

CHAPTER 76

BEACH PROFILES AT TORREY PINES, CALIFORNIA

David G. Aubrey, Douglas L. Inman and Charles E. Nordstrom
Scripps Institution of Oceanography, University of California
La Jolla, California 92093

ABSTRACT

Beach profiles have been measured at Torrey Pines Beach, California for four years and correlated with tides and accurate spectral estimates of the incident wave field. Characteristic equilibrium beach profiles persist for time spans of up to at least two weeks in response to periods of uniform incident waves. These changes in the beach profiles are primarily due to on-offshore sediment transport which can be related to variations in wave characteristics and tidal phase. The most rapid readjustment of the beach profile occurs during high wave energy conditions coincident with spring tides. Alternatively, the highest berm building is associated with moderate to low waves that coincide with spring tides.

INTRODUCTION

The movement of sediment in the nearshore zone can be divided into two distinct directional modes: transport along the shore and transport onshore-offshore. It is convenient to think in terms of these two orthogonal modes when evaluating the erosion and accretion of sediment on a coast exposed to waves having seasonal variations in both energy and direction. Prediction of the longshore transport of sediment as a function of incident wave parameters is possible using empirical relations (e.g., Inman, Komar and Bowen, 1968; Galvin, 1976) and quasi-theoretical considerations (Inman and Bagnold, 1963; Komar and Inman, 1970; and Longuet-Higgins, 1970). However, at this time it is not possible to predict the magnitude of onshore-offshore sediment motion given a knowledge of sediment characteristics, tidal variations, and incident wave characteristics. The present study represents an attempt to provide empirical correlations between incident wave and tidal characteristics and onshore-offshore sediment motion.

It is necessary initially to determine whether the concept of an equilibrium beach profile is valid in a natural environment. The equilibrium energy profile is defined by Inman and Bagnold (1963) as the profile (depth as a function of distance offshore) which would eventually be attained when a nearshore area with a particular set of environmental characteristics (e.g., sand size, shelf width, and slope) is acted upon by a given set of driving forces (e.g., waves, currents, and tides). The equilibrium concept implies that the profile has ceased to vary with time and the driving force is constant. The equilibrium profile has been generated in the laboratory, but never fully documented in the field. Winant and Aubrey (1976) and Winant, Inman and Nordstrom (1975) verify the existence of characteristic stable beach forms for summer and winter wave conditions at Torrey Pines Beach, California, by analyzing the profiles using the objective analytical technique of empirical eigenfunctions.

The seasonal onshore-offshore motion of sediment has been previously described by numerous investigators (e.g., Shepard, 1950; Zeigler, et al, 1959; Gorsline, 1966; Sonu and Van Beek, 1971). Shepard (1950) measured seasonal beach changes along the Southern California beaches of the order of two meters vertically. A comprehensive study by Nordstrom and Inman (1975) along a section of coastline north of La Jolla, California, described changes at the location of the summer berm and winter bar of the order of 1 meter. Other researchers have found similar changes in different geographic locations. The beaches cited in the above references respond to the energetic waves characteristic of winter conditions by eroding the berm and moving the sediment offshore. The less energetic waves typical of summer conditions move sediment shoreward, building up the berm. Besides these seasonal large scale motions, the beach responds to smaller time scale events such as storms or long periods of extremely low wave energy. No field studies to date have been able to adequately quantify these wave-related sediment redistributions.

Laboratory studies have been undertaken in an attempt to delineate the erosional and accretionary regimes. These studies emphasize the importance of the wave steepness in determining the form of the profile. The results are given in terms of a critical wave steepness: for wave steepness above this value, a barred (no berm) profile develops, while for a wave steepness below this critical value, a profile with a berm develops (Johnson, 1949; Rector, 1954; Scott, 1954; Watts, 1954; Saville, 1957). The laboratory results are not directly applicable to natural beaches because of an inability to correctly scale both kinematics and dynamics in laboratory experiments. Kemp (1961) suggested that the critical wave steepness is inversely proportional to the wave period, so the critical steepness on natural beaches with a 10 second wave period would be only 10 percent of the critical steepness of a one second wave.

Field experiments have not yet defined the critical wave steepness for natural beaches, primarily because intensive beach profiling projects have not been complemented by good wave measurements. The general observation is that large waves create a barred profile, but the effect of wave period is uncertain. The present study attempts to determine empirically the effect of seasonally varying incident waves on a fine-grained sand beach at Torrey Pines Beach, California. Figure 1 shows the location of the study area. The beach is a long, relatively straight stretch of coastline backed by 100 meter high cliffs. In general, the cliffs contribute little to the sediment budget in the area. The net direction of longshore transport is to the south, where sediment is lost down the La Jolla and Scripps Submarine Canyon systems (Inman, Nordstrom, and Flick, 1976). The direction of littoral drift is seasonally dependent. During the winter, the waves are primarily from the north, while during the summer, there is a high incidence of waves coming from the south. The mean energy density for the area, as defined by the variance, $\langle \eta^2 \rangle$, is approximately 550 cm²; where the variance is related to the energy per unit surface area of the waves $E = \rho g \langle \eta^2 \rangle = 1/8 \rho g H_{rms}^2$. This is equivalent to a root-mean-square wave height of 66 cm.

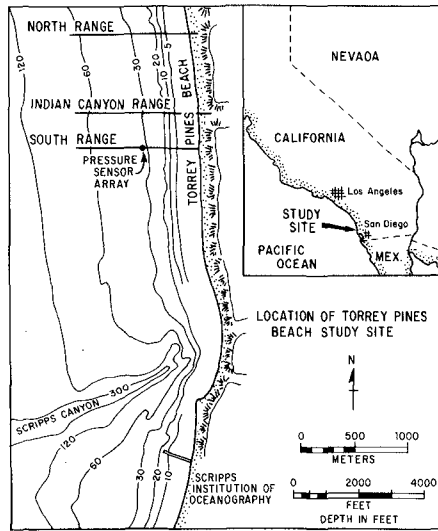


Figure 1. Location map of Torrey Pines Beach, California, showing position of the three rangelines (from Nordstrom and Inman, 1975).

DATA COLLECTION

The profile data was taken over a four year period along the three rangelines shown in Figure 1. For the first two years, the profile data was taken at monthly intervals, while in the succeeding two years, the profile data was taken at daily, weekly, or biweekly intervals. The surveying technique is described in Nordstrom and Inman (1975). Briefly, the surveys consist of an onshore profile extending from the beach backshore at the base of the sea cliffs out to a depth of approximately 1.5 meters. The profile is taken at low tide with a surveyor's rod and transit. Since the survey line is well defined by rangeline marker, this part of the survey is extremely accurate. At least once a month, an offshore survey is also made on the same day as one of the onshore surveys. The method is shown schematically in Figure 2. At high tide, a fathometer survey is made along the rangelines. The boat position is defined by the rangeline and a sextant angle. As soon as practical after the fathometer survey, scuba divers measure a series of arrays of four brass reference rods extending from the bottom at depths of 5, 7, 10, 15, and 20 meters along each rangeline. Since the change in length of the reference rods from survey to survey is an accurate measure of the actual change in sand level, the fathogram can be corrected to minimize the errors that are inherent in fathometer surveys (Inman, 1953). This surveying combination is sufficient to define almost all portions of the profile. During periods of intense wave activity, it is not always possible to measure the profile in the breaker zone, so there is some uncertainty about the profile at this point while the storm waves are present.

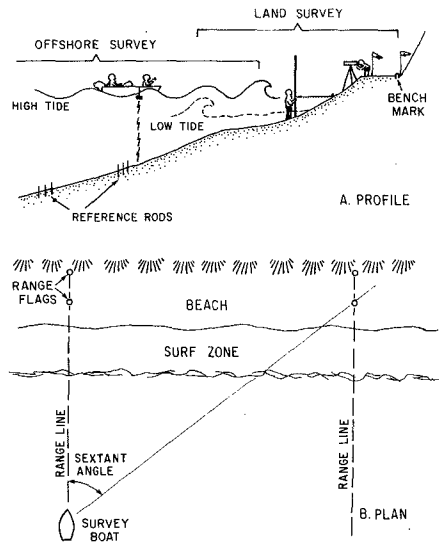


Figure 2. Schematic diagram of the onshore-offshore profiling technique employed in this study (from Nordstrom and Inman, 1975).

The wave data consists of both frequency and directional spectral estimates. The wave measuring system was described by Lowe, Inman and Brush (1972). Data is collected at one of the shelf stations of the Shelf and Shore (SAS) System depicted in Figure 3, and telemetered directly to the laboratory four times a day, each run having an hour duration. The data is automatically stored on digital magnetic tape. The shelf station consists of a surface piercing buoyant spar which is connected by a universal joint to an anchor assembly. The spar contains the transmitting package, which transmits the output of two accelerometers, mounted on the spar, and the output from a linear array of pressure sensors mounted on the bottom. Both frequency and directional spectral estimates are derived from the pressure sensor array (Pawka, Inman, Lowe and Holmes, 1976).

The shelf station is located in 10 meters of water off Torrey Pines Beach. The wave data cited in this study is the energy measured at the 10 meter depth location, corrected to energy density at the water surface. Since directional data were obtained, the resolution into on-offshore and longshore components, and the effect of breaker characteristics will be considered in a later paper. The solid lines in the figures to follow which refer to wave energy represent the energy variance, $\langle \eta^2 \rangle$, as measured by the SAS system. The dashed lines were taken from visual wave observations of breaker height at Torrey Pines Beach, at times when the SAS system was inoperative. The dashed values represent estimates of the energy density at the 10 meter depth calculated from the observed breaker heights.

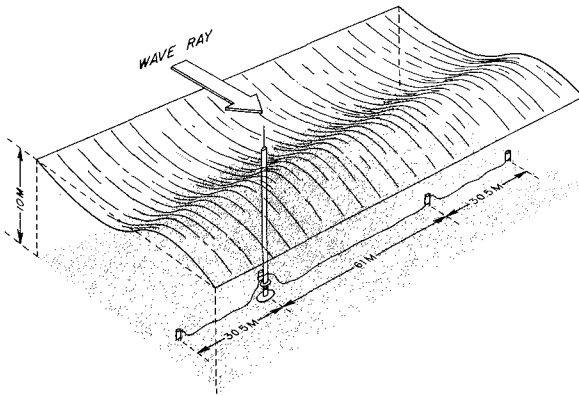


Figure 3. Shelf station portion of the Shelf and Shore (SAS) System used to collect frequency and directional spectral estimates. The pressure sensors are aligned in a linear array parallel to the beach in a water depth of 10 meters (from Pawka, et al, 1976).

The beach profile data is stored on magnetic tapes, and is processed on an Interdata Model 70 minicomputer. The volume calculations plotted on the following figures were evaluated by the computer. Tide data was taken from local tide calendars.

RESULTS

As a further test of the validity of the concept of equilibrium profiles on natural beaches, a series of profiles associated with high and low energy waves are compared. Figures 4 and 5 show equilibrium beach configurations for a high energy wave condition (winter type) and a lower wave energy condition (summer type), respectively. These profiles were taken at Indian Canyon Range. Figure 4 shows a sequence of three profiles taken over a two week time period during the winter of 1975-76. The wave energy was high immediately preceding each of the surveys. On 30 December 1975, there was an intense winter storm with an energy variance of 2100 cm^2 . Prior to the 9 January 1976 survey, wave energies were greater than 600 cm^2 , while before the 15 January 1976 survey, wave energies were about 750 cm^2 . The maximum change in sand volume above mean sea level (MSL) between any of the two profiles during this two week period was 2.5 m^3 per meter length of beach. It has been established that the seasonal summer to winter beach changes for this beach are about $120 \text{ m}^3/\text{m}$ beach length (Nordstrom and Inman, 1975). Thus, this small change implies that after the storm eroded the beach on 30 December 1975, the beach above MSL maintained itself in a constant, or equilibrium, configuration.

Figure 5 shows a sequence of three profiles taken over a two week period in August 1975, showing an equilibrium configuration for summer conditions. The maximum volume change among these profiles was $5 \text{ m}^3/\text{m}$ of beach length. During this time period, the waves were uniform and had an average energy density of about 250 cm^2 . Although a little accretion occurred at depths of approximately -2 meters, the beach face slope was extremely constant.

Both of these examples demonstrate that in natural beach environments, a dynamic equilibrium can be established given the same input wave conditions acting on a stable profile over a period of time. The presence of tidal variations complicates the situation, but does not alter the essential concept of a dynamic beach equilibrium.

INDIAN CANYON RANGE

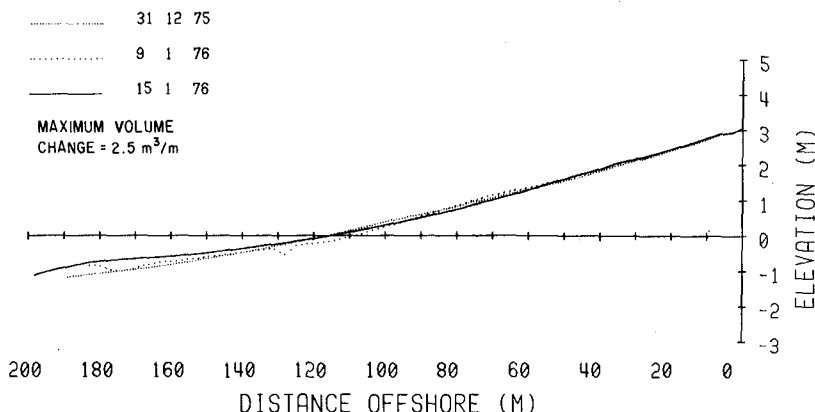


Figure 4. Typical equilibrium beach profiles for Torrey Pines Beach during winter wave conditions.

The second part of this study examines the response of the beach to varying wave and tidal conditions. Figures 6, 7, and 9 show three examples of the response of the beach to these varying forcing conditions. Figure 6 covers the time period from November 1973 through March 1974. The top part of the figure is a plot of the sand volume changes on the beach for the three ranges. The sand volume changes are those above a datum of 1 meter below mean sea level, and are relative to the surveys of 6 June 1972 as reported in Nordstrom and Inman (1975). The sand volume change is calculated from the backshore out to approximately 1 meter depth in these figures. The middle part of the figure plots the maximum daily tidal range (the tide at Torrey Pines is mixed with a pronounced diurnal inequality). The lower part of the figure is a plot of the wave energy variance $\langle \eta^2 \rangle$. The storms during this period were intense, and pronounced beach erosion occurred. After the storms of late December 1973, the beach eroded along all three ranges, and a winter-type profile was established. After that, North and South Ranges remained at a nearly constant level, while Indian Canyon continued to erode due to the action of rainwater flowing down the canyon immediately behind the rangeline. The maximum erosion is normally associated with the coincidence of large waves and high spring tide. The lower energy waves in late March were accompanied by accretion at all three ranges.

INDIAN CANYON RANGE

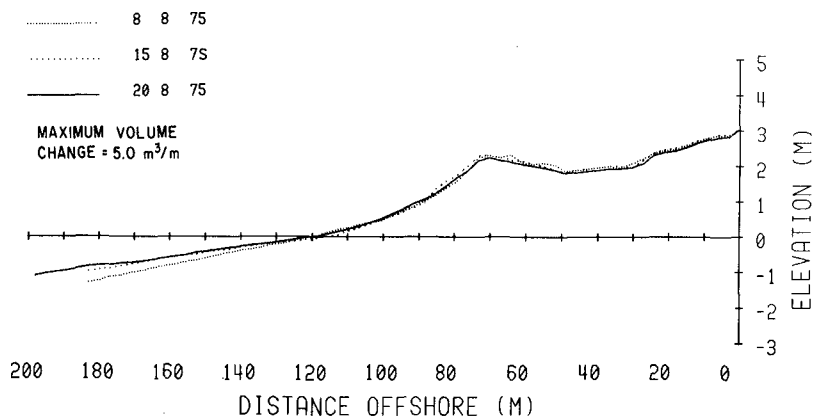


Figure 5. Typical equilibrium beach profiles for Torrey Pines Beach during summer wave conditions.

Figure 7 shows the gradual accretion of a summer beach by the lower energy waves that occurred during the spring and summer of 1975. As before, the bottom portion of the figure shows the wave energy density. The maximum daily tidal range is shown in the middle part of the figure, while the top part shows the sand volume changes for all three ranges. Several large wave events occurred during this time period. Except for these five events, the energy density is low. The volume changes indicate a gradual accretion on the beaches. The slow accretion during the summer is due in part to the periods of erosion of the beach associated with the occasional large waves of summer. Note that the high energy waves of 20-21 July 1975 which coincided with a spring tide caused erosion at all three ranges. The erosion accompanying the large waves of 5 May, 21 May, and 18 June 1975 was minimized in part because the large waves were coincident with neap tides, so that the waves were not as effective in eroding the berm. Had the tidal range been large, more erosion would have taken place.

Figure 8 shows a series of profiles measured from April through July 1975 at South Range. The berm that is evident in the 24 April 1975 (24-4-75) profile is gone in the 7 May profile, following the passage of the storm of 5 May 1975. Between 4 June and 27 June, there is a net progressive accretion of sand on the beach face, and a migration of sand shoreward as shown by the middle portion of Figure 8. The three profiles in July 1975 illustrate the pronounced berm accretion associated with spring tides and moderate wave action (compare profiles 8-7-75 and 15-7-75); and the subsequent rapid erosion associated with a brief period of high waves on 20 July 1975 (see profile 22-7-75).

BEACH FACE SAND VOLUME CHANGES

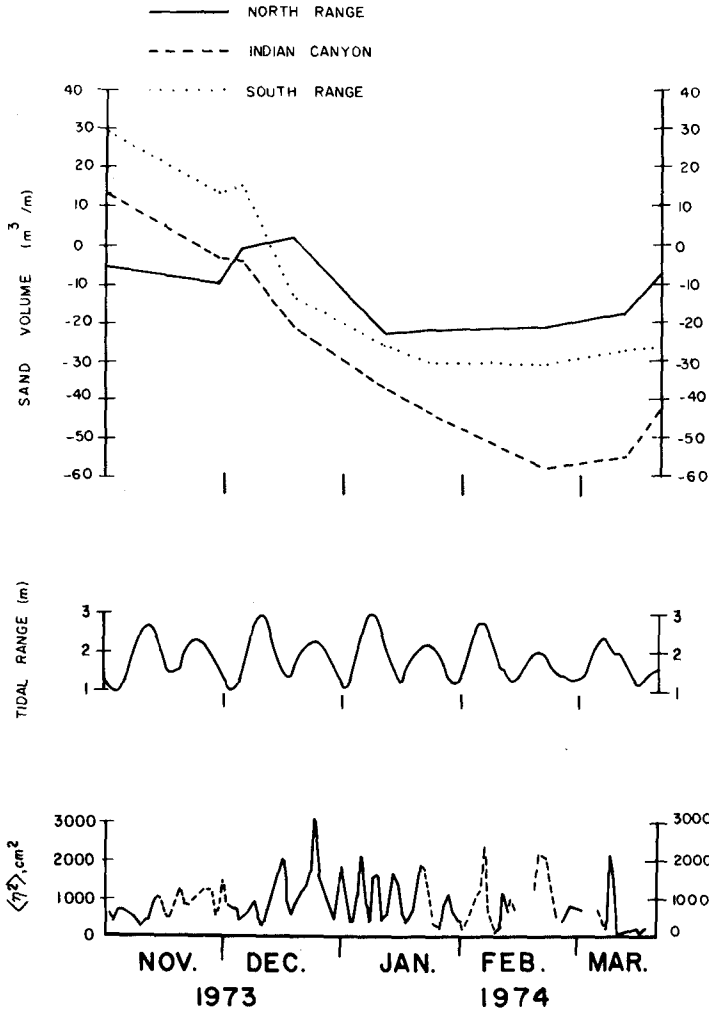


Figure 6. Changes in sand volume above the datum of 1 m below mean sea level relative to the surveys of 6 June 1972, compared with the maximum daily range and total wave energy density for the period of November 1973 through March 1974. The data for this figure was obtained from Nordstrom & Inman (1975).

BEACH FACE SAND VOLUME CHANGES

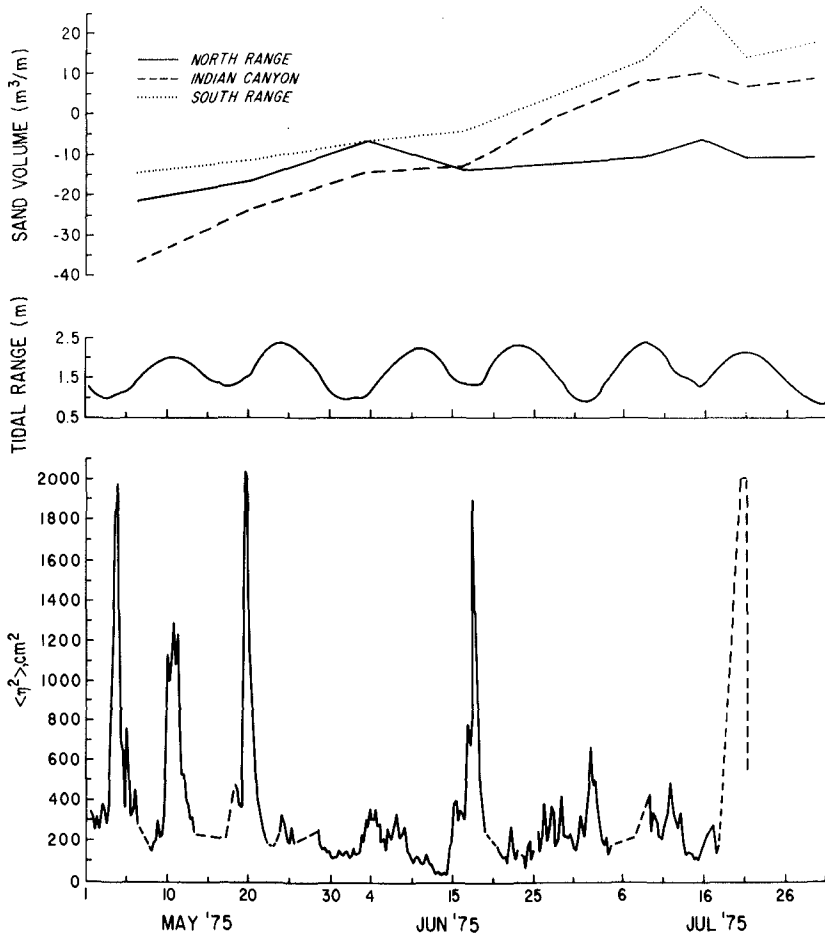


Figure 7. Changes in sand volume above the datum of 1 m below mean sea level relative to the surveys of 6 June 1972, compared with the maximum daily tidal range and total wave energy density for the period of May through July 1975.

SOUTH RANGE

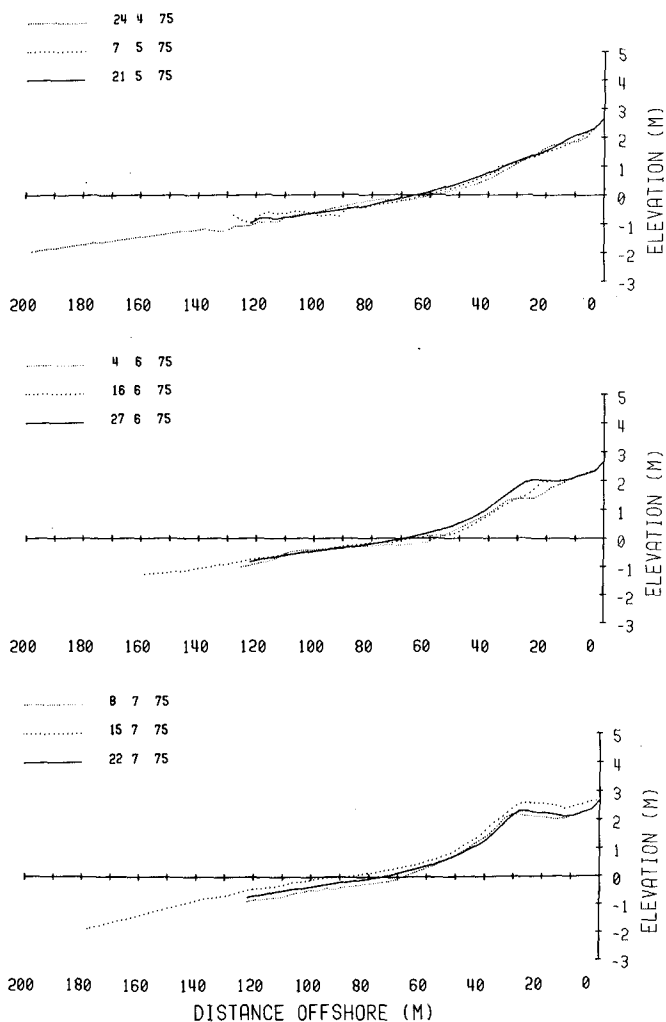


Figure 8. Sequence of beach profiles at South Range for period of May through July 1975.

Figure 9 shows the beach response for the period of December 1975 through February 1976. As before, the lower portion of the figure shows the wave energy density, the middle portion shows the maximum daily tidal range, and the upper portion shows the sand volume changes for the three ranges. Two distinct storms dominate the wave activity, one on 27 December and one on 30 December 1975. The first of these occurred during a period of neap tides and was accompanied by erosion at all three ranges. The second storm occurred during spring tides and was accompanied by more intense erosion at all three ranges. Following these storms, the volume changes at North and South Ranges were similar, and responded to the lower wave energies in the aftermath of the storms. Indian Canyon Range showed some erosion in mid-January, contrary to the trend at the other two ranges. This was due to erosion from rain runoff channeled onto the beach by the canyon behind the rangeline. The rain was accompanied by low energy waves, but the stream discharge was sufficient to erode the beach at Indian Canyon Range. Stream discharge across the beach was also responsible for the erosion in mid-February 1976 at Indian Canyon Range. North and South Ranges both eroded following the coincidence of large waves and spring tides on 14 February 1976. Indian Canyon showed an apparent accretion as the cut in the beach due to rain runoff was beginning to fill in.

Figure 10 shows a sequence of beach profiles at South Range for this same time period. The erosion associated with the storm of 30 December 1975 is apparent in the upper plot of the figure. The berm was totally eroded and the material deposited at a depth greater than -2 meters. The beach face slope decreased during the storm. The slight erosion associated with the 27 December 1975 storm can also be seen. The central plot shows that there was little change in the profile during January 1976, as the wave energy was similar during this time span. The lower plot shows a migration of sediment shoreward between 28 January and 11 February 1976, while there was slight erosion accompanying the larger waves of 14 February 1976. Similar plots for North Range and Indian Canyon Range show the same trends, except for the aforementioned erosion at Indian Canyon due to stream discharge across the beach.

CONCLUSIONS

A condition of approximate dynamic equilibrium is attained on natural sand beaches when the incident wave field remains approximately uniform over sufficiently long periods of time. Once achieved, a condition of approximate equilibrium may exist for periods of two weeks or longer, as evidenced by a minimal redistribution of sediment of 2 to 5 m³ per meter length of beach. Also, the variation in the distribution of sediment along a range perpendicular to the beach can be explained in large part by assuming these variations are due to onshore-offshore movement of sediment, and not a divergence or convergence in the longshore drift. Furthermore, these changes are correlated with the input wave conditions; in this paper they were examined only in terms of the total energy density of the waves, $\langle \eta^2 \rangle$.

The profile associated with large, winter-type waves is most rapidly achieved when large waves are coincident with spring tides. Large waves coincident with neap tides do not maximize the foreshore erosion.

Waves of low energy density build up the beach face and berm, creating a steep beach face slope. The most pronounced berm accretion is associated

BEACH FACE SAND VOLUME CHANGES

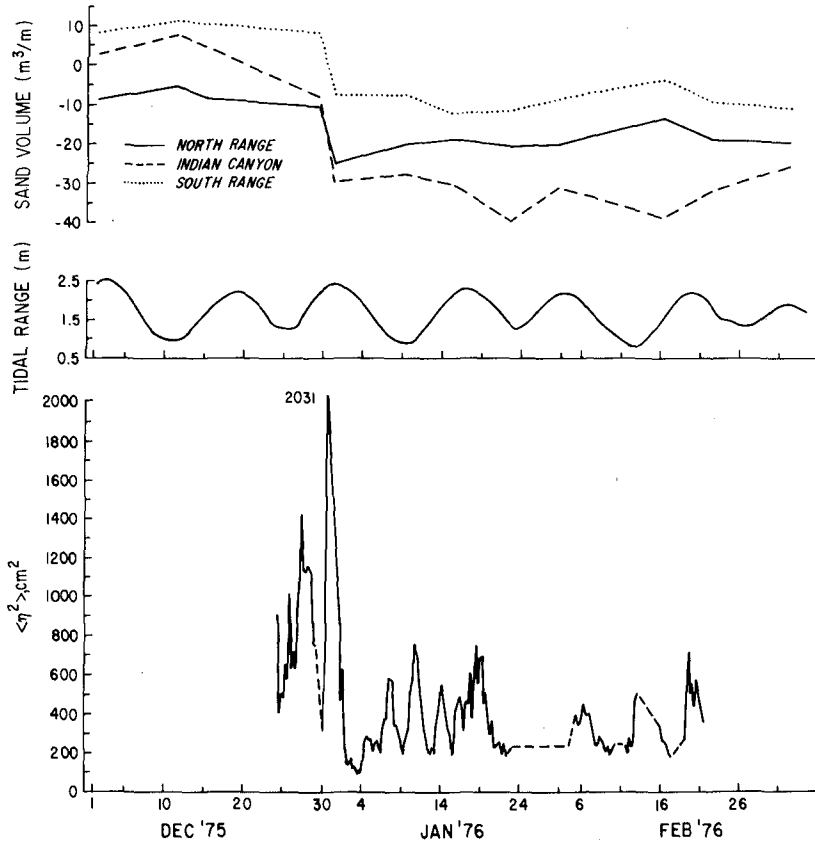


Figure 9. Changes in sand volume above the datum of 1 m below mean sea level relative to the surveys of 6 June 1972, compared with the maximum daily tidal range and total energy density for the period of December 1975 through February 1976.

SOUTH RANGE

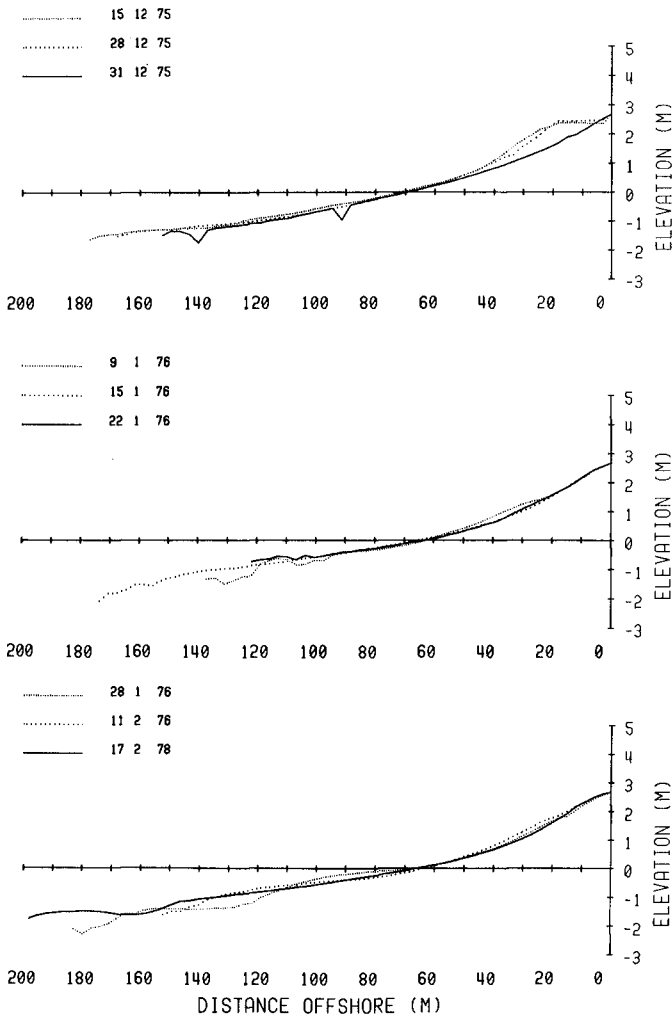


Figure 10. Sequence of beach profiles at South Range for period of December 1975, through February 1976.

with the coincidence of low to moderate wave intensity and spring tides. The profile which is associated with these low waves is rapidly modified by changing wave conditions such as storms.

ACKNOWLEDGMENTS

This study was supported by the Office of Naval Research, Geography Programs, under contract with the University of California.

REFERENCES

- Galvin, C. J. Jr. and P. Vitale, 1976, "Longshore transport prediction -SPM 1973 revision", Abstracts Volume, 15th Int. Conf. on Coastal Eng., Amer. Soc. Civil Eng., p 133-35.
- Gorsline, D. S., 1966, "Dynamic characteristics of west Florida Gulf Coast beaches", Marine Geol., vol 4, p 187-206.
- Inman, D. L., 1953, "Areal and seasonal variations in beach and nearshore sediments at La Jolla, California", U. S. Army Corps of Eng., Beach Erosion Board, Tech Memo 39, 82 pp.
- Inman, D. L. and R. A. Bagnold, 1963, "Littoral Processes", p 529-553 in M. N. Hill (ed) The Sea, vol 3, The Earth Beneath the Sea, Interscience Publ., 963 pp.
- Inman, D. L., P. D. Komar and A. J. Bowen, 1969, "Longshore transport of sand", Proc. 11th Conf. on Coastal Eng., Amer. Soc. Civil Eng., vol 1, p 298-306.
- Inman, D. L., C. E. Nordstrom, and R. E. Flick, 1976, "Currents in submarine canyons: an air-sea-land interaction", p 275-310, Annual Review of Fluid Mech., vol 8, 418 pp.
- Johnson, J. W., 1949, "Scale effects in hydraulic models involving wave motion", Trans. Amer. Geophys. Union, vol 30, p 517-25.
- Kemp, P. H., 1961, "The relationship between wave action and beach profile characteristics", Proc. 7th Conf. on Coastal Eng., Amer. Soc. Civil Eng., p 262-77.
- Komar, P. D. and D. L. Inman, 1970, "Longshore sand transport on beaches", Jour. Geophys. Res., vol 75, no 30, p 5914-27.
- Longuet-Higgins, M. S., 1970, "Longshore currents generated by obliquely incident sea waves, parts 1 and 2", Jour. Geophys. Res., vol 75, no 33, p 6778-6801.
- Lowe, R. L., D. L. Inman, and B. M. Brush, 1972, "Simultaneous data system for instrumenting the shelf", Proc. 13th Conf. on Coastal Eng., Amer. Soc. Civil Eng., p 95-112.

- Nordstrom, C. E. and D. L. Inman, 1975, "Sand level changes on Torrey Pines Beach, California", U. S. Army Corps of Eng., Coastal Eng. Res. Center, Misc. Paper No 11-75, 166 pp.
- Pawka, S. S., D. L. Inman, R. L. Lowe, and L. C. Holmes, 1976, "Wave climate at Torrey Pines Beach, California", U. S. Army Corps of Eng., Coastal Eng. Res. Center, Tech Paper No 76-5, 372 pp.
- Rector, R. L., 1954, "Laboratory study of the equilibrium profile of beaches", U. S. Army Corps of Eng., Beach Erosion Board, Tech Memo No 41, 38 pp.
- Saville, T., 1957, "Scale effects in two-dimensional beach studies", Int. Assoc. Hydraulic. Res., Lisbon, Portugal.
- Scott, T., 1954, "Sand movement by waves", U. S. Army Corps of Eng., Beach Erosion Board, Tech Memo No 48, 37 pp.
- Shepard, F. P., 1950, "Beach cycles in Southern California", U. S. Army Corps of Eng., Beach Erosion Board, Tech Memo No 20, 26 pp.
- Sonu, C. J. and J. L. Van Beek, 1971, "Systematic beach changes on the outer banks, North Carolina", Jour. Geol., vol 79, p 416-425.
- Watts, G. M., 1954, "Laboratory study on the effect of varying wave periods on the beach profiles", U. S. Army Corps of Eng., Beach Erosion Board, Tech Memo No 53, 21 pp.
- Winant, C. D. and D. G. Aubrey, 1976, "Stability and impulse response of empirical eigenfunctions", Proc. 15th Int. Conf. on Coastal Eng., Amer. Soc. Civil Eng.
- Winant, C. D., D. L. Inman, and C. E. Nordstrom, 1975, "Description of seasonal beach changes using empirical eigenfunctions", Jour. Geophys. Res., vol 80, no 15, p 1979-86.
- Ziegler, J. M., C. R. Hayes, and S. D. Tuttle, 1959, "Beach changes during storms on outer Cape Cod, Massachusetts", Jour of Geol., vol 67, no 3, p 318-336.