AN ABSTRACT OF THE THESIS OF

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Title: BEACH PROFILE CHANGES AND ONSHORE-OFFSHORE SAND TRANSPORT ON THE OREGON COAST

Abstract Approved: Redacted for Privacy
Paul D. Komar

Two beaches with significant differences in grain size and thus in beach profile morphology and response to wave conditions were studied on the Oregon coast. Gleneden Beach, just south of Siletz Spit and Lincoln City, has a median grain size of 0.36 mm (medium sand) and a steep beach face slope, while Devil's Punchbowl Beach has a median grain size of 0.23 mm (fine sand) and low concave-up beach face slope.

Eleven beach profile surveys were obtained at Gleneden Beach and twelve at Devil's Punchbowl Beach between August 1976 and April 1977; on average once every two weeks during spring tides. Gleneden Beach showed the typical change from a swell profile with a wide berm that prevails during summer months to a storm profile with little or no berm that exists during the stormy winter months. This transition occurred in August and September, being completed by early November. The finer-grained Devil's Punchbowl Beach also showed general erosion during the fall. However, a transition from a swell profile to a storm profile is not as clear there as the beach has little berm, even in mid-summer, and always has a concave-up appearance typical of the winter storm profile.

Gleneden Beach and Devil's Punchbowl Beach did not always agree in their responses to the changing wave conditions. One may be eroding at the same time the other is accreting. These differences in response to changing wave conditions appear to result from their differences in grain size.

Volume changes of the erosion or deposition at the two beaches were computed from successive beach profiles. The coarser-grained Gleneden Beach showed larger changes in erosion and deposition, the maximum erosion being 0.71 m^3 per meter of profile length, while the finer-grained Devil's Punchbowl Beach showed a maximum erosion of 0.25 m^3 per meter of profile length. Attempts were made at relating the erosion or deposition and the volumes of erosion/deposition to the wave breaker heights and deep-water wave steepness that occurred between the beach profile sequences. There is only a vague relationship between the volumes of beach erosion/deposition and the wave heights, the probability of erosion increasing and the volume of sand eroded increasing with increasing wave breaker heights. The maximum wave heights that occur during the time interval appear to be most important to the volume of erosion, erosion volumes being large if storm breaker heights reach 5 to 6 meters or greater. Deposition prevails when the average breaker heights fall below 4 meters and storms are limited to breaker heights less than 5 meters. The deep-water wave steepness shows little relationship to the erosion or deposition volumes, indicating that the wave period is not as important a parameter as the wave height to beach erosion.

BEACH PROFILE CHANGES AND ONSHORE-OFFSHORE SAND TRANSPORT ON THE OREGON COAST

by

Nicolás Antonio Aguilar Tuñón

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Typed by Cheryl Schurg for Nicolás Antonio Aguilar Tuñón

This work is dedicated to my parents:

Nicolás Aguilar
Hermenegilda Sánchez de Aguilar

and to my children:

José Gregorio Aguilar Pereira
Patricia Josefina Aguilar Pereira

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BEACH PROFILE CHANGES AND ONSHORE-OFFSHORE SAND TRANSPORT ON THE OREGON COAST

INTRODUCTION

The beach profile configuration, in nature and laboratory wave tanks, is a function of the intensity of energy dissipation by the waves breaking on the beach. Beach profile changes are due to storms, longshore sand transport, tides, and coastal winds (Komar, 1976). Monitoring all of these variables at the same time in order to obtain the variations in the beach profile is difficult.

The principal observed variation commonly found in beach profiles is an annual one which reflects the overall changes in the energy level of the waves between the summer and winter seasons. Some of the first measurements of this annual shift were determined on California beaches by Shepard (1950). The overall shift in profile type is illustrated in Figure 1. During the summer when small waves prevail in California, Shepard (1950) found that the beach profiles are characterized by a wide berm and a relatively smooth offshore profile. Storms during the winter months remove sand from the berm and shift it to offshore bars (Figure 1). Because of the seasonality of the profile types, Shepard used the terms *summer profile* and *winter profile* to denote them. Such shifts are not always seasonal, however, so other terminology has been suggested. This report will use the terms *swell profile* and *storm profile* after Komar (1976) and Figure 1 because of the relationship of the profile types to swell waves and storm waves. However, as in California, the Oregon beach profiles are approximately seasonal as found by Shepard (1950).

The two types of beach profiles are most commonly related to the

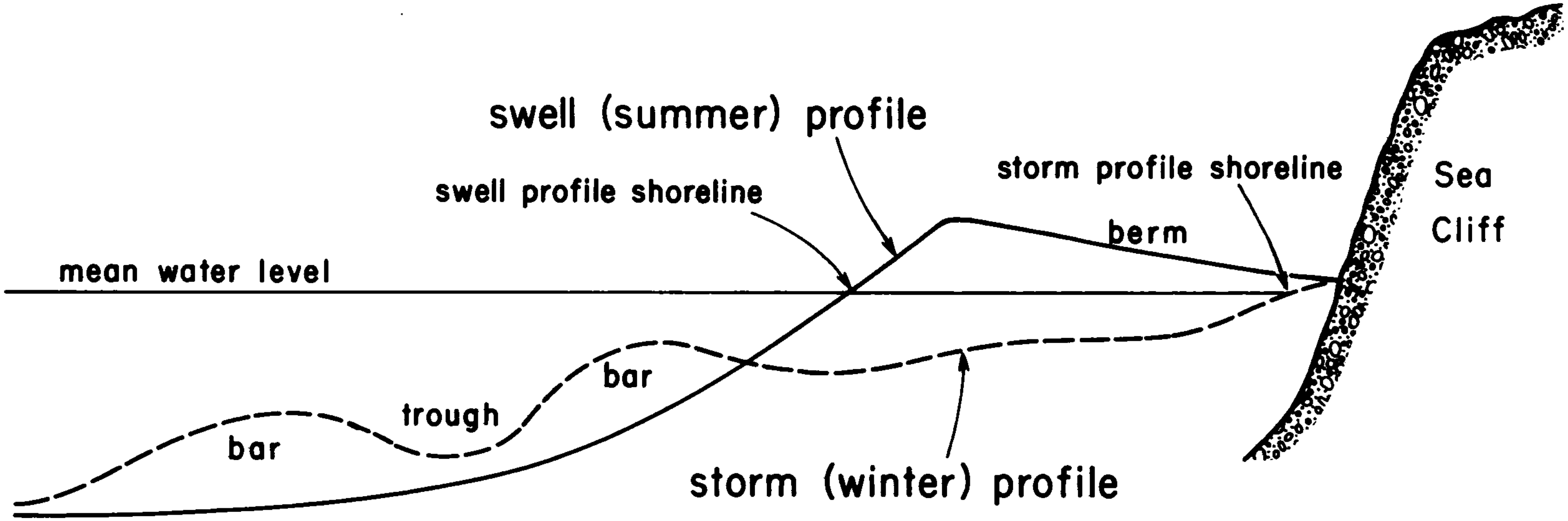

Figure 1. The storm (winter) beach profile with bars versus the swell (summer) profile with a pronounced berm that occurs under fair-weather conditions. [*After* Komar (1976)]

steepness of the waves, H_∞/L_∞, where H_∞ is the deep-water wave height and L_∞ the deep-water wave length. The deep-water wave length is related to the wave period T by

$$L_\infty = \frac{g}{2\pi} T^2 \tag{1}$$

where g is the acceleration of gravity. Thus the wave steepness includes the deep water wave height and wave period. In wave tank experiments, Johnson (1949) found that the beach profile changed from a swell profile to a storm profile when the wave steep H_∞/L_∞ reached a value of 0.025 to 0.03. Rector (1954) and Watts (1954) found the critical wave steepness to be 0.012, lower than the values given by Johnson (1949). Using waves in a wave tank as large as those on actual beaches, Saville (1957) found a critical wave steepness of 0.0064, much lower than the other studies. Iwagaki and Noda (1963) and Nayak (1971) have shown that the value of the critical wave steepness for the change from a swell profile to a storm profile depends on the ratio H_∞/D, where D is the mean grain size of the beach sediment; however, their two studies did not particularly agree. Dean (1973) presents a model for the shift in profile type based on a consideration of the trajectory of a suspended sand particle during its fall to the bottom, acted upon at the same time by the horizontal water motions of the waves. He finds that the critical wave steepness depends on the ratio of the settling velocity of the beach sediment to the period of the waves.

All considerations of a critical wave steepness for the shift in profile type accept that the deep-water wave height H_∞ and the wave period T are the major parameters important in the process since they govern the value of the wave steepness. All previous studies do clearly demonstrate that the deep-water wave height, or the breaker height or wave energy (which depends on the wave height), is important in the shift in profile type. However, as discussed in Komar (1976, p. 293), it is not clear that the wave period T is an important parameter. This is particularly demonstrated by the study of Dolan (1966) on North Carolina beaches. Dolan found a significant correlation between the onshore-offshore shifts of sand and the profile type with the wave height or energy, but almost no correlation with the wave period.

The purpose of this study is to examine the annual changes in beach profiles on the Oregon coast and to attempt to relate these changes to the wave conditions. Of particular interest is the erosion of the beach during the winter months, as this erosion removes the protection the beach offers to the coastal property. When most of the beach berm has been removed, the waves are able to wash directly against the coastal sea cliffs or dunes (Komar, et al., 1976). This results in erosion of coastal properties as has occurred on Siletz Spit (Rea, 1975; Komar and Rea, 1976) and on Bayocean Spit (Terich and Komar, 1974; Komar and Terich, 1977). The ultimate purpose of the investigation is to allow the prediction of the amount of beach erosion or deposition (the onshore-offshore shifts of beach sand) from a knowledge of the wave conditions. Waves measured daily at the Marine Science Center in Newport on the mid-Oregon coast could thus be used to predict beach erosion along the coast.

Only two previous investigations of beach profile changes have centered their attention on the Oregon coast. The first involved an extensive study of west-coast beaches for the Navy during and immediately following World War II. Most of their beach investigations took place in California, but some data were obtained on Oregon and Washington beaches. The results of the investigations are contained in a series of unpublished reports (Johnson and Bascom, 1950; Annonymous, 1947; Isaacs, 1947). Beach profiles were obtained through use of a dukw, a six-wheeled amphibious vehicle. Use of the dukw allowed them to obtain beach profiles across the entire nearshore to beyond the breaker zone, whereas subsequent beach profile investigations, including our own, are confined to the inner portion of the surf zone. Examples of beach profiles they obtained are shown in Figure 2; a pair of profiles of the beach at Manzanita on the north Oregon coast, separated by nineteen days. It is seen that there are appreciable changes in the beach profiles during those nineteen days, both to the middle bar and to the portion of beach above MLLW. The changes cannot be related to the wave conditions, however, which were not measured.

Our investigation can be viewed as a continuation of the studies of Oregon beach profiles undertaken by Fox and Davis (1974, in press) during June 1973 to May 1974. They examined the response of the beach to the changing waves, winds, and tides during that period. They found that during the winter season large volumes of sand were removed from the beach by the wave swash and nearshore currents. The beach would partially recover during non-storm periods even during the winter. The sand removed from the berm is stored in offshore bars, and returns to the beach in the form of small intertidal bars that migrate onshore.

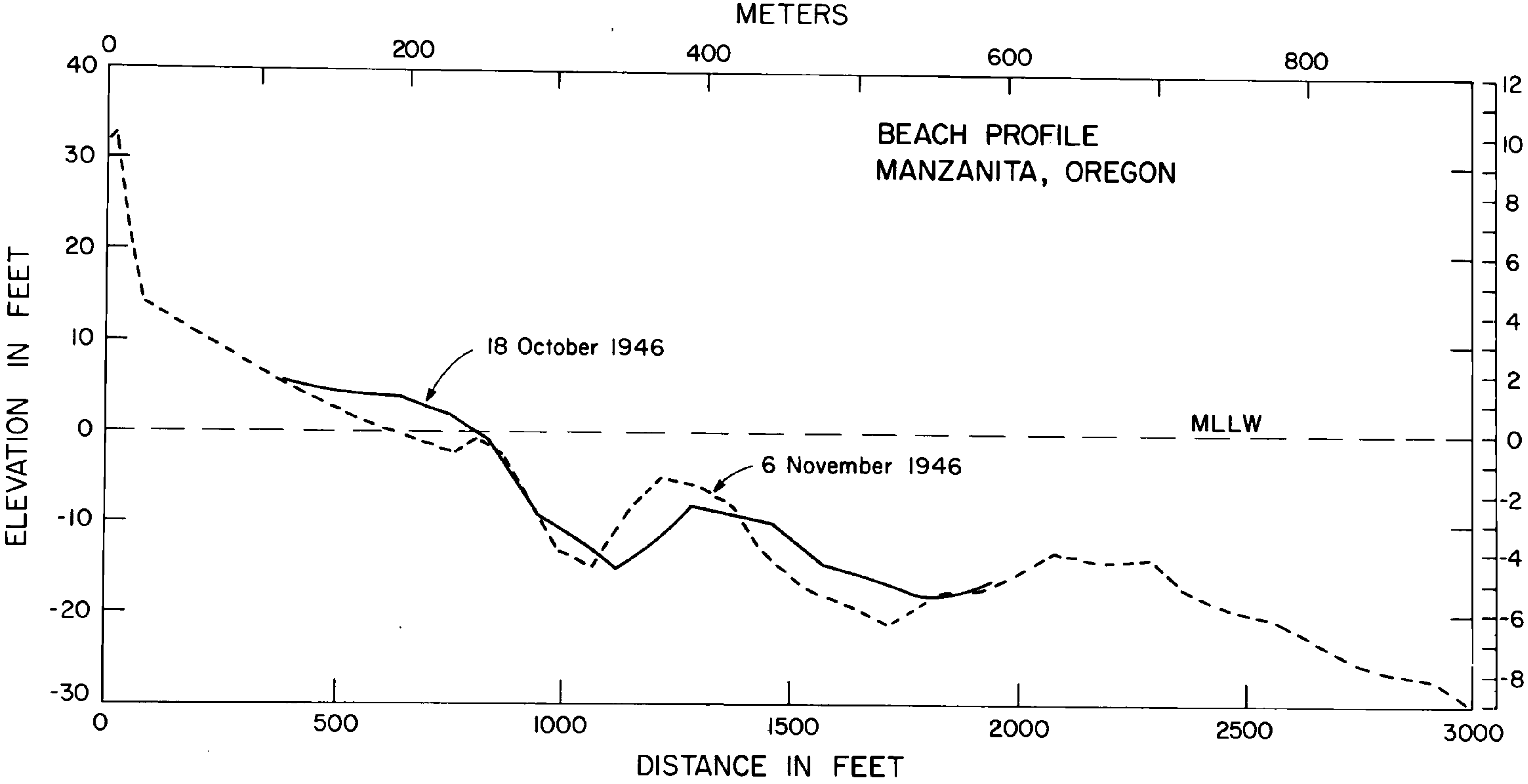

Figure 2. Two beach profiles separated by 19 days obtained with a dukw at Manzanita on the north Oregon coast. [*After* Issacs (1947)]

The total volume of sand involved in the annual exchange in beach profile types was about 110^3/linear meter of beach.

BEACH PROFILE LOCATIONS

Profiles have been obtained at two beach locations on the Oregon coast, beaches that provide a significant difference in grain size and thus in beach profile morphology and response to the wave conditions. The coarser-sand beach is represented by a stretch of beach at Gleneden Beach, to the immediate south of Siletz Spit and 9.2 kilometers south of Lincoln City (Figure 3). More precisely, the beach profiles were obtained at the northern edge of Gleneden Beach State Park and the private property to the immediate north of the park. Figure 4 shows a typical beach profile at Gleneden Beach with the grain-size parameters along its length. It is seen that there are some variations, but with the sand generally being approximately 0.36 mm in median size and thus classified as medium sand according to the classification of Wentworth (1922). When the beach profiles at Gleneden Beach have pronounced longshore troughs it is found that gravel is concentrated in the trough. Because the beach consists of relatively coarse sediment, it has a steep profile and beach face slope, fitting the relationship of increasing beach slope with increasing grain size [Bascom, 1951; Wiegel, 1964; and Komar, 1976 (p. 303-308)]. Coarse sand beaches also respond in changing their beach profiles to varying wave conditions much faster than do finer grain-sized beaches. Thus Gleneden Beach may be expected to be in closer equilibrium or correspondence with the prevailing wave conditions.

The second beach where profiles have been obtained for this study is located from 410 to 510 meters south of Devil's Punchbowl at Otter Rock, 11.6 km north of Newport (Figure 5). The profiles were obtained

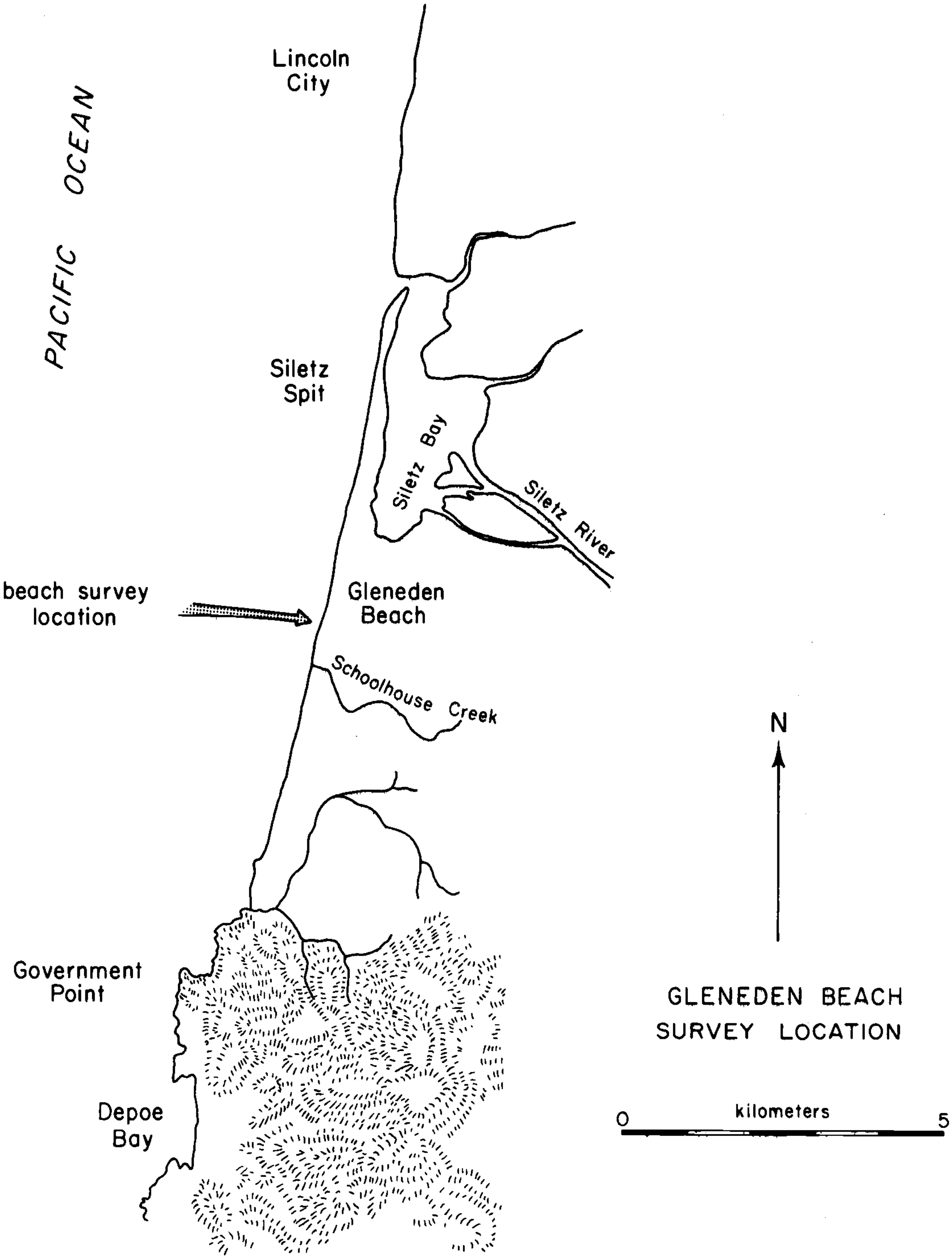

Figure 3. Location of the beach profiles obtained at Gleneden Beach south of Siletz Spit and Lincoln City.

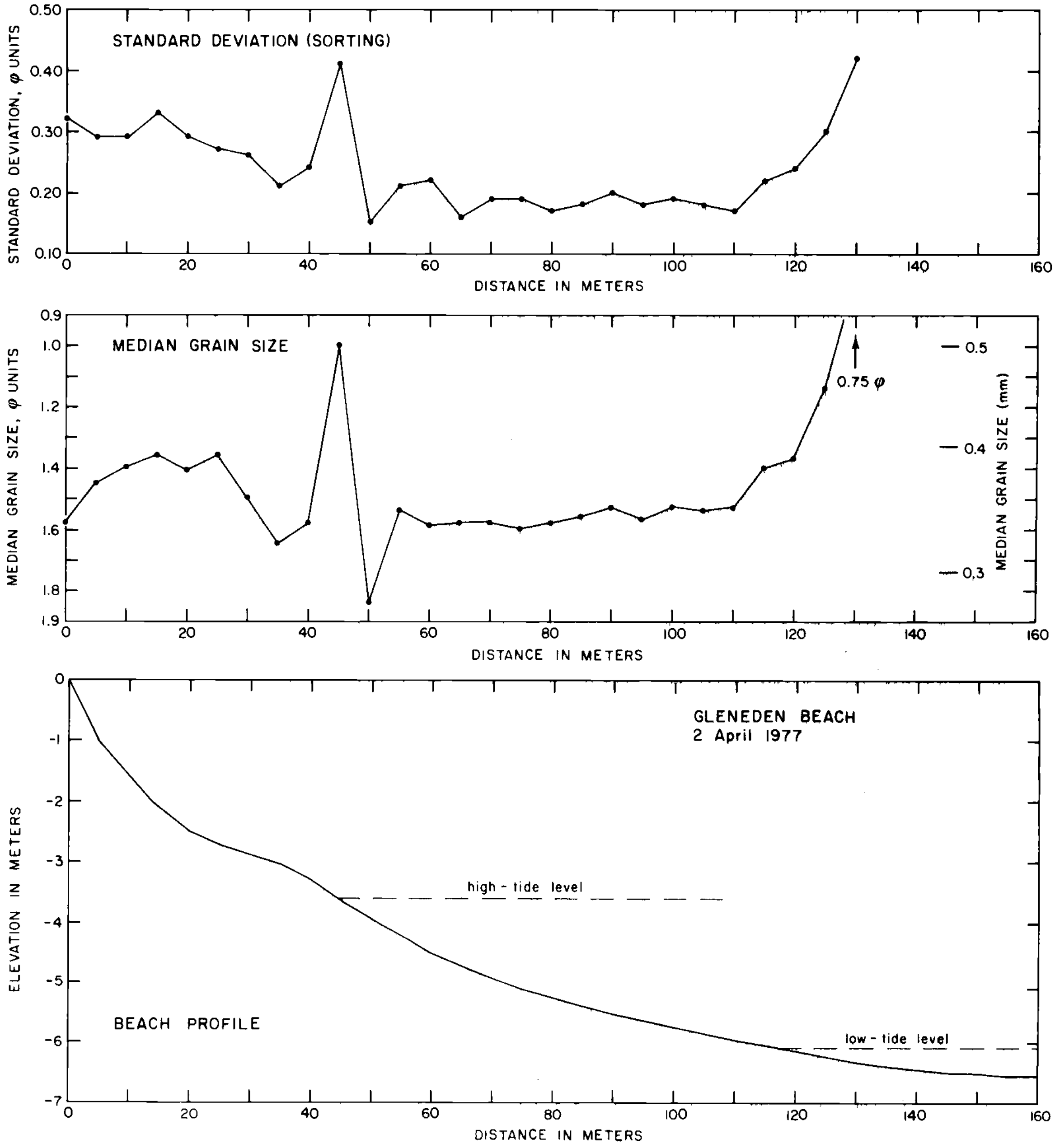

Figure 4. Grain-size parameters along a beach profile at Gleneden Beach obtained on 2 April 1977. Profile elevations relative to stake top at shoreward end. Grain-size parameters were obtained from a settling-tube analysis of the size distribution.

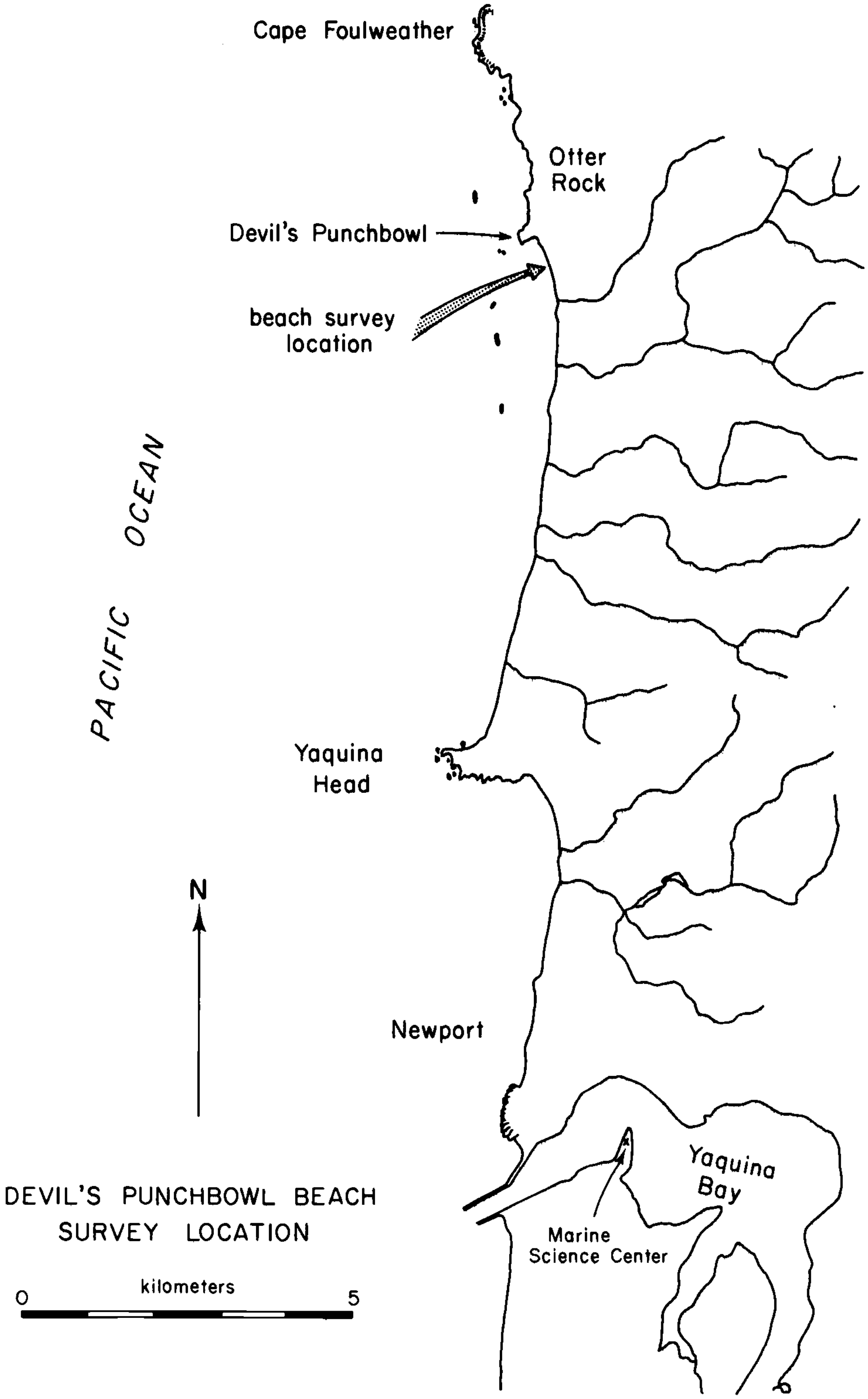

Figure 5. Location of the beach profiles obtained just to the south of Devil's Punchbowl at Otter Rock, Oregon.

at a sufficient distance from Devil's Punchbowl itself that the rocky headland does not interfere with the waves at the profile locations and should therefore not significantly effect the beach response. Figure 6 shows a typical beach profile at the Devil's Punchbowl area with the grain-size parameters along its length. It is seen that the beach there is principally in the fine grain size with a median diameter of approximately 0.23 mm. Thus the beach is much finer than at Gleneden Beach and the beach slope much lower. As will be seen, the response of the beach to changing waves is also considerably different. There is also a change in the overall mineralogy of the beach at Devil's Punchbowl during the year. In the summer when the berm is widest, the beach consists mainly of quartz and feldspar, both clear to cream colors giving the overall beach a light color. During the winter sand is shifted offshore from the upper beach, exposing a concentration of heavy minerals, mainly hornblende, epidote and garnet. As a result the beach is much darker, almost black, with a distinct green tinge due to the epidote. Interesting and attractive selective sorting of the different heavy-mineral grains occurs, giving streaks of pink where the garnet is concentrated and green where the epidote is concentrated. This heavy mineral concentration is very fine grained as can be seen in the size distributions of the shoreward-most samples of Figure 6. Gleneden Beach does not show similar concentrations of heavy minerals, the entire beach consisting of quartz-feldspar sand throughout the year.

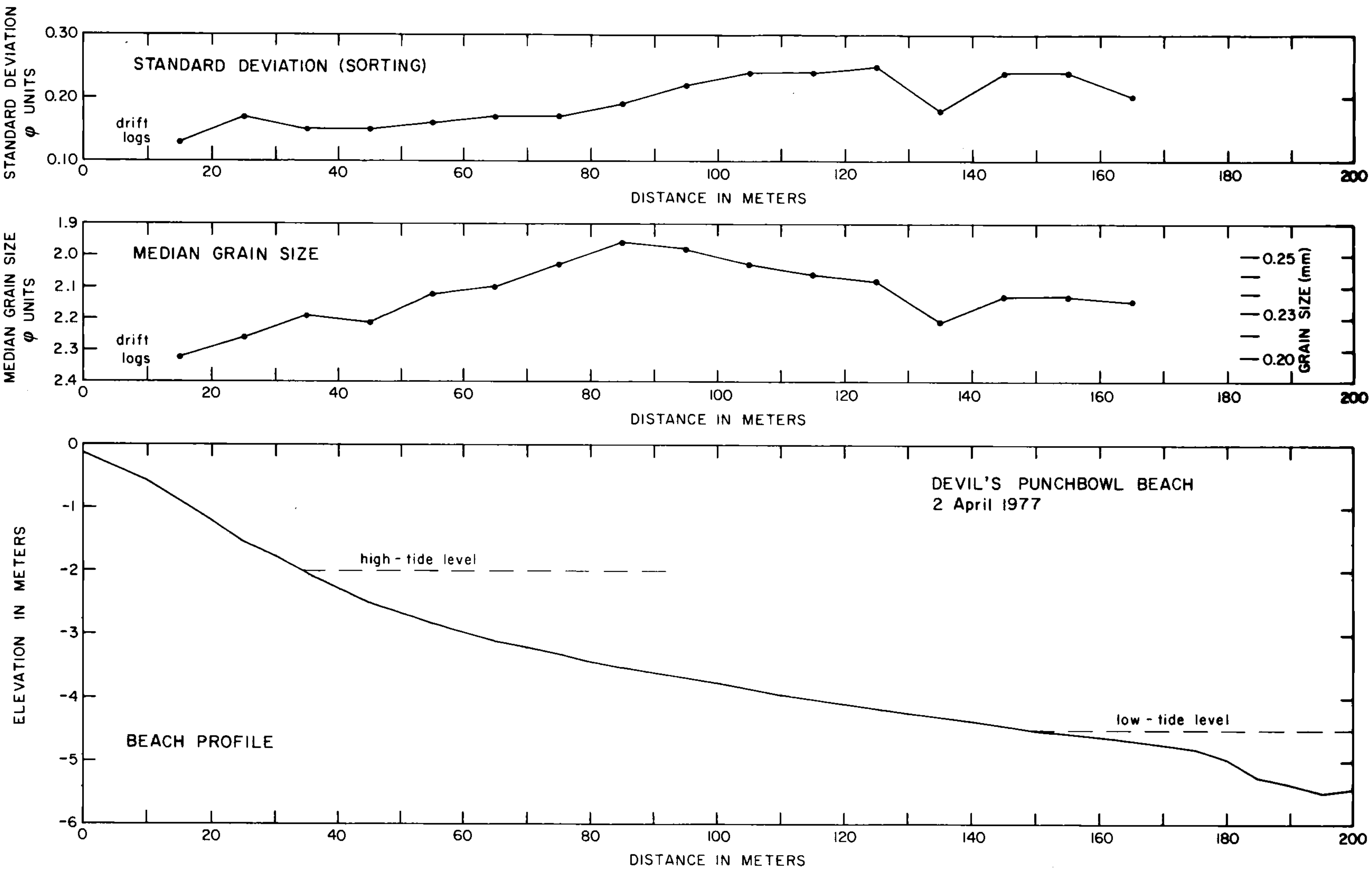

Figure 6. Grain-size parameters along a beach profile at Devil's Punchbowl Beach obtained on 2 April 1977. The parameters were obtained from a settling-tube analysis of the size distribution. Profile elevations relative to stake top at shoreward end.

TECHNIQUES OF INVESTIGATION

Beach Profiles

The profiling technique used in this investigation is the same as that described by Emery (1961), Hoyt (1971), Fox and Davis (1974), Davis Fingleton and Pritchett (1975) and Davis (1976). The equipment consists of the following:

a. Two wooden rods, each 1.5 meters long, with graduations at 0.5 cm intervals (Figure 7).

b. A 5.0 meter nylon rope which maintains a constant horizontal distance between profile stations for each measurement (Figure 7).

As diagramed in Figure 8, the technique involves using the horizon to determine a level horizontal sighting, the shoreward-most person recording the distance from the top of his stake to the horizontal level defined by the horizon and the top of the seaward person's stake. That recorded distance equals the vertical change in the beach profile between those two stations five meters apart. If the beach profile is sloping upward toward the sea, then the horizontal level is defined by the horizon and the landward stake, the recording being done on the seaward stake (the distance its top is above the horizontal). Good weather conditions are of course required for this profiling approach as the horizon must be visible; this was the case during the course of the study.

The surveys are best accomplished with three persons, two doing the actual surveying and a third recording their measurements. The

Figure 7. Surveying at Devil's Punchbowl Beach by the method of Emery (1961) with two 1.5-meter long graduated staffs separated by 5 meters as measured with the rope.

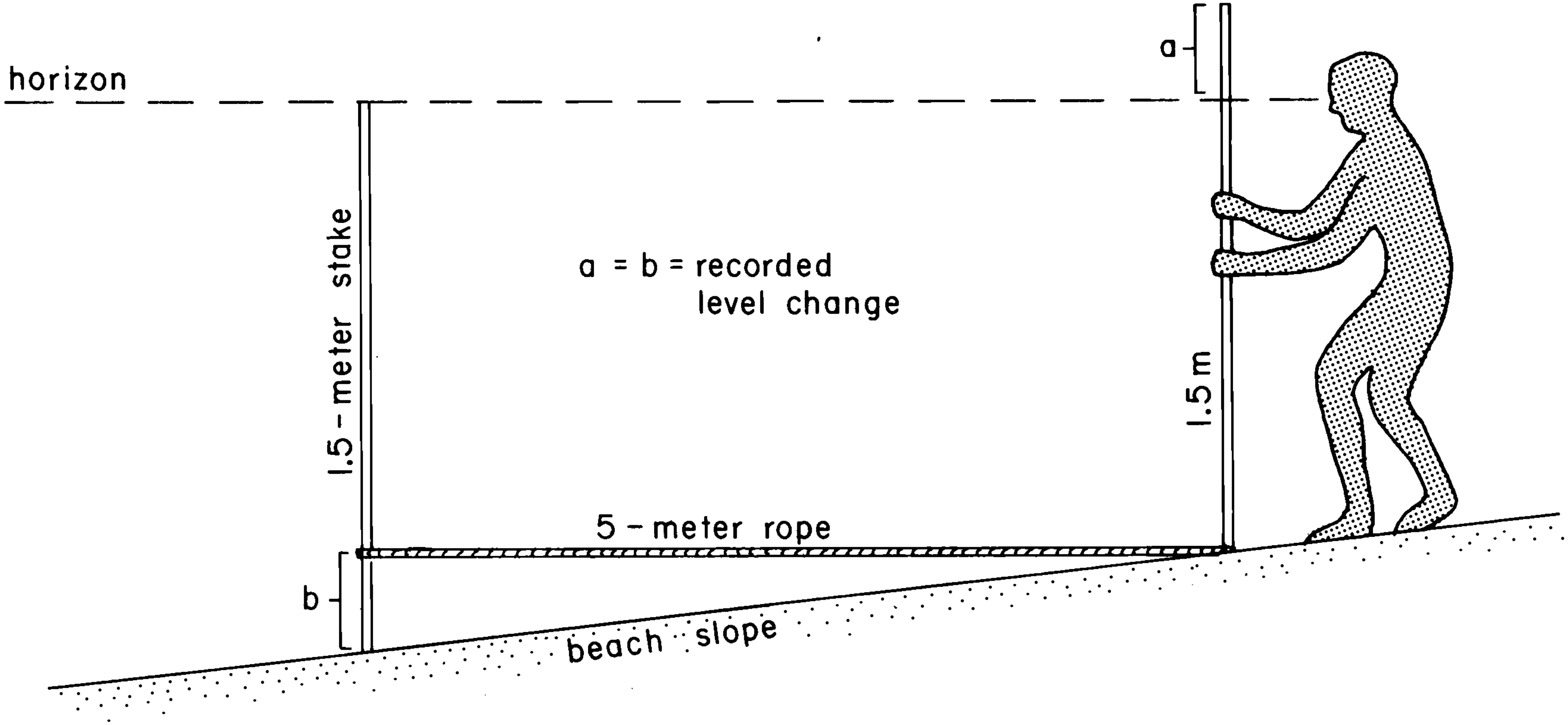

Figure 8. The basic principals of the stake-and-rope method of Emery (1961) for determination of the beach profile. The distance a from the top of the shoreward stake is the recorded measurement as it is equal to the distance b , the vertical change in the beach level over the 5-meter horizontal distance between the two stakes.

surveys are continued seaward as far as possible requiring the survey team to wear wet-suits.

Emery (1961) and Davis (1976) discuss the accuracy of the line-and-stakes survey method. The lengths of surveyed profiles at both Oregon coast locations was well within the range indicated by Emery (1961) where no curvature correction is required. Davis (1976) mentions that Czerniak (1973) analyzed the method and found a possibility of a cumulative error with the result that the measured profile could be 0.3 m (1 foot) in error vertically at the seaward end from the actual profile. Because of the possibility of introducing a cumulative error into the measured beach profile, it is necessary that all measurements be carefully obtained and that the recorder obtains the correct value. Little error is probably introduced on the exposed portion of the beach as great care was maintained in making the measurements. However, more error is probably introduced in the portion of the profile done in the water. This is partly because the stakes tend to sink into the sand as the water rushes by. In rough surf the surveyors are also washed about, making surveying difficult. Probably the problem causing the most error, however, is the difficulty in seeing the horizon as the large breaking waves obscure it for much of the time. Unfortunately the amount of error is difficult to evaluate. On one occasion the same profile was surveyed twice with only a few minutes between the successive surveys. The good agreement between the two indicates that the surveying technique is sufficiently accurate for the purposes of this investigation.

Twelve surveys were made at Devil's Punchbowl Beach and eleven at

Gleneden Beach. The surveys were conducted on average once every two weeks during spring tides so as to have as much exposed beach as possible. The dates of the surveys are listed in Table 1. On each occasion Gleneden Beach was surveyed first, the survey beginning just before the low tide, and it generally took one hour to complete. Four wooden stakes and one iron stake were located at the top of the beach along the base of the sea cliff; the distance between the stakes was 60 meters (Figure 9). These stakes served as base marks for the survey lines, and the tops of the stakes provided a base level to which subsequent surveys could be compared. Similarly, three wooden stakes were located at the base of the cliff along Devil's Punchbowl Beach as reference points for the three survey lines there; the distance between stakes was 50 meters (Figure 10). The purpose of having multiple survey lines, five at Gleneden Beach and three at Devil's Punchbowl Beach, was to allow longshore variations in the beach erosion and deposition patterns to be averaged out. The chief cause of these variations was expected to be rip currents which would hollow out more of the beach producing an embayment. If a single survey line were used and it happened to be the location of a rip current then the resulting erosion would not correspond well to the wave conditions. As it turned out there was little problem with rip current embayments at either beach location. This was a matter of chance, especially at Gleneden Beach where rip current embayments could be seen both to the north and south of the survey area throughout the winter. None existed in the survey area itself until the very last survey on 2 April 1977 when there were pronounced changes from one survey line to the next. Similarly, no problem arose at Devil's

TABLE I. Surveying dates.

Gleneden Beach		Devil's Punchbowl Beach	
Survey Number	Date	Survey Number	Date
1	27 August 1976	1	27 August 1976
2	07 October 1976	2	07 October 1976
3	06 November 1976	3	30 October 1976
4	20 November 1976	4	07 November 1976
5	05 December 1976	5	20 November 1976
6	19 January 1977	6	05 December 1976
7	02 February 1977	7	19 January 1977
8	17 February 1977	8	02 February 1977
9	05 March 1977	9	17 February 1977
10	16 March 1977	10	05 March 1977
11	02 April 1977	11	16 March 1977
		12	02 April 1977

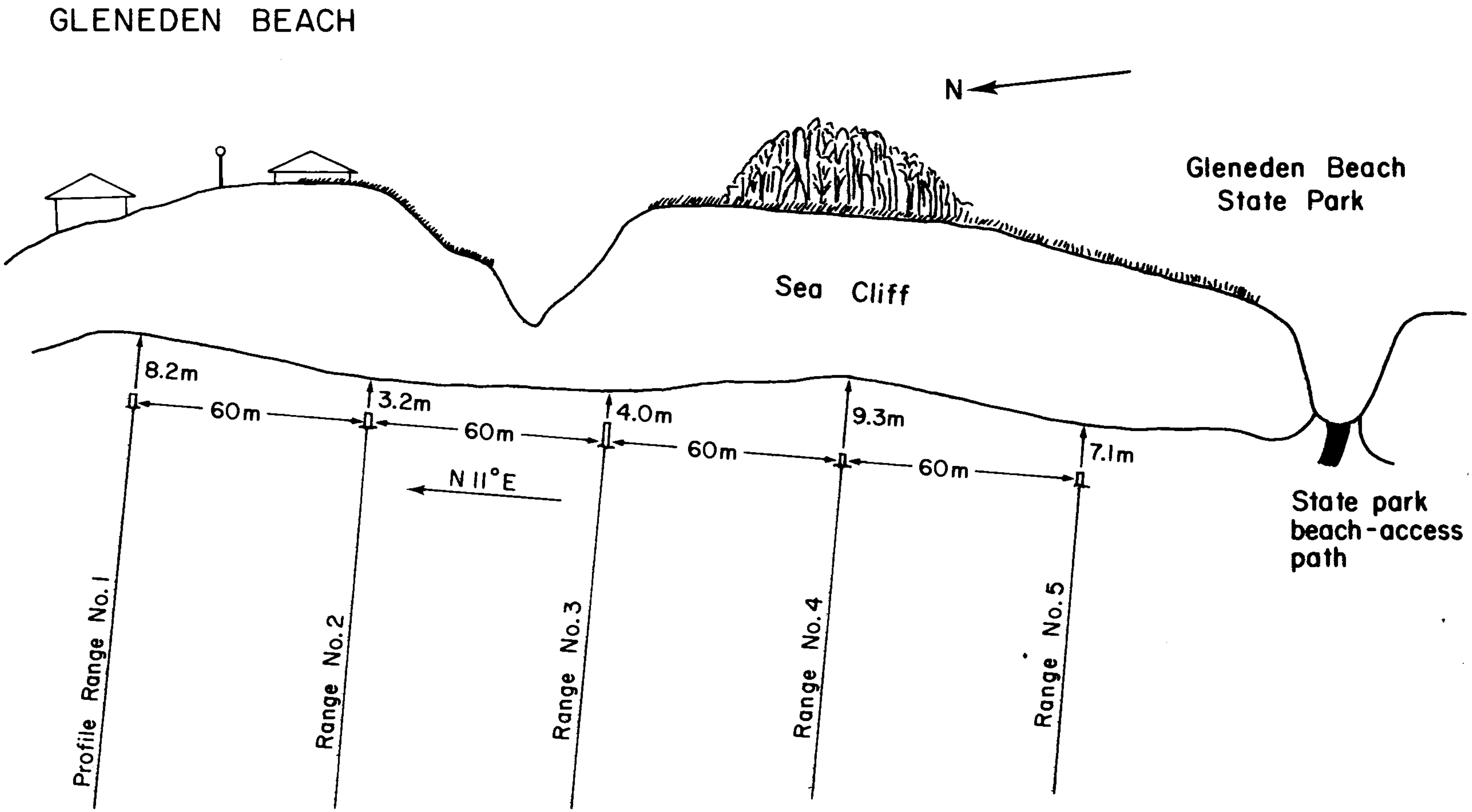

Figure 9. Arrangement of stakes and profile ranges at Gleneden Beach.

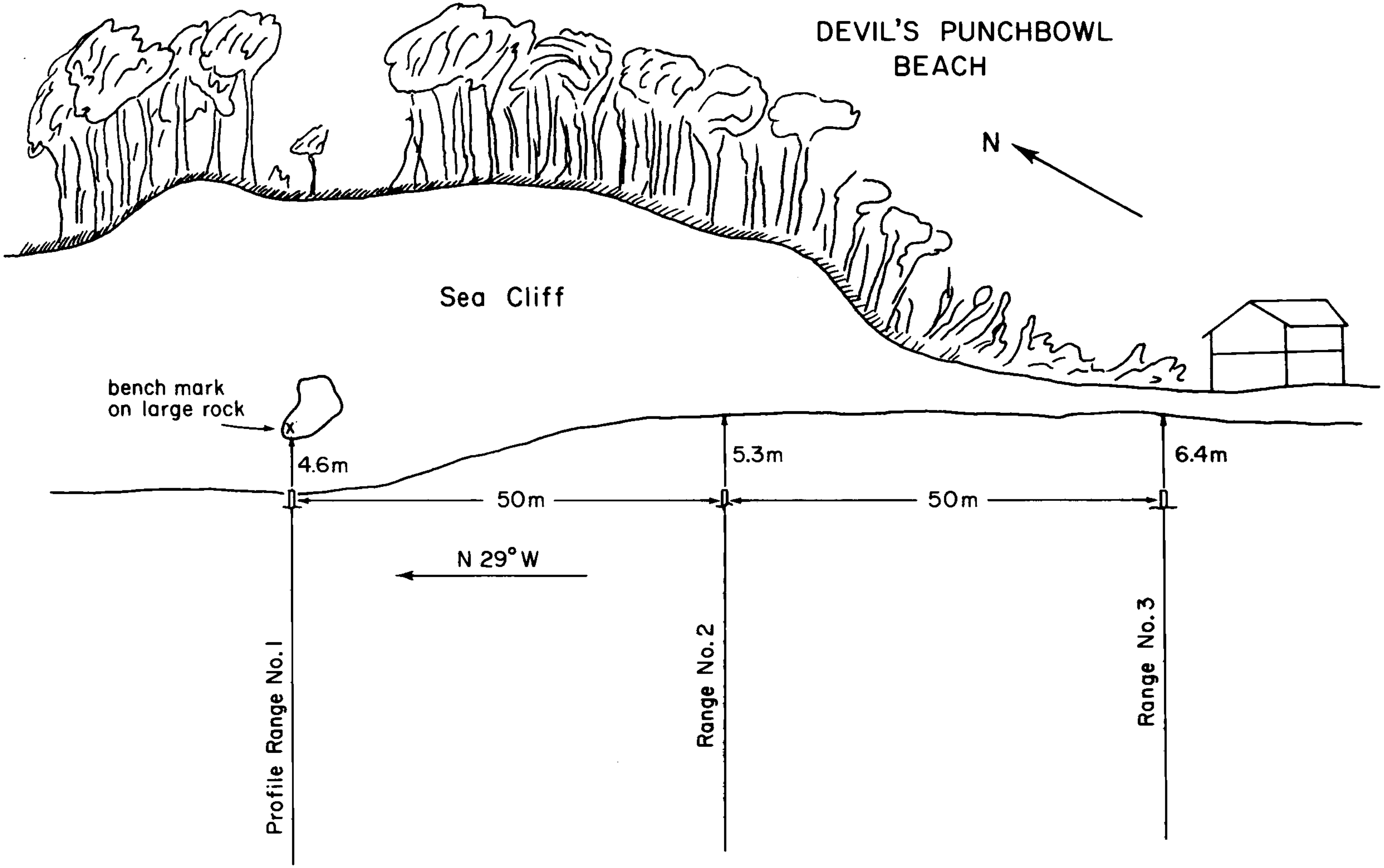

Figure 10. Arrangement of stakes and profile ranges at Devil's Punchbowl Beach.

Punchbowl Beach because of the presence of rip current embayments. However, having multiple survey lines served another purpose in that stakes would sometimes be lost and have to be replaced. The history of stake loss and replacement is indicated in Figure 11. At Gleneden Beach two stakes and survey lines were lost due to the replacement of riprap along the sea cliff, covering the stakes. The other principal loss was due to people pulling the stakes up, the area being a park with heavy use even during the winter. Even our iron stake set in concrete was lost, some individual having bent it back and forth until it snapped. The principal problem with stake loss at Devil's Punchbowl Beach was caused by the drift logs moving around during high spring tides and either covering the stakes or breaking them off. Fortunately, with all our stake losses and replacements, one stake at each location survived for the entire study period. Most of the determinations of beach erosion and deposition are obtained from those two survey lines with confirmation checks from the other survey lines to insure that there were no appreciable longshore variations.

Wave Measurements

The sea wave conditions were recorded daily during ten minute intervals every six hours (0100, 0700, 1300 and 1900 Pacific Standard Time) at the Marine Science Center in Newport, Oregon, with a portable, long period, vertical velocity, Teledyne-Geotech seismometer (Model SL-210). The seismometer detects microseisms produced by the ocean waves, probably by a mechanism of pressure formed by standing waves produced by the incoming waves combining with reflected waves (Longuet-

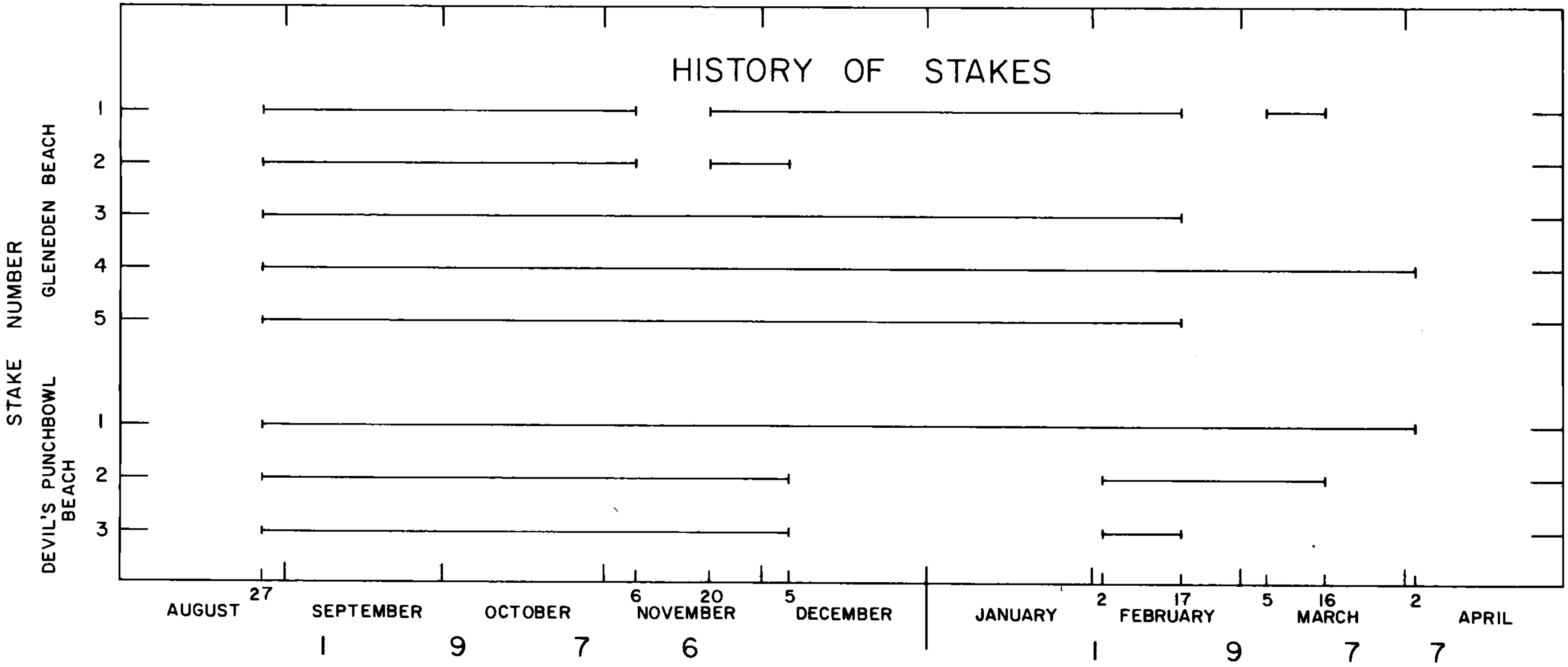

Figure 11. The history of stake losses at Gleneden Beach and Devil's Punchbowl Beach.

Higgins, 1950). The system has been in operation at Newport since May 1971; it is described by Enfield (1974), Quinn, Creech and Zopf (1974), Zopf, et al. (1976), Bodvarsson (1975), and Komar, et al. (1976).

Microseism are defined by Darbyshire (1962) as small variations in the Earth's surface of period 4-10 seconds and amplitudes up to 20 microns. Longuet-Higgins (1950) considers the case of the generation of standing waves in shallow water by the reflection of the progressive waves from the offshore zone. He shows that in a standing wave the mean pressure on the bottom varies with half the period (twice the frequency) of the original waves and with an amplitude proportional to the square of the wave amplitude.

This theoretical approach of Longuet-Higgins has been confirmed by correlations between measured wave conditions and the microseisms produced (Quinn, et al., 1974; Zopf, et al., 1976). Zopf, et al. use the measured peak to peak deflection and the corresponding zero-crossing periods of the seismometer record for the empirical calibration of the seismic system at Newport. They obtain the equation

$$d = K \frac{H_\infty^2}{P^3} \tag{2}$$

where d is the recorded peak to peak deflection in percent of full-scale, H_∞ is the deep-water wave height, P is the seismic signal period, and K is an empirical constant to be determined. P has an exponent of 3 because of the velocity transducer in the seismometer. The measured values of H_∞ for the empirical correlations were obtained by three methods; (1) visual observations, (2) pressure sensor records, and (3) fathometer data which yields a measure of the wave height. A value

K = 32 was obtained from 403 observations and a linear regression of visually observed values (H_∞) of wave height versus the inferred values (H_s) gave the equation

$$H_\infty = 1.07H_s - 0.87 \tag{3}$$

where the heights are given in feet. The correlation is shown in Figure 12 with a correlation coefficient of 0.87 and a standard error of estimate of 1.61 feet.

Creech (1977) indicates that from the seismometer record the average height of the highest 10 percent of the waves, $H_{1/10}$, is determined. This value is reduced by 20 percent by using Longuet-Higgins' (1952) formula, $H_{1/3} = 0.80H_{1/10}$, to obtain the significant wave height $H_{1/3}$. All wave heights given in this study will be significant wave heights, the average of the highest one-third of the waves.

Because the seismic system was empirically correlated with waves measured at a water depth of 12 meters (40 feet) off Newport, it now yields wave estimates for that depth. As discussed in Komar, et al. (1976), these waves can be considered to be deep-water waves with little introduction of error. Waves of period less than 5.5 seconds would be deep-water waves (Komar, 1976, p. 43). Larger wave periods would be intermediate water waves. However, treating all the waves as deep-water waves greatly simplifies the calculations and introduces an error never more than 9 percent and generally much less. This amount of error is well within the uncertainties of the basic measurements and is therefore warrented.

In some cases we will want to know what the corresponding breaking

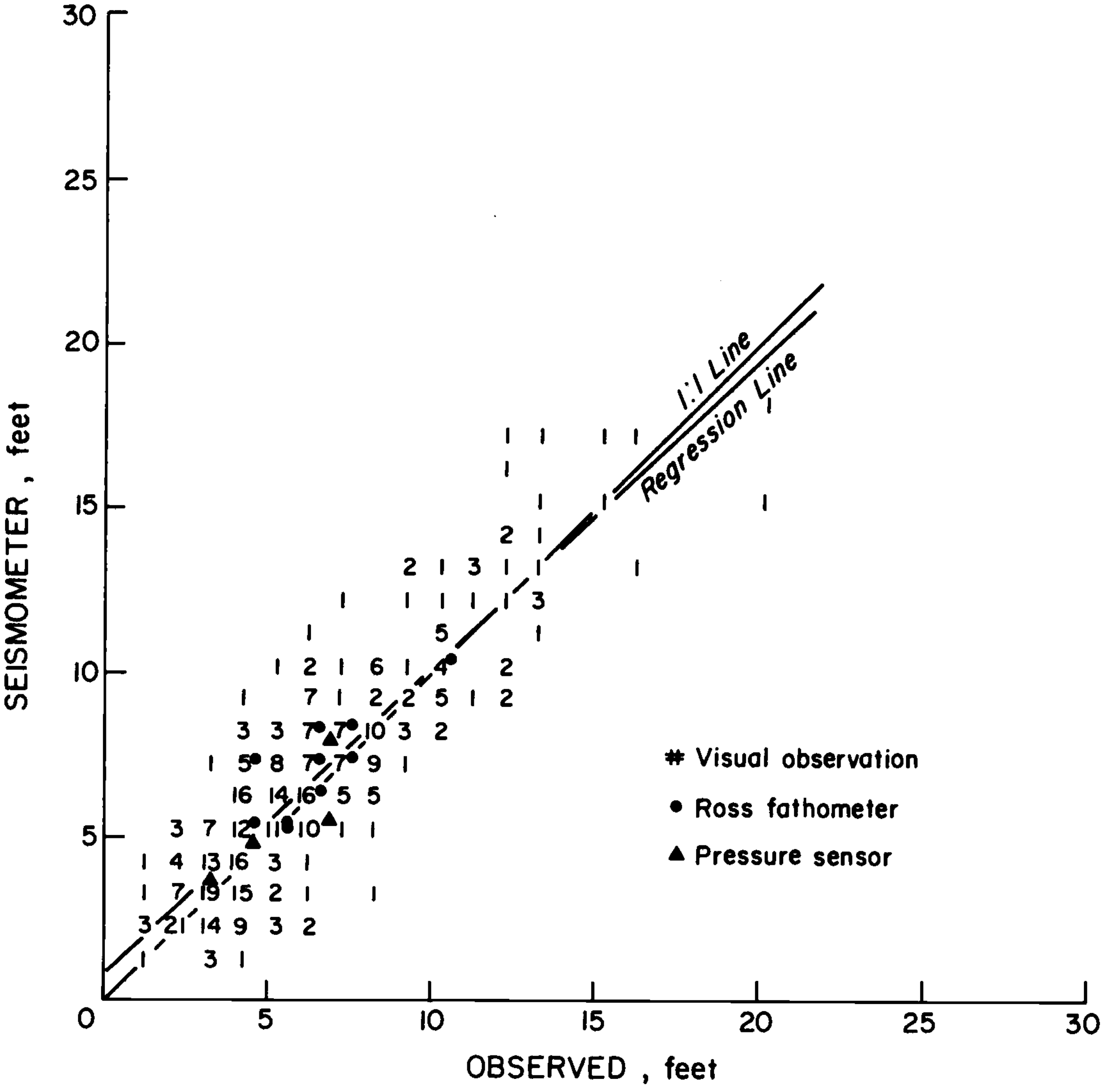

Figure 12. Regression agreement between the observed significant wave height as determined with a pressure sensor, visual observations, and a wave-recording fathometer, compared to the predicted wave height from the microseismometer record. Data without an accompanying symbol are for visual observations. [*After* Zopf, et al. (1976) and Creech (1977)]

wave heights are at the coastline. Komar and Gaughan (1973) derive an equation of the form

$$H_b = 0.39\, g^{1/5}(T\, H_\infty^2)^{2/5} \qquad (4)$$

from which the breaker height H_b can be calculated from the measured deep-water wave height and period obtained from the microseismometer; g is the acceleration of gravity (981 cm/sec^2). This equation is based on the available laboratory and field measurements of breaker heights and simultaneous offshore wave parameters. Although the type of breaker (spilling versus plunging) depends on the beach slope, the value of its height does not. Equation (4) was used to calculate the significant breaking wave heights given in Figure 17 and discussed later.

BEACH PROFILES

Figure 13 contains the eleven profiles obtained at Gleneden Beach along profile range #4 (Figure 9) on the dates shown. The stake at range #4 was not lost during the course of the study so all profile elevations and horizontal distances are relative to the top of the stake. Other ranges showed basically the same profile types and changes through time.

Profile 1 of Figure 13, obtained on 27 August 1976, shows a berm 70 meters in width sloping upward in a seaward direction on its outer half to a crest followed by a steeply sloping beach face. Such a profile with a low in the berm and a sharp berm crest is a typical swell (summer) profile for this location. The landward sloping berm is produced by waves washing over the berm crest, depositing sand and then ponding in the low of the mid-berm. Bascom (1954) shows similar profiles at Carmel, California.

Profile 2 of Figure 13, obtained on 7 October 1976, shows that the berm has been partially eroded away, and Profile 3 and subsequent profiles show no berm, the beach instead consisting of an offshore sloping beach face, a typical concave-upward storm (winter) profile. Thus, between Profiles 1 and 3 there has been a shift in the profile type as illustrated schematically in Figure 1. The profile type that prevails during the summer has been transformed to the type found during winter on Oregon beaches. Sand removed from the portion of profile surveyed has presumably moved offshore into the bars such as those of Figure 2; unfortunately, our surveys do not extend to sufficient depths to show

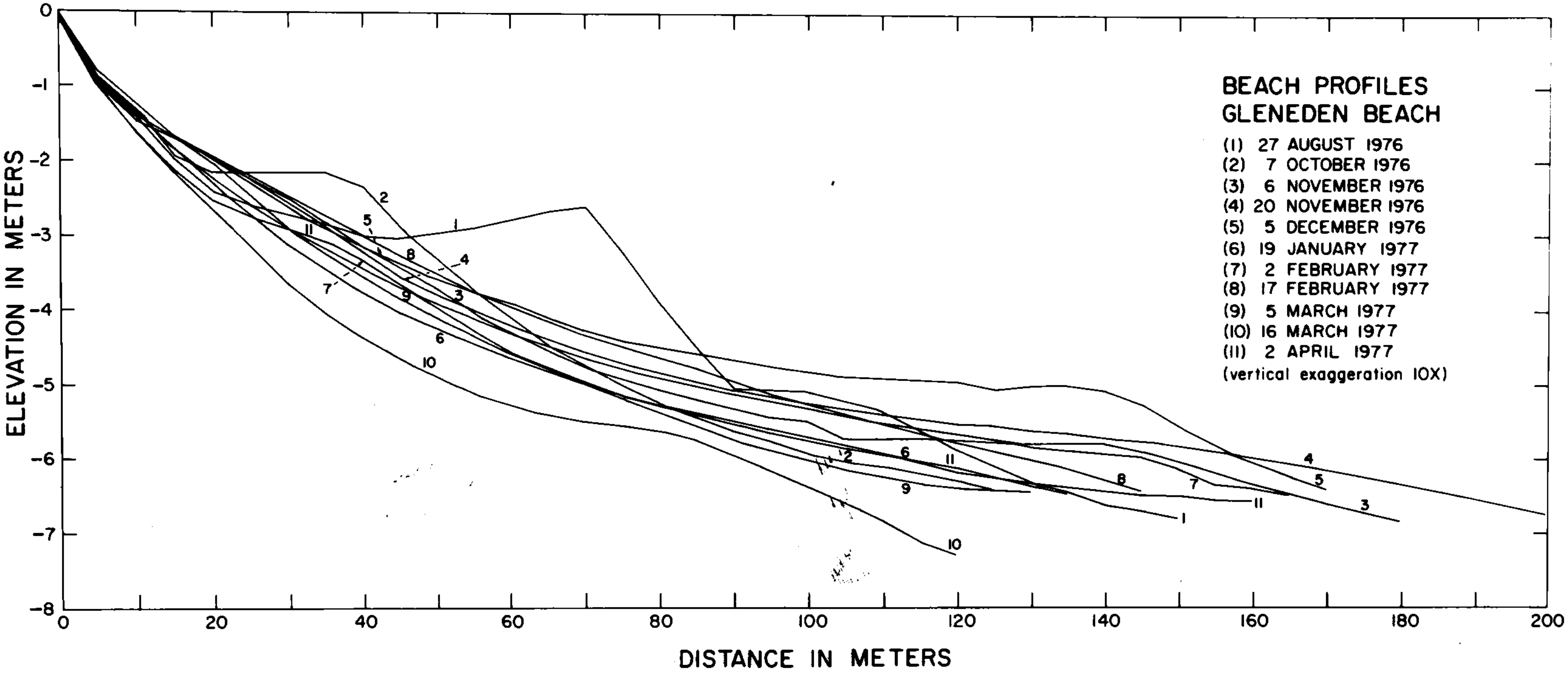

Figure 13. The eleven beach profiles obtained during this study at Gleneden Beach along profile range #4 on the dates shown. Profile elevations are relative to stake top at shoreward end.

this.

Figures 14, 15 and 16 give the profiles obtained along survey range #1 at Devil's Punchbowl Beach (Figure 10). In Figure 14 the profiles are offset vertically to avoid crossing, while Figure 15 contains representative profiles to illustrate the vertical changes in the profiles and thus the amount of erosion or deposition. Being a fine-grained sand beach, the vertical changes are seen to be much less than at the coarse-grained Gleneden Beach. At Devil's Punchbowl Beach there is little if any berm, even in Profile 1 (27 August 1976). At the back of the beach is a 10-meter wide portion covered with drift logs that could be termed a beach berm. Otherwise, the exposed beach profile at all times, even in mid-summer, consists of a concave-upward beach face. A common feature of the beach at Devil's Punchbowl is a pronounced longshore trough and offshore bar. The surveys generally entered the trough but seldom extended far enough seaward to reach the bar. One exceptionally long profile that did cross the bar is shown in Figure 16. At that time the bar top to trough bottom relief was 1.3 meters; at low tide the water depth in the trough was 1.5 meters. In spite of the pronounced troughs at this location, longshore currents occupying the trough were not strong. What longshore currents that did exist were part of a cell circulation, the currents feeding rip currents both north and south of the survey area. The rip currents were also very weak and at all times of observation did not significantly hollow out embayments into the beach. The waves always broke essentially parallel to the shoreline, not generating longshore currents by that mechanism.

During the time of the study (27 August 1976 to 2 April 1977) no

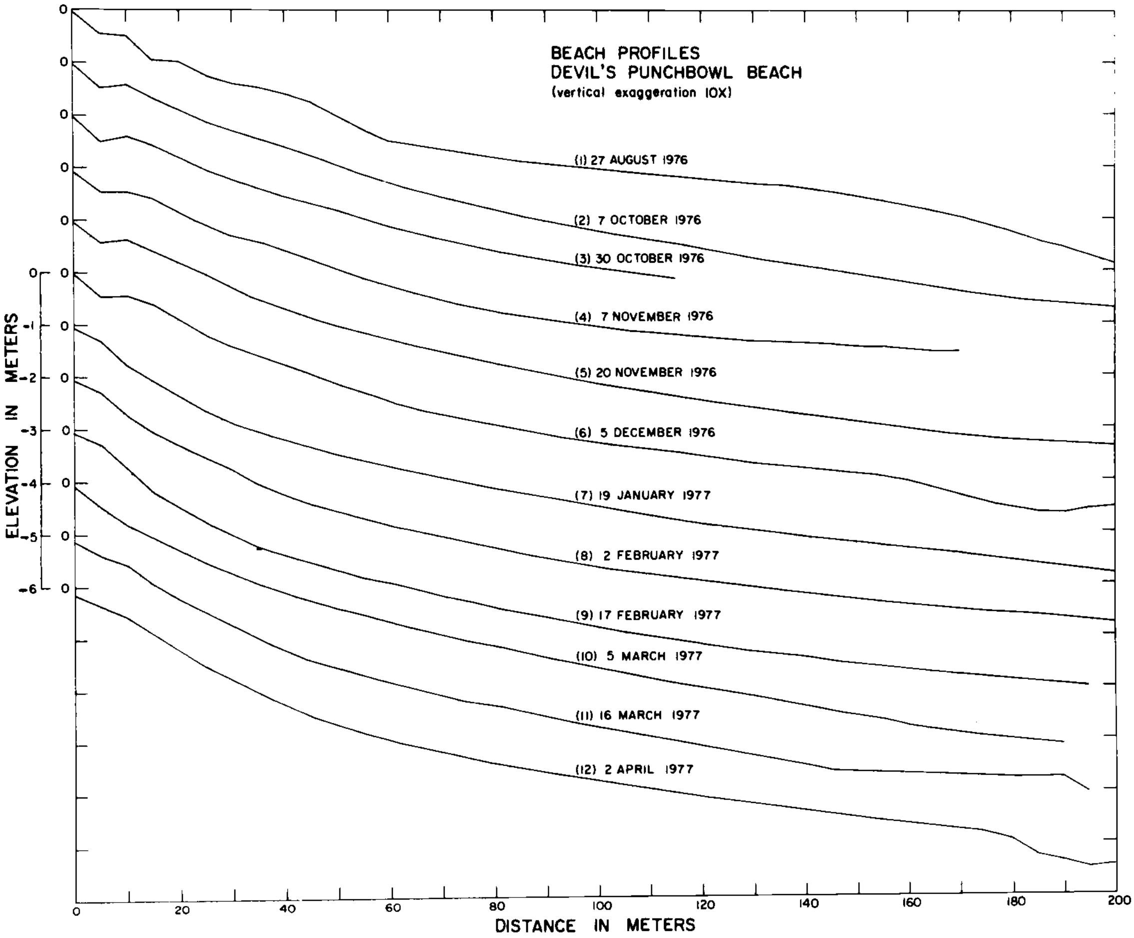

Figure 14. The twelve beach profiles obtained during this study at Devil's Punchbowl Beach along profile range #1 on the dates shown. The profiles are offset vertically so that they can be distinguished.

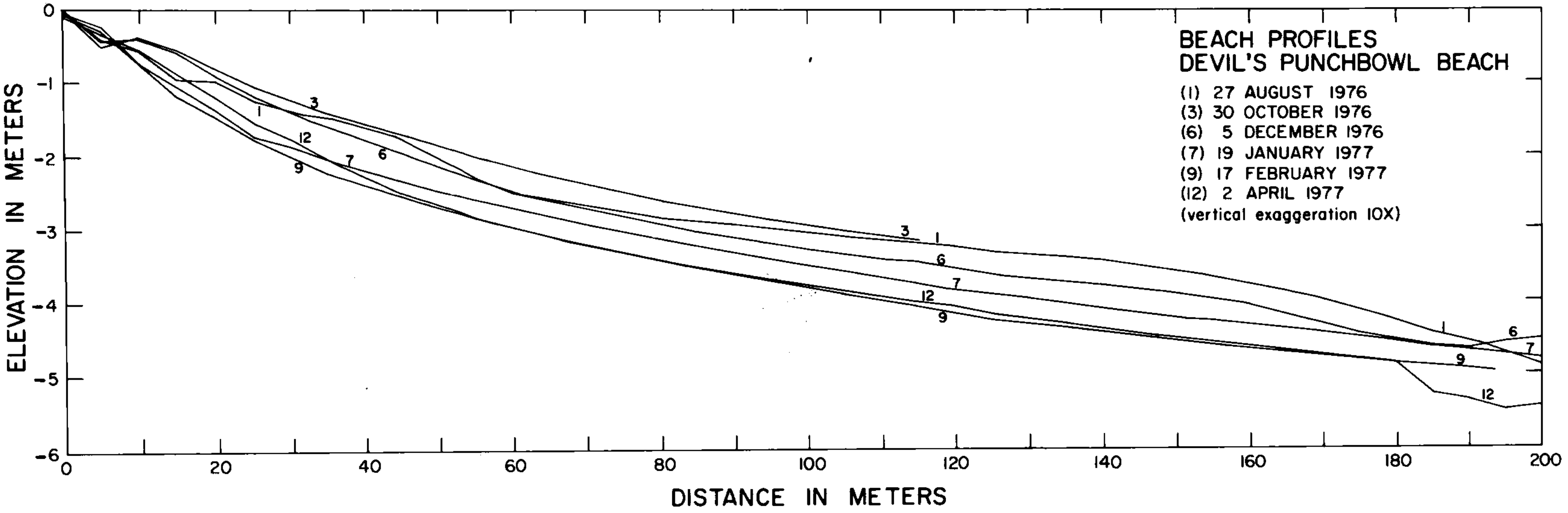

Figure 15. Selected beach profiles from Devil's Punchbowl Beach, also given in Figure 14, but not offset so that the vertical changes in the beach level can be seen. Profile elevations are relative to the stake top at the shoreward end.

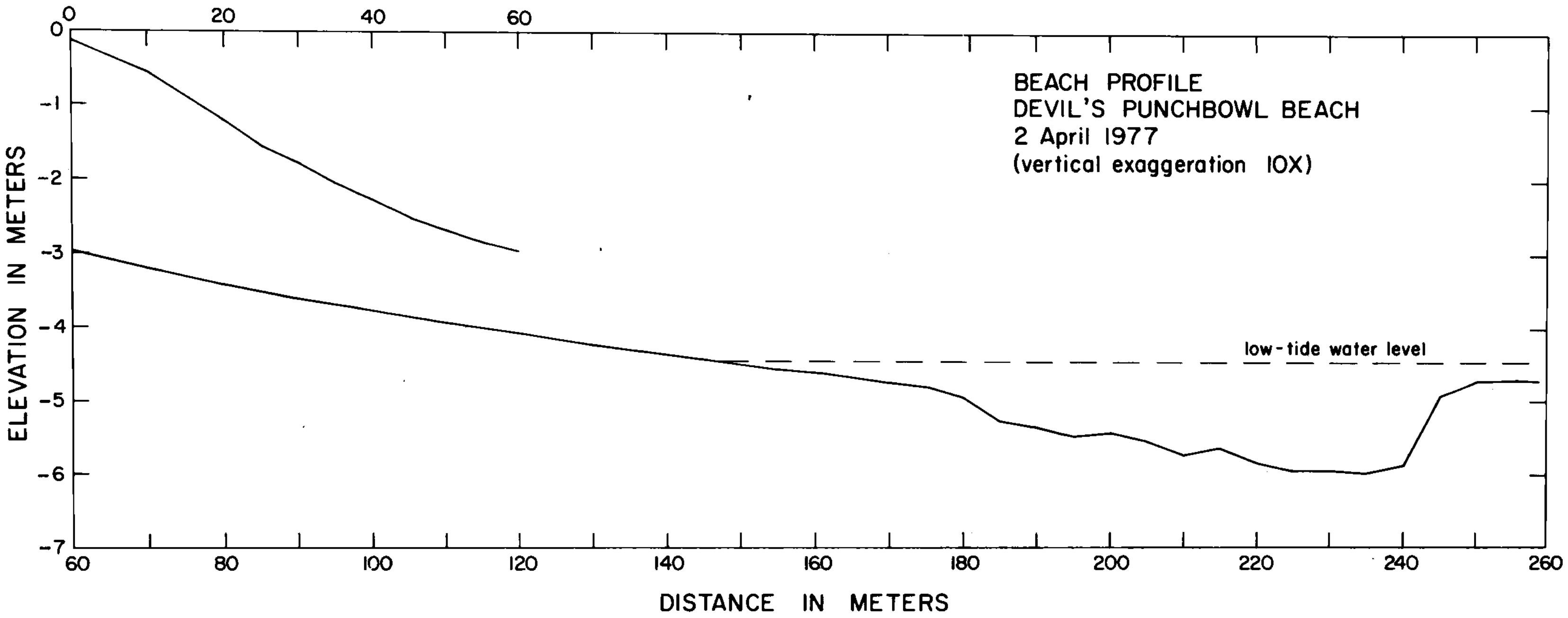

Figure 16. Beach profile at Devil's Punchbowl Beach on 2 April 1977 showing a pronounced longshore trough and offshore bar. Profile elevations are relative to the stake top at the shoreward end.

bars were observed to migrate landward onto the beach face as shown by Fox and Davis (1974). Such shoreward migrating bars occur during the transition from a storm period to a period of lower swell waves. Although this can occur at any time of year, even mid-winter (Fox and Davis, 1974), such shoreward migrating bars should be best developed in the spring time when the typical storm (winter) profile is transforming to the swell (summer) profile. A visit to Devil's Punchbowl Beach on 26 April 1977 showed the existence of an onshore migrating bar, just as those documented by Fox and Davis at South Beach, south of Newport. The shoreward moving bar formed a trough to its immediate landward side. This trough cut down through the beach sand, exposing the Tertiary rock which composes the sea cliffs backing the beach. Such an occurrence of a pronounced trough on the inner beach and the exposure of bed-rock did not occur earlier when we were obtaining profiles for relating onshore-offshore shifts of sand to the wave conditions.

BEACH EROSION AND DEPOSITION

The beach profiles of Figures 13, 14 and 15 have been used to compute volumes of beach erosion or accumulation for the two profiling locations. The amounts of erosion or deposition between two successive beach profiles is obtained simply by subtracting one profile from the other, assigning positive values (+) to areas where the second profile in time is higher than the first (deposition), and negative (-) in areas where erosion occurred and the second profile is lower than the first. The procedure actually involved application of the trapezoid rule for approximating areas, given in most calclulus texts [for example, Granville, Smith and Longley, 1946 (p. 119-120)]. This procedure yields a cross-sectional area between two successive profiles, taking into consideration areas of accretion versus erosion. This resulting area can be thought of as the volume of erosion or accretion per unit length of beach in the longshore direction. This volume represented by the change between two successive profiles is a function of the profile lengths. If the profiles had been somewhat longer, the volume of calculated erosion or deposition would in most cases be greater. To help eliminate this factor of profile length dependence, the computed volumes were normalized by dividing by the profile lengths. The result is the volume of erosion or deposition per unit profile length (cubic meters/meter).

The results of this analysis are presented in Figure 17 together with the measured wave steepness, H_∞/L_∞, and breaker height, H_b, obtained from the microseismometer system at Newport. The wave conditions

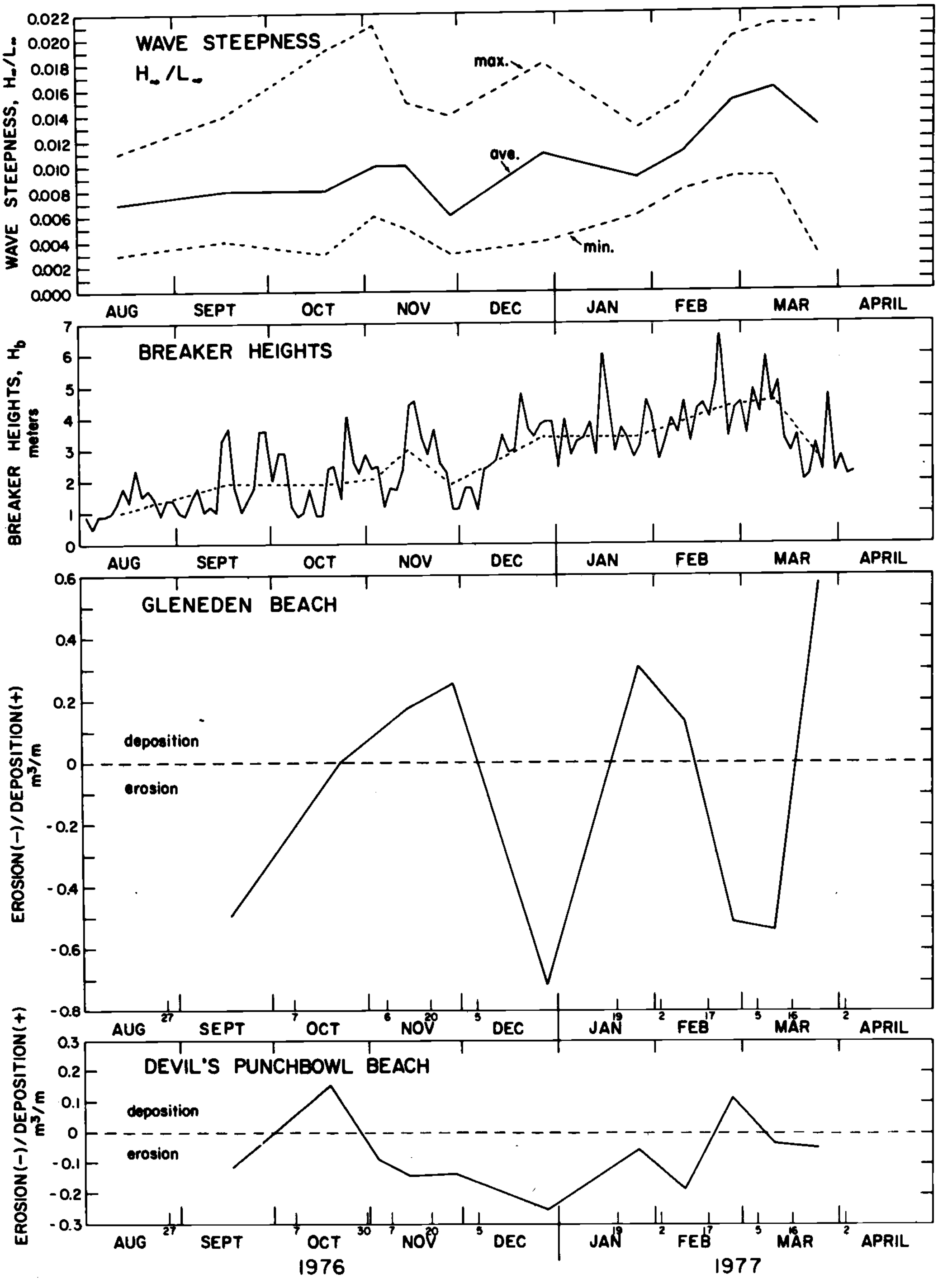

Figure 17. Beach erosion/deposition throughout the study period versus the wave steepness and breaker height. Dates of the surveys are shown, upon which the erosion/deposition evaluations are based. The wave steepness values are averages for the intervals between surveys (maximum and minimum values are also given). Daily breaker heights are shown as well as the average values between surveys.

TABLE II. The volumes of beach sand per unit profile length eroded and deposited.

1. Gleneden Beach

Survey Numbers	Date	Deposition (+) m^3/m	Erosion (-) m^3/m
1-2	27 Aug. 76-07 Oct. 76		0.4948
2-3	07 Oct. 76-06 Nov. 76	0.0013	
3-4	06 Nov. 76-20 Nov. 76	0.1791	
4-5	20 Nov. 76-05 Dec. 76	0.2569	
5-6	05 Dec. 76-19 Jan. 77		0.7107
6-7	19 Jan. 77-02 Feb. 77	0.3075	
7-8	02 Feb. 77-17 Feb. 77	0.1377	
8-9	17 Feb. 77-05 Mar. 77		0.5085
9-10	05 Mar. 77-16 Mar. 77		0.5382
10-11	16 Mar. 77-02 Apr. 77	0.5778	

2. Devil's Punchbowl Beach

Survey Numbers	Date	Deposition (+) m^3/m	Erosion (-) m^3/m
1-2	27 Aug. 76-07 Oct. 76		0.1173
2-3	07 Oct. 76-30 Oct. 76	0.1549	
3-4	30 Oct. 76-07 Nov. 76		0.0883
4-5	07 Nov. 76-20 Nov. 76		0.1417
5-6	20 Nov. 76-05 Dec. 76		0.1330
6-7	05 Dec. 76-19 Jan. 77		0.2526
7-8	19 Jan. 77-02-Feb. 77		0.0557
8-9	02 Feb. 77-17 Feb. 77		0.1849
9-10	17 Feb. 77-05 Mar. 77	0.1152	
10-11	05 Mar. 77-16 Mar. 77		0.0377
11-12	16 Mar. 77-02 Apr. 77		0.0497

TABLE III. Breaker heights and wave steepness data.

Date	H_b Average	H_b Max.	H_b Min.	H_∞/L_∞ Average	H_∞/L_∞ Max.	H_∞/L_∞ Min.
1 Aug.-27 Aug.	1.21	2.4	0.5	0.007	0.011	0.003
27 Aug.-07 Oct.	1.91	3.7	0.9	0.008	0.014	0.004
07 Oct.-06 Nov.	1.96	4.1	0.9	0.008	0.021	0.003
06 Nov.-20 Nov.	3.00	4.6	1.7	0.010	0.015	0.005
20 Nov.-05 Dec.	1.91	3.7	1.1	0.006	0.014	0.003
05 Dec.-19 Jan.	3.44	6.0	1.0	0.011	0.018	0.004
19 Jan.-02 Feb.	3.36	4.6	2.7	0.009	0.013	0.006
02 Feb.-17 Feb.	3.93	5.6	3.2	0.011	0.015	0.008
17 Feb.-05 Mar.	4.35	6.6	3.0	0.015	0.020	0.008
05 Mar.-16 Mar.	4.53	6.0	2.9	0.016	0.021	0.009
16 Mar.-02 Apr.	2.76	4.7	1.7	0.013	0.021	0.003

Heights and wavelength are in meters.

show the usual general increase in breaker heights and wave steepness as the winter months are entered (Komar, et al., 1976). There are considerable fluctuations as storm systems, producing large waves, are separated by periods lacking storms over the north Pacific and thus having lower wave conditions. The largest waves measured during the study occurred on 21 February 1977 when breaker heights reached a significant wave height of 6.6 meters. Larger waves have been measured by the microseismometer system since its installation in 1971, the largest breakers of 7.0 meters height occurring on 24-25 December 1972, causing considerable erosion at Siletz Spit to the north of Gleneden Beach (Figure 4) (Komar, et al., 1976; Komar and Rea, 1976). On 9 March 1977 breaker heights with a significant wave height of 6.0 meters caused renewed erosion on Siletz Spit, but not as much as earlier erosion episodes of 1972-73 and in the spring 1976. The storm on 21 February 1977 with the largest waves did not cause significant erosion on Siletz Spit, but probably contributed to later spit erosion by removal of some of the beach fronting the spit property, just as it did at Gleneden Beach as documented by the profiles of this study (Figures 13 and 17). Appendix I contains an analysis of the storm system producing the waves from 28 February to 11 March 1977, the period of erosion on Siletz Spit.

The values of the wave steepness, H_∞/L_∞, tend to be more erratic than the breaker height because the steepness includes both the measured wave height and period, each with their inherent measurement errors. For this reason, Figure 17 includes a plot of the average, maximum and minimum values of the wave steepness for the time intervals between profiles. The amount of erosion or deposition versus the prevailing wave steepness will be discussed later (Figure 19).

The resulting computations of beach erosion and deposition, Figure 17, further demonstrate that the volumes involved are much greater at the coarse-grained Gleneden Beach than at the finer-grained Devil's Punchbowl Beach. Of interest is that there is not a simple progressive erosion of the exposed beach as the winter months are entered, there being periods of net deposition between subsequent profiles even during the mid-winter. Nor is there always agreement between the two beaches, at times one beach showing a net accretion while the other is eroding. This cannot be accounted for by errors of profiling or in longshore variations caused by rip currents; both possibilities were considered and discounted by examining profiles at all surveying ranges. It would appear that not only does the finer-grained Devil's Punchbowl Beach show lesser volumes of change than the coarser-grained Gleneden Beach, but its response may be entirely different as to whether erosion or deposition occurs.

Figure 18 shows directly the relationship between the amount of erosion or deposition between two successive profiles and the average breaker height that prevailed during that time. Also given are the total ranges of breaker heights observed during each period, the data bars extending from the maximum to the minimum observed breaker heights. It can be seen that there is only a vague relationship between the amount of erosion/deposition and the average breaker height. What little trend that does exist indicates that with increasing breaker

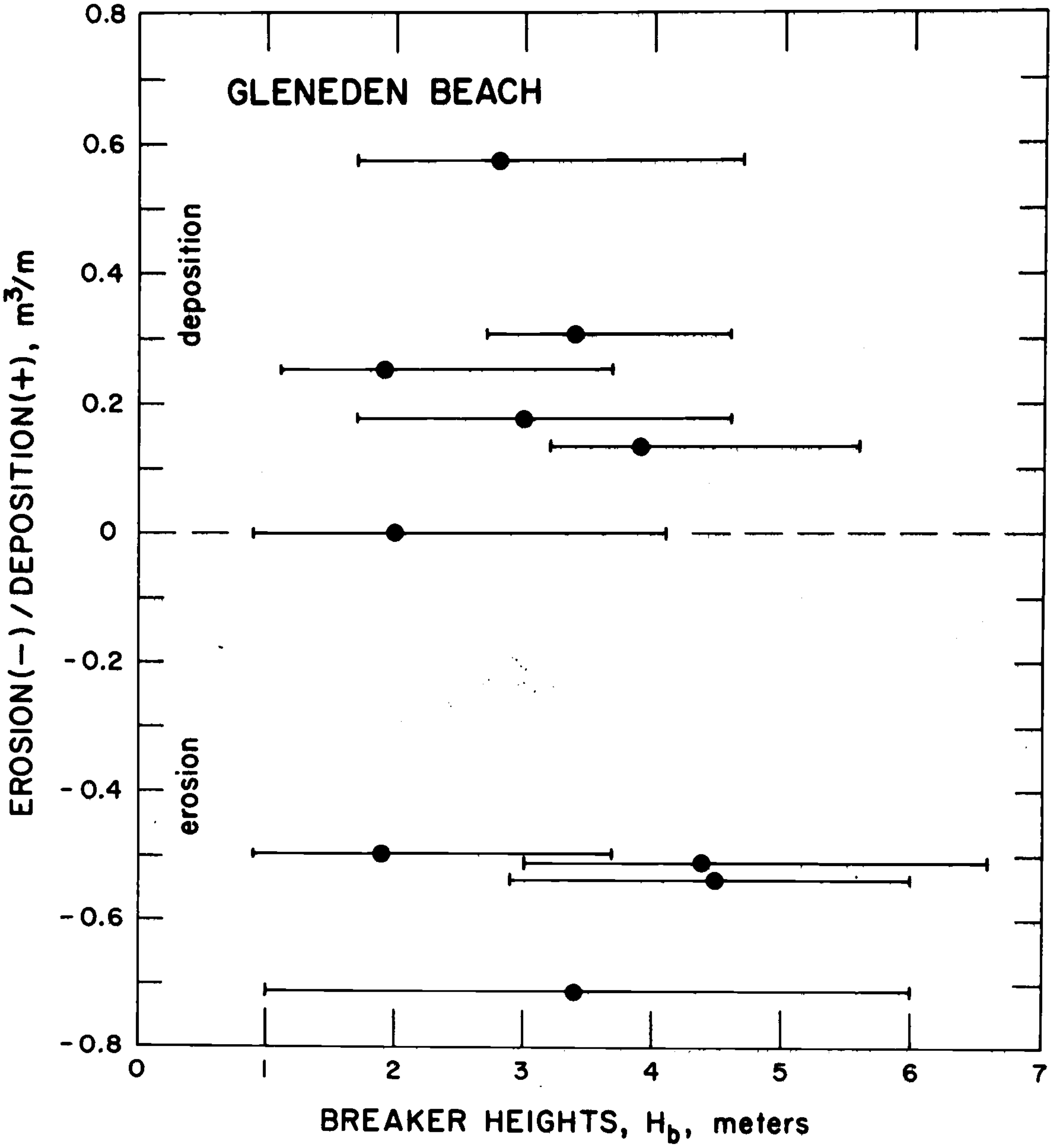

Figure 18. The volumes of beach sand per unit profile length eroded or deposited on the beach versus the average breaker wave heights that prevailed between the successive profiles upon which the erosion or deposition is based. The data bars show the entire range of breaker heights, the minimum and maximum values observed during the period.

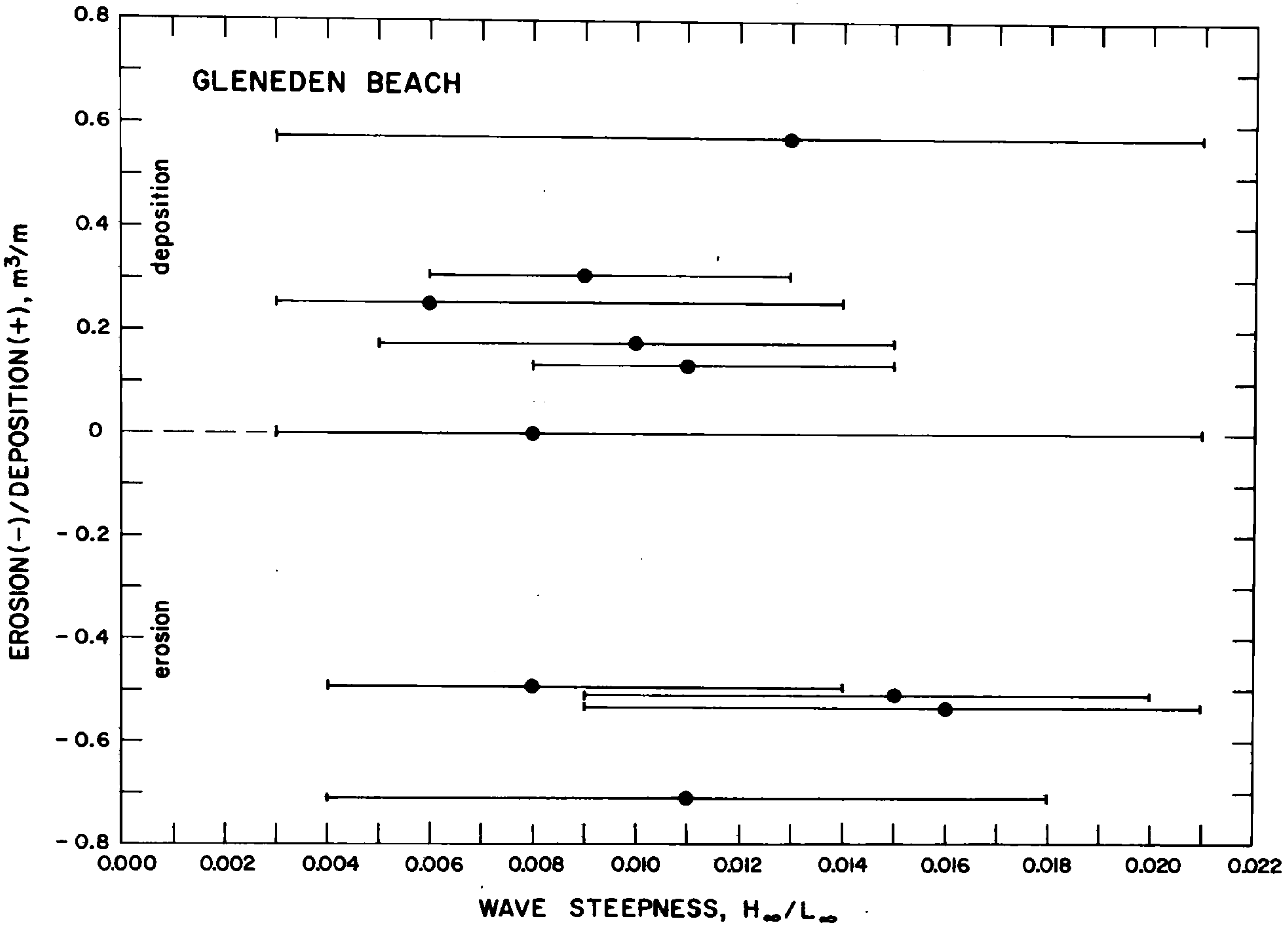

Figure 19. The volumes of beach sand per unit profile length eroded or deposited versus the deep-water wave steepness. The data points give the average wave steepness, whereas the data bars give the entire range of values observed during the period of time between the successive beach profiles upon which the erosion/deposition values are based.

height, there is a shift from deposition to erosion and an increase in the amount of erosion. This is logically as it should be. More important to the erosion/deposition might be the maximum and minimum wave conditions that occur during the time period. For example, the one large storm during the period, represented by the maximum breaker height, might be responsible for the beach erosion while the average or minimum breaker heights do little to change the volumes of sand on the exposed beach. This certainly appears to be the case as one single large storm with breaker heights in excess of 6 meters usually initiates erosion on Siletz Spit (Rea, 1975; Komar and Rea, 1976; Komar and McKinney, in press). In the case of beach deposition, it would appear the deposition occurs when there is no major storm during the period and the breaking waves average around 4 meters or less. The minimum wave breaker heights that occur during the period do not appear to be significant, not differing between the periods of erosion and deposition (Figure 18). This may result because the minimum waves have such little energy and power that they are unable to appreciably change the volume of sand on the exposed beach; they may cause some beach deposition, but its importance is small compared with the volume changes associated with the average or maximum waves during that time period.

A further complication is the time element. This is especially apparent in Figure 18 where it is seen that erosion was produced by waves averaging only 2 meters in breaker height with the maximum waves of the time period reaching only 3.7 meters. This occurred at the initial transition between the swell profile that prevails during the summer and the storm profile that occurs during the winter months. As the wave conditions are initially changing the beach profile in its full summer condition is most out of equilibrium with the increasing wave heights. For this reason, during the transition period, an increase in wave height to even 2 to 3.7 meters produces a large volume erosion. Once the beach profile has shifted more toward the winter storm profile, then those same wave heights would cause little if any volume erosion. It is not inconceivable that at that time they would even cause some beach deposition. Thus there may be a range of wave heights that one time of year cause erosion whereas at another time of year they cause accretion on the exposed beach. Of importance is the condition of the beach profile at the time the waves occur, whether it is shifted well into the swell (summer) configuration or into the opposite extreme, the storm (winter) profile.

Figure 19 shows a similar analysis, but relating the volume of erosion/deposition to the prevailing deep-water wave steepness. A comparison with Figure 18 reveals that the wave steepness shows even a poorer relationship to the erosion/deposition than does the breaker heights. There is only a slight indication that with increasing wave steepness there is an increasing tendency toward erosion rather than deposition and an increase in the volume of erosion. The inclusion of the wave period in the analysis to yield a wave steepness rather than dealing with the wave height or energy alone does not appear to be warranted. This agrees with the findings of Dolan (1966).

SUMMARY OF CONCLUSIONS

The series of beach profiles obtained at Gleneden Beach from 27 August 1976 to 2 April 1977 show a typical change from a swell profile with its extensive berm, which prevails during the summer months, to a storm profile with little berm which prevails during the stormy winter months. This transition occurred in August and September, and was basically completed in early November. Although the period of beach profiling did not cover the return of the swell (summer) profile in the spring of 1977, the beginnings of it were observed during late April when offshore bars begin to migrate back onshore and fresh quartz sand was deposited over much of the beach.

The finer-grained Devil's Punchbowl Beach also showed general erosion during the fall. However, any transition from a swell to a storm profile is not as clear there as the beach always has a concave up appearance more typical of the winter storm profile, and even in mid-summer the beach has little berm.

Both beaches can experience periods of sand accretion on their upper exposed portions even during the winter time. Any decrease in the overall wave storm activity allows some recovery of the beach, resulting in deposition. This was also shown by Fox and Davis (1974, in press).

Of interest is that Gleneden Beach and Devil's Punchbowl Beach did not always agree in their responses to the changing wave conditions. At times one beach may erode while the other shows accretion. The presence of variability due to rip currents and simple errors in obtaining the beach profiles could be ruled out. The differences in response would appear to be more basic, revealing responses of a fine-grained beach versus one that is considerably coarser grained.

Volume changes of the erosion or deposition are much higher at the coarser-grained Gleneden Beach than at the fine-grained Devil's Punchbowl Beach. This results in appreciably greater changes in the vertical extent of the level of Gleneden Beach. This agrees with previous investigations which have shown larger changes in coarse grained beaches.

There is only a vague relationship between the volumes of beach erosion and deposition and the wave breaker heights that prevail during the period between successive beach profiles. With an increase in wave breaker heights there is an increase in the probability of erosion over deposition and an increase in the volume of sand eroded. Such a relationship is not straight-forward in that it is most likely the maximum wave breaker heights associated with a pronounced storm that cause beach erosion, not the average wave conditions. On the other hand, in the absence of a major storm, it is probably the average wave conditions that produce a shoreward shift of sand and beach deposition. The minimum wave conditions that occur during the time period appear to be irrelevant unless they last for a considerable period of time, as they have little energy with which to shift sand back onshore. The time element is also an important factor. The indication is that waves of a certain height may cause erosion during one time of year (the fall) and beach accretion at another time (the spring). Of importance here is the conditions of the beach profile at the time the waves occur, whether it more closely approaches the swell (summer) profile or the storm (winter) profile. The more the beach profile is out of equilibrium with a given set of wave conditions, the greater the amount of volume change (ie., the more erosion or deposition). There cannot be expected to be a simple relationship between beach erosion/deposition and a factor such as wave height.

For Gleneden Beach, Figure 17 indicates that beach erosion will prevail when the average wave breaker heights reach about 4 meters; but more important are that the maximum breaker heights during storms reach 5 to 6 meters or greater. Deposition prevails when the average breaker heights fall below 4 meters and storms are limited to breaker heights less than 5 meters.

The wave steepness, H_∞/L_∞, shows an even poorer relationship to the beach erosion/deposition than does the breaker height. Thus the wave period, which enters into the calculation of the wave-length L_∞, would not appear to be as important parameter as the wave height alone in causing beach erosion or deposition.

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APPENDIX

APPENDIX I

STORM ANALYSIS: 26 February 1977 through 9 March 1977

The computerized semi-automated wave forecasting system developed by Enfield (1974) was used for the analysis of the storms during the period between 26 February 1977 through 9 March 1977. The system is described by Enfield (1974), Creech (1976) and McKinney (1977), so it will be discussed only briefly here. It is a coastal forecasting system which forecasts the significant wave height and average period of waves in deep water, the techniques being applicable to any deep-water location. The system combines the principles of three sources; the wave spectrum approach of Pierson, Neuman and James (1955), the graphical method for measuring fetches used by Wilson (1955), and the fetch-limited spectrum developed by Liu (1971). The semi-automated wave forecasting system is based on the principles used by Pierson, et al. (1955). They assume that the energy in each frequency band of the wave spectrum is generated in the fetch area, propagated over the ocean at group velocity, with reduction equal to the angular spreading loss, and recombined with other frequency bands at the forecast or hindcast point to give the predicted spectrum.

The inputs for the hindcast computer program of Enfield (1974) are the time of forecast, time the fetch started, time the fetch reaches the coast, and the fetch parameters (average wind speed, duration, decay distance, fetch length, and angular spreading factor) which have been measured from surface pressure charts. Given the wind speed, duration, and fetch length, the program computes the total wave energy within a fetch and the energy distribution within the spectrum. Spectral components are separated and each component is propagated as a unit to the hindcast area. Long period waves, which travel fastest, arrive first. Shorter period waves from the leeward end of the fetch, and longer period waves from the rear of the fetch arrive next. The energies of these waves are summed for each set time interval and corrected to wave height and period. Also for each time interval, the program calculates the fetch velocity by determining an effective generation distance for each spectral component whose energy will be affecting the hindcast area. Each spectral component is also associated with an unique spreading factor (interpolated between initial and final values) which determines the percent of the original energy of that frequency which reaches the hindcast area (Creech, 1976). The program output is significant wave height and period at the hindcast site for the time period specified (Figure 20).

Once the hindcast wave parameters have been obtained, these data were then compared with the significant wave heights and periods recorded by the wavemeter at the Marine Science Center (Figure 21).

Fetch histories and wave hindcasts were determined for the high wave-activity period between 26 February 1977 through 9 March 1977. National Meteorological Center Final Northern Hemisphere Surface Pressure Analysis Charts (published daily at 0000, 0600, 1200 and 1800 GMT) were examined to locate the fetches most likely to affect the Newport area. Four hindcast days were determined, 28 February, and 3, 6, and 9 March at 0900 GMT. The fetches associated with the hindcast days were 4, 8, 7 and 7, respectively. Twenty-four of the twenty-six fetches

TABLE IV. Storm wave data from the wavemeter at Newport.

Date	H_∞ Meters	T Seconds	H_b Meters
26 February 1977	3.3	11.5	4.3
27 February 1977	2.6	11.4	3.5
28 February 1977	3.6	10.8	4.5
1 March 1977	3.6	10.8	4.5
2 March 1977	2.6	11.1	3.5
3 March 1977	3.9	11.7	4.9
4 March 1977	3.6	13.6	4.9
5 March 1977	2.4	13.0	3.5
6 March 1977	3.0	12.2	4.1
7 March 1977	4.5	11.9	5.6
8 March 1977	4.8	12.3	5.9
9 March 1977	4.9	12.2	6.0

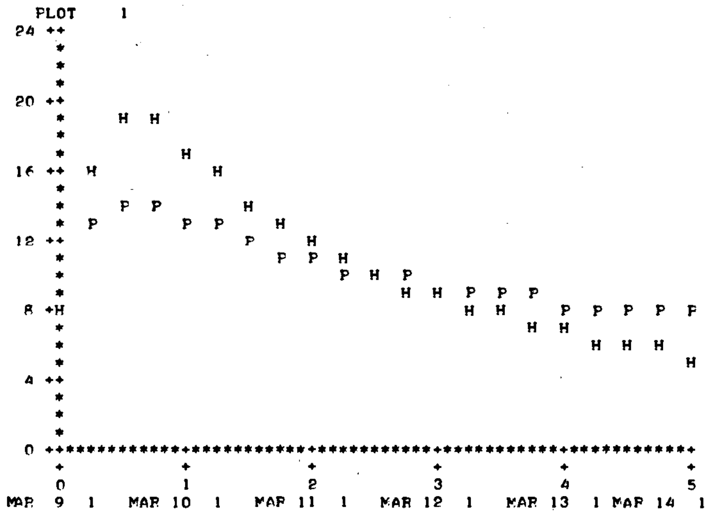
The values are daily averaged values.

TABLE V. Fetch history.

Date and Fetch Parameters	Average of All Fetches	Range
26 February 1977 - 28 February 1977		
2 fetches		
Wind speed (knots)	30	30
Duration (hrs.)	30	18-42
Initial decay distance (n. mi.)	500	0-1000
Final decay distance (n. mi.)	0	0
Initial fetch length (n. mi.)	575	500-600
Final fetch length (n. mi.)	550	500-600
Fetch velocity (knots)	24	24
1 March 1977 - 9 March 1977		
8 fetches		
Wind speed (knots)	35	30-40
Duration (hrs.)	30	12-48
Initial decay distance (n. mi.)	1219	0-1800
Final decay distance (n. mi.)	331	0-850
Initial fetch length (n. mi.)	575	350-800
Final fetch length (n. mi.)	588	500-700
Fetch velocity (knots)	33	21-44

```
#*WAVE
WHEN IS OUR FIRST FORECAST FOR(GMT)?
MONTH:
MAR
DAY=9
HOUR =  9
TIME FETCH # 1 STARTED(GMT)?
MONTH:
MAR
DAY=7
HOUR =  18

PARAMETER
 NUMBER        PARAMETER
 ------        ---------
   1      WIND SPEED =   40
   2      DURATION (HOURS) = 36
   3      INITIAL DECAY DISTANCE =    1600
   4      FINAL DECAY DISTANCE = 0
   5      INITIAL FETCH LENGTH = 350
   6      FINAL FETCH LENGTH =   700
   7      INITIAL SPREADING FACTOR = .13
   8      FINAL SPREADING FACTOR =   1.0
WANT TO CHANGE  THE VALUE OF ANY PARAMETERS(YES/NO)  ?  NO
DOES FETCH REACH COAST BEFORE  6Z MAR  9
(YES/NO)NO
INPUT ANOTHER FETCH(YES/NO)  ?  NO
MONTH  DAY  HOUR(PST)  SIG.HGT.  PERIOD(S)
 MAR     9      1         7.9       8.5
 MAR     9      7        15.5      12.5
 MAR     9     13        18.6      13.9
 MAR     9     19        18.8      13.9
 MAR    10      1        17.2      13.1
 MAR    10      7        15.9      12.5
 MAR    10     13        14.1      11.8
 MAR    10     19        13.0      11.3
 MAR    11      1        11.7      10.7
 MAR    11      7        10.9      10.4
 MAR    11     13         9.9      10.0
 MAR    11     19         9.3       9.7
 MAR    12      1         8.6       9.4
OCCASIONAL WAVES TO TWICE FORECAST HEIGHT AND 10% OF WAVES TO
 4/3 FORECAST HEIGHT MAY BE EXPECTED (FROM NATURAL WAVE STATISTICS)
```



```
WANT TO CALCULATE EFFECT OF EBB CURRENT(YES/NO)?NO


WANT TO DO ANOTHER FORECAST ?   NO
```

Figure 20. Teletype fetch input conversation and output heights and periods for a simple semi-automated hindcast.

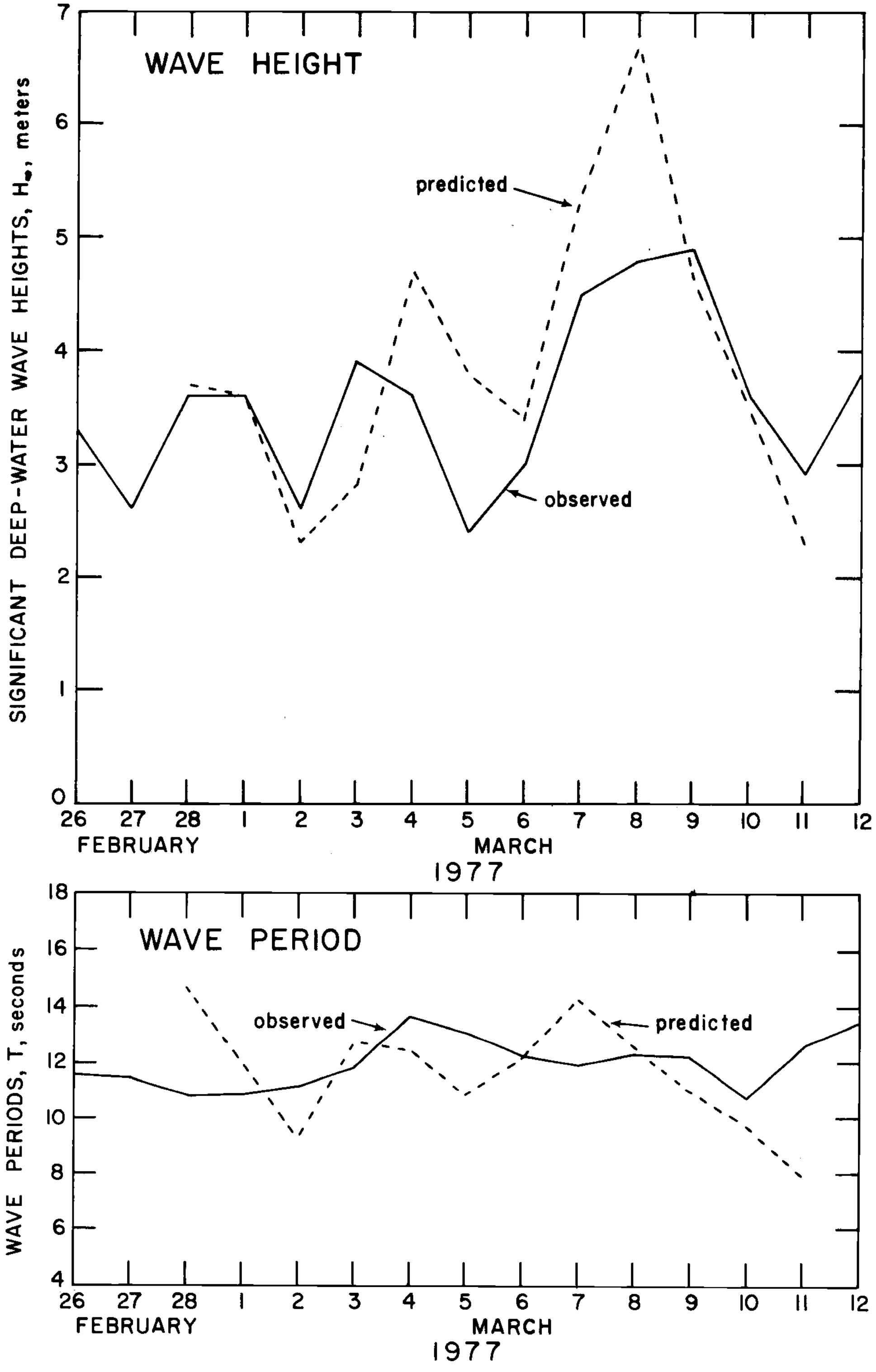


Figure 21. Comparison between the predicted and observed significant wave heights and periods in the Newport area between 28 February 1977 through 11 March 1977.

were moving fetches, thus the wind continued to transfer energy to the waves as both travelled toward Newport. The average fetch was 32 knots (16 m/sec) and the hindcast and observed waves were about 12 seconds so the wave group velocity would be about 18 knots (9 m/sec). The comparison between the hindcast values for the storm with the observed values shows a close agreement for the periods (Figure 21). For the wave heights there are significant differences during March 3, 4, 5 and 8. The cause of the discrepancy could be a high estimate of the wind speed and duration.