2.4	396.	6.1	18.413	46.1	76.	-3.57	6.7	8.52	106.	5.
15/9	F	3.0	10.2	132.	81.	1.3	533.	2.5	7.768	13.5	0.	0.00	0.0	0.00	0.	5.
16/9	F	3.5	9.0	104.	53.	1.9	415.	4.6	12.335	28.9	-6.	-3.22	6.3	8.98	109.	5.
17/9	F	5.5	7.4	141.	90.	4.6	280.	16.5	47.867	169.3	0.	0.00	0.0	0.00	0.	4.
18/9	F	4.0	9.0	97.	46.	2.4	415.	5.7	18.413	46.1	6.	-3.92	6.3	9.09	105.	0.
19/9	F	3.0	6.1	104.	53.	2.3	191.	11.8	7.768	42.3	0.	0.00	0.0	0.00	0.	0.
20/9	F	4.0	7.2	170.	61.	2.9	265.	11.1	18.413	67.3	0.	0.00	0.0	0.00	0.	1.
21/9	F	7.0	9.0	131.	80.	5.5	415.	13.1	98.683	242.0	74.	-2.91	5.6	10.23	115.	5.
22/9	F	7.0	10.5	93.	42.	4.7	564.	8.3	98.683	176.7	-42.	-2.97	6.1	9.43	108.	1.
23/9	F	5.0	10.2	121.	70.	2.9	533.	5.5	35.963	67.3	139.	-2.90	5.1	11.25	123.	2.
24/9	F	3.5	11.7	101.	50.	1.5	701.	2.1	12.335	18.0	0.	0.00	0.0	0.00	0.	4.
25/9	F	6.5	9.4	171.	60.	4.7	492.	10.3	79.011	176.7	-140.	-2.80	5.9	9.55	106.	5.
26/9	F	10.0	12.5	166.	67.	6.7	800.	8.4	287.705	359.1	0.	0.00	0.0	0.00	0.	1.
27/9	F	8.0	9.9	131.	80.	6.1	502.	12.1	147.305	297.7	-50.	-2.77	6.1	9.43	106.	0.
28/9	F	7.5	11.0	143.	88.	4.9	620.	8.0	121.375	192.1	0.	0.00	0.0	0.00	0.	2.
29/9	F	8.0	14.5	152.	79.	4.1	1076.	3.8	147.305	134.5	60.	-2.44	5.5	10.34	102.	3.
30/9	F	8.5	14.5	160.	71.	4.5	1076.	4.2	176.686	162.0	0.	0.00	0.0	0.00	0.	0.
1/10	F	5.5	9.7	141.	90.	3.5	482.	7.3	47.867	98.0	-47.	-2.33	5.9	9.66	101.	0.
2/10	F	5.0	9.9	100.	49.	3.0	502.	6.0	35.963	72.0	-14.	-2.62	6.7	8.52	101.	2.
3/10	F	4.5	8.0	94.	43.	3.2	328.	9.6	26.217	81.9	0.	0.00	0.0	0.00	0.	5.
4/10	F	3.0	10.1	123.	72.	1.4	522.	2.6	7.768	15.7	-2.	-3.24	7.3	7.84	100.	4.
5/10	F	1.5	6.5	100.	49.	0.7	216.	3.5	0.971	3.9	-17.	-2.94	6.9	8.18	99.	4.
6/10	F	4.5	12.2	101.	50.	2.1	762.	2.7	26.217	35.3	7.	-3.41	6.8	8.41	101.	4.
7/10	F	4.5	10.8	108.	57.	2.3	597.	3.9	26.217	42.3	8.	-3.11	6.7	8.52	104.	5.
8/10	F	4.0	9.8	104.	53.	2.2	492.	4.4	18.413	38.7	40.	-2.87	6.1	9.43	105.	5.
9/10	F	4.0	10.7	154.	77.	2.0	586.	3.4	18.413	32.0	-30.	-3.16	5.9	9.55	103.	5.
10/10	F	5.0	11.4	163.	68.	2.6	665.	3.9	35.963	54.1	-60.	-2.80	6.9	8.30	98.	3.
11/10	F	5.5	10.4	158.	73.	3.3	554.	5.9	47.867	87.1	0.	0.00	0.0	0.00	0.	4.
12/10	F	7.0	9.7	171.	60.	5.1	482.	10.5	98.683	208.1	67.	-2.62	6.2	9.20	103.	1.
17/10	F	5.0	7.8	190.	41.	3.8	312.	12.2	35.963	115.5	0.	-3.26	6.8	8.41	111.	5.
18/10	F	4.0	9.1	112.	61.	2.3	424.	5.5	18.413	42.3	20.	-3.49	6.6	8.64	109.	3.
19/10	F	5.5	12.6	167.	64.	2.7	813.	3.3	47.867	58.3	-49.	-2.93	6.1	9.43	102.	3.
20/10	F	5.5	7.7	153.	78.	4.4	304.	14.6	47.867	154.9	8.	-3.19	6.3	9.08	101.	4.
21/10	F	5.0	10.1	91.	40.	2.9	522.	5.6	35.963	67.3	36.	-3.22	6.6	8.64	100.	4.
22/10	F	4.5	8.4	94.	43.	3.0	361.	8.3	26.217	72.0	-5.	-3.35	6.7	8.52	107.	4.
23/10	F	5.0	8.1	97.	46.	3.7	336.	10.9	35.963	109.5	24.	-3.25	6.3	9.09	109.	4.
24/10	F	4.5	8.2	106.	55.	3.1	344.	9.0	26.217	76.9	-14.	-3.66	7.9	7.16	109.	4.
25/10	F	4.5	8.3	119.	68.	3.0	353.	8.6	26.217	72.0	-7.	-4.09	7.0	8.18	113.	5.
26/10	F	5.0	9.4	153.	78.	3.2	452.	7.0	35.963	81.9	29.	-4.38	6.3	9.09	103.	5.
27/10	F	5.5	11.0	131.	82.	3.1	620.	5.0	47.867	76.9	16.	-3.91	5.8	9.77	126.	0.
28/10	F	4.5	10.0	100.	49.	2.5	512.	4.9	26.217	50.0	-23.	-3.84	6.3	8.08	116.	5.
29/10	F	4.5	8.4	92.	41.	3.0	361.	8.3	26.217	72.0	85.	-3.49	8.0	7.16	103.	4.
30/10	F	5.0	10.7	113.	62.	2.8	586.	4.7	35.963	62.7	57.	-2.99	6.8	8.41	108.	2.
31/10	F	5.0	9.0	138.	87.	3.3	415.	7.9	35.963	87.1	29.	-3.48	7.3	7.84	106.	3.
1/11	F	4.5	7.5	126.	75.	3.4	288.	11.7	26.217	92.5	16.	-3.63	6.9	8.30	105.	4.
2/11	F	4.5	8.0	133.	82.	3.2	328.	9.6	26.217	81.9	27.	-3.49	7.2	7.95	115.	4.
3/11	F	4.5	9.5	106.	55.	2.7	462.	5.8	26.217	58.3	9.	-3.81	6.8	8.41	116.	4.
4/11	F	4.0	5.5	184.	47.	3.9	155.	24.9	18.413	121.7	-14.	-4.22	6.9	8.30	117.	4.
5/11	F	6.0	11.6	171.	60.	3.4	689.	4.9	62.144	92.5	-69.	-3.34	7.2	7.05	100.	3.
6/11	F	6.0	10.3	167.	64.	3.8	543.	7.0	62.144	115.5	7.	-3.48	7.6	7.90	100.	0.
7/11	F	5.0	9.0	136.	85.	3.3	415.	7.9	35.963	87.1	36.	-3.91	7.2	7.95	105.	4.
8/11	F	5.5	10.5	152.	79.	3.3	564.	5.8	47.867	87.1	97.	-3.98	6.9	8.30	113.	3.
9/11	F	6.0	9.1	164.	67.	4.3	424.	10.1	62.144	147.9	54.	-4.01	6.7	8.52	116.	4.
10/11	F	7.5	11.0	165.	66.	4.9	620.	8.0	121.375	192.1	33.	-4.15	6.7	8.52	126.	4.
11/11	F	6.0	10.9	144.	87.	3.6	608.	5.9	62.144	103.7	117.	-4.62	5.7	10.00	137.	5.
12/11	F	1.0	5.6	95.	44.	0.5	161.	2.9	0.208	2.0	-101.	-4.40	6.8	8.41	128.	5.
13/11	F	6.0	8.9	144.	87.	4.4	406.	10.8	62.144	154.9	-51.	-3.98	7.4	7.73	115.	2.
14/11	F	6.0	10.9	128.	77.	3.6	608.	5.9	62.144	103.7	4.	-3.96	8.3	6.82	113.	3.
15/11	F	5.5	12.2	137.	86.	2.8	762.	3.7	47.867	67.7	18.	-3.89	9.4	6.02	119.	4.
16/11	F	2.0	6.6	116.	65.	1.1	223.	5.1	2.302	9.7	1.	-4.07	8.5	6.70	117.	3.
17/11	F	6.0	10.5	113.	62.	3.7	564.	6.6	62.144	109.5	28.	-3.59	8.3	6.82	121.	3.
18/11	F	5.0	8.6	109.	58.	3.4	379.	9.1	35.963	92.5	15.	-3.53	8.8	6.48	123.	3.
19/11	F	4.5	9.0	114.	63.	2.8	415.	6.8	26.217	62.7	23.	-3.03	11.1	5.11	125.	2.
20/11	F	6.5	9.0	163.	68.	4.9	415.	11.8	79.011	192.1	-47.	-2.78	13.4	4.20	119.	0.
21/11	F	6.5	10.8	149.	82.	4.1	597.	6.8	79.011	134.5	1.	-3.96	11.8	4.77	118.	0.
22/11	F	7.0	12.4	109.	62.	4.0	787.	5.0	98.683	128.0	7.	-3.96	10.4	5.45	119.	0.
23/11	F	8.0	12.3	177.	54.	4.9	775.	6.3	147.305	192.1	30.	-3.98	9.2	6.14	120.	0.
24/11	F	6.5	9.4	106.	85.	4.7	452.	10.3	79.011	176.7	49.	-3.96	9.6	5.91	123.	0.
25/11	F	6.5	9.3	150.	81.	4.7	443.	10.7	79.011	176.7	-11.	-4.07	10.2	5.97	123.	1.
26/11	F	6.0	11.0	123.	72.	3.5	620.	5.7	62.144	98.0	53.	-3.97	10.2	5.97	133.	2.
27/11	F	5.0	10.6	123.	72.	2.8	575.	4.9	35.963	62.7	45.	-3.74	9.3	6.14	137.	2.
28/11	F	2.5	8.9	95.	44.	1.7	406.	2.9	4.495	11.5	-21.	-3.91	10.0	5.68	137.	2.
29/11	F	4.0	10.2	117.	66.	2.1	533.	3.9	18.413	35.3	17.	-3.75	10.0	5.80	136.	2.
30/11	F	2.0	9.6	106.	55.	0.8	472.	1.7	2.302	5.1	4.	-3.87	11.3	5.00	136.	2.

DATE	STN	HB	T	THET'	THET	HO	LO	SO	EO	EO'	G	TAUFS	GET	CUTGET	U	C
6/1	AA	1.5	10.6	100.	85.	0.5	575.	0.8	0.971	2.0	4.	-6.06	8.0	7.05	106.	0.
8/1	AA	2.5	8.7	119.	66.	1.2	388.	3.1	4.495	11.5	-46.	-6.64	8.5	6.70	104.	0.
9/1	AA	3.0	8.4	120.	65.	1.0	361.	4.5	7.708	20.5	0.	0.00	0.0	0.00	0.	0.
10/1	AA	2.0	9.6	120.	65.	0.8	472.	1.7	2.302	5.1	33.	-7.02	8.2	6.93	104.	0.
11/1	AA	2.5	11.8	110.	75.	0.9	713.	1.2	4.495	6.5	0.	0.00	0.0	0.00	0.	0.
15/1	AA	1.0	8.4	113.	72.	0.3	361.	0.9	0.208	0.7	-27.	-5.62	7.7	7.39	102.	0.
17/1	AA	4.0	10.5	122.	63.	2.0	564.	3.6	18.413	32.0	64.	-5.86	7.5	7.61	103.	0.
20/1	AA	1.5	11.4	117.	68.	0.4	665.	0.6	0.971	1.3	0.	0.00	0.0	0.00	0.	0.
21/1	AA	1.0	11.1	120.	65.	0.2	631.	0.4	0.208	0.3	0.	0.00	0.0	0.00	0.	0.
22/1	AA	1.0	9.5	107.	78.	0.3	462.	0.6	0.208	0.7	0.	0.00	0.0	0.00	0.	0.
24/1	AA	1.5	10.7	82.	77.	0.5	586.	0.8	0.971	2.0	-52.	-5.97	7.0	8.07	99.	0.
25/1	AA	2.5	10.6	93.	88.	1.0	575.	1.7	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
26/1	AA	2.0	7.9	91.	86.	0.9	320.	3.0	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
27/1	AA	2.5	9.6	91.	86.	1.1	492.	2.2	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
28/1	AA	2.0	8.8	104.	81.	0.9	396.	2.1	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
29/1	AA	3.0	10.0	112.	73.	1.3	575.	2.3	7.708	13.5	0.	0.00	0.0	0.00	0.	0.
30/1	AA	2.5	11.2	112.	73.	0.9	642.	1.5	4.495	6.5	0.	0.00	0.0	0.00	0.	0.
7/2	AA	1.5	9.8	93.	88.	0.5	492.	1.0	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
14/3	AA	2.5	9.0	82.	77.	1.2	415.	2.8	4.495	11.5	0.	0.00	0.0	0.00	0.	0.
16/3	AA	4.0	9.1	127.	58.	2.3	424.	5.5	18.413	42.3	193.	-5.77	6.2	9.20	124.	0.
22/3	AA	3.5	8.2	120.	65.	2.1	344.	6.1	12.335	35.3	-16.	-5.63	7.0	8.07	118.	0.
23/3	AA	3.0	8.6	124.	61.	1.6	379.	4.2	7.708	20.5	0.	0.00	0.0	0.00	0.	0.
27/3	AA	1.5	11.7	101.	84.	0.4	701.	0.6	0.971	1.3	0.	0.00	0.0	0.00	0.	0.
28/3	AA	2.0	11.1	94.	89.	0.7	631.	1.1	2.302	3.9	10.	-5.90	6.9	8.18	123.	0.
30/3	AA	2.5	8.9	86.	81.	1.2	406.	2.9	4.495	11.5	0.	0.00	0.0	0.00	0.	0.
31/3	AA	2.0	10.7	127.	58.	0.7	586.	1.2	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
4/4	AA	3.0	8.2	82.	77.	1.7	344.	4.9	7.708	23.1	0.	0.00	0.0	0.00	0.	0.
5/4	AA	3.0	8.9	102.	83.	1.5	406.	3.8	7.708	18.0	-29.	-6.42	6.0	8.69	118.	0.
6/4	AA	2.0	8.6	103.	82.	0.9	379.	2.3	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
7/4	AA	1.5	8.0	99.	86.	0.6	328.	1.9	0.971	2.9	0.	0.00	0.0	0.00	0.	0.
11/4	AA	4.0	13.5	121.	64.	1.6	933.	1.7	18.413	20.5	-2.	-6.25	7.0	8.07	115.	0.
12/4	AA	4.0	13.4	114.	71.	1.6	919.	1.7	18.413	20.5	0.	0.00	0.0	0.00	0.	0.
13/4	AA	3.5	12.3	118.	67.	1.4	775.	1.8	12.335	15.7	0.	0.00	0.0	0.00	0.	0.
14/4	AA	3.0	12.4	117.	68.	1.1	787.	1.4	7.708	9.7	0.	0.00	0.0	0.00	0.	0.
24/4	AA	2.0	11.5	98.	87.	0.7	677.	1.0	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
25/4	AA	1.5	7.9	90.	85.	0.6	320.	1.9	0.971	2.9	-5.	0.00	0.0	0.00	0.	0.
26/4	AA	2.0	5.1	116.	69.	1.5	133.	11.0	2.302	18.0	0.	-5.61	7.5	7.61	117.	0.
10/6	AA	2.0	12.0	117.	68.	0.6	737.	0.8	2.302	2.9	0.	0.00	0.0	0.00	0.	0.
11/6	AA	2.5	12.0	118.	67.	0.9	737.	1.2	4.495	6.5	0.	0.00	0.0	0.00	0.	0.
12/6	AA	1.5	15.4	109.	76.	0.3	1214.	0.3	0.971	0.7	0.	0.00	0.0	0.00	0.	0.
13/6	AA	3.0	12.0	122.	63.	1.1	737.	1.6	7.708	9.7	0.	0.00	0.0	0.00	0.	0.
14/6	AA	3.0	11.7	114.	71.	1.2	701.	1.7	7.708	11.5	0.	0.00	0.0	0.00	0.	0.
15/6	AA	3.0	9.2	87.	82.	1.5	433.	3.5	7.708	18.0	0.	0.00	0.0	0.00	0.	0.
20/6	AA	5.0	13.3	116.	69.	2.2	900.	2.5	35.903	38.7	20.	-5.96	7.3	7.84	115.	0.
21/6	AA	4.0	10.7	109.	76.	2.0	586.	3.4	18.413	32.0	0.	0.00	0.0	0.00	0.	0.
22/6	AA	2.0	9.8	106.	79.	0.8	492.	1.6	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
23/6	AA	2.5	11.2	114.	71.	0.9	642.	1.5	4.495	6.5	0.	0.00	0.0	0.00	0.	0.
24/6	AA	3.5	13.0	107.	78.	1.3	865.	1.5	12.335	13.5	0.	0.00	0.0	0.00	0.	0.
25/6	AA	3.0	11.0	109.	76.	1.3	620.	2.0	7.708	13.5	0.	0.00	0.0	0.00	0.	0.
26/6	AA	4.0	14.5	122.	63.	1.5	1070.	1.4	18.413	18.0	0.	0.00	0.0	0.00	0.	0.
27/6	AA	5.0	14.1	126.	59.	2.1	1010.	2.1	35.903	35.3	-18.	-5.40	7.6	7.50	112.	0.
28/6	AA	3.5	8.4	88.	83.	2.1	361.	5.7	12.335	35.3	0.	0.00	0.0	0.00	0.	0.
29/6	AA	4.5	8.8	84.	79.	2.9	396.	7.2	26.217	67.3	0.	0.00	0.0	0.00	0.	0.
30/6	AA	3.5	10.2	132.	53.	1.7	533.	3.2	12.335	23.1	0.	0.00	0.0	0.00	0.	0.
1/7	AA	2.5	10.6	126.	59.	1.0	575.	1.7	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
2/7	AA	2.5	9.6	87.	82.	1.1	492.	2.2	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
4/7	AA	4.0	8.3	111.	74.	2.6	353.	7.2	18.413	54.1	0.	0.00	0.0	0.00	0.	0.
5/7	AA	3.0	8.0	115.	70.	1.7	328.	5.3	7.708	23.1	0.	0.00	0.0	0.00	0.	0.
6/7	AA	3.0	10.2	105.	80.	1.3	533.	2.5	7.708	13.5	0.	0.00	0.0	0.00	0.	0.
7/7	AA	4.5	12.7	92.	87.	2.0	826.	2.4	26.217	32.0	0.	0.00	0.0	0.00	0.	0.
8/7	AA	3.5	12.0	99.	86.	1.4	737.	2.0	12.335	15.7	0.	0.00	0.0	0.00	0.	0.
22/7	AA	5.0	14.0	121.	64.	2.1	1004.	2.1	35.903	35.3	0.	0.00	0.0	0.00	0.	0.
23/7	AA	5.5	14.4	121.	64.	2.4	1062.	2.2	47.867	46.1	0.	0.00	0.0	0.00	0.	0.
25/7	AA	2.0	12.2	92.	87.	0.6	762.	0.8	2.302	2.9	0.	0.00	0.0	0.00	0.	0.
26/7	AA	2.5	7.2	99.	86.	1.5	265.	5.5	4.495	18.0	-2.	-5.54	7.7	7.39	116.	0.
29/7	AA	4.0	9.3	125.	60.	2.3	443.	5.1	18.413	42.3	0.	0.00	0.0	0.00	0.	0.
30/7	AA	3.5	7.9	127.	58.	2.2	320.	6.9	12.335	38.7	0.	0.00	0.0	0.00	0.	0.
31/7	AA	5.0	12.2	112.	73.	2.4	762.	3.2	35.903	46.1	0.	0.00	0.0	0.00	0.	0.
1/8	AA	3.5	7.5	95.	90.	2.3	288.	8.0	12.335	42.3	-35.	-5.05	7.9	7.16	108.	0.
2/8	AA	3.0	9.6	79.	74.	1.4	492.	2.9	7.708	15.7	0.	0.00	0.0	0.00	0.	0.
3/8	AA	4.0	6.8	63.	58.	3.1	237.	13.2	18.413	76.9	0.	0.00	0.0	0.00	0.	0.
4/8	AA	2.0	9.4	82.	77.	0.8	452.	1.8	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
5/8	AA	1.0	8.4	129.	56.	0.3	361.	0.9	0.208	0.7	0.	0.00	0.0	0.00	0.	0.
6/8	AA	2.5	7.0	120.	65.	1.5	251.	6.0	4.495	18.0	0.	0.00	0.0	0.00	0.	0.
8/8	AA	4.0	7.8	131.	54.	2.7	312.	8.7	18.413	58.3	0.	-4.60	7.6	7.50	100.	0.
9/9	AA	2.0	7.1	100.	85.	1.1	250.	4.1	2.302	9.7	0.	0.00	0.0	0.00	0.	2.
10/9	AA	3.5	6.2	61.	56.	2.8	197.	14.2	12.335	62.7	0.	0.00	0.0	0.00	0.	1.
11/9	AA	2.5	7.1	74.	69.	1.5	250.	5.7	4.495	18.0	0.	0.00	0.0	0.00	0.	2.
12/9	AA	4.5	7.2	128.	57.	3.5	265.	13.2	26.217	98.0	0.	0.00	0.0	0.00	0.	1.
13/9	AA	4.0	7.2	127.	58.	2.9	265.	11.1	18.413	67.3	19.	-4.85	7.6	7.50	112.	2.
14/9	AA	3.0	8.3	93.	88.	1.7	353.	4.7	7.708	23.1	0.	0.00	0.0	0.00	0.	1.
15/9	AA	1.5	11.6	115.	70.	0.4	689.	0.6	0.971	1.3	0.	0.00	0.0	0.00	0.	2.
16/9	AA	3.0	7.6	89.	84.	1.8	296.	6.1	7.708	25.9	0.	0.00	0.0	0.00	0.	2.
17/9	AA	3.5	9.2	90.	85.	1.9	433.	4.4	12.335	28.9	0.	0.00	0.0	0.00	0.	1.
18/9	AA	3.5	11.5	81.	76.	1.5	677.	2.2	12.335	18.0	0.	0.00	0.0	0.00	0.	2.
19/9	AA	2.0	9.4	77.	72.	0.8	452.	1.8	2.302	5.1	-2.	-5.80	7.6	7.50	113.	2.
20/9	AA	2.0	9.0	127.	58.	0.8	415.	2.0	2.302	5.1	0.	0.00	0.0	0.00	0.	2.
21/9	AA	4.0	12.6	116.	69.	1.7	813.	2.1	18.413	23.1	0.	0.00	0.0	0.00	0.	2.
22/9	AA	4.5	10.9	71.	66.	2.3	608.	3.8	26.217	42.3	0.	0.00	0.0	0.00	0.	2.
23/9	AA	3.5	11.1	116.	69.	1.6	631.	2.5	12.335	20.5	0.	0.00	0.0	0.00	0.	2.
24/9	AA	2.0	10.0	90.	85.	0.7	512.	1.5	2.302	3.9	0.	0.00	0.0	0.00	0.	2.
25/9	AA	4.0	8.5	129.	56.	2.5	370.	6.7	18.413	50.0	0.	0.00	0.0	0.00	0.	2.
26/9	AA	6.0	11.4	122.	63.	3.4	665.	5.1	62.148	92.5	10.	-6.47	7.3	7.84	114.	2.
27/9	AA	4.5	9.6	92.	87.	2.6	472.	5.6	26.217	54.1	0.	0.00	0.0	0.00	0.	1.
28/9	AA	5.0	11.0	110.	75.	2.7	620.	4.3	35.903	58.3	0.	0.00	0.0	0.00	0.	1.
29/9	AA	4.5	14.0	125.	60.	1.8	1004.	1.8	26.217	25.9	0.	0.00	0.0	0.00	0.	1.
30/9	AA	5.5	12.1	123.	62.	2.6	750.	3.8	47.867	62.7	0.	0.00	0.0	0.00	0.	1.
1/10	AA	4.0	9.1	121.	64.	2.3	424.	5.5	18.413	42.3	0.	0.00	0.0	0.00	0.	1.
2/10	AA	3.0	9.9	107.	78.	1.4	502.	2.8	7.708	15.7	0.	0.00	0.0	0.00	0.	2.
3/10	AA	2.5	10.0	63.	58.	1.0	512.	2.0	4.495	8.0	-3.	-5.82	7.7	7.39	111.	1.
4/10	AA	2.0	9.4	94.	89.	0.8	452.	1.8	2.302	5.1	0.	0.00	0.0	0.00	0.	2.
5/10	AA	1.0	7.1	72.	67.	0.4	258.	1.4	0.208	1.3	0.	0.00	0.0	0.00	0.	1.
6/10	AA	3.0	8.7	80.	75.	1.6	388.	4.1	7.708	20.5	0.	0.00	0.0	0.00	0.	2.
7/10	AA	2.0	13.5	72.	67.	0.6	933.	0.6	2.302	2.9	0.	0.00	0.0	0.00	0.	2.
8/10	AA	2.0	10.5	80.	75.	0.7	564.	1.3	2.302	3.9	0.	0.00	0.0	0.00	0.	2.
9/10	AA	1.5	10.0	78.	73.	0.5	512.	1.0	0.971	2.0	0.	0.00	0.0	0.00	0.	2.
10/10	AA	2.5	10.3	119.	66.	1.0	543.	1.9	4.495	8.0	0.	0.00	0.0	0.00	0.	3.
11/10	AA	3.5	10.8	123.	62.	1.6	597.	2.7	12.335	20.5	4.	-5.88	7.6	7.50	111.	3.
12/10	AA	5.0	12.6	134.	51.	2.4	813.	2.9	35.903	46.1	0.	0.00	0.0	0.00	0.	2.
17/10	AA	4.0	7.6	147.	38.	2.8	296.	9.4	18.413	62.7	-17.	-4.83	7.6	7.50	111.	2.
18/10	AA	1.5	9.6	95.	90.	0.5	472.	1.1	0.971	2.0	0.	0.00	0.0	0.00	0.	2.
19/10	AA	4.5	11.2	132.	53.	2.3	642.	3.5	26.217	42.3	0.	0.00	0.0	0.00	0.	2.
20/10	AA	2.0	10.3	135.	50.	0.7	543.	1.3	2.302	3.9	0.	0.00	0.0	0.00	0.	2.
21/10	AA	3.0	7.5	67.	62.	1.6	288.	6.4	7.708	25.9	0.	0.00	0.0	0.00	0.	2.
22/10	AA	4.0	6.7	62.	57.	3.2	230.	13.8	18.413	81.9	0.	0.00	0.0	0.00	0.	2.
23/10	AA	3.0	9.2	79.	74.	1.5	433.	3.5	7.708	18.0	0.	0.00	0.0	0.00	0.	2.
24/10	AA	2.0	10.2	90.	85.	0.7	533.	1.4	2.302	3.9	0.	0.00	0.0	0.00	0.	2.
25/10	AA	2.5	9.2	77.	72.	1.1	433.	2.6	4.495	9.7	0.	0.00	0.0	0.00	0.	2.
26/10	AA	4.5	10.7	108.	77.	2.4	580.	4.0	26.217	46.1	-10.	-5.32	7.9	7.16	108.	2.
27/10	AA	3.5	8.7	85.	80.	2.0	388.	5.1	12.335	32.0	0.	0.00	0.0	0.00	0.	3.
28/10	AA	2.5	7.1	82.	77.	1.5	258.	5.7	4.495	18.0	0.	0.00	0.0	0.00	0.	2.
29/10	AA	4.0	7.9	64.	59.	2.7	320.	8.4	18.413	58.3	0.	0.00	0.0	0.00	0.	2.
30/10	AA	4.0	8.5	82.	77.	2.5	370.	6.7	18.413	50.0	0.	0.00	0.0	0.00	0.	1.
31/10	AA	3.0	8.2	104.	81.	1.7	344.	4.9	7.708	23.1	0.	0.00	0.0	0.00	0.	1.
1/11	AA	4.0	7.1	90.	85.	3.0	258.	11.6	18.413	72.0	0.	0.00	0.0	0.00	0.	1.
2/11	AA	1.5	7.9	83.	78.	0.6	320.	1.9	0.971	2.9	0.	0.00	0.0	0.00	0.	2.
3/11	AA	2.0	9.8	77.	72.	0.8	492.	1.6	2.302	5.1	0.	0.00	0.0	0.00	0.	2.
4/11	AA	2.5	8.0	151.	34.	1.3	328.	4.0	4.495	13.5	0.	0.00	0.0	0.00	0.	2.
5/11	AA	4.5	10.2	152.	33.	2.5	533.	4.7	26.217	50.0	0.	0.00	0.0	0.00	0.	1.
6/11	AA	2.5	8.6	122.	63.	1.2	379.	3.2	4.495	11.5	0.	0.00	0.0	0.00	0.	2.
7/11	AA	4.5	9.3	117.	68.	2.7	443.	6.1	26.217	58.3	0.	0.00	0.0	0.00	0.	1.
8/11	AA	2.5	9.2	116.	69.	1.1	433.	2.6	4.495	9.7	10.	-4.53	7.1	7.95	109.	1.
9/11	AA	3.5	9.5	122.	63.	1.8	462.	4.0	12.335	25.9	0.	0.00	0.0	0.00	0.	2.
10/11	AA	3.0	10.7	99.	86.	1.3	586.	2.2	7.708	13.5	0.	0.00	0.0	0.00	0.	1.
11/11	AA	2.0	11.9	90.	85.	0.6	725.	0.9	2.302	2.9	0.	0.00	0.0	0.00	0.	1.
12/11	AA	1.0	9.7	87.	82.	0.3	482.	0.6	0.208	0.7	0.	0.00	0.0	0.00	0.	1.
13/11	AA	2.5	9.4	112.	73.	1.1	452.	2.5	4.495	9.7	0.	0.00	0.0	0.00	0.	2.
14/11	AA	4.0	11.2	118.	67.	1.9	642.	2.9	18.413	28.9	0.	0.00	0.0	0.00	0.	2.
15/11	AA	2.0	11.1	117.	68.	0.7	631.	1.1	2.302	3.9	-7.	-5.13	7.8	7.27	107.	1.
16/11	AA	2.0	6.1	79.	74.	1.6	191.	6.4	2.302	11.5	0.	0.00	0.0	0.00	0.	2.
17/11	AA	2.0	10.0	97.	88.	0.7	512.	1.5	2.302	3.9	0.	0.00	0.0	0.00	0.	2.
18/11	AA	3.0	8.7	87.	82.	1.0	388.	4.1	7.708	20.5	0.	0.00	0.0	0.00	0.	2.
19/11	AA	2.0	8.0	70.	65.	0.9	328.	2.9	2.302	6.5	0.	0.00	0.0	0.00	0.	2.
20/11	AA	3.5	7.6	135.	50.	2.3	290.	7.7	12.335	42.3	0.	0.00	0.0	0.00	0.	2.
21/11	AA	2.0	10.7	117.	68.	0.7	580.	1.2	2.302	3.9	0.	0.00	0.0	0.00	0.	2.
22/11	AA	3.0	11.7	119.	66.	1.2	701.	1.7	7.708	11.5	-10.	-5.21	7.7	7.39	109.	2.
23/11	AA	5.0	13.3	122.	63.	2.2	900.	2.5	35.903	38.7	0.	0.00	0.0	0.00	0.	1.
24/11	AA	5.0	11.8	112.	73.	2.5	713.	3.5	35.903	50.0	0.	0.00	0.0	0.00	0.	2.
25/11	AA	3.0	10.8	115.	70.	1.3	597.	2.1	7.708	13.5	0.	0.00	0.0	0.00	0.	2.
26/11	AA	2.5	8.7	109.	76.	1.2	388.	3.1	4.495	11.5	0.	0.00	0.0	0.00	0.	2.
27/11	AA	3.0	10.4	87.	82.	1.3	554.	2.4	7.708	13.5	0.	0.00	0.0	0.00	0.	2.
28/11	AA	2.5	11.0	82.	77.	1.0	620.	1.5	4.495	8.0	0.	0.00	0.0	0.00	0.	2.
29/11	AA	1.5	7.4	88.	83.	0.7	280.	2.3	0.971	3.9	-1.	-5.10	7.8	7.27	112.	2.
30/11	AA	1.5	9.3	85.	80.	0.5	443.	1.2	0.971	2.0	0.	0.00	0.0	0.00	0.	2.

DATE	STN	HB	T	THET'	THET	HO	LO	SO	EO	EO'	G	TAUFS	BET	CUTBET	D	C
4/1	BB	1.5	7.9	107.	84.	0.6	320.	1.9	0.971	2.9	-8.	-3.10	8.5	8.75	84.	0.
8/1	BB	2.5	8.3	110.	87.	1.3	353.	3.6	4.495	13.5	-66.	-1.90	7.7	7.19	75.	0.
9/1	BB	2.5	8.6	113.	90.	1.2	379.	3.2	4.495	11.5	0.	0.00	0.0	0.00	0.	0.
10/1	BB	2.0	8.6	107.	84.	0.9	379.	2.3	2.302	6.5	23.	-1.40	7.0	8.07	80.	0.
11/1	BB	2.0	9.6	106.	83.	0.8	472.	1.7	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
15/1	BB	1.5	8.7	118.	85.	0.6	380.	1.4	0.971	2.9	-14.	-1.63	7.4	7.73	78.	0.
17/1	BB	3.0	7.4	112.	89.	1.9	280.	6.6	7.768	28.9	-17.	-1.73	7.5	7.61	75.	0.
20/1	BB	1.5	7.6	102.	79.	0.6	296.	2.2	0.971	2.9	-78.	-2.35	8.9	6.36	69.	0.
21/1	BB	1.0	9.1	103.	80.	0.3	424.	0.7	0.208	0.7	17.	-2.50	8.3	6.82	69.	0.
22/1	BB	1.0	7.3	113.	90.	0.4	273.	1.3	0.208	1.3	0.	0.00	0.0	0.00	0.	0.
24/1	BB	2.0	8.6	94.	71.	0.9	379.	2.3	2.302	6.5	-14.	-2.53	8.9	6.38	70.	0.
25/1	BB	1.5	9.9	102.	79.	0.5	502.	1.0	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
26/1	BB	2.0	9.6	107.	84.	0.8	472.	1.7	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
27/1	BB	2.0	8.1	104.	81.	0.9	336.	2.8	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
28/1	BB	2.0	7.8	101.	78.	1.0	312.	3.1	2.302	8.0	7.	-1.94	7.9	7.18	70.	0.
29/1	BB	2.5	10.0	106.	83.	1.0	512.	2.0	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
30/1	BB	2.0	9.1	116.	87.	0.8	424.	1.9	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
7/2	BB	1.0	9.5	101.	78.	0.3	462.	0.6	0.208	0.7	104.	-1.65	6.9	8.30	78.	0.
14/3	BB	2.0	8.9	84.	61.	0.8	406.	2.1	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
16/3	BB	4.5	11.1	113.	90.	2.3	631.	3.6	26.217	42.3	-30.	-1.82	7.1	7.95	70.	0.
22/3	BB	2.5	8.3	110.	84.	1.3	353.	3.6	4.495	13.5	99.	-2.31	6.6	8.64	83.	0.
23/3	BB	2.5	9.2	112.	89.	1.1	433.	2.6	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
27/3	BB	1.5	10.6	104.	81.	0.5	575.	0.8	0.971	2.0	0.	0.00	0.0	0.00	0.	0.
28/3	BB	1.5	9.7	102.	79.	0.5	482.	1.0	0.971	2.0	-35.	-2.32	7.6	7.50	81.	0.
30/3	BB	2.0	8.6	87.	64.	0.9	379.	2.3	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
31/3	BB	2.0	9.2	113.	90.	0.8	433.	1.9	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
4/4	BB	3.5	9.2	102.	79.	1.9	433.	4.4	12.335	28.9	-90.	-4.00	8.8	6.48	67.	0.
5/4	BB	2.5	9.8	108.	85.	1.1	492.	2.2	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
6/4	BB	2.0	8.0	107.	84.	0.9	328.	2.9	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
7/4	BB	1.0	6.3	108.	85.	0.4	203.	2.1	0.208	1.3	0.	0.00	0.0	0.00	0.	0.
11/4	BB	3.0	11.7	120.	83.	1.2	701.	1.7	7.768	11.5	93.	-1.13	6.6	8.64	75.	0.
12/4	BB	3.5	11.0	112.	89.	1.6	620.	2.5	12.335	20.5	0.	0.00	0.0	0.00	0.	0.
13/4	BB	2.5	11.1	111.	88.	0.9	631.	1.5	4.495	6.5	0.	0.00	0.0	0.00	0.	0.
14/4	BB	2.0	9.8	119.	84.	0.8	492.	1.6	2.302	5.1	0.	0.00	0.0	0.00	0.	0.
24/4	BB	1.5	7.1	102.	79.	0.7	258.	2.7	0.971	3.9	0.	0.00	0.0	0.00	0.	0.
25/4	BB	1.5	6.8	98.	75.	0.7	237.	3.0	0.971	3.9	0.	0.00	0.0	0.00	0.	0.
26/4	BB	2.5	6.0	120.	83.	1.7	184.	9.5	4.495	23.1	-18.	-2.22	7.4	7.73	66.	0.
10/6	BB	4.0	11.7	108.	85.	1.8	701.	2.6	18.413	25.9	0.	0.00	0.0	0.00	0.	0.
11/6	BB	3.0	13.2	117.	86.	1.0	892.	1.2	7.768	8.0	0.	0.00	0.0	0.00	0.	0.
12/6	BB	2.5	9.2	110.	87.	1.1	433.	2.6	4.495	9.7	0.	0.00	0.0	0.00	0.	0.
13/6	BB	3.5	13.0	113.	90.	1.3	865.	1.5	12.335	13.5	0.	0.00	0.0	0.00	0.	0.
14/6	BB	4.0	12.0	117.	86.	1.8	737.	2.4	18.413	25.9	0.	0.00	0.0	0.00	0.	0.
15/6	BB	4.0	8.4	108.	85.	2.5	361.	7.0	18.413	50.0	0.	0.00	0.0	0.00	0.	0.
20/6	BB	4.5	11.4	107.	84.	2.2	665.	3.3	26.217	38.7	-22.	-4.91	7.5	7.61	78.	0.
21/6	BB	2.5	10.7	109.	86.	1.0	580.	1.7	4.495	8.0	0.	0.00	0.0	0.00	0.	0.
22/6	BB	2.0	8.6	110.	87.	0.9	379.	2.3	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
23/6	BB	2.0	10.4	116.	87.	0.7	554.	1.3	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
24/6	BB	3.5	10.5	106.	83.	1.7	564.	2.9	12.335	23.1	0.	0.00	0.0	0.00	0.	0.
25/6	BB	2.0	14.3	102.	79.	0.5	1047.	0.5	2.302	2.0	0.	0.00	0.0	0.00	0.	0.
26/6	BB	3.0	11.3	112.	89.	1.2	654.	1.9	7.768	11.5	0.	0.00	0.0	0.00	0.	0.
27/6	BB	4.0	11.9	113.	90.	1.8	725.	2.5	18.413	25.9	0.	0.00	0.0	0.00	0.	0.
28/6	BB	3.0	7.5	87.	64.	1.8	288.	8.4	7.768	25.9	26.	-4.58	7.5	7.61	78.	0.
29/6	BB	3.0	8.8	94.	71.	1.6	396.	3.9	7.768	20.5	0.	0.00	0.0	0.00	0.	0.
30/6	BB	3.0	11.1	124.	79.	1.2	631.	2.0	7.768	11.5	0.	0.00	0.0	0.00	0.	0.
1/7	BB	2.0	10.5	114.	89.	0.7	564.	1.3	2.302	3.9	0.	0.00	0.0	0.00	0.	0.
2/7	BB	2.5	8.4	99.	76.	1.2	361.	3.5	4.495	11.5	-40.	-3.16	7.0	8.07	76.	0.
4/7	BB	3.5	7.9	91.	68.	2.2	320.	6.9	12.335	38.7	0.	0.00	0.0	0.00	0.	0.
5/7	BB	3.5	8.1	103.	80.	2.1	336.	6.4	12.335	35.3	0.	0.00	0.0	0.00	0.	0.
6/7	BB	3.0	8.8	97.	74.	1.6	396.	3.9	7.768	20.5	0.	0.00	0.0	0.00	0.	0.
7/7	BB	3.0	9.3	105.	82.	1.5	443.	3.3	7.768	18.0	-39.	-2.29	6.8	8.41	72.	0.
8/7	BB	3.0	10.0	98.	75.	1.4	512.	2.7	7.768	15.7	0.	0.00	0.0	0.00	0.	0.
22/7	BB	3.0	10.4	115.	88.	1.3	554.	2.4	7.768	13.5	77.	-2.67	6.3	9.09	77.	0.
23/7	BB	5.5	12.3	113.	90.	2.8	775.	3.6	47.807	62.7	0.	0.00	0.0	0.00	0.	0.
25/7	BB	1.5	8.2	102.	79.	0.6	344.	1.7	0.971	2.9	0.	0.00	0.0	0.00	0.	0.
26/7	BB	2.0	7.2	102.	79.	1.0	265.	3.9	2.302	8.0	0.	0.00	0.0	0.00	0.	0.
29/7	BB	3.5	8.9	114.	89.	1.9	400.	4.8	12.335	28.9	0.	0.00	0.0	0.00	0.	0.
30/7	BB	3.5	12.3	117.	86.	1.4	775.	1.8	12.335	15.7	0.	0.00	0.0	0.00	0.	0.
31/7	BB	3.0	7.5	110.	87.	1.8	288.	6.4	7.768	25.9	88.	-4.92	8.0	7.05	74.	0.
1/8	BB	2.0	6.3	101.	78.	1.2	203.	5.9	2.302	11.5	0.	0.00	0.0	0.00	0.	0.
2/8	BB	2.5	8.3	91.	68.	1.3	353.	3.6	4.495	13.5	0.	0.00	0.0	0.00	0.	0.
3/8	BB	3.0	5.2	89.	66.	2.6	138.	19.1	7.768	54.1	0.	0.00	0.0	0.00	0.	0.
4/8	BB	2.5	7.5	92.	69.	1.4	288.	4.8	4.495	15.7	0.	0.00	0.0	0.00	0.	0.
5/8	BB	1.0	9.3	123.	80.	0.3	443.	0.6	0.208	0.7	0.	0.00	0.0	0.00	0.	0.
6/8	BB	3.0	5.4	117.	86.	2.5	149.	17.1	7.768	50.0	0.	0.00	0.0	0.00	0.	0.
8/8	BB	3.5	7.4	122.	81.	2.3	280.	8.4	12.335	42.3	69.	-4.48	6.9	8.30	77.	0.
9/9	BB	2.5	5.9	113.	90.	1.8	178.	10.0	4.495	25.9	0.	0.00	0.0	0.00	0.	1.
10/9	BB	3.0	5.1	77.	54.	2.7	133.	20.3	7.768	58.3	0.	0.00	0.0	0.00	0.	0.
11/9	BB	2.5	6.1	87.	64.	1.7	191.	9.0	4.495	23.1	0.	0.00	0.0	0.00	0.	0.
12/9	BB	4.0	8.1	122.	81.	2.6	336.	7.8	18.413	54.1	24.	-1.76	5.8	9.77	73.	3.
13/9	BB	3.0	6.7	107.	84.	2.1	230.	8.9	7.768	35.3	0.	0.00	0.0	0.00	0.	0.
14/9	BB	2.0	7.5	92.	69.	1.0	288.	3.5	2.302	8.0	0.	0.00	0.0	0.00	0.	0.
15/9	BB	2.0	8.7	113.	90.	0.9	388.	2.2	2.302	6.5	50.	-1.70	5.1	11.14	82.	0.
16/9	BB	2.0	5.8	88.	65.	1.3	172.	7.5	2.302	13.5	0.	0.00	0.0	0.00	0.	0.
17/9	BB	3.0	8.5	102.	79.	1.6	370.	4.4	7.768	20.5	-94.	-2.58	5.7	10.00	72.	0.
18/9	BB	3.0	7.6	97.	74.	1.9	296.	6.1	7.768	25.9	0.	0.00	0.0	0.00	0.	1.
19/9	BB	1.5	7.3	88.	65.	0.7	273.	2.4	0.971	3.9	139.	-1.16	5.1	11.25	84.	1.
20/9	BB	1.5	6.5	114.	89.	0.7	216.	3.5	0.971	3.9	0.	0.00	0.0	0.00	0.	0.
21/9	BB	2.0	8.7	104.	81.	0.9	388.	2.2	2.302	6.5	0.	0.00	0.0	0.00	0.	0.
22/9	BB	2.5	8.2	97.	74.	1.3	344.	3.7	4.495	13.5	-8.	-1.45	5.3	10.80	84.	1.
23/9	BB	2.5	11.9	109.	86.	0.9	725.	1.2	4.495	6.5	0.	0.00	0.0	0.00	0.	3.
24/9	BB	1.5	10.1	106.	83.	0.5	522.	0.9	0.971	2.0	40.	-1.56	5.1	11.18	84.	2.
25/9	BB	3.0	8.3	111.	88.	1.7	353.	4.7	7.768	23.1	0.	0.00	0.0	0.00	0.	1.
26/9	BB	5.0	11.7	114.	89.	2.5	701.	3.6	35.963	50.0	-68.	-1.34	5.5	10.34	79.	1.
27/9	BB	4.5	7.3	103.	80.	3.5	273.	12.7	26.217	98.0	0.	0.00	0.0	0.00	0.	0.
28/9	BB	3.0	10.2	112.	89.	1.3	533.	2.5	7.768	13.5	18.	-2.15	5.4	10.45	76.	4.
29/9	BB	3.5	12.8	113.	90.	1.4	839.	1.6	12.335	15.7	0.	0.00	0.0	0.00	0.	1.
30/9	BB	4.0	13.0	113.	90.	1.6	865.	1.9	18.413	20.5	-50.	-1.88	5.7	10.11	73.	0.
1/10	BB	2.5	8.4	113.	90.	1.2	361.	3.5	4.495	11.5	0.	-1.47	5.6	10.23	74.	0.
2/10	BB	2.0	9.5	90.	67.	0.8	462.	1.7	2.302	5.1	-10.	-2.08	6.3	8.98	71.	1.
3/10	BB	2.5	9.1	92.	69.	1.2	424.	2.7	4.495	11.5	0.	0.00	0.0	0.00	0.	4.
4/10	BB	1.5	8.4	95.	72.	0.6	361.	1.6	0.971	2.9	37.	-2.07	5.6	10.23	71.	4.
5/10	BB	1.0	5.1	84.	61.	0.5	133.	3.9	0.208	2.0	-16.	-2.39	5.7	9.77	72.	4.
6/10	BB	2.0	7.1	80.	57.	1.1	258.	4.1	2.302	9.7	29.	-1.86	5.7	10.11	75.	4.
7/10	BB	2.0	8.5	87.	64.	0.9	370.	2.4	2.302	6.5	1.	-1.95	5.4	10.45	76.	4.
8/10	BB	2.5	9.2	90.	67.	1.1	433.	2.6	4.495	9.7	8.	-1.92	5.3	10.60	83.	4.
9/10	BB	1.0	7.0	82.	59.	0.4	251.	1.5	0.208	1.3	0.	-2.21	5.5	10.34	82.	4.
10/10	BB	2.5	11.6	115.	88.	0.9	689.	1.3	4.495	6.5	-17.	0.00	5.8	9.89	80.	2.
11/10	BB	2.5	10.6	116.	87.	1.0	575.	1.7	4.495	8.0	0.	0.00	0.0	0.00	0.	2.
12/10	BB	4.5	11.1	119.	84.	2.3	631.	3.6	26.217	42.3	2.	-1.64	5.7	10.11	78.	1.
17/10	BB	2.0	7.8	104.	81.	1.0	312.	3.1	2.302	8.0	0.	0.00	0.0	0.00	0.	2.
18/10	BB	1.5	9.7	94.	71.	0.5	482.	1.0	0.971	2.0	-7.	-1.91	5.6	10.11	75.	2.
19/10	BB	3.0	10.5	120.	83.	1.3	564.	2.3	7.768	13.5	6.	-1.52	5.9	9.66	74.	1.
20/10	BB	2.0	6.5	113.	90.	1.2	216.	5.3	2.302	11.5	0.	-1.61	5.9	9.66	76.	2.
21/10	BB	2.5	9.2	87.	64.	1.1	433.	2.6	4.495	9.7	5.	-1.70	6.0	9.55	70.	0.
22/10	BB	3.0	6.7	81.	58.	2.1	230.	8.9	7.768	35.3	-2.	-2.15	6.1	9.43	78.	3.
23/10	BB	3.0	7.6	92.	69.	1.8	296.	6.1	7.768	25.9	0.	-2.03	6.0	9.55	74.	2.
24/10	BB	2.0	9.3	87.	64.	0.8	443.	1.8	2.302	5.1	-3.	-2.01	5.7	10.00	74.	3.
25/10	BB	2.0	7.9	101.	78.	1.0	288.	3.5	2.302	8.0	17.	-1.90	6.1	9.43	74.	2.
26/10	BB	2.0	9.4	103.	80.	0.8	452.	1.8	2.302	5.1	0.	0.00	0.0	0.00	0.	3.
27/10	BB	3.5	6.6	97.	74.	2.6	223.	11.8	12.335	54.1	-12.	-1.83	6.0	9.55	76.	3.
28/10	BB	2.5	7.0	97.	74.	1.5	251.	6.0	4.495	18.0	4.	-1.72	6.1	9.43	75.	2.
29/10	BB	3.0	6.9	87.	64.	2.0	244.	8.2	7.768	32.0	-24.	-2.41	6.3	9.09	77.	2.
30/10	BB	4.0	8.6	84.	61.	2.5	379.	6.5	18.413	50.0	-5.	-2.09	6.4	8.98	74.	1.
31/10	BB	3.0	8.6	113.	90.	1.6	379.	4.2	7.768	20.5	42.	-2.32	5.6	10.11	72.	3.
1/11	BB	3.0	5.5	92.	69.	2.5	155.	16.2	7.768	50.0	0.	0.00	0.0	0.00	0.	4.
2/11	BB	1.5	7.6	98.	71.	0.6	296.	2.2	0.971	2.9	5.	-1.94	5.8	9.89	78.	2.
3/11	BB	2.5	9.8	75.	52.	1.1	492.	2.2	4.495	9.7	23.	-2.41	5.6	10.11	75.	4.
4/11	BB	1.5	7.1	130.	73.	0.7	258.	2.7	0.971	3.9	0.	0.00	0.0	0.00	0.	3.
5/11	BB	3.0	7.0	120.	83.	2.0	251.	7.8	7.768	32.0	-36.	-1.89	5.8	9.77	76.	0.
6/11	BB	3.0	7.8	119.	84.	1.8	312.	5.7	7.768	25.9	2.	-1.62	5.8	9.89	74.	0.
7/11	BB	3.0	10.3	104.	81.	1.3	543.	2.5	7.768	13.5	-2.	-1.63	5.7	10.00	75.	2.
8/11	BB	3.0	8.0	113.	90.	1.7	328.	5.3	7.768	23.1	0.	0.00	0.0	0.00	0.	2.
9/11	BB	3.0	8.8	120.	83.	1.6	396.	3.9	7.768	20.5	1.	-1.85	5.7	10.00	75.	2.
10/11	BB	2.5	11.1	111.	88.	0.9	631.	1.5	4.495	6.5	-16.	-1.94	6.1	9.43	74.	2.
11/11	BB	1.5	7.5	100.	77.	0.6	280.	2.3	0.971	2.9	5.	-2.34	6.1	9.32	73.	0.
12/11	BB	1.0	5.4	82.	59.	0.5	149.	3.3	0.208	2.0	19.	-2.02	5.7	10.00	77.	2.
13/11	BB	2.0	9.4	117.	86.	0.8	452.	1.8	2.302	5.1	-31.	-1.64	6.2	9.20	73.	0.
14/11	BB	2.0	9.3	98.	75.	0.8	443.	1.8	2.302	5.1	-14.	-1.91	6.4	8.86	71.	0.
15/11	BB	1.5	12.8	104.	81.	0.4	839.	0.5	0.971	1.3	0.	0.00	0.0	0.00	0.	2.
16/11	BB	2.0	5.8	91.	68.	1.3	172.	7.5	2.302	13.5	17.	-2.16	6.3	8.98	72.	2.
17/11	BB	2.0	7.3	95.	72.	1.0	273.	3.8	2.302	8.0	21.	-3.78	5.9	9.66	73.	3.
18/11	BB	2.0	7.5	94.	71.	1.0	288.	3.5	2.302	8.0	25.	-3.27	6.1	9.32	85.	3.
19/11	BB	1.0	6.2	79.	56.	0.4	197.	2.2	0.208	1.3	-10.	-2.39	6.1	9.43	86.	3.
20/11	BB	2.5	8.3	127.	76.	1.3	353.	3.6	4.495	13.5	-14.	-1.97	6.3	8.98	83.	3.
21/11	BB	1.5	7.8	110.	87.	0.6	312.	2.0	0.971	2.9	-14.	-1.95	6.3	8.98	79.	2.
22/11	BB	3.0	11.0	118.	85.	1.3	620.	2.0	7.768	13.5	0.	0.00	0.0	0.00	0.	1.
23/11	BB	2.5	9.2	117.	86.	1.1	433.	2.6	4.495	9.7	5.	-2.14	6.2	9.20	73.	0.
24/11	BB	3.0	10.4	104.	81.	1.3	554.	2.9	7.768	13.5	-18.	-2.07	6.7	8.52	73.	0.
25/11	BB	3.0	9.0	112.	89.	1.5	415.	3.7	7.768	18.0	-8.	-2.95	6.9	8.30	72.	0.
26/11	BB	1.5	7.7	107.	84.	0.6	304.	2.1	0.971	2.9	7.	-3.25	6.7	8.52	73.	0.
27/11	BB	2.5	8.5	98.	75.	1.2	370.	3.3	4.495	11.5	12.	-2.66	6.3	8.98	73.	3.
28/11	BB	1.5	9.6	78.	55.	0.5	472.	1.1	0.971	2.0	3.	-3.22	6.4	8.86	72.	3.
29/11	BB	0.5	9.8	99.	76.	0.2	172.	0.9	0.036	0.3	0.	0.00	0.0	0.00	0.	3.
30/11	BB	0.5	5.7	77.	54.	0.2	166.	1.0	0.036	0.3	0.	0.00	0.0	0.00	0.	2.

APPENDIX 3:2

POLYNOMIAL CORRELATION AND REGRESSION OF PROCESS VARIABLES FOR YEAR'S DATA

* significant
** most significant at stated level of confidence
*** best predictor equation

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	.01
CC	DIR	HT	38	1	16	1.47	6.98	***	—
				2	17	1.48	3.57	*	—
CC	DIR	PER	38	1	<1	2.16	0.01	—	—
				2	14	2.03	2.74	—	—
				3	19	2.00	2.64	—	—
CC	HT	PER	38	1	14	2.00	5.68	***	—
				2	16	2.00	3.44	*	—
				3	18	2.00	2.55	—	—
				4	19	2.02	1.98	—	—
F	DIR	HT	38	1	13	1.40	5.47	***	—
				2	13	1.42	2.68	—	—
				3	13	1.44	1.75	—	—
F	DIR	PER	38	1	5	1.57	1.74	—	—
				2	11	1.54	2.13	—	—
				3	12	1.55	1.62	—	—
				4	15	1.55	1.45	—	—
				5	25	1.48	2.15	—	—
F	HT	PER	38	1	11	1.52	4.31	***	—
				2	17	1.49	3.47	*	—
				3	17	1.51	2.34	—	—
				4	17	1.53	1.71	—	—
				5	20	1.53	1.57	—	—
AA	DIR	HT	39	1	23	1.02	11.03	**	***
				2	29	0.99	7.41	*	*
				3	30	1.00	4.97	*	*
				4	39	0.95	5.40	*	*
				5	47	0.90	5.77	*	*
AA	DIR	PER	39	1	1	2.33	0.35	—	—
				2	2	2.35	0.43	—	—
				3	6	2.33	0.74	—	—
				4	6	2.36	0.56	—	—
AA	HT	PER	39	1	8	2.24	3.29	—	—
				2	27	2.03	6.63	**	***
				3	27	2.06	4.32	*	*

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	.01
BB	DIR	HT	39	1	21	0.82	9.56	**	***
				2	21	0.82	4.79	*	—
				3	26	0.81	4.17	*	—
BB	DIR	PER	39	1	7	1.78	2.62	—	—
				2	14	1.73	3.00	—	—
				3	15	1.75	1.99	—	—
BB	HT	PER	39	1	12	1.74	4.85	*	—
				2	12	1.75	2.56	—	—
				3	25	1.64	3.99	***	—
				4	29	1.62	3.55	*	—

CONVERSE OF THE ABOVE RELATIONSHIPS

CC	HT	DIR	38	1	16	25.96	6.98	***	—
				2	16	26.34	3.39	*	—
				3	22	25.72	3.26	—	—
				4	23	26.05	2.42	—	—
CC	PER	DIR	38	1	<1	28.36	0.01	—	—
				2	20	25.77	4.30	***	—
				3	20	26.08	2.86	—	—
				4	22	26.22	2.28	—	—
CC	PER	HT	38	1	14	1.49	5.68	***	—
				2	20	1.45	4.37	*	—
				3	20	1.47	2.84	—	—
F	HT	DIR	38	1	13	20.83	5.47	***	—
				2	19	20.47	3.97	*	—
				3	20	20.56	2.86	—	—
				4	22	20.67	2.27	—	—
				5	24	20.68	2.01	—	—
F	PER	DIR	38	1	5	21.83	1.74	—	—
				2	16	20.76	3.36	***	—
				3	16	21.07	2.18	—	—
				4	20	20.90	2.05	—	—
				5	27	20.20	2.42	—	—
F	PER	HT	38	1	11	1.42	4.31	***	—
				2	15	1.40	3.09	—	—
				3	17	1.40	2.36	—	—
				4	21	1.40	2.13	—	—
				5	21	1.42	1.67	—	—
				6	29	1.36	2.13	—	—
AA	HT	DIR	39	1	23	16.24	11.03	**	***
				2	24	16.36	5.65	*	*
				3	24	16.57	3.71	*	—
AA	PER	DIR	39	1	1	18.41	0.35	—	—
				2	4	18.33	0.84	—	—
				3	6	18.48	0.70	—	—
				4	6	18.73	0.53	—	—

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	SIGNIFICANT AT .01
AA	PER	HT	39	1	8	1.11	3.29	—	—
				2	9	1.13	1.70	—	—
				3	9	1.14	1.17	—	—
BB	HT	DIR	39	1	21	9.80	9.56	**	***
				2	26	9.59	6.32	*	*
				3	31	9.37	5.31	*	*
				4	32	9.48	3.93	*	—
BB	PER	DIR	39	1	7	10.62	2.62	—	—
				2	7	10.77	1.28	—	—
				3	12	10.63	1.52	—	—
				4	16	10.51	1.62	—	—
BB	PER	HT	39	1	12	0.86	4.85	***	—
				2	12	0.87	2.36	—	—
				3	16	0.86	2.22	—	—
				4	26	0.82	2.99	*	—

APPENDIX 3:3

MEAN MONTHLY PROCESS VALUES

	JAN	FEB	MAR	APR	JUN	JUL	AUG	SEP	OCT	NOV
					Breaker Height (Hb)					
CC	1.9	—	2.9	2.7	4.3	4.1	3.3	4.4	3.5	3.4
F	3.4	2.5	4.1	3.9	4.9	5.1	3.9	5.3	4.7	5.2
AA	2.1	1.5	2.6	2.7	3.3	3.6	2.9	3.6	3.0	2.8
BB	1.9	1.0	2.3	2.3	3.2	3.0	2.5	2.8	2.4	2.1
					Wave Period (T)					
CC	9.5	—	9.8	9.7	11.7	10.3	8.3	9.7	9.4	9.4
F	9.6	11.0	9.9	10.0	11.2	10.0	9.3	9.4	9.6	9.6
AA	10.0	9.8	9.7	10.0	11.6	10.6	8.1	9.7	9.5	9.6
BB	8.6	9.5	9.5	8.8	10.8	9.3	7.1	8.5	8.4	8.2
					Wave Direction (θ')					
CC	134	—	146	132	137	126	129	133	120	136
F	141	122	144	139	134	135	135	133	125	137
AA	108	93	108	105	111	109	100	103	95	105
BB	107	101	104	110	109	106	105	104	97	103
					Wave Approach Angle (θ)					
CC	69	—	72	67	70	63	45	59	52	68
F	76	71	77	72	75	74	61	65	61	68
AA	74	88	72	76	71	74	68	70	69	71
BB	83	78	80	83	83	82	75	80	73	76
					Deep Water Wave Height (Ho)					
CC	0.8	—	1.6	1.3	2.1	2.2	2.2	2.7	1.9	1.9
F	1.9	1.0	2.4	2.1	2.6	3.1	2.4	3.5	2.9	3.3
AA	0.9	0.5	1.3	1.2	1.4	1.8	1.7	1.9	1.5	1.3
BB	0.9	0.3	1.0	1.1	1.4	1.5	1.7	1.6	1.3	1.0
					Deep Water Wave-Length (Lo)					
CC	467	—	497	505	710	559	372	507	463	464
F	485	620	503	527	660	522	464	484	478	490
AA	516	492	486	546	709	604	342	500	468	489
BB	382	462	462	416	616	453	265	392	376	364
					Wave Steepness (So)					
CC	.0018	—	.0034	.0040	.0031	.0042	.0091	.0062	.0047	.0048
F	.0044	.0015	.0048	.0053	.0043	.0063	.0070	.0085	.0066	.0074
AA	.0018	.0010	.0031	.0030	.0024	.0035	.0059	.0049	.0039	.0031
BB	.0023	.0006	.0022	.0031	.0027	.0038	.0085	.0055	.0038	.0034

	JAN	FEB	MAR	APR	JUN	JUL	AUG	SEP	OCT	NOV
				Wave Energy per Foot of Wave Crest (Eo)						
CC	4,400	—	16,875	11,355	27,141	33,667	14,848	47,806	17,759	20,089
F	16,475	4,495	38,656	28,388	10,843	50,089	21,085	65,363	33,312	51,175
AA	3,947	971	6,635	7,392	12,801	17,059	9,145	17,529	10,211	9,033
BB	2,460	288	5,507	4,796	10,546	10,437	5,636	8,548	5,489	3,711
				Wave Energy per Square Foot (Eo')						
CC	9.7	—	33.0	21.8	37.9	51.8	60.0	80.4	39.2	43.7
F	36.7	8.0	73.6	48.0	59.8	87.8	59.9	116.4	72.9	99.7
AA	7.8	2.0	16.3	12.9	19.9	27.5	31.0	32.0	24.2	18.3
BB	6.9	0.7	10.8	11.0	18.3	21.5	26.8	24.0	15.4	10.7

APPENDIX 4:1

POLYNOMIAL CORRELATION AND REGRESSION OF RESPONSE VARIABLES FOR YEAR'S DATA

* significant
** most significant at stated level of confidence
*** best predictor equation

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	.01
CC	GAINS	TEXTR	85	1	8	0.56	7.65	**	*
				2	10	0.56	4.40	*	—
				3	10	0.57	2.98	*	—
				4	10	0.57	2.21	—	—
				5	16	0.55	2.98	*	—
				6	20	0.54	3.21	*	*
				7	21	0.54	2.95	*	*
				8	21	0.55	2.57	*	—
				9	24	0.54	2.57	*	—
				10	32	0.51	3.46	*	***
CC	GAINS	SLOPE (β)	85	1	9	0.48	7.91	*	*
				2	25	0.44	13.41	**	***
				3	25	0.44	9.18	*	*
				4	25	0.44	6.80	*	*
				5	26	0.44	5.48	*	*
				6	26	0.45	4.51	*	*
				7	26	0.45	3.82	*	*
				8	26	0.45	3.39	*	*
				9	27	0.45	3.04	*	*
				10	27	0.46	2.70	*	*
CC	GAINS	SLOPE ($\cot\beta$)	85	1	5	1.57	4.55	*	—
				2	16	1.48	7.91	*	**
				3	16	1.49	5.22	**	*
				4	16	1.50	3.87	*	*
				5	17	1.51	3.13	*	—
				6	17	1.52	2.59	*	—
				7	17	1.53	2.20	*	—
				8	17	1.53	1.95	—	—
				9	17	1.54	1.73	—	—
CC	GAINS	SHORE POS.	85	1	10	7.62	9.14	*	*
				2	22	7.12	11.75	**	***
				3	27	6.96	9.85	*	*
				4	29	6.91	7.99	*	*
				5	29	6.93	6.50	*	*
				6	29	6.97	5.35	*	*
				7	29	7.01	4.55	*	*
				8	29	7.05	3.96	*	*
				9	30	7.05	3.61	*	*
				10	31	7.06	3.32	*	*

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	SIGNIFICANT AT .01
CC	TEXTR	SLOPE (β)	85	1	5	0.49	4.34	**	—
				2	5	0.49	2.16	—	—
				3	7	0.49	1.92	—	—
				4	7	0.49	1.54	—	—
				5	7	0.50	1.22	—	—
				6	10	0.49	1.37	—	—
CC	TEXTR	SLOPE ($\cot\beta$)	85	1	7	1.56	5.95	***	—
				2	7	1.56	3.03	—	—
				3	9	1.56	2.55	—	—
				4	9	1.56	1.99	—	—
				5	9	1.57	1.58	—	—
				6	12	1.55	1.85	—	—
				7	13	1.56	1.68	—	—
F	GAINS	TEXTR	92	1	<1	0.69	<1	—	—
				2	12	0.65	5.81	**	*
				3	12	0.65	3.86	*	—
				4	13	0.65	3.21	*	—
				5	14	0.65	2.79	*	—
				6	14	0.66	2.30	*	—
				7	17	0.65	2.41	*	—
				8	17	0.65	2.12	*	—
				9	27	0.62	3.34	*	*
				10	33	0.59	3.99	*	***
F	GAINS	SLOPE (β)	92	1	6	1.71	5.60	**	—
				2	7	1.71	3.55	*	—
				3	8	1.71	2.39	—	—
				4	8	1.72	1.78	—	—
				5	14	1.67	2.84	*	—
				6	14	1.68	2.34	*	—
				7	14	1.69	2.00	—	—
				8	14	1.70	1.74	—	—
				9	16	1.70	1.69	—	—
				10	17	1.69	1.71	—	—
F	GAINS	SLOPE ($\cot\beta$)	92	1	6	1.64	6.20	*	—
				2	10	1.61	5.00	*	*
				3	10	1.62	3.30	*	—
				4	10	1.63	2.48	—	—
				5	22	1.53	4.89	**	***
				6	23	1.53	4.23	*	*
				7	23	1.53	3.68	*	*
				8	23	1.54	3.19	*	*
				9	25	1.53	3.06	*	*
				10	27	1.52	3.05	*	*

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	.01
F	GAINS	SHORE	92	1	5	14.40	4.79	***	—
		POS.		2	5	14.46	2.51	—	—
				3	6	14.51	1.79	—	—
				4	6	14.59	1.34	—	—
				5	6	14.67	1.06	—	—
				6	8	14.62	1.16	—	—
				7	8	14.70	0.99	—	—
				8	8	14.78	0.87	—	—
				9	11	14.63	0.11	—	—
				10	11	14.71	0.98	—	—
F	TEXTR	SLOPE	92	1	11	1.66	11.09	**	**
		(β)		2	11	1.67	5.55	*	*
				3	12	1.68	3.89	*	—
				4	14	1.66	3.50	*	—
				5	14	1.67	2.82	*	—
F	TEXTR	SLOPE	92	1	14	1.57	15.00	**	***
		(cotβ)		2	15	1.57	7.97	*	*
				3	16	1.57	5.44	*	*
				4	21	1.53	5.70	*	*
				5	21	1.54	4.51	*	*
AA	GAINS	TEXTR	27	1	<1	0.66	<1	—	—
				2	<1	0.68	<1	—	—
				3	5	0.68	<1	—	—
				4	8	0.68	<1	—	—
				5	8	0.70	<1	—	—
				6	10	0.70	<1	—	—
				7	10	0.72	<1	—	—
				8	13	0.73	<1	—	—
AA	GAINS	SLOPE	27	1	18	0.45	5.41	**	—
		(β)		2	26	0.44	4.14	*	—
				3	29	0.44	3.08	*	—
				4	29	0.45	2.21	—	—
				5	34	0.46	2.12	—	—
				6	34	0.46	1.69	—	—
				7	47	0.42	2.40	—	—
				8	54	0.40	2.60	*	—
AA	GAINS	SLOPE	27	1	23	0.47	7.42	**	—
		(cotβ)		2	34	0.46	6.17	*	***
				3	37	0.45	4.41	*	—
				4	37	0.46	3.17	*	—
				5	40	0.45	2.80	*	—
				6	40	0.47	2.22	—	—
				7	52	0.43	2.91	*	—
				8	56	0.42	2.86	*	—
				9	59	0.42	2.74	*	—
				10	61	0.42	2.55	*	—

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	SIGNIFICANT AT .01
AA	GAINS	SHORE POS.	27	1	17	5.68	5.29	—	—
				2	17	5.80	2.54	—	—
				3	48	4.72	6.96	**	***
				4	48	4.83	4.99	*	*
				5	48	4.92	3.87	*	—
				6	48	5.02	3.14	*	—
				7	49	5.15	2.56	*	—
				8	49	5.27	2.16	—	—
AA	TEXTR	SLOPE (β)	27	1	<1	0.50	<1	—	—
				2	12	0.48	1.63	—	—
				3	38	0.41	4.73	***	—
				4	41	0.41	3.77	*	—
				5	45	0.41	3.41	*	—
AA	TEXTR	SLOPE (cotβ)	27	1	<1	0.54	<1	—	—
				2	11	0.52	1.49	—	—
				3	36	0.45	4.33	**	—
				4	38	0.45	3.38	*	—
				5	42	0.45	3.05	*	—
				6	43	0.46	2.47	—	—
BB	GAINS	TEXTR	77	1	<1	0.83	<1	—	—
				2	<1	0.83	<1	—	—
				3	10	0.80	2.82	***	—
				4	11	0.80	2.18	—	—
				5	11	0.81	1.72	—	—
				6	15	0.79	2.11	—	—
				7	16	0.79	1.93	—	—
				8	16	0.80	1.68	—	—
				9	20	0.78	1.95	—	—
				10	24	0.77	2.17	*	—
BB	GAINS	SLOPE (β)	78	1	5	0.87	3.80	—	—
				2	10	0.85	4.28	*	—
				3	11	0.85	3.12	*	—
				4	18	0.82	4.10	*	*
				5	19	0.82	3.39	*	*
				6	20	0.82	2.92	*	—
				7	23	0.82	2.93	*	*
				8	25	0.81	2.89	*	*
				9	36	0.75	4.31	**	***
				10	38	0.75	4.09	*	*
BB	GAINS	SLOPE (cotβ)	78	1	5	1.13	3.71	—	—
				2	8	1.11	3.18	*	—
				3	8	1.12	2.28	—	—
				4	19	1.06	4.15	*	*
				5	20	1.06	3.69	*	*
				6	21	1.06	3.15	*	*
				7	23	1.05	3.02	*	*
				8	24	1.05	2.79	*	—
				9	35	0.98	4.07	**	**
				10	37	0.98	3.88	*	*

STN	INDEP. VAR.	DEP. VAR.	n	ORD. OF POLY.	PCNT EXPL. VAR.	STD. ERR. EST.	F-RATIO	SIGNIFICANT AT .05	.01
BB	GAINS	SHORE POS.	78	1	10	4.19	8.21	**	***
				2	10	4.22	4.06	*	—
				3	13	4.19	3.52	*	—
				4	13	4.21	2.63	*	—
				5	13	4.22	2.18	—	—
				6	13	4.25	1.81	—	—
				7	14	4.27	1.58	—	—
				8	14	4.30	1.38	—	—
				9	17	4.25	1.56	—	—
				10	19	4.22	1.59	—	—
BB	TEXTR	SLOPE (β)	77	1	20	0.79	19.29	**	**
				2	20	0.80	9.53	*	*
				3	20	0.80	6.33	*	*
				4	21	0.81	4.84	*	*
				5	21	0.81	3.82	*	*
				6	21	0.82	3.24	*	*
				7	22	0.82	2.81	*	—
BB	TEXTR	SLOPE ($\cot\beta$)	77	1	21	1.03	19.98	**	***
				2	21	1.03	9.86	*	*
				3	21	1.04	6.61	*	*
				4	22	1.04	5.18	*	*
				5	22	1.05	4.09	*	*
				6	23	1.05	3.44	*	*
				7	23	1.06	2.92	*	*

APPENDIX 4:2

MEAN[1] MONTHLY RESPONSE VALUES

	JAN	FEB	MAR	APR	JUN	JUL	AUG	SEP	OCT	NOV
					GAINS (G)					
CC	-97	—	-28	86	-158	-25	3	-12	-139	86
F	179	33	-114	129	-20	-303	59	202	158	337
AA	-24	—	187	-36	2	-2	-35	27	-34	26
BB	-150	104	34	-15	4	86	69	51	55	-25
					FORESHORE TEXTURE (σ_{fs})					
CC	-2.15	—	-2.65	-1.89	-1.52	-2.49	-3.80	-2.48	-2.74	-2.41
F	-3.51	-3.31	-2.95	-2.94	-2.06	-4.21	-3.30	-3.05	-3.26	-3.74
AA	-6.33	—	-5.77	-6.09	-5.68	-5.54	-4.83	-5.71	-5.46	-5.01
BB	-2.12	-1.65	-1.82	-2.45	-4.75	-3.26	-4.48	-1.73	-1.95	-2.26
					FORESHORE SLOPE (β)					
CC	4.3	—	3.9	4.1	3.6	4.8	4.8	4.6	4.0	4.0
F	7.0	8.6	8.6	7.6	6.6	9.2	9.0	6.1	6.6	8.6
AA	7.8	—	6.7	7.0	7.5	7.7	7.8	7.5	7.7	7.6
BB	7.8	6.9	7.1	7.6	7.5	7.0	6.9	5.4	5.8	6.1
					SHORELINE POSITION (D)					
CC	316	—	316	316	317	304	314	292	320	318
F	108	136	122	127	107	90	87	109	106	120
AA	103	—	122	117	114	116	108	113	110	109
BB	74	78	78	69	78	75	77	79	68	75

[1] Except for gains which are cumulative volumes to the end of each month.

APPENDIX 4:3

ERROR DETERMINATION FOR THE SHORELINE, WINTER STORM BERM, AND VEGETATION LIMIT POSITIONS ALONG 17 TRANSECTS FOR 1942 AND 1973.

The error in the horizontal distance values as plotted in Figure 4:25 derives from two causes; scale distortion between the 1942 and the 1973 photos, and the practical impossibility of exactly picking the mean sea level positions. The first of these can be quantified, the second can only be estimated. Each will be dealt with separately.

Scale distortion is mainly due to aircraft tilt and/or high ground relief. For the coastal strip under study, distortion due to ground relief can be safely ignored, both for the 1942 photos and for the 1973 photos. Tilt in the 1942 photos, shown at 45,000 feet is also minimal but is taken into account in the error determination. The major source of error results from camera tilt in the hand-held photography of 1973. These errors are always negative. That is, the scale distance on the airphoto is always less than the actual ground distance.

The amount of error in the photos was determined empirically by measuring the distances between mutually identifiable sets of points on the 1942 and 1973 photos. Kissam (1956) gives the probable error of any single measurement as:

$$0.6745(\Sigma v^2/(n-1))^{1/2}$$

where n is the number of measurements in the error determination, and v is the difference between each individual measurement. Applying this formula to the measurements taken from the Hapuku photos, a probable error of twenty-two feet in 1,256 feet, or ± 1.75 per cent was calculated.

Unlike scale distortion, error in estimating mean sea level is independent of horizontal distance. Fortunately, the study beaches are steep and so not only is the position of the water line (Weber, 1970) relatively easy to locate, but horizontal translation of the mean sea level position is small. The probable error in locating mean sea level was estimated to range from a maximum of ± 6.0 feet on the flat foreshore slopes near CC to a minimum of ± 2.5 feet on the steepest slopes near F and AA.

The accompanying table lists the horizontal distances from the base points[1] to the three index points for each transect and the probable errors for each, in feet. Probable errors are also included for each index point, and the total probable error in the estimation of the shoreline position is also given.

KEY

A	Transect number
B	Date of photography
C	Distance (feet) from base point to vegetation limit
D	Probable error of vegetation limit due to scale distortion (feet)
E	Distance (feet) from base point to crest of winter storm berm
F	Probable error of winter storm berm due to scale distortion (feet)
G	Distance (feet) from base point to shoreline (M.S.L.)
H	Probable error of shoreline due to scale distortion (feet)
I	Probable error os shoreline due to estimation of M.S.L.
J	Total probable error of shoreline location (feet)

		VEG. LIMIT		WINTER BERM		SHORELINE POSITION			
A	B	C	D	E	F	G	H	I	J
1	1942	153	2.7	333	5.8	429	7.5	6.0	13.5
	1973	134	2.3	324	5.7	448	7.8	6.0	13.8
2	1942	103	1.8	3.0	5.4	404	7.1	6.0	13.1
	1973	130	2.3	346	6.1	468	8.2	6.0	14.2
3	1942	230	4.0	398	7.0	571	10.0	6.0	16.0
	1973	324	5.7	546	9.6	674	11.8	6.0	17.8
4	1942	337	5.9	396	6.9	632	11.1	5.5	16.6
	1973	364	6.4	549	9.6	674	11.8	5.5	17.3

[1] See text, Chapter IV.

		VEG. LIMIT		WINTER BERM		SHORELINE POSITION			
A	B	C	D	E	F	G	H	I	J
5	1942	356	6.2	387	6.8	456	8.0	3.5	11.5
	1973	329	5.8	413	7.2	470	8.2	3.5	11.7
6	1942	310	5.4	339	5.9	396	6.9	3.0	9.9
	1973	257	4.5	306	5.4	355	6.2	3.0	9.2
7	1942	333	5.8	356	6.2	406	7.1	2.5	9.6
	1973	272	4.8	344	6.0	373	6.5	2.5	9.0
8	1942	335	5.9	383	6.7	423	7.4	2.5	9.9
	1973	283	5.0	344	6.0	396	6.9	2.5	9.4
9	1942	126	2.2	153	2.7	186	3.3	2.5	5.8
	1973	55	1.0	92	1.6	132	2.3	2.5	4.8
10	1942	339	5.9	375	6.6	414	7.2	2.5	9.7
	1973	177	3.1	230	4.0	292	5.1	2.5	7.6
11	1942	82	1.4	170	3.0	257	4.5	2.5	7.0
	1973	104	1.8	173	3.0	216	3.8	2.5	6.3
12	1942	52	0.9	119	2.1	172	3.0	2.5	5.5
	1973	87	1.5	136	2.4	174	3.0	2.5	5.5
13	1942	?	—	121	2.1	165	2.9	2.5	5.4
	1973	91	1.6	116	2.0	138	2.4	2.5	4.9
14	1942	121	2.1	155	2.7	188	3.3	2.5	5.8
	1973	130	2.3	150	2.6	182	3.2	2.5	5.7
15	1942	57	1.0	86	1.5	186	3.3	3.0	6.3
	1973	82	1.4	103	1.8	137	2.4	3.0	5.4
16	1942	98	1.7	163	2.9	228	4.0	4.0	8.0
	1973	113	2.0	146	2.6	202	3.5	4.0	7.5
17	1942	100	1.8	151	2.6	180	3.2	4.0	7.2
	1973	84	1.5	115	2.0	163	2.9	4.0	6.9

APPENDIX 4:4

GRAIN SIZE, SORTING, AND HYPOTHETICAL TRANSPORT DIRECTIONS FOR NEARSHORE BOTTOM SAMPLES

Nearshore Sample No.	Grain Size $M\phi$	Sorting $\sigma\phi$
1	3.13	0.459
2	3.21	0.441
3	3.00	0.415
4	0.80	0.489
5	2.26	0.813
6	0.98	0.437
7	1.08	0.391
8	-1.70	0.339
9	2.28	1.114
10	-0.42	0.905
11	0.09	0.920
12	3.04	0.703
13	1.25	0.536

KEY[1]

A increase
B decrease
C no change
D improve
E deteriorate
F no change
G transport indicated?

CONDITIONS INDICATIVE OF TRANSPORT AWAY FROM SOURCE

Grain Size			Sorting			
A	B	C	D	E	F	G
*			*			YES
		*	*			YES
	*		*			YES
	*				*	YES

[1]Parenthesized stars under either "A" or "B", indicate a small change in grain size (<0.5ϕ) and/or sorting (<0.1), and for these, the possibility of no significant change also exists, and has been shown under "C". A parenthetic "YES" indicates that at least one, but not all of the paired size-sorting trends does not indicate littoral transport away from the source.

Sample Stations		Grain Size A	B	C	Sorting D	E	F	G
1	2		(*)	(*)	(*)		(*)	(YES)
2	1	(*)		(*)		(*)	(*)	
2	3	(*)		(*)	(*)		(*)	(YES)
3	2		(*)	(*)		(*)	(*)	(YES)
3	11	*				*		
11	3		*		*			YES
3	12		(*)	(*)		*		
12	3	(*)		(*)	*			YES
11	4		*		*			YES
4	11	*				*		
4	12		*			*		
12	4	*			*			YES
4	10	*				*		
10	4		*		*			YES
4	13		(*)	(*)		(*)	(*)	(YES)
13	4	(*)		(*)	(*)		(*)	(YES)
11	12		*		*			YES
12	11	*				*		
10	13		*		*			YES
13	10	*				*		
12	13	*			*			YES
13	12		*			*		
10	5		*		(*)		(*)	YES
5	10	*				(*)	(*)	
5	6	*			*			YES
6	5		*			*		
6	7		(*)	(*)	(*)		(*)	(YES)
7	6	(*)		(*)		(*)	(*)	
7	8	*			(*)		(*)	YES
8	7		*			(*)	(*)	(YES)
8	9		*			*		
9	8	*			*			YES

APPENDIX 4:5

GRAIN SIZE, SORTING, AND HYPOTHETICAL TRANSPORT DIRECTIONS FOR YEARLY MEAN FORESHORE SAMPLES

	CC	F	AA	BB
Grain size (yearly mean phi)	-2.5	-3.4	-5.7	-2.5
Sorting (yearly mean standard deviation)	0.67	0.87	0.61	1.07

KEY

A increase
B decrease
C no change
D improve

E deteriorate
F no change
G transport indicated?

Sample Stations		Grain Size A	B	C	Sorting D	E	F	G
CC	F	*				*		
F	CC		*		*			YES
F	AA	*			*			YES
AA	F		*			*		
AA	BB		*			*		
BB	AA	*			*			YES