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Distribution of sand within selected littoral cells of the Pacific Northwest

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Beach sand acts as a buffer to wave energy, protecting the shoreline from erosion. Estimates of the quantity and distribution of beach sand in littoral cells of the PNW are critical to the understanding and prediction of shoreline erosion or accretion. This study was initiated in order to: 1) document the distribution of sand in littoral cells of the Pacific Northwest; 2) determine the factors which have brought

about these present distributions; and 3) address the relationship of beach sand distribution to shoreline stability.

Eight littoral cells were chosen to represent the variety of smaller cells present in the Pacific Northwest. The eight littoral cells are: the La Push and Kalaloch Cells of Washington, the Cannon Beach, Otter Rock, Newport, and Gold Beach Cells of Oregon, and the Crescent City and Eureka Cells of Northern California. Aerial photographs were analyzed for the eight cells, utilizing photo sets taken before and after the 1983-1987 El Niño-related erosion event. Data on beach width and orientation and on terrace location and height were collected from maps and aerial photographs for analysis. Forty-six beaches in the eight littoral cells were surface profiled to mean low low water using standard surveying techniques, and surveyed geophysically to determine the depth to the wave cut platform. The results of the surveys were used to estimate the area and volume of sand in each of the selected cells. Slopes of the beach face and beach widths were determined from the survey results. Sand samples were collected at mid-beach face from 48 beaches within the selected cells as were representative samples from 22 terraces. Grain size analyses were performed for the collected beach and terrace samples in order to develop information on possible sources and direction of transport for the beach sand.

Results of the study indicate that beach sand distribution within littoral cells of the Pacific Northwest varies as a function of: 1) proximity to sand sources such as rivers, terraces, and the presence of relict sands; 2) location of sand sinks such as dune fields and estuaries; 3) shoreline orientation; 4) shoreline configuration; 5) the direction of net sediment transport within the littoral zone; and 6) the location of barriers to sand transport. Based on sand distributions and grain size trends, the net transport direction of sediment is to the north within the Cannon Beach, Otter Rock, Newport, Crescent City, and Eureka Cells. The net transport direction is to the south for the northern third of the Kalaloch Cell, while the southern two-thirds show net transport to the north. The Gold Beach Cell shows both north and south transportation of sediments away from the abrupt change in shoreline orientation in the Redhouse Beach to High Tide Beach area. The net littoral drift of the La Push Cell similarly shows a diversion of beach sand to the south and north from an area near the middle of the cell.

The potential for erosion of a given area is related to: 1) the total quantity of source sands available on a given beach, and more importantly, 2) the quantity of sand above mean high high water (MHHW) on each beach. The sand above MHHW is important because it is this sand which acts as the final buffer to storm wave attack. There is a high correlation between areas experiencing erosion and those areas which have the least sand in storage above mean high high water within a littoral cell.

DISTRIBUTION OF SAND WITHIN SELECTED LITTORAL CELLS OF THE PACIFIC NORTHWEST

by

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INTRODUCTION

Estimates of beach sand distribution in littoral cells are critical to the understanding and prediction of shoreline erosion or accretion in dynamic coastal zones (Inman and others, 1986). Beach sand acts as a buffer to incident wave energy, thereby protecting unconsolidated terrace, dune, and other backshore deposits from erosion by storm surges (Komar and others, 1976a). The longshore distribution of sand along the Pacific Northwest coast might vary as a function of local sand sources and sinks, barriers to longshore transport, orientation of coastline, and position within the littoral cell (Bodin, 1982; Clemens and Komar, 1988a; Peterson and others, 1987). However, few previous investigations have addressed beach sand distribution in the PNW. In this study, the distribution of sand will be documented for eight littoral cells in the PNW. An attempt has been made to relate sand distribution to shoreline erosional history and to the potential for future erosion in the eight study cells.

This study was initiated in order to (1) document the distribution of sand in littoral cells of the Pacific Northwest; (2) determine the factors which have brought about these distributions; and (3) address the relationship of beach sand distribution to shoreline stability (Peterson and others, 1987). Aerial photographs were analyzed for the eight study cells, utilizing photo sets taken before and after the 1983-1987 El Niño-related erosion event as documented by Komar (1986) and Peterson and others (1990a). Data on beach width and orientation, dune field location and extent, terrace location and height were collected from maps and aerial photographs. The data was entered into EXCEL spreadsheets for analysis and eventual database input. Forty-six beaches in eight littoral cells were surface profiled to mean low low water and surveyed by seismic refraction to determine the depth to the wave cut platform. The survey data were used to estimate (1) the volume of sand occupying beach segments within each cell and (2) the total volume of sand in each of the eight selected cells. Grain size analyses were performed for the selected beach and terrace samples in order to yield information on possible sources and direction of transport for the beach sand.

Results of the study indicate that beach sand volume varies as a function of: (1) proximity to sand sources such as rivers, terraces, and the presence of relict sands; (2) location of sand sinks such as dune fields and estuaries; (3) shoreline orientation; (4) shoreline configuration; (5) the direction of net sediment transport within the littoral zone; and (6) the location of barriers to sand transport.

The potential for future erosion in study cells is strongly related to: (1) the total quantity of source sands available in a given area, and more importantly; (2) the quantity of sand above mean high high water (MHHW) on each beach segment.

BACKGROUND

SIGNIFICANCE OF BEACH SAND DISTRIBUTION

Beaches serve as the interface between the dynamic ocean and the relatively stable continent. Waves generated offshore constantly attack the shoreline with erosive energy. The configuration of beaches and sea cliffs change in response to forces exerted on them by wave action, ocean tides, eustatic sea level change, landsliding, surface weathering, vertical tectonic movement, and the effects of man (Komar and others, 1976a; Komar and others, 1976b). The sand on a beach acts as a buffer between the ocean and the land, absorbing and dispersing the forces of wave impact over a large area, and thus lessening its ability to focus erosive energy on the bases of sea cliffs and bluffs. Shoreline instability becomes a concern when man imposes a sense of permanence to this dynamic zone by building "permanent" structures. Today the Pacific Northwest coastal region faces many shoreline problems associated with the local variability of beach sand buffer and associated shoreline erosion or dune accretion (Komar, 1983 for example). Coastal land use problems include: (1) private and public shoreline zoning and set backs for development; (2) shoreline protection structures (private and public);

and (3) management of source sands. The management of source sands includes disposal of dredge sands, trapping of river source sands behind dams and shoreline protection structures (groins, jetties, revetments, and sea walls), and shoreline protection effects on new sand supply from sea cliff sources.

In order to answer these and other shoreline management questions, it is first necessary to ask: What are the abundances and distributions of the sands on our beaches? How does the distribution of sand affect shoreline configuration and short-term sea cliff stability? Does sand grain size affect a beach's potential for erosion? What is the net transport direction and rate of movement of beach sand in the cells? What controls the stability of shorelines, and what role does the abundance and distribution of beach sand play? This study is aimed at the documentation and analysis of the distribution of beach sands in the Pacific Northwest as a first step toward answering the above questions. Beach sand and shoreline parameters such as orientation, slope, width, etc. are documented and analyzed for their relationships to sand distribution and shoreline stability.

STUDY AREA

In an attempt to gain a regional perspective on the longshore distribution of sand in the Pacific Northwest, eight littoral cells were chosen between Cape Mendocino in northern California and Cape Flattery, Washington (Figure 1). The Pacific Northwest lies in a geologically diverse and tectonically active zone at the convergent margins of the Juan de Fuca (oceanic) and North American (continental) plates (Figure 2). The coastal physiographic subprovinces of the Pacific Northwest are: the Olympic Mountains, the Coast Ranges, and the Klamath Mountains (Figure 3). Vertical and lateral motions associated with the subduction of the Gorda and Juan de Fuca Plates beneath the continent have obducted or uplifted a complex assortment of lithologic units along the continent's edge, forming the three coastal subprovinces. The structures present within these zones influence the shoreline morphology. For example, resistant headlands are juxtaposed to less resistant terrace sands along faults and at volcanic centers (Peterson and others, 1986a). The lithology of these subprovinces is reflected in the composition of beach sands in the Pacific Northwest because drainage basins in these areas have ultimately supplied much of the sediment now present on the beaches. Low-grade metamorphism occurred during the underthrusting of the Olympic Mountains, which consist of complexly folded and disrupted basalts and sediments beneath less disturbed

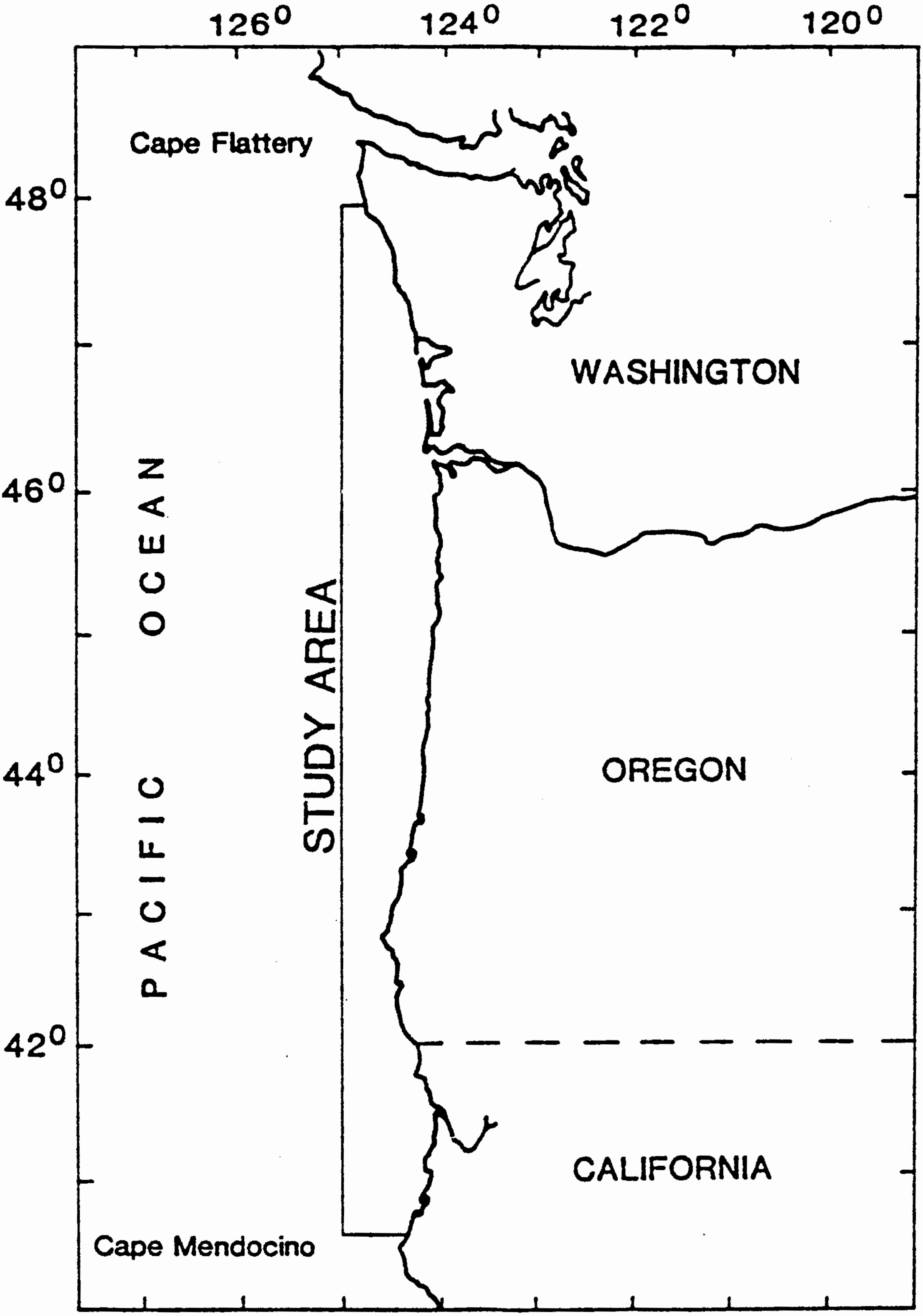


Figure 1. Study area location.

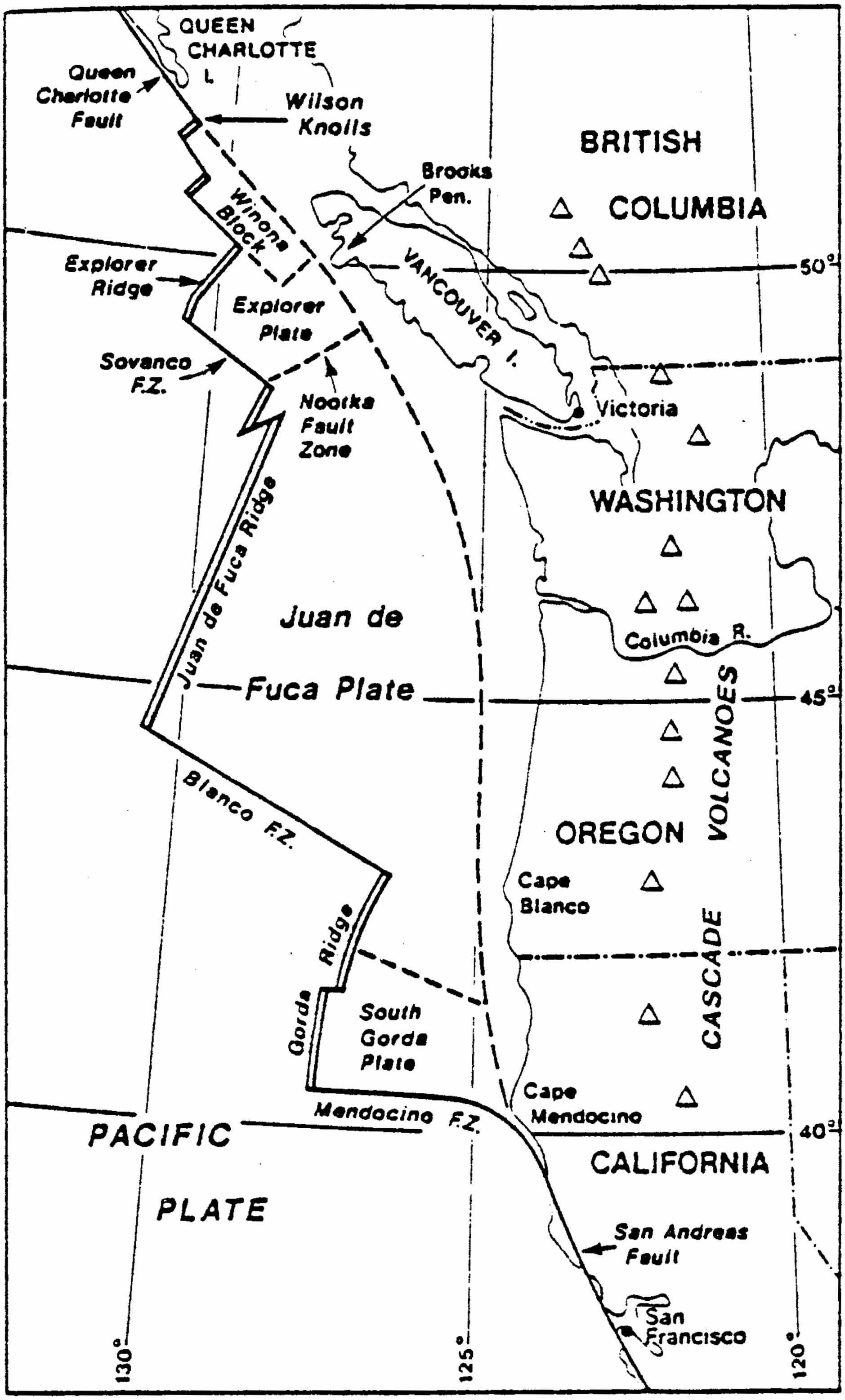


Figure 2. Plate tectonics map of the Pacific Northwest. From Rogers, 1988.

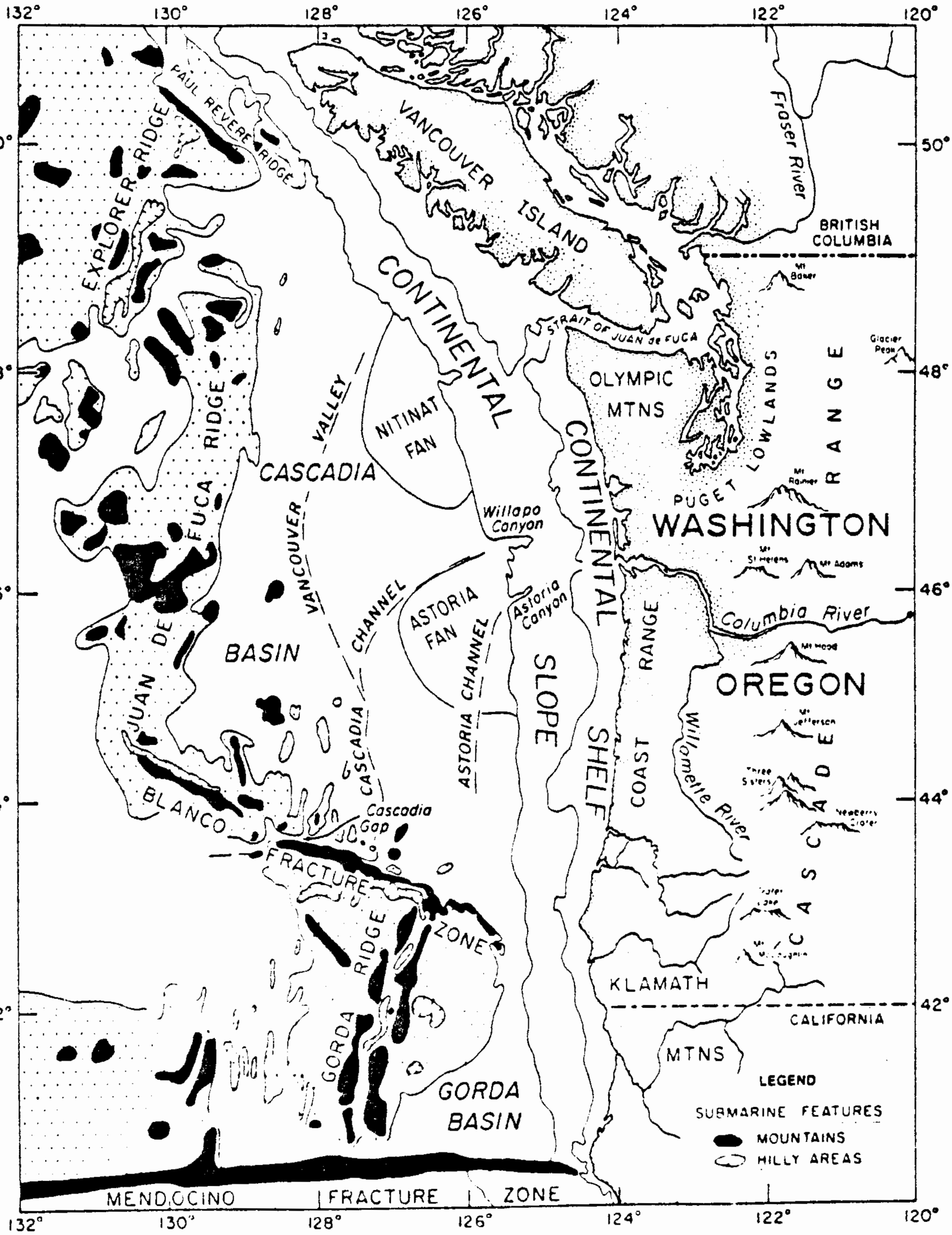


Figure 3. Physiographic features of the Pacific Northwest. From Kulm and others, 1984.

Tertiary sedimentary and volcanic rocks (Muhs and others, 1987). The Klamath Mountains of southwestern Oregon and northwestern California consist of at least four imbricated thrust sheets: 1) the Western Paleozoic and Triassic Belt, 2) the Western Jurassic Belt, 3) the Central Metamorphic Belt, and 4) the Eastern Klamath Belt. These tectonic packages are bounded by east-dipping thrust faults and are composed of sedimentary and volcanic rocks which have been subjected to high pressure-low temperature metamorphism.

The area between the Klamath and Olympic Mountains is occupied by the Oregon and Washington coast range. Beginning in the early Eocene and extending to the middle Eocene, extrusion of basalts and concurrent sedimentation began to form an island arc. Continued volcanism and sedimentation occurred during the late Eocene. Separating the Oregon and Washington sections of the coast range is the Columbia River which has the largest discharge of any river in the Pacific Northwest.

Large spits such as the Ocean Shores and Long Island Spits in southwestern Washington front significant portions of the coastline where sediment supply from the Columbia River has been plentiful. Spit orientations (to the north or south of inlets) are generally equally distributed in the study area. This has led some coastal researchers to believe that no net transport of sediments is occurring along this coastline (for example Komar and others, 1976b).

Multiple uplifted marine terraces are present throughout the coastal zone of the Pacific Northwest. The terraces are discontinuous, with height range controlled in part by local tectonic uplift.

Continuous beaches in the Pacific Northwest range in size from less than 100 meters long and 20 meters wide to more than 80 kilometers long and more than 400 meters in width from the bluff to mean low low water (see Results). In the Oregon Klamath Mountains and the northern Olympic Peninsula, beaches are generally small and discontinuous, occupying coves eroded from the less resistant rock. Beaches of northernmost California, central Oregon, and southwest Washington are generally continuous and are broken by resistant headlands which may inhibit or eliminate the longshore transport of sand. Sand can thus be confined to the area between the headlands forming a littoral cell, or zone of restricted longshore sand transport. Some beaches, such as those in the Florence to Reedsport area of Oregon, have extensive backdune areas storing large quantities of sand (Cooper, 1958) while some other beaches in northern California and southern Oregon are bordered by highly resistant cliffs attaining heights of over a hundred meters. Some beaches are apparently accreting, such as the Chapman Beach area of the Cannon Beach Cell, while in many other areas, shoreline protection measures are being taken to stop the erosion of the sea cliffs or dunes.

The littoral zone is the zone bounded by high and low tide. A littoral cell is a continuous area within the coastal zone in which sand and other beach sediment may move under the influence of waves and currents. A complete cycle of littoral sedimentation is formed which includes sediment sources, transportation paths, and sediment sinks (Inman and others, 1986). Littoral cells are generally bounded by the protrusion of resistant headlands seaward of the recessed shoreline, but may also be bounded by a series of lesser protrusions or even large changes in shoreline orientation. Such protrusions restrict sand movement along shore, thus confining sand to discrete zones. The cell boundaries in this study were determined through analysis of beach width from maps and aerial photographs, and finally through visual inspection of beach width and grain size changes between sites visited. Most of the cells chosen have headlands as their endpoints. Others, such as Seal Rocks at the south end of the Newport Cell, consist of a series of small barriers to longshore transport of sand. Cells were chosen in an attempt to represent the variation in cell types present in the Pacific Northwest. Factors used in the final selection of cells included cell latitude, geomorphology, orientation, length, apparent sand source(s), sand quantity, erosional history, and accessibility. The littoral cells chosen for detailed study in this project are (Figure 4): (1) the La Push Cell; (2) the Kalaloch Cell; (3) the Cannon

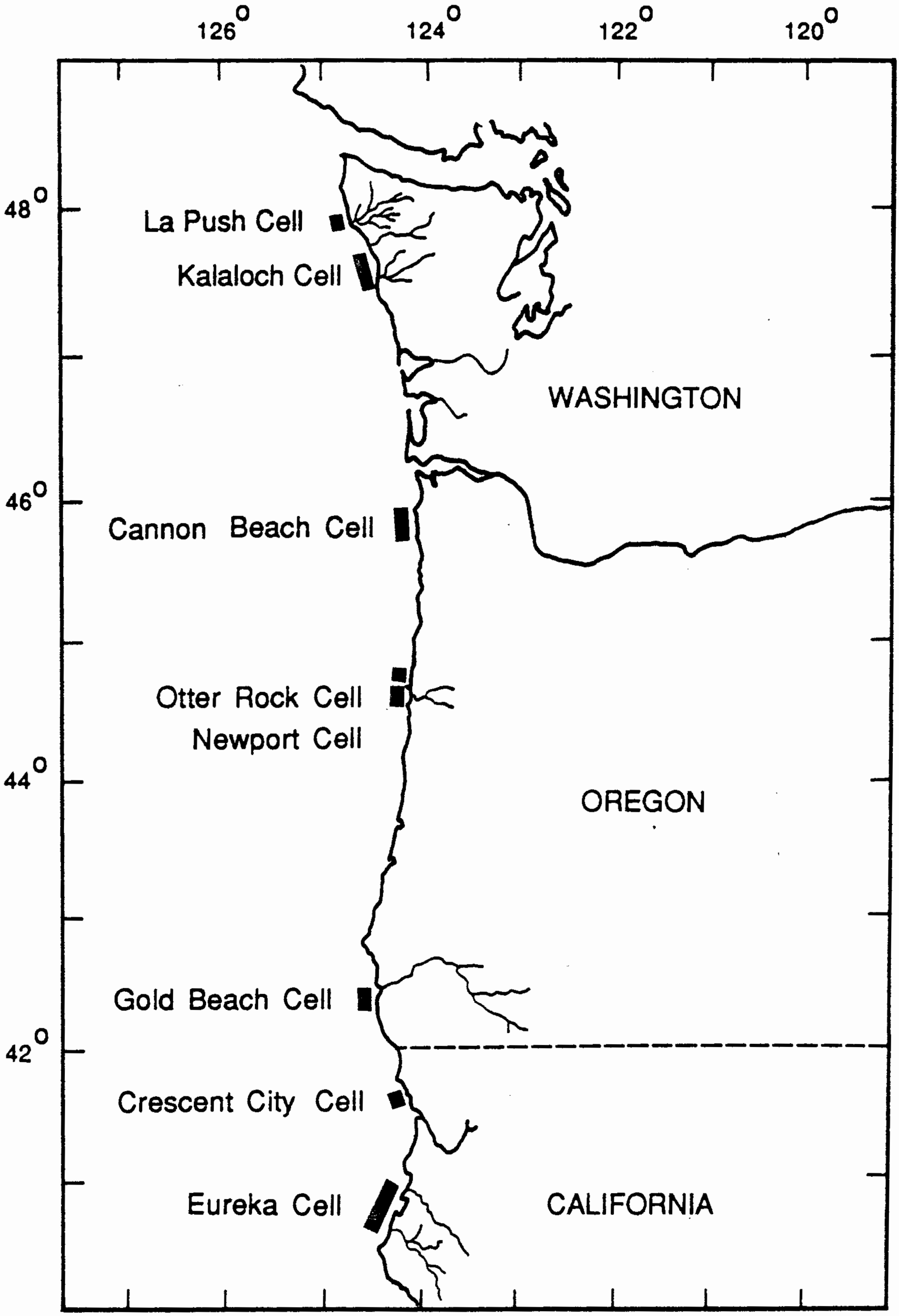


Figure 4. Location of littoral cells studied.

Beach Cell; (4) the Otter Rock Cell; (5) the Newport Cell; (6) the Gold Beach Cell; (7) the Crescent City Cell; and (8) the Eureka Cell.

1) The La Push Cell is approximately 5.6 km in length and extends from N5311600, E376050 (Universal Transverse Mercator coordinate system) at the north end of the cell to N5305600, E378000 at the south (Figure 5). The Quillayute River, the largest drainage feature in this cell, enters the beach near the south end of the cell (4.3 km from the north cell boundary) and is by far the largest river entering the cell. Ellen Creek, a much smaller stream, enters near the north end of the cell (1.1 km from the north cell boundary). A terrace which ranges from 60 to 100 meters in height runs the length of the northern half of the cell; while large sea cliffs front the southern half of the cell. The cell is bounded by an unnamed headland to the north and by the Quateata headland to the south. Current erosion is limited to the area north of the Quillayute River entrance (Tom Terich, personal communication, 1989) in the La Push Cell while the southern portion of the cell contains a narrow dune field between 35 and 93 meters in width.

2) The Kalaloch Cell is approximately 42 km in length and extends from N5291150, E390900 at the north end of the cell, to N5250400, E399600 at the south (Figure 6). The cell is bounded by Hoh Head at the north and Pratt Cliff at the south. The largest river in the Kalaloch Cell is the

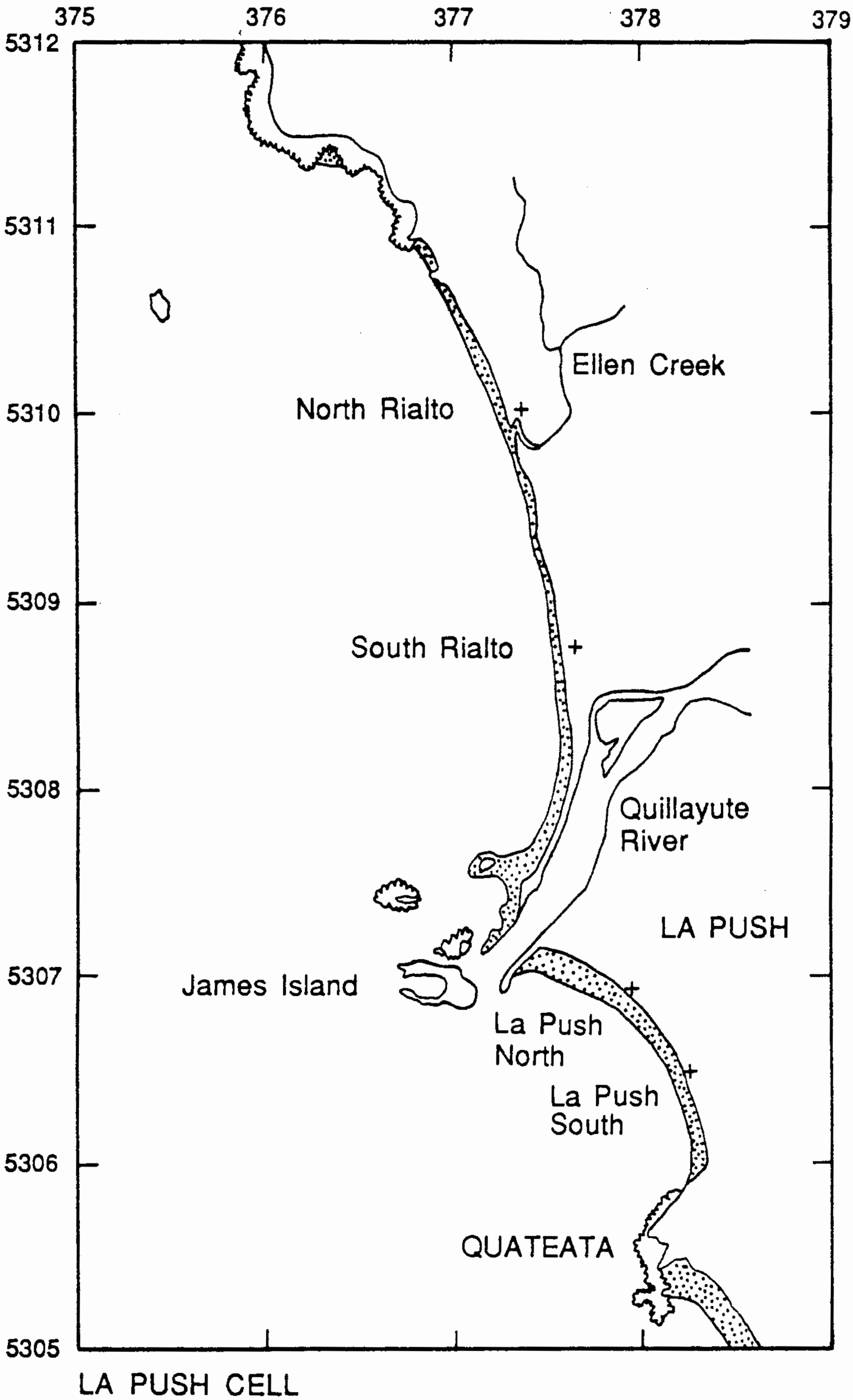


Figure 5. Map of the La Push Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

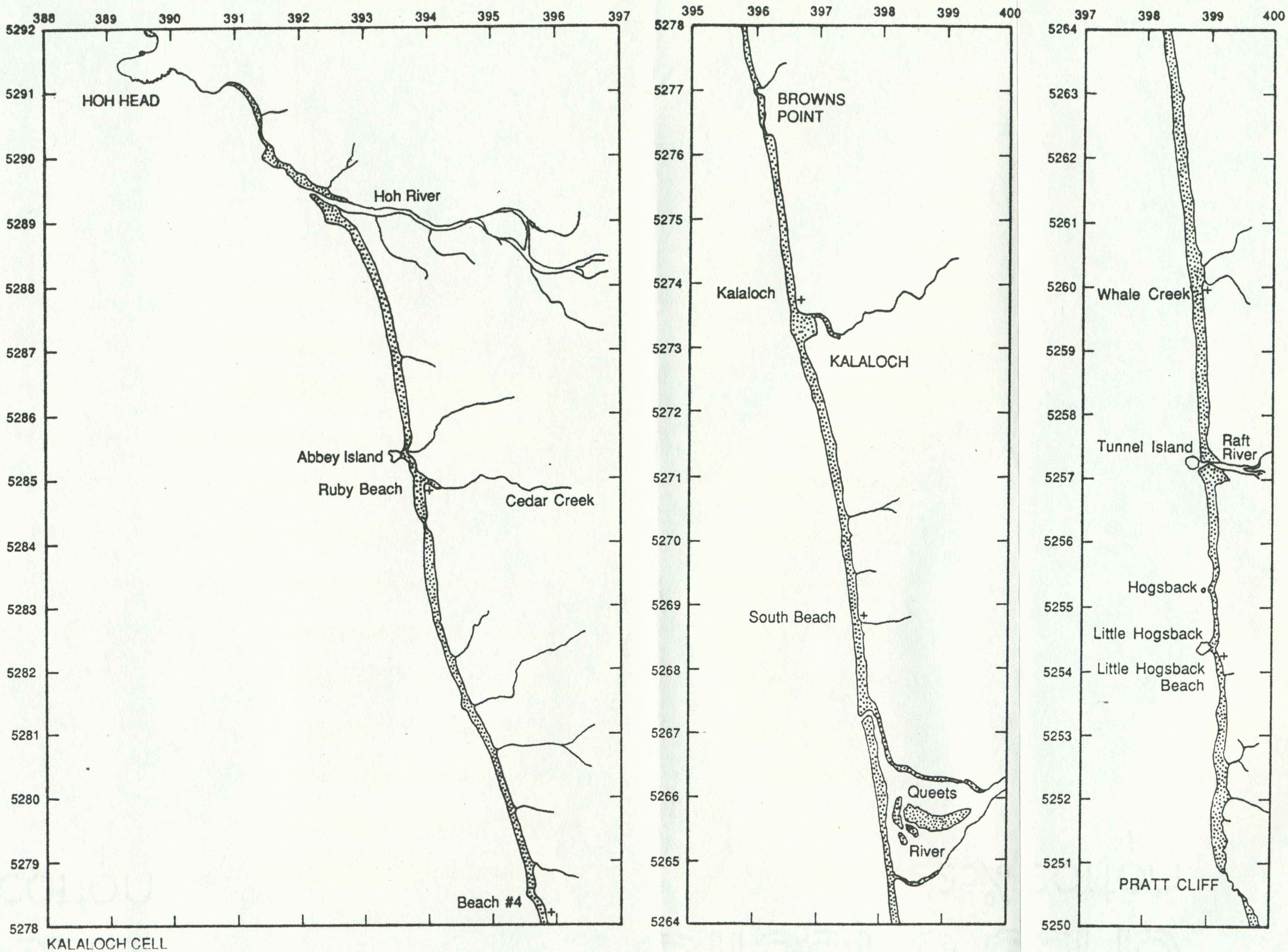


Figure 6. Map of the Kalaloch Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

Queets River which enters the beach zone approximately 26 km from the northern headland. Other smaller drainages which enter the cell include Cedar Creek, Steamboat Creek, and Whale Creek. A terrace ranging from approximately 5 to 90 meters in height runs the entire length of the cell except where eroded by the larger drainage systems.

3) The Cannon Beach Cell extends from N5084150, E424900 to N5069700, E424650 and is approximately 15 km in length (Figure 7). The cell is bounded by Tillamook Head to the north and by Cape Falcon to the south. Smaller headlands at the southern portion of the cell (Arch Cape and Hug Point) might partially restrict sand transport. The cell has no large drainage systems. A low terrace up to 30 meters in height extends intermittently from the southern cell boundary to the Ecola Creek entrance. North of Ecola Creek, the terrace is covered by a large dune complex which reaches nearly 20 meters in height. The city of Cannon Beach borders much of the northern portion of the littoral cell. Portions of the cell have experienced significant erosion (Tolovana Beach) while residents of the Chapman Beach area have had to remove sand from the growing dune complex (Rosenfeld, 1988).

4) The Otter Rock Cell stretches from N4955400, E415900 at the north to N4947400, E414500 at the south (Figure 8). The cell is nearly eight km in length and is bounded by Otter Crest at the north and Yaquina Head at the

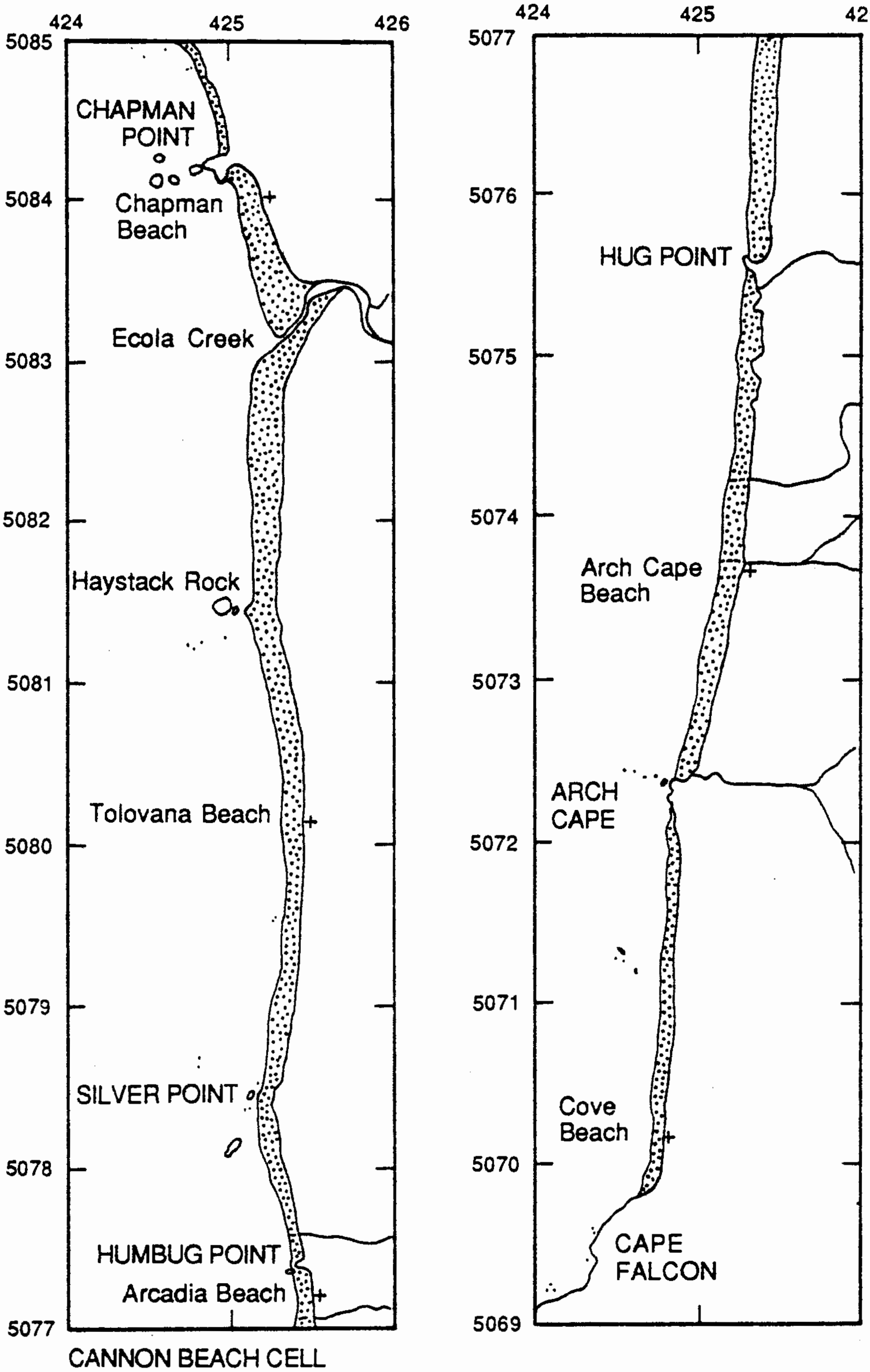


Figure 7. Map of the Cannon Beach Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

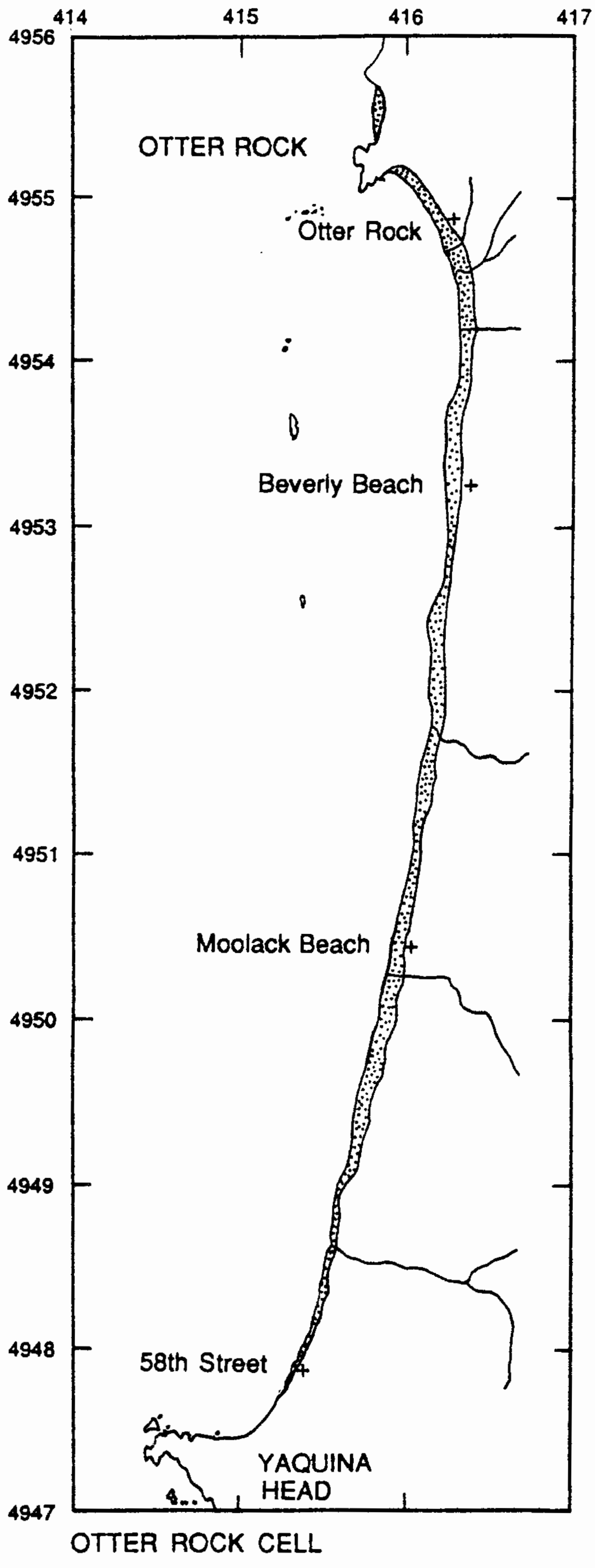


Figure 8. Map of the Otter Rock Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

south. Terraces ranging in height from 18 to 40 meters run the length of the cell. No streams or rivers enter the Otter Rock Cell. The town of Otter Rock is situated upon a terrace surface at the northern end of the cell.

5) The Newport Cell lies between N4947100, E415800 and N4927250, E413850 (Figure 9). Yaquina Head bounds the cell to the north while Seal Rock is the apparent southern cell boundary (Peterson and others, 1990a). The Newport Cell is approximately 20 km in length and has a prominent terrace which runs the length of the cell except in the vicinity of Yaquina Bay. The terrace ranges between approximately 6 and 43 meters in height. The largest drainage system in the cell is the Yaquina River which enters the cell by way of Yaquina Bay which is a reported sand sink (Kulm and Byrne, 1966). The bay entrance is approximately 6.5 km from Yaquina Head to the north. Lost Creek enters the coast through a small break in the terrace surface approximately 5.5 km from the southern end of the cell. The only other significant drainage system is Beaver Creek which enters the cell approximately 3 km from the southern cell boundary.

6) The Gold Beach Cell (Figure 10) begins at Otter Point (N4702000, E382000) and continues south approximately 14 km to Cape Sebastian (N4688150, E382450). The largest drainage in the cell is the Rogue River which enters the coastal zone approximately five km from the northern cell boundary. Hunter's Creek enters the cell approximately six

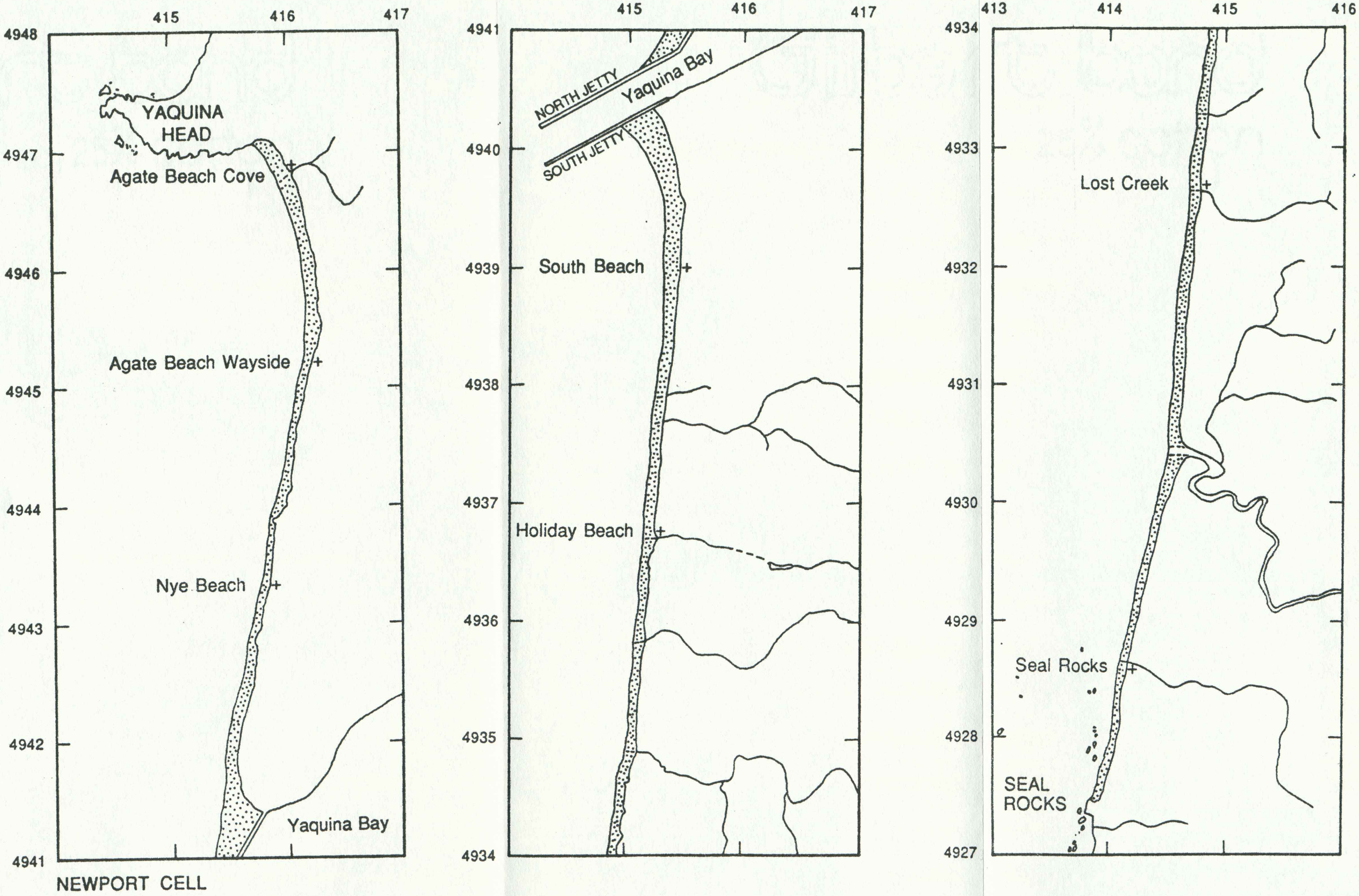


Figure 9. Map of the Newport Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

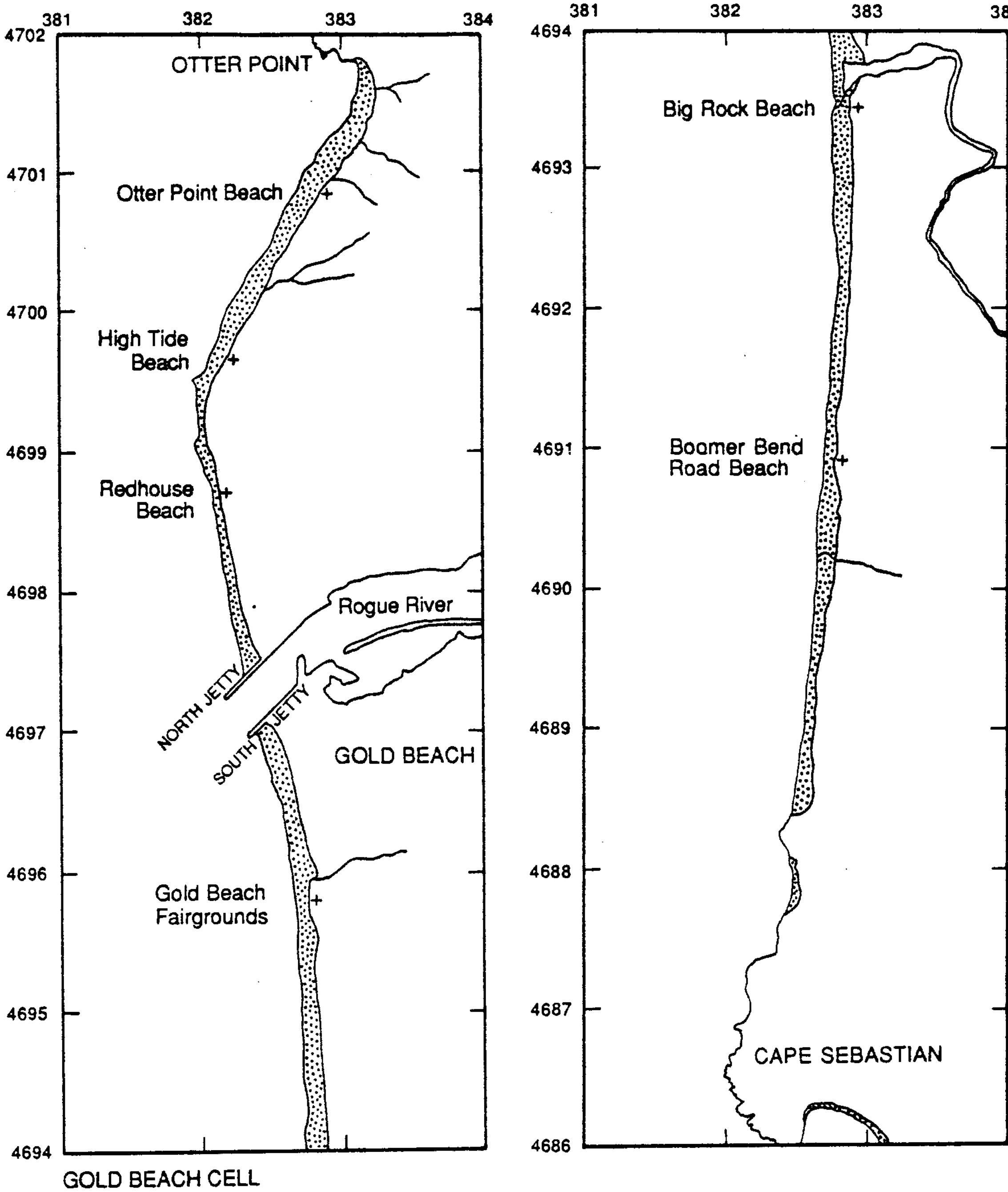


Figure 10. Map of the Gold Beach Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

km from Cape Sebastian to the south. A low terrace extends from the Rogue River entrance north to Otter Point where it reaches nearly 45 meters in height.

7) The Crescent City Cell (Figure 11) lies in a well-sheltered cove created by the Crescent City Harbor breakwater structures and the Point St. George headland to the north (N4621950, E400300) and White Knob to the south (N4617200, E405000). The cell is approximately 5 km in length and contains no significant drainage systems. A low terrace (6-20 m in height) is present in the southern half of the cell and increases in height to the south.

8) The Eureka Cell (Figure 12), the largest cell studied in this project, extends nearly 66 km from Jepona Point on Trinidad Head at the north (N4543600, E405750) to False Cape (N4485250, E382650). The Eel River enters the cell approximately 49 km from the northern headland and is the dominant drainage system in the Eureka Cell. The Mad River is the next largest drainage system and enters the cell approximately 8 km from the northern headland. An extremely long spit system, nearly 50 km in length, occupies the center of the cell, forming two large tidal inlets: Humboldt Bay and Eel River estuary. No significant tributaries enter the Humboldt Bay.

In addition to the 46 beaches sampled and surveyed in the eight selected littoral cells, 87 beaches over the entire coastline of the Pacific Northwest were studied

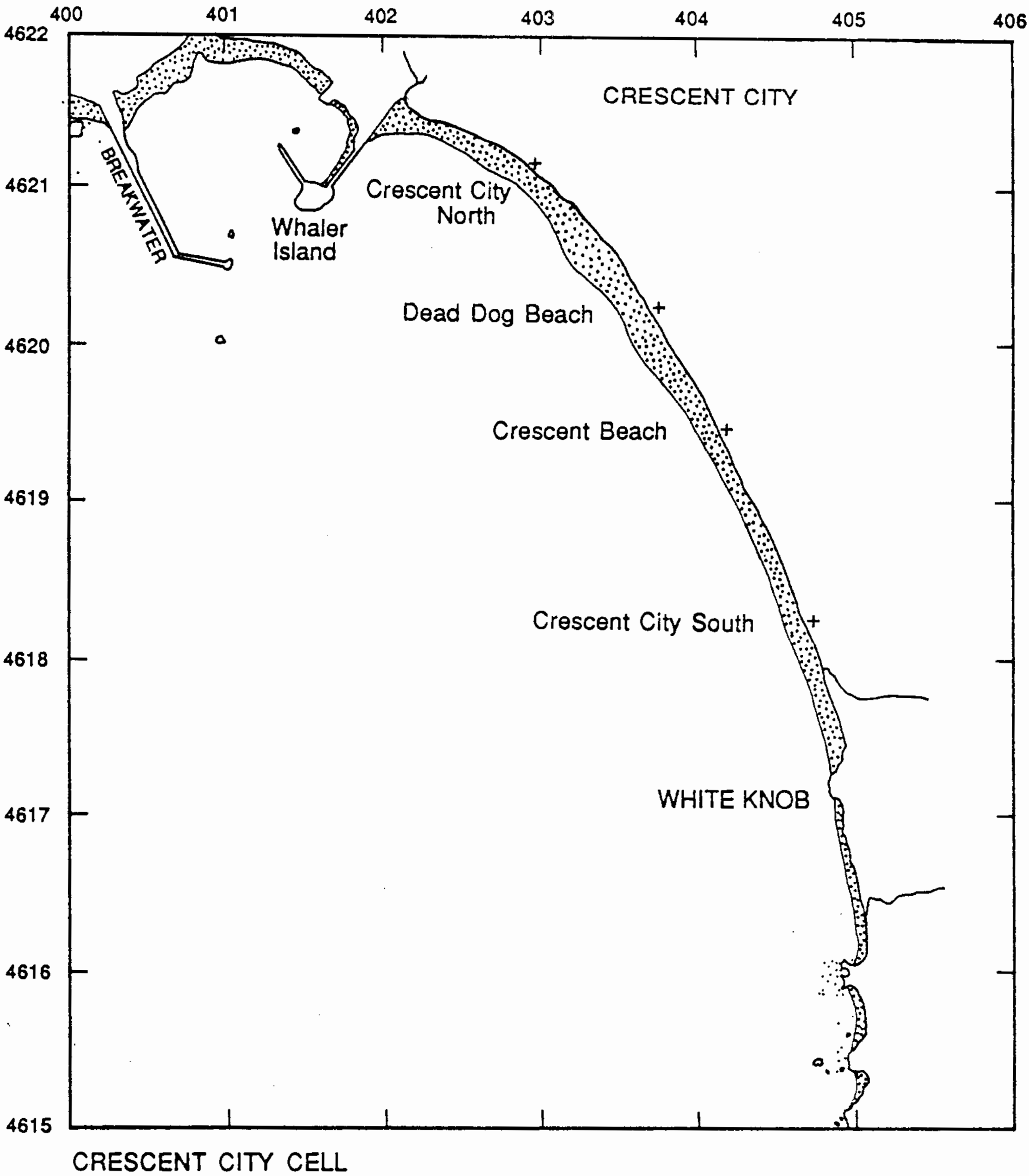


Figure 11. Map of the Crescent City Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

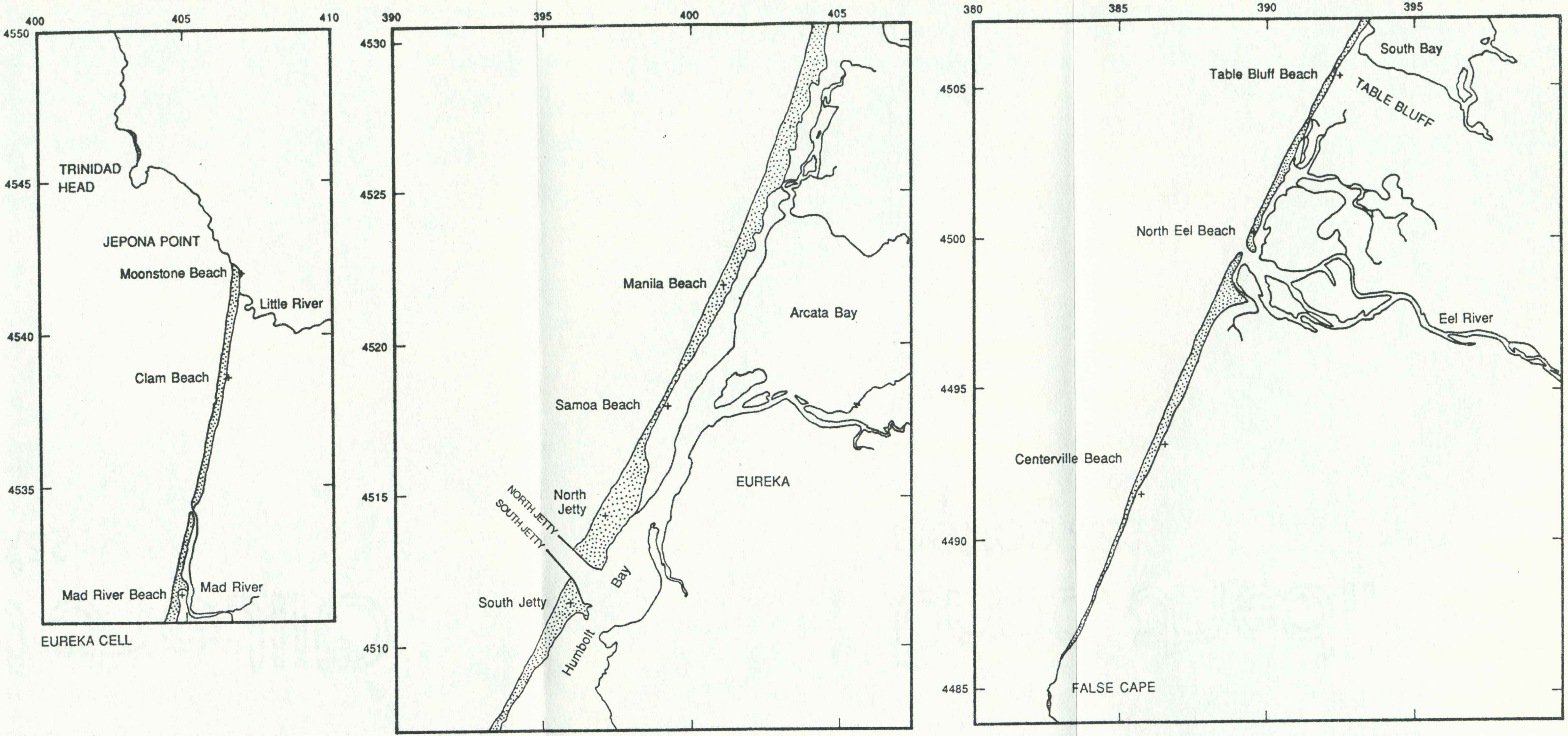


Figure 12. Map of the Eureka Cell. Base from U.S.G.S. 7.5' topographic quadrangles.

(sampled and observed), and the entire coast was analyzed using aerial photography (Peterson and others, 1990b). Based on this broad study of the Pacific Northwest, the cells selected are thought to be representative of the variation of beach sand distribution in smaller cells in the Pacific Northwest.

PREVIOUS WORK

The study of beaches in the United States began on the east coast in the late 1800's and this area continues to receive the most research (Fink and Nelson, 1980 for example). By comparison, fewer than a half dozen studies of the Pacific Northwest coastal zone were performed prior to the mid-1900's (Pardee, 1934; Twenhofel, 1943). The east coast was populated first and is more densely populated. Likewise, the southern California coast has received considerable recent attention due to problems encountered as development of the coastal zone has progressed (Inman and others, 1986).

Although some principles of shoreline dynamics as developed through studies of beach systems from the U.S. east coast and California have application to the beaches of the Pacific Northwest, the fundamental differences between passive margin coasts and active margin beaches of the Pacific Northwest must be kept in mind. These differences include: (1) width of the coastal plain; (2) gradient of coastal rivers; (3) distance between coastal river sources; (4) development of coastal terraces; and (5) structural controls on shoreline/shelf morphology and littoral cell development. Along coast transport and landward retreat of barrier island systems are the dominant processes of beach sand dynamics for much of the southeastern and Gulf coasts of the U.S. (Fink and Nelson, 1980). The ultimate supply of sand to the barriers is uncertain. While large rivers do serve as sediment suppliers to some beaches, other beach barriers appear to lack any up-drift sediment sources. For example, Tanner (1987) used beach ridge and grain size analysis in a study of various beaches from the east coast of the Americas which determined that sand supply is apparently limited to shoreward transport from the shelf rather than by shore parallel transport for many beaches. Models for shore parallel transport along the west coast (Komar and Inman, 1970) were developed through studies of southern California beaches and have received continued supporting evidence from beach studies and dredging records for over two decades (Inman and others, 1986). The fact that net transport directions are to the south in many cells in southern California has lead to the popular conception that sediment transport is to the south for the entire west coast of North America, including the Pacific Northwest. Caution must be used in applying models from other coastal areas to the Pacific Northwest, where climatic, oceanographic and geologic conditions may be substantially different from other U.S. coastal zones.

A sandy beach attempts to maintain an equilibrium sand distribution based on the conditions it is subjected to. For example, a beach in equilibrium under low energy wave conditions will begin to change immediately if subjected to high energy wave conditions (Dean, 1983). Tunon and Komar (1978) have shown that as wave height increases, the beach profile changes from a swell to a storm profile with a net transport of sediment to the offshore (erosion). As wave height decreases, there is a net transport of sediment onshore (deposition). The degree of erosion or deposition is dependent on the degree to which the profile is out of equilibrium with the waves. The apparent relative stability of any portion of the shoreline is dependant on the time scale over which it is observed. Within a given area, there may be much seasonal change in the distribution of sand on a beach, while on the scale of a year or more there might be little or no net change. Beaches may also show interannual changes in beach sand distribution only after a significant (multi-year) lapse of time. In an attempt to understand why changes in sand distribution occur it is necessary to understand what factors are forcing these changes. Some factors likely to be important in the distribution of sand on beaches of the Pacific Northwest are: geomorphology, vertical tectonics/sea level change, sediment supply, sediment transport, and climatic forcing (Peterson and others, 1990b). Following is a summary of previous work pertinent to beach sand distribution in the Pacific Northwest.

GEOMORPHOLOGY

The geomorphology of the Pacific Northwest coastal zone varies widely but can be categorized into the following types: 1) narrow, discontinuous, short, "pocket beaches", backed by resistant rocks (typical of the Klamath Mountains in southern Oregon and parts of the Olympic Peninsula); 2) larger, continuous beaches with associated rivers or embayments, bounded by resistant headlands and backed by low resistance sea cliffs of sedimentary rock or terraces (typical of the Oregon Coast Range and portions of the Olympic Peninsula); and 3) broad, very long, continuous beaches associated with major rivers with high sediment output, bounded by resistant headlands, and backed by extensive dune fields or wide spits (especially the beaches associated with the Columbia, Eel, and Umpqua Rivers. Headlands act as barriers to longshore sand movement and divide the coastal zone of the Pacific Northwest into possibly as many as 103 littoral cells or subcells (Peterson and others, 1990b). The degree of blockage of longshore sediment transport by headlands is in part a function of the projection of the headland. The further a headland projects oceanward, the more efficient the barrier becomes. However, shoreline curvature adjacent to the headland might also affect longshore transport (Peterson and others, 1987).

Terraces of varying ages are found in most areas in the Pacific Northwest and are certain to be sources of sand to some Pacific Northwest beaches (Clemens and Komar, 1988b). Few direct studies of the supply of sand by terraces have been made. It has been proposed that terraces supply the bulk of the sand for the beaches in northern and central Oregon (Runge, 1966). Most of the rivers associated with this region enter the coastal zone through estuaries which presently trap most of the coarse river sediment (Clemens and Komar, 1988a). Because of the variation in geomorphology along the coast, the relative importance of different sand sources must be evaluated on a cell by cell basis.

The effects of Pleistocene glaciation within the study area are confined to (1) the Olympic Mountains and the glaciofluvial outwash deposits which occupy terraces in the coastal zone (Thorson, 1980) and (2) isolated peaks within the Klamath Mountains and Cascade Mountains, which are the sediment source areas for some coastal rivers.

River systems entering the coastal zone of the Pacific Northwest vary in size from the Columbia River which drains much of the Pacific Northwest to intermittent streams active only during times of peak rainfall. Of the cells selected for this study, the dominant river systems are the Quillayute River of the La Push Cell, the Queets and Hoh Rivers of the Kalaloch Cell, the Yaquina River of the Newport Cell, the Rogue River of the Gold Beach Cell, and the Eel River of the Eureka Cell. River systems are not associated with the Cannon Beach, Otter Rock, and Crescent City Cells.

Seastacks, shallow reefs, and islands in the nearshore and/or inner shelf protect beach areas immediately shoreward because incident wave energy is spent on their seaward face. These offshore obstacles occur in all of the study cells except the Crescent and Eureka Cells of northern California. Beaches are often wider behind nearshore seastacks and islands (Haystack rock in the Cannon Beach Cell for example) due to the protection of the beach from wave attack. Because wave crests are refracted on protrusions such as headlands, islands, and seastacks, wave energy can become focused on adjacent beaches causing local effects in both sand transport and deposition.

TECTONIC FORCING/SEA LEVEL CHANGE

Beach deposits, being the interface between the land and sea, are constantly adjusting to changes in sea level, wave climate, sediment supply, and erosion. Changes in the elevation of the continent relative to sea level, either through vertical tectonic movement of the land or the rising and falling of the ocean, results in perturbations of beach sand distributions. For example, uplift of land or drop in sea level would force the position of the shoreline oceanward (regression) and possibly create a broad onshore terrace. Conversely, a rise in sea level or subsidence within the coastal zone would allow the position of the shoreline to move shoreward (transgression) and result in drowned river mouths and sea cliff retreat. It is generally agreed that the average level of the oceans (eustatic sea level) of the world is still rising (Monastersky, 1987). This eustatic sea level rise (2mm/yr) has been attributed to the ending of the last glacial period and it is possibly enhanced by the present atmospheric warming trend (Monastersky, 1987). The magnitude of this rise varies throughout the world and with time. Estimates of Holocene eustatic rise for the Pacific Northwest are on the order of 7-10 mm/year until about 4,000 years ago, and less than 2.5 mm/year thereafter (Clark and Lingle, 1979).

Within the last ten years, the tectonic stability of the Pacific Northwest has been the subject of much controversy. The long held view that the Cascadia subduction zone is inactive has given way to the realization that the margin is both tectonically active and seismogenic (Atwater, 1987). Much of the evidence for this new view has come through analysis of marine terrace deposits and intertidal estuary sediments preserved within the coastal zone. Terraces have been used to demonstrate the net tectonic uplift since late Pleistocene time. Net uplift rates range between 0.2 and 0.6 mm/yr for Pleistocene terrace deposits in Washington and Oregon (West and McCrumb, 1988). Muhs and others (in press) have shown that the uplift rate for the late Pleistocene Whiskey Run and Cape Blanco terraces in southern Oregon to be 0.45-1.05 mm/yr and 0.81-01.49 mm/yr respectively. The complex tectonic framework in the southern Oregon area suggests that these displacements are due to deformation within local structures (McInelly and Kelsey, 1990). Holocene terraces have only been preserved in the southernmost section of the study area, in the Cape Mendocino area. The net uplift rate for these terraces ranges between 3 and 4 mm/yr (Carver and others, 1989).

Estuarine tidal deposits form in bays or at the intersection of rivers or streams with the shore and indicate relative sea level positions through time. They are particularly useful because the biota which inhabit the estuaries are limited to discrete elevation zones. By studying the marsh record in Pacific Northwest estuaries, it is possible to determine changes in relative sea level elevations which have occurred during their deposition (Atwater, 1987). Darienzo and Peterson (1990) have used the sedimentary records of estuaries from northern Oregon to show that reversing periods of rapid subsidence of 1-1.5 meters, and gradual uplift of 0.5-1.0 meter in the level of salt marshes relative to the sea level have occurred episodically for at least the past 3,000 years. A view is emerging that the coastal zone of the Pacific Northwest is in constant motion, with segments of varying size showing slow steady motion broken by sudden jerks (Darienzo and Peterson, 1990). The effects of the vertical motions on the beach will be discussed in the following section.

Post glacial isostatic rebound is responsible for at least some of the uplift of the land in the area of the Olympic Peninsula (Thorson, 1980). The overlapping effects of eustatic sea level rise, subduction zone tectonic response, and isostatic rebound in different parts of the coastal zone make it difficult to determine the relative importance of each of these processes separately.

The combination of tectonic deformation, both regionally and along local faults and folds, and eustatic sea level rise have largely produced the highly variable shoreline morphology present in the Pacific Northwest today. The resulting littoral cells are of varying size and are backed by dune fields, rocky sea cliffs, marine terraces, or barrier spits.

BEACH SEDIMENT SOURCES

The first study of beach sand sources in the Pacific Northwest was performed by Twenhofel (1943) who identified the rivers of southern Oregon and northern California as the sources of black sand deposits present in terraces of Oregon.

Based on heavy mineral analyses of beach and river sands of selected sites in the Pacific Northwest, Kulm and others (1968) divided the Pacific Northwest into 4 main sources of littoral sediments corresponding to geographical basin groups. These basins are (from south to north): Klamath-South Coast Basins, Umpqua and Mid-Coast Basins, all basins drained by the Columbia River, and the North Coast Basin. Kulm and others (1968) note a systematic increase in the percentage of pyroxene and a decrease in amphibole content from the southern Oregon beaches to the northern beaches. Metamorphic minerals such as blue-green hornblende, actinolite/tremolite, and epidote decrease from south to north also. These trends, in addition to the presence of glaucophane in the beach sands of southern and central Oregon led Kulm and others (1968) to suggest that the predominant direction of sediment transport over very long time scales is from the south to north along the Oregon Coast. This work also indicates the importance of offshore (shelf) or retreating terrace sand sources in supplying many modern beach deposits in northern Oregon.

Through the use of heavy mineral analysis, Schiedegger and others (1971) outline four major sediment sources for the Oregon continental shelf: the Columbia River Basin, the Oregon Coast Range, the Klamath-Siskiyou Mountains, and terrace deposits of the central Oregon coast. The dominant direction of littoral transport has been to the north on the continental shelf for the past 18,000 years (Scheidegger and others, 1971). Littoral processes have apparently been more efficient in the past during times of lower sea level, transporting sands 250 kilometers to the north on the continental shelf. As sea level approached its present position, a reduction of sand supply and the presence of erosionally resistant headlands have limited the northward transport during the last 3,000 years (Schiedegger and others, 1971).

Clemens and Komar (1988a) identified four principle beach-sand sources for the Oregon coastline. These sources are: the Columbia River on the north, a Coast Range volcanic source, sands from the Umpqua River on the south Oregon coast, and a metamorphic source from the Klamath Mountains of southern Oregon and northern California. Most Oregon beach sands consist of mixtures of these four components although at present, headlands prevent along-coast sand movements. Thus the compositions seen must be considered relict, reflecting an along-coast mixing of mineralogies from the four sources during lowered sea levels when blockage by headlands was less effective. Some modification of the relict compositions has likely resulted from additions of sand to the beaches from sea cliff erosion and from local river sources over the last several thousand years. Presently the Columbia River supplies beach sand southward only to the first headland, Tillamook Head, with most sediment being transported to the north. At Tillamook Head a change in mineralogy and grain rounding occurs with angular, recently supplied sand to the north and more rounded relict sand to the south (Clemens and Komar, 1988a). For the purposes of this study the term "relict sand" will be used to describe only the component of the modern beach sand deposit which was bound into the littoral cell during the last sea level rise (consistent with Clemmens and Komar, 1988a). Additions of beach sand to littoral cells by terrace, river, or offshore sources, are considered modern or active sources to the beach even though the sediments themselves may actually be older.

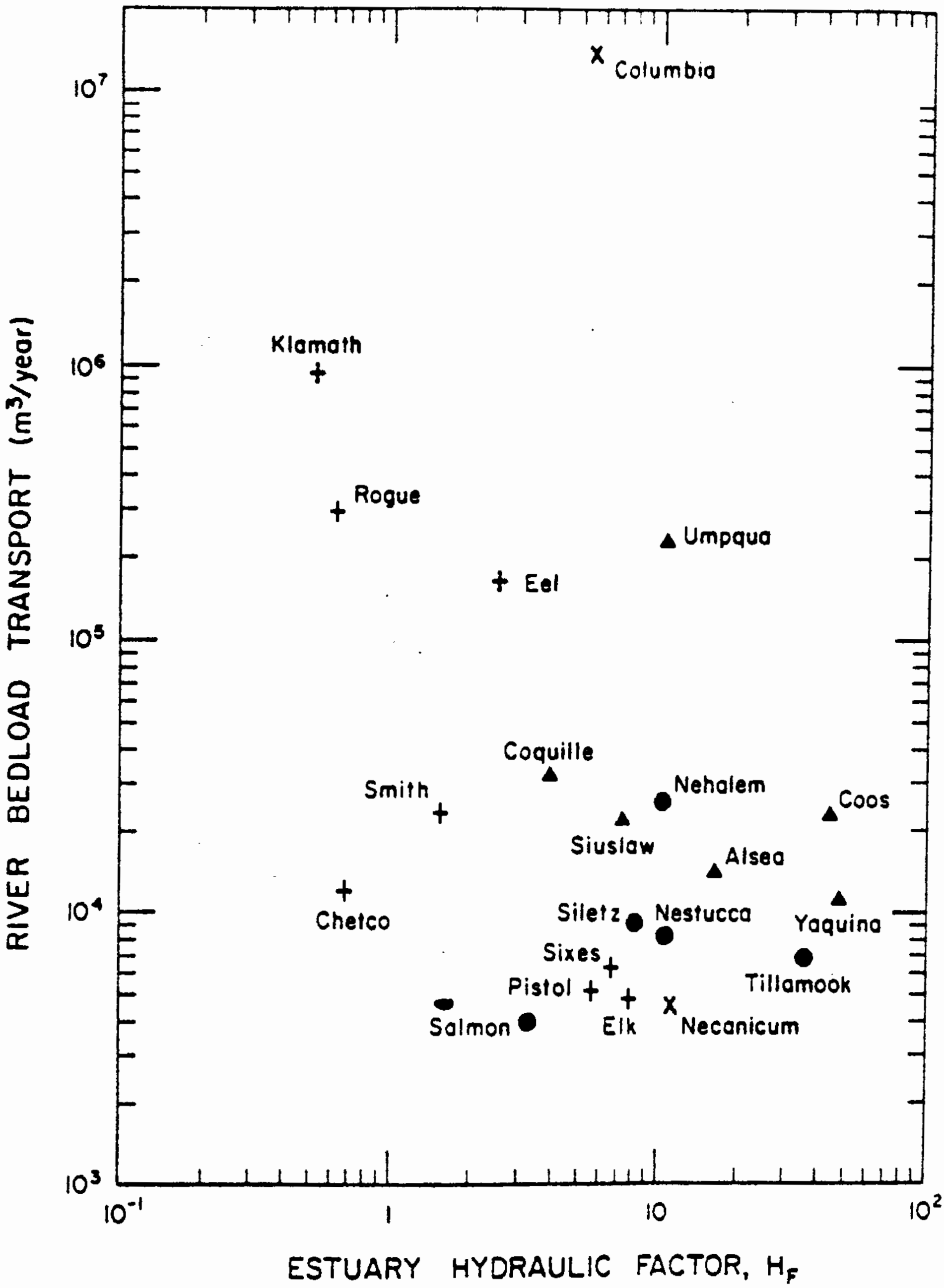
In the northern part of the study area the nearshore sands (less than 30m depth) between Grays Harbor and Cape Flattery indicate a local sediment source and are characterized by clinopyroxene, garnet, and amphibole (Venkataranthnam and McManus (1973). Orthopyroxene characterizes Columbia River sediments and it is present in significant portions only in nearshore sands between Grays Harbor and the Columbia River. Heavy mineral rich zones at greater depths do not show these patterns, as orthopyroxene is abundant all along the shelf indicating that northerly transport of sediments on the Washington margin was more efficient during previous, lower stands of sea-level.

Modern Sources of Beach Sand

Runge (1966) states that the marine terraces now are the major sources of sediment to the beaches of northern and central Oregon although most of the sediment was originally derived from river sources.

Evidence from sediment mineralogy and grain rounding studies indicates that sands derived from most rivers draining the Oregon Coast Range are presently trapped in estuaries and are not significant sources of beach sand (Clemens and Komar 1988b). However, Peterson and others (1984), in their study of high-gradient estuaries of the Pacific Northwest, show that when river discharge is high, during times of peak winter rain runoff, river sediment may bypass the estuary and become a source for Pacific Northwest beaches. As the evolution of the estuary continues there is a reduction of the tidal prism volume relative to the fluvial discharge. As this occurs beach sand is less likely be drawn into the estuary by tidal action, and coarser grained river sediments are allowed to bypass the estuary.

The hydraulic factor - H_F (mean tidal prism volume / mean fluvial discharge volume over six hours of a half tidal cycle) developed by Peterson and others (1984) is a qualitative way to determine the importance of an estuary as a source of sand to beaches. Estuaries with a high value for H_F will be tidally dominated and act as traps of river and beach sediments while low values for H_F will show fluvial dominance and thus a greater throughput of river sediment to the beach. Figure 13 shows the river bedload transport in cubic meters per year versus the hydraulic



Estimated annual bedload quantities for the rivers and the H_F hydraulic factors for their estuaries as an indication of their bypassing of sand to the adjacent ocean beaches. (x = rivers from the Columbia south to Tillamook Head; ▲ = rivers between Tillamook Head and Cascade Head; ● = rivers from Cascade Head to the southern extent of the study area; + = rivers south of the study area.)

<u>Figure 13.</u> Estimated annual bedload transport rates and hydraulic factor for rivers of the PNW. From Clemens and Komar, 1988a.

factor H_F for rivers of Oregon and northern California (Clemens and Komar, 1988a). Rivers falling in the upper left portion of this figure have the most potential as beach sand sources. The Eel and Rogue Rivers, located in the Eureka and Gold Beach Cells respectively, show significant fluvial domination and can thus be viewed as potential sources of beach sediment.

From the discussion above it is clear that there is no single source of beach sand along the Pacific Northwest coast. Specific sources or combinations of beach sand sources might be important in some areas, but absent from others. The supply of sand to the beaches is likely to vary along the coast as a function of: 1) river discharge, 2) estuarine hydrology, 3) sea cliff composition, and 4) the presence of inner-shelf sand deposits.

TRANSPORT DIRECTION

The beach sand distribution of an area is the net result of sediment transportation which is a function of waves, currents, and wind direction and speed. Wave orbital motion mobilizes sediment as waves propagate into the nearshore (Komar, 1976). Sediment is kept in suspension by the continued shoaling of waves. The superposition of local nearshore currents will cause sediment transport onshore-offshore and alongshore. Longshore currents are produced by waves approaching the shoreline at oblique angles.

Longshore sediment transport models have been developed and tested for straight, uniform beaches where the wave energy and direction are known (Komar, 1976). The velocity of currents transporting sediments past a section of beach can be determined from the equation

$$V=1.19(gH_b)^{1/2}\sin\alpha_b\cos\alpha_b$$

where H_b is the constant breaking wave height, g is the gravitational acceleration, and αb is the angle of oblique wave approach (Komar and Holman, 1986). The current direction on a given beach and thus the transport direction for beach sediments changes frequently as a function of variable wave direction. The net transport of sediments is determined by the sum of the individual transport vectors and is constrained by physical factors including beach orientation, wave climate, sediment supply, cell length and the presence of barriers to transport such as headlands, jetties, and estuaries. The net volume of sediments transported across a point on a beach (in m^3 day $^{-1}$) can be predicted from the equation

$$Q_s=6.8(ECn)_b\sin\alpha_b\cos\alpha_b$$

where $(ECn)_b$ is the energy flux or power of the breaking waves (Komar and Holman, 1986). Because of the difficulties of measuring wave parameters, and the fact that the models apply only to straight, uniform beaches, the transport of beach sediment has been determined for very few locations, and there have been no measurements made for Pacific Northwest beaches (Komar, 1976). Furthermore, direction and volume of sediment transport at a given area and time may not be representative of the long-term, net sediment transport for that area. Variations in the direction of wave attack (from northwest to southwest) along the central Oregon coast indicate that longshore sand transport direction may reverse over time periods of seasons, north in winter and south in summer (Kulm and Byrne, 1966). This has led to more empirical methods of determining net littoral transport directions. The equal distribution of bay spit orientations to the north and south and the symmetric deposition of beach sand on opposite sides of harbor jetties in Oregon has lead some researchers to speculate that a long term balance between opposing directions of transport exists (Komar and others, 1976b). Peterson and others (1990a) and Komar (1986) agree that there may be a zero net littoral drift over decadal time scales while interannual events of anomalous wave climate (such as the 1982-1983 El Niño event) are responsible for short term sand displacements (see Climatic Forcing below).

Plopper (1978) used sediment texture and heavy mineral analysis in his study of the hydraulic sorting of beach sands on the southern two-thirds of the Washington coastline. Plopper concluded that although samples were collected in the summer months when conditions (winds from the northwest) would favor southward transport of beach sediment, textural and compositional trends indicate that the net northward transport of beach sediments during the winter months overshadows the brief summer transport reversal. The main sediment source for the area south of the Quinault River mouth at Point Grenville is the Columbia River.

Schwartz and others (1985) used geomorphology and sedimentologic indicators including sediment accumulation and erosion, stream direction diversions, beach width and height, sediment size gradation, and cliff morphology to determine the net sediment drift direction for most of the Pacific coast of Washington. The results of this analysis are that net littoral drift along Washington beaches is dominantly to the north. This contradicts the condition of no net littoral drift reported for Oregon (Komar, 1986).

For the area from False Cape to Trinidad Head, Northern California, Bodin (1982) used the ratio of heavy to light minerals, heavy mineralogy (including tremolite-actinolite, hornblende, glaucophane, pyroxenes, epidote, garnet, sillimanite, sphene, and apatite), and textural analysis of 80 samples to conclude that the net transport direction is to the north and that the Eel River is the main sediment source. Bodin's work showed that there was a strong decrease in grain size to the north within the study area. This grain size trend is believed to be due to hydraulic sorting or selective transport by longshore currents. Larger grain sizes lag behind smaller, more easily transported grains. Because at least two other process can result in longshore variations in grain size (Komar, 1976), grain size trends must be used in conjunction with other information (such as mineralogy) in order to be sure that the observed patterns are indeed indicative of transport direction. Bodin (1982) also revealed that the Humboldt Bay filters out the heavier and coarser sediments from the sediments being transported alongshore and that the Mad River is not an important source of sand for the area.

While qualitative studies of longshore transport indicate net northward transport for cells in Washington and northern California, the Oregon coast is reported to show no such evidence of net longshore sand transport.

CLIMATIC FORCING

The Pacific Northwest coastline is a high wave energy coast which receives strong winter winds from the south to southwest and moderate summer winds from the north to northwest (Muhs and others, 1987). This results in a general trend of sand transport along beaches to the north during the winter and to the south during the summer (Muhs and others, 1987). However, seasonal longshore transport rates have not actually been measured on the beaches. Hunter and others (1983), conclude that the onshore net sand transport direction is 45° Az for the Pacific Northwest with dune building being relatively more effective during the summer when beach sand cohesion is lowest.

The El Niño of 1982-1983 resulted in abnormally high erosion rates for the entire west coast of the United States (Komar, 1986). The abnormally high sea level and southern position of storm systems produced by the El Niño combined with the occurrence of high spring tides and multiple storms with breaker heights in excess of 7 meters to cause anomalous wave approach angles and intensity (Komar, 1986). The El Niño Southern Oscillation (ENSO) resulted in a southward shift, by 10 to 15 degrees latitude (1,000-1,500 km) of the winter geostrophic wind guide, a proxy for winter storm tracks (Peterson and others, 1990a). The more southerly wave approach shifted the angle of wave attack to a more southerly approach. This resulted in the removal of sand from the southern ends of littoral cells and deposition of sand in the northern end of many cells. This loss of sand from southern cell segments allowed extensive erosion to occur during the winters of 1983, 1984, and 1985. The return of beach sand from 1986 to the present has restored sand buffers to most but not all of the southern cell segments (Peterson and others, 1990a).

SHORELINE CHANGE/BEACH EROSION

The factors summarized above (geomorphology, tectonic forcing/sea level change, sediment supply, sediment transport, and climatic forcing) have combined to produce great variation and changes in shorelines of the Pacific Northwest. For the purposes of this study, the term shoreline erosion shall be used to refer to the escarpment of the stabilized foredune, the large-scale removal of beach sand from a beach segment, the landward retreat of sea cliffs and terraces, or any combination of the three. Byrne (1963) conducted one of the first studies of erosion in the Pacific Northwest, relating erosional susceptibility to local geologic structure. Documentation of erosion events are numerous (for example, Rea and Komar, 1975; Terich and Komar, 1973; Terich and Komar, 1974), however, very few studies have precisely determined the causes of these erosional events and almost none of the erosional events were predicted ahead of time. Short term erosional events may be predictable for some sites. For example, Komar and others (1976a) concluded that severe erosion of Siletz Spit during the winter of 1972-73 was caused by the presence of wave breaker heights of 7.0 meters produced by storms and the focusing of wave energy by locally developed bars and rip current channels. Steep, coarse grained beaches on spits might be particularly susceptible to rip embayments and the associated focusing of erosive wave energy. For this reason, it is important to know the depth of the wave-cut platform, the grain size, and the profile of beaches if prediction of erosional events is to be made. By comparison, larger scale erosional sites might be predicted from beaches down drift of transport barriers. For example, Peterson and others (1990a) have shown that interannual climatic forcing was responsible for the northward displacement of some 4-8 x 10^6 m^3 beach sand between 1983 and 1987 north of Yachats Point in the central Oregon Coast. This left a seven km segment exposed to wave attack for several years (Peterson and others, 1990a). Similarly other beaches to the north of headlands have experienced multi-year erosional events. The periodic erosion of Netarts Spit in Oregon during the winters of 1982/83, 1983/84, 1984/85, and 1987/88 has been shown to be related to the 1982-83 El Niño (Komar and others, 1989). Although interannual climatic forcing is considered to be an anomalous event, the recognition of these events has only recently been possible. Such events may have been responsible for previous sand redistributions (Peterson and others, 1990a). For this reason it important to know cell boundaries, available sand distributions and shoreline geometry.

METHODS OF INVESTIGATION

In order to document sand distribution for the Pacific Northwest cells chosen for this study, estimates of sand volume within the littoral zone and beach morphology were measured through surface profiling and determination of the wave-cut platform depth. These static sand budgets are the logical starting point for coastal studies because they will yield information on the quantity of sand buffer present on beaches of the Pacific Northwest. Grain size analysis of beach and terrace sands was performed to gain information on possible sediment sources and transport directions. Aerial photographs were analyzed in order to document temporal and spatial changes in beach width.

AERIAL PHOTOGRAPH ANALYSIS

Aerial photographs from the entire Pacific Northwest coast were analyzed by Mark Darienzo and Robert Carson at half kilometer spacing for beach orientation, terrace type and height, dune width, distance from northern headland, and width of beach before and after the 1982-1983 El Niño. Positions were recorded from USGS 7.5' topographic maps using the Universal Transverse Mercator (UTM) system. In addition, low altitude aerial photographs of the four Oregon cells chosen for detailed study were taken during the summer of 1989 and analyzed for beach width. Deteriorating flying conditions (fog/rain) in the later part of the 1989 field season precluded aerial photography of the cells in northern California and Washington.

SAMPLE COLLECTION

Beach Samples

Beach sand samples were collected from each of the beaches surveyed in Northern California, Oregon, and Washington between June 24 and September 5, 1989. A total of 48 representative samples were collected at mid-beach face to a depth of approximately six centimeters. Approximately 1,500 cm^3 of sand was collected to insure that sufficient quantities of <.025 mm fractions were available for heavy mineral separation and analysis. Collection was restricted to times of fair weather to assure samples represented normal summer transport and deposition.

Terrace Samples

Representative samples were collected from 22 terrace sites within selected cells of the Pacific Northwest. The terraces sampled in this study were composed of mixtures of cobble to clay sized clasts of littoral, fluvial, or glacio-fluvial origin. These terrace sites were selected on the basis of apparent representative contribution of sediment to adjacent beaches. Igneous, metamorphic, and sedimentary rocks exposed in many sea cliffs in the Pacific Northwest are highly resistant to erosion, and they do not supply large quantities of sand-sized material to the beach. Shales or mudstones do not contribute to beach deposits in the Pacific Northwest because the fine-grained material (fine sand, silt, and clay) is easily transported offshore. The lithology of the sandy terrace deposits is highly variable alongshore requiring several samples from different terrace sections for representative analysis. After studying the terrace exposures at selected sites, a 1500 cm^3 (approximately) sample representative of the exposure was collected for grain size and mineralogical analysis.

GRAIN SIZE ANALYSIS

Beach Samples

Beach sands collected in the field during the summer of 1989 were analyzed for grain size parameters in order to determine longshore trends in transport direction and possible sources of the sand. Samples were individually homogenized and a 150 gram (approximately) sample was extracted. The sample splits were rinsed with H_2O and decanted four to six times to dissolve and remove salts and organic material. Samples were then dried and weighed to an accuracy of a tenth of a gram. Samples containing grains greater than 2mm in diameter were sieved to determine the weight percent of the >2mm fraction (gravel). Of the 133 beach samples analyzed, 23 samples (17%) contained grains >2mm in diameter. Of these, 10 samples (43%) contained >5% of grains >2mm in diameter. Samples containing less than 5% of grains >2mm in diameter were split using standard splitters to 0.80 - 1.20 gram for settling tube analysis (the portion >2mm in diameter was eliminated from the sample). Samples containing more than 5% sample weight of grains >2mm in diameter were sieved to 1/2 phi intervals using a ROTAP. The sieved interval splits were weighed to an accuracy of 0.001 gram for statistical analysis.

The settling tube system used in the grain size analysis consists of a PVC tube (200 cm in length and 20.32 cm in diameter) filled with water. The sample is mounted to the underside of a PVC disc which is lowered to the open water surface at the top end of the tube when settling analysis begins. Upon contact with the water surface the tension between the mounting medium and the sand grains is broken and the grains begin to fall through the water column. Because large grain sizes travel with a greater velocity through the water column (due to a greater ratio of weight to surface area) than do smaller grain sizes, the water column effectively sorts the grain sizes. As the grains reach the lower end of the column (largest grains first) they begin to accumulate on a plate attached to a strain gauge. The strain gauge produces a voltage which is sent through an analog-digital converter to a microcomputer.

A BASIC program calibrated for Pacific Northwest beach sands was used to convert this data into a computer file containing time, cumulative weight percent, phi size, and raw voltage for use in statistical analysis. Duplicate analyses of some samples were run to determine the precision of the method. The duplicate runs showed no significant variation in the determination of grain size parameters.

Terrace Samples

Terrace samples were split and weighed for bulk density determination. A measure of sample bulk density is needed to convert sample size fraction splits into sediment source tonnages for future erosion volumes. A 200 ml sample was then wet-sieved to determine the proportion by weight of gravel (>2mm), sand (2mm - 0.061mm), and silt/clay (<0.061-mm) present. The sand portion was split to between 0.80 and 1.40 grams and then run on the settling tube (procedure outlined above) to determine the characteristics of the sand-sized fraction.

BEACH PROFILING

Eight cells were chosen for surface profiling and determination of depth to wave-cut platform. Surveying began June 24, 1989 and concluded August 21, 1989. Survey equipment included a WILD T2 theodolite (accurate to one second) and a top mounted PENTAX electronic distance meter (EDM). The accuracy of the technique is estimated to be within +/- one cm horizontal distance and +/- one cm vertical elevation. The accuracy of the surveying technique was well within the limits needed for the reconnaissance and baseline surveying purposes of the project. A total of 107 across-shore profiles were surveyed on 46 beach segments within the selected cells. Through visual observation and map analysis, a location was chosen for surveying which represented the cell segment. Temporary steel stakes (2m in length) were driven into the ground at each beach so that profile lines could be reoccupied at a later date. At each staked site, one to three profiles were measured perpendicular to the shoreline (at approximately 200 meters alongshore spacing between adjacent profiles) to estimate the local variation in sand topography (Figure 14). The justification for longshore and cross-shore profile intervals is that of Phillips (1985). Through the use of semivariance analysis, Phillips concluded that where the primary purpose of survey profiles is to estimate beach volumes and static sediment budgets, only a reasonable approximation of the beach surface or a reliable estimate of mean elevation is necessary. The instrument was positioned near the center of the profile (usually at the berm or dune crest) and between 10 and 20 points were surveyed across-shore from either the foot of the sea cliff or vegetated dune crest to the mean low low water level. The elevation and time of sea level measured at the swash zone during

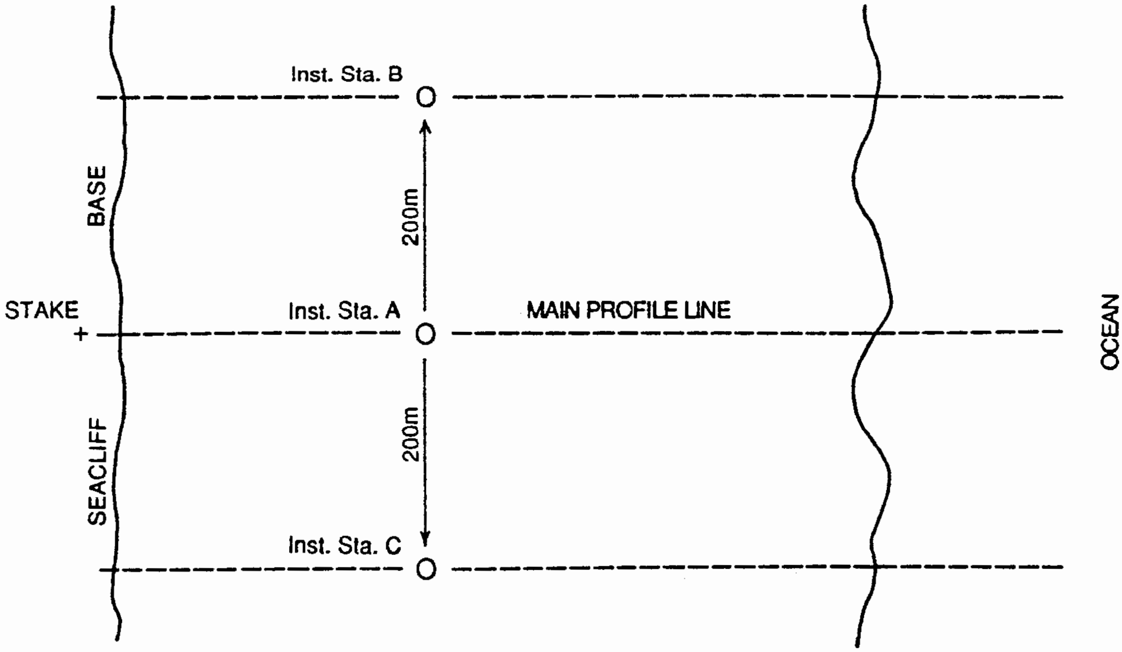


Figure 14. Profile surveying process.

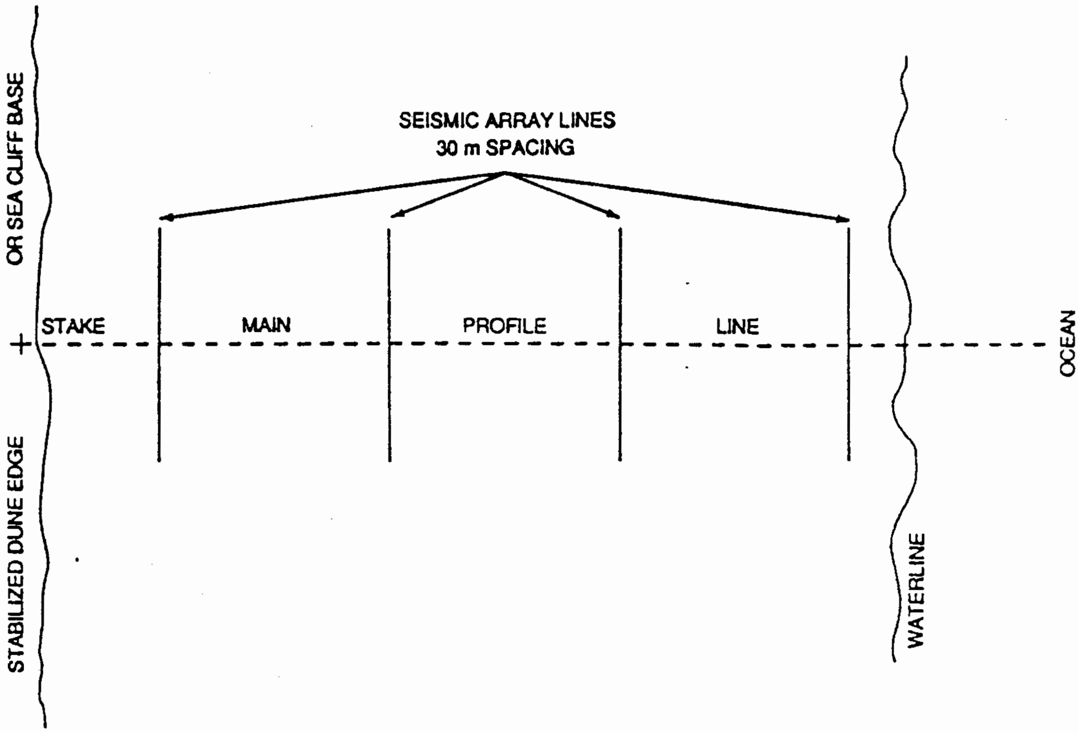
surveying was recorded for tie in to NOAA Tide Tables (1989). Slope distances and vertical angles were recorded in the field and converted to true distance and elevation at a later date using a software program (EXCEL) and adjusted to mean tide level (MTL) using NOAA tide tables. The term mean tide level refers to the tidal datum midway between mean high and mean low water as established during the National Tidal Datum Epoch (NOAA Tide Tables, 1989). The slope of the beach at the mid-beachface (the position of beach sand sampling) was later calculated from constructed profiles.

DETERMINATION OF WAVE-CUT PLATFORM DEPTH

The depth to the wave cut platform was determined for each surveyed beach in order to estimate the area of sand present in the beach profile. The wave cut platform is generally overlain by loose unconsolidated beach sand. The sand's acoustic velocity varies between about 250 to 1700 m/s. The acoustic velocity varies as a function of grain size, degree of saturation, and packing of grains. The lithology of the wave cut platform exposed on beaches and in sea cliffs of the Pacific Northwest varies from dense igneous rock which is highly resistant to erosion to poorly cemented sandstones and mudstones which offer little resistance to erosion. The acoustic velocity of these varying lithologies is generally greater than about 1900 m/s. At each staked across-shore profile line, a series of geophysical survey lines were run at 25 to 30 meter spacings parallel to the shoreline (Figure 15). A twelve channel analog seismograph with geophones and chart recorder were used to detect and record acoustic waves generated with either a sledge hammer and steel plate or a small electrically ignited explosive device (500 grain black powder shotgun shell producing 105k joules of energy). Distance to the survey stake, and geophone spacings were measured with a 50 meter tape. Geophone spacing alongshore ranged between 1 and 4 meters depending on the estimated depth to the platform at the site and the effective sound penetration through the sand. Velocities and intercept times were picked from the chart recordings (Figure 16). Depths to the platform (high velocity layer) interface were determined using seismic refraction equations given in Robinson and Coruh (1988):

$$z_1=\frac{X_c}{2}\left(\frac{V_2-V_1}{V_2+V_1}\right)^{1/2}, \qquad z_1=\frac{T_1V_1V_2}{2\left(V_2^2-V_1^2\right)^{1/2}}$$

where z_1 is the depth to the first interface, T_1 is the intercept time, V_1 is the velocity in the uppermost layer, V_2 is the velocity of the lower layer, and X_c is the cross-over distance. For more information on seismic refraction techniques, see Basic Exploration Geophysics (Robinson and Coruh, 1988).



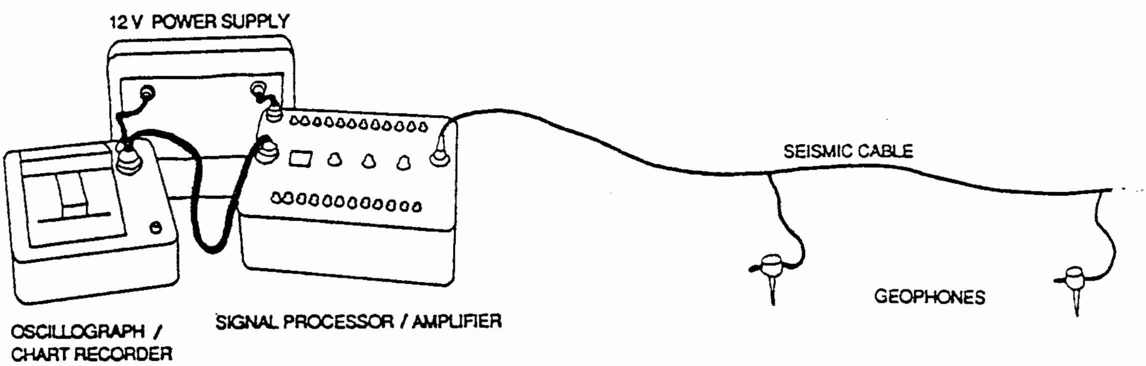
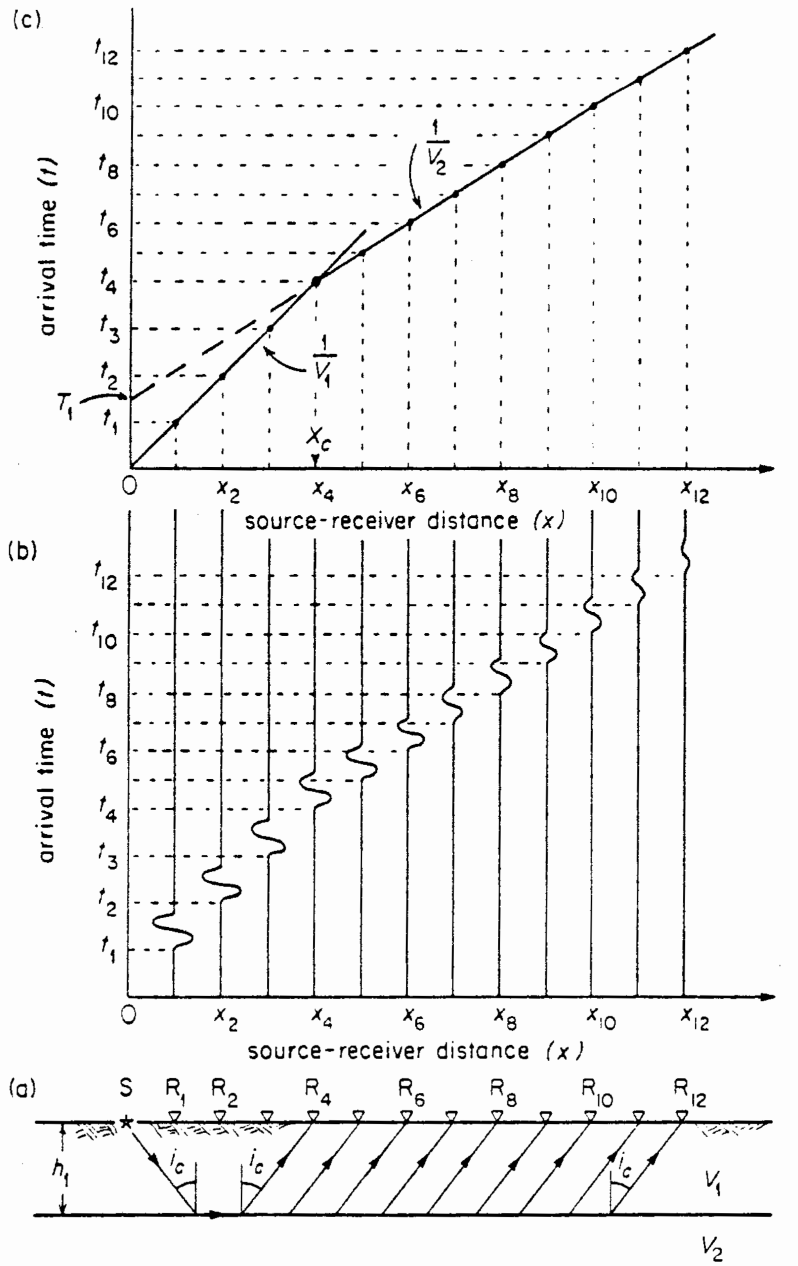


Figure 15. Geophysical surveying process.

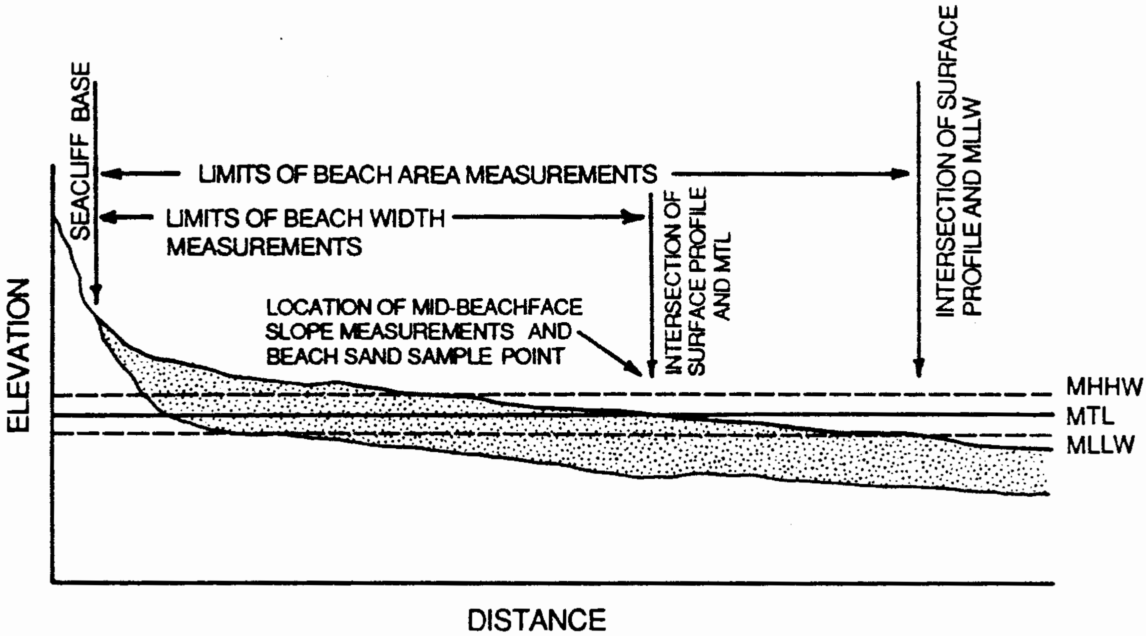


Wave paths, seismogram, and travel time curve for direct waves and waves critically refracted from a horizontal plane boundary. The figure shows recording of direct and refracted waves by a 12-channel system. (a) The critical ray from the source (S) refracts along the interface and back to the surface at the receivers from R_5 to R_{12}. (b) The seismogram consists of traces observed at receivers. Each trace represents ground vibration as a function of time. Onset times of the first arriving waves are marked on the vertical time axis, and the distances from the source to receivers are marked on the horizontal axis. (c) Time–distance curves are constructed by drawing lines through alignments of points that show arrival times at different distances. Slopes of the lines indicate the velocities.

Figure 16. Analysis of seismic refraction chart recording. From Robinson and Coruh, 1988.

SAND CROSS-SECTIONAL AREA AND VOLUME ESTIMATION

Sand cross-sectional areas were measured on a digitizing tablet from profiles constructed from the surveying and platform depth data. Three measurements were recorded for each beach: 1) the area of sand above mean high high water (A_{MHHW}), 2) the area of sand above mean low low water (A_{MLLW}), and 3) the total area of sand (A_{tot}) above the platform or an arbitrary depth cutoff of -10 m mean tide level (Figure 17). The term mean high high water refers to the arithmetic mean of the higher high water heights of a mixed tide observed over a specific 19 year Metonic cycle - the National Tidal Datum Epoch (NOAA Tide Tables, 1989). Mean low low water is the arithmetic mean of the lower low water heights of a mixed tide observed over the same 19 year period. The 10 m depth cutoff was chosen because this is the maximum expected depth of swash zone scouring. It is also the approximate limit of acoustic signal penetration of the 12 channel seismic refraction system used in this study. The point where mean low low water intersects the beach face was used as the seaward break in the profile cross-section area measurements. The base of the sea cliff, the beginning of permanent vegetation, or the foredune crest (the legal boundary between private uplands and public tidelands; Gutstadt, 1990), is used as the landward break, depending



Note: MHHW, MTL, and MLLW refer to mean high high water, mean tide level, and mean low low water respectively.

Figure 17. Measurement of beach areas used in study.

upon which was present at the profile site. These lines also represent the extent of the "active" beach.

Sand volumes for the eight selected cells were estimated through extrapolation of the sand cross-sectional area, determined for each staked profile to the longshore distances between stake sites. The longshore distance of extrapolation was established for each beach section through the use of aerial photo and map analysis, and by reconnaissance of the beaches from local vantage points. The surveyed profiles were compared to 1989 aerial photograph data (available for Oregon cells only) to insure that the site selection was indeed representative of the beach sections over which extrapolation would take place (see results). The ratio of the average beach width for the beach section to the beach width at the survey site as determined from aerial photographs was computed (R_1) for each beach section. The ratio R_1 ranged between 0.57 and 1.40 over the study area, with an average of 1.0025. Of the 20 beaches for which 1989 aerial data was available, only 3 fell outside a range of 0.75 to 1.25. Values of R_1 which deviate considerably from 1.00 are found in areas in which beach width changes rapidly with longshore distance. These areas are usually found at the ends of cells near the transition between beach and headland (see results). The fact that site selection beach widths were found to be generally representative of adjacent beach widths for the

Oregon cells lends support to the similar use of selected representative sites in Washington and California cells for which no 1989 aerial photograph data were available (see results).

The beach areas determined by survey (A_s) were then adjusted to the average beach width by multiplying them by the ratio (R_1) (for the areas with 1989 aerial photograph data) prior to extrapolation into the longshore direction:

$$R_1=\frac{AW_{ap}}{W_{ap}} \quad , \quad A'=A_s R_1$$

The volume of sand was determined by multiplying the adjusted areas (A') by the longshore distance of extrapolation (Dl_s). For example:

$$V_{MLLW}=A'_{MLLW}\, D_{ls}$$

Three sand volumes are recognized based on the sand area measurements described above: 1) the total sand in the cell (V_{tot}), 2) the sand above MLLW (V_{MLLW}), and 3) the sand above MHHW (V_{MHHW}).

STATISTICAL ANALYSIS

Beach and Terrace Samples

Cumulative weight versus settling time graphs were constructed for the grain size data files generated during settling tube analysis to check the data for consistency and irregularities that might be caused by vibration of the instrument or other factors. A BASIC program was then used to pick data points from the data file, which are used to determine the statistical measures of the sample (grain size frequency, distribution, etc.). The equations used to calculate the statistical measures for the sample are those of Inman (1952). The sample grain size statistics were then converted from phi scale to metric scale through the use of a software program (EXCEL).

Correlation of Beach Parameters

The correlation of beach parameters such as grain size and distance within cell, mid-beachface slope and distance within cell, and sand volume with distance within cell were determined using standard statistical formulae given in Davis (1986). For example, a correlation coefficient of r= 0.97 between beach volume and distance within the cell would indicate that sand volumes increased with distance north in the cell. Negative correlations would indicate the study parameter decreased with distance in the cell. In addition, correlation coefficients between parameters such as beach sand grain size and beach width are given. A positive correlation would indicate that the dependent parameter increased with the independent parameter. A negative correlation would indicate the dependent parameter decreased with the independent parameter. The significance of each correlation coefficient was tested by using the t-test:

$$t=\frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

where r is the correlation coefficient and n is the number of samples. Critical values for t given in Davis (1986) were used to test the hypothesis that the parameter correlations were significantly different than zero. A 10% level of significance was chosen because of the reconnaissance nature of the study. Only correlations in which the null hypothesis could be rejected at a 10% level of significance are presented below.

RESULTS

AERIAL PHOTOGRAPH ANALYSIS

Aerial photograph and map analyses were performed in order to (1) document beach parameters and (2) compare the results of the field survey and sampling data. The complete results of aerial photograph analysis of the eight selected littoral cells in the Pacific Northwest are presented in Appendix I. The beach parameters measured from aerial photography included shoreline orientation, beach widths before and after the 1983 El Niño, beach widths at the time of the field study (Oregon cells only), terrace height and platform type, and dune width (measured from pre-1983 photos). The data were taken at half kilometer distances longshore and are recorded with reference to location name, N-S and E-W UTM coordinates, and to approximate distance in kilometers from the apparent northern headland or cell boundary. All measurements are recorded in meters except shoreline orientation which is measured in degrees azimuth. Platform types are defined as: 1) T1- low terrace, 2) T2- high terrace, 3) T3- visibly eroding terrace, 4) U2- moderate to high sea cliff, 5) U3- visibly eroding cliff, 6) B2- moderate to high wave cut bench, and 7) D- dune field. Combinations of the descriptors above are used where combinations of shoreline types are present. For example, T1D would be used to describe a low terrace with dunes either covering it or dunes developed on the terrace surface.

The width of beaches in the cells selected for this study vary from 0 to over 500 meters (aerial photograph data). Figures 18 through 25 show the relationship between beach width at different times and N-S UTM distance determined from aerial photograph analysis for each cell. The changes in beach width from pre-1983 to post-1983 are shown in Figures 26 through 32 for the cells for which this data were available. Negative values represent a narrowing of the beach while positive numbers represent the widening of the beach. These figures show that in some cells, significant displacements of sand occurred during the 1983 El Niño. Figures 33 through 36 show the change in beach width between the pre-1983 data and the present (1989) data. These figures show the degree to which the cells have readjusted to "normal" climatic conditions following El Niño induced sand displacements.

The orientation of the beach was measured from topographic maps in order to see if sand distribution is related to beach orientation or sediment transport direction. Beach orientation is defined in this study as the direction the beach faces (normal to the trend of the shoreline) and is measured in degrees azimuth. The

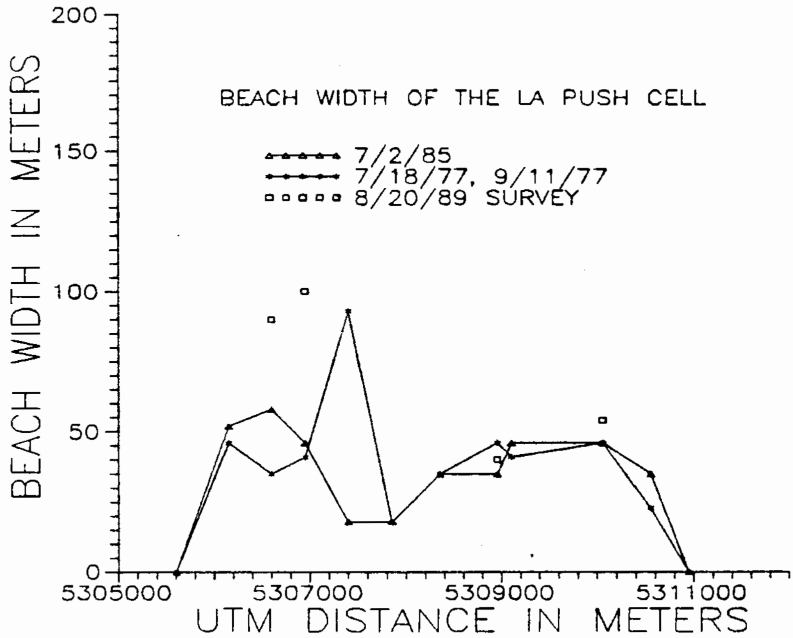


Figure 18. Beach width versus distance for the La Push Cell.

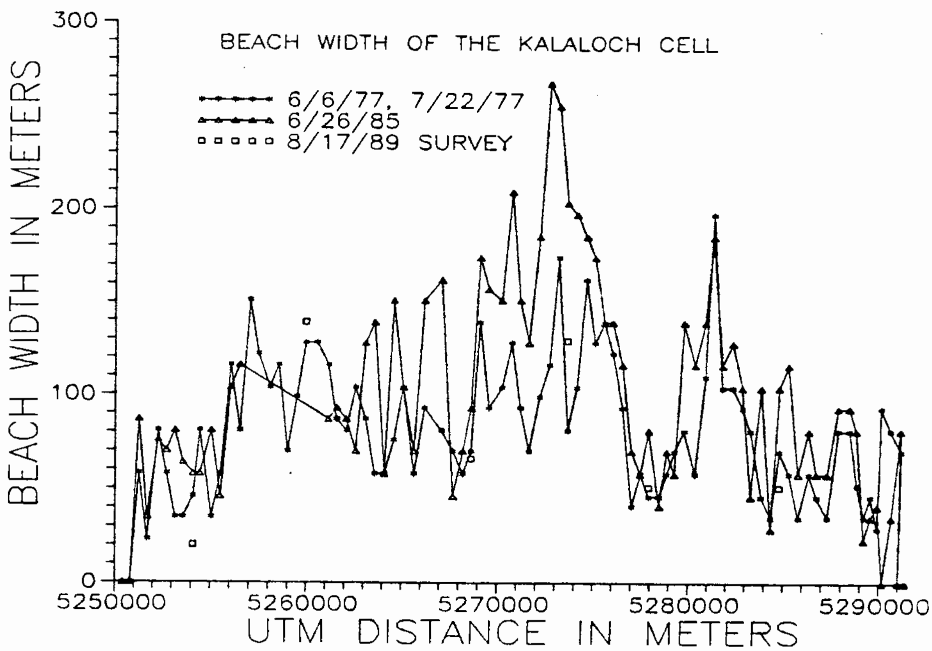


Figure 19. Beach width versus distance for the Kalaloch Cell.

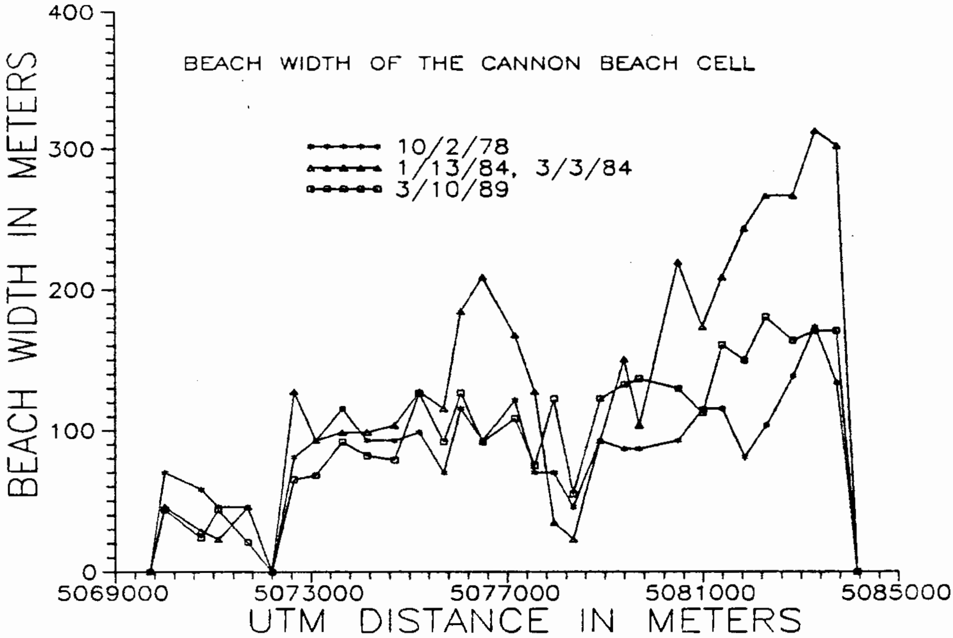


Figure 20. Beach width versus distance for the Cannon Beach Cell.

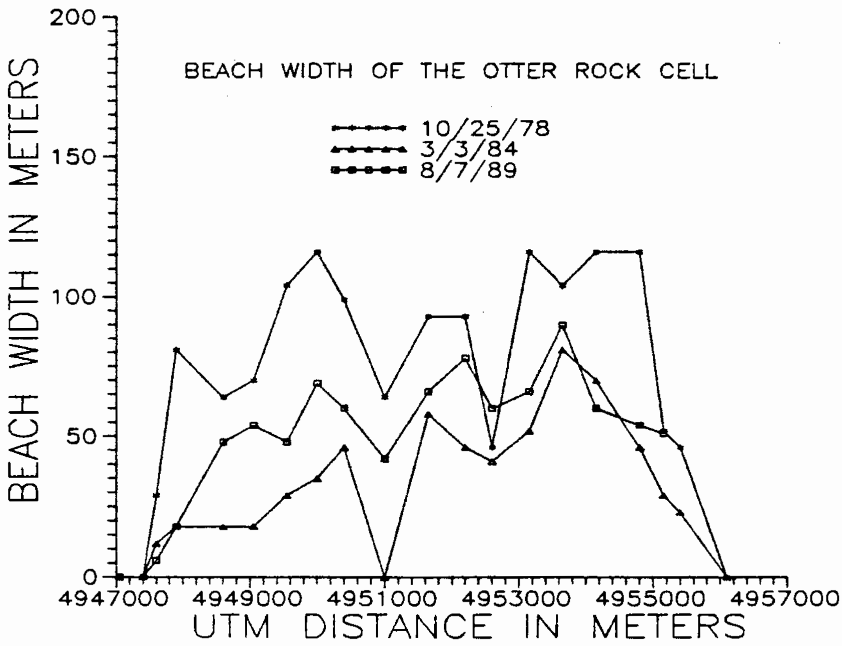


Figure 21. Beach width versus distance for the Otter Rock Cell.

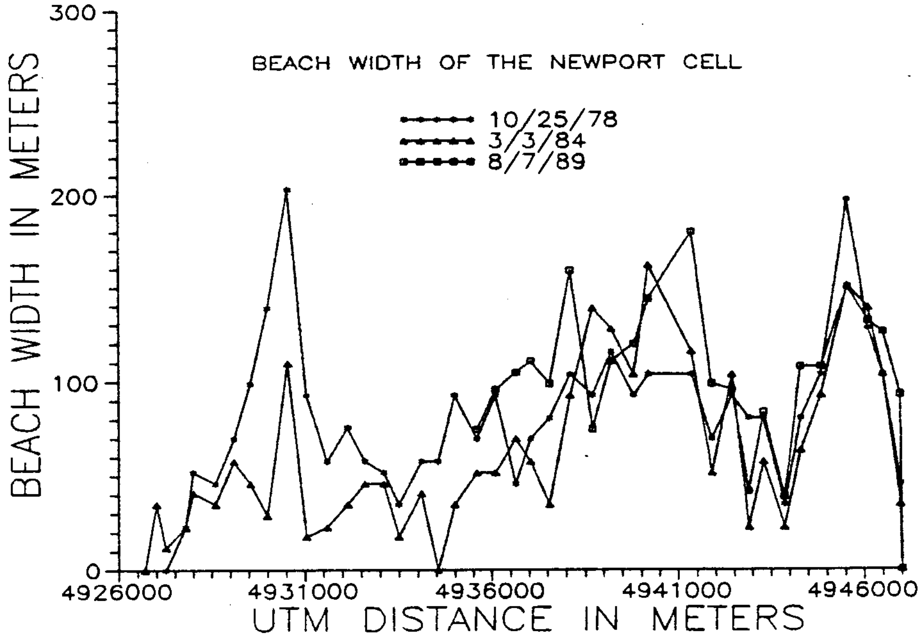


Figure 22. Beach width versus distance for the Newport Cell.

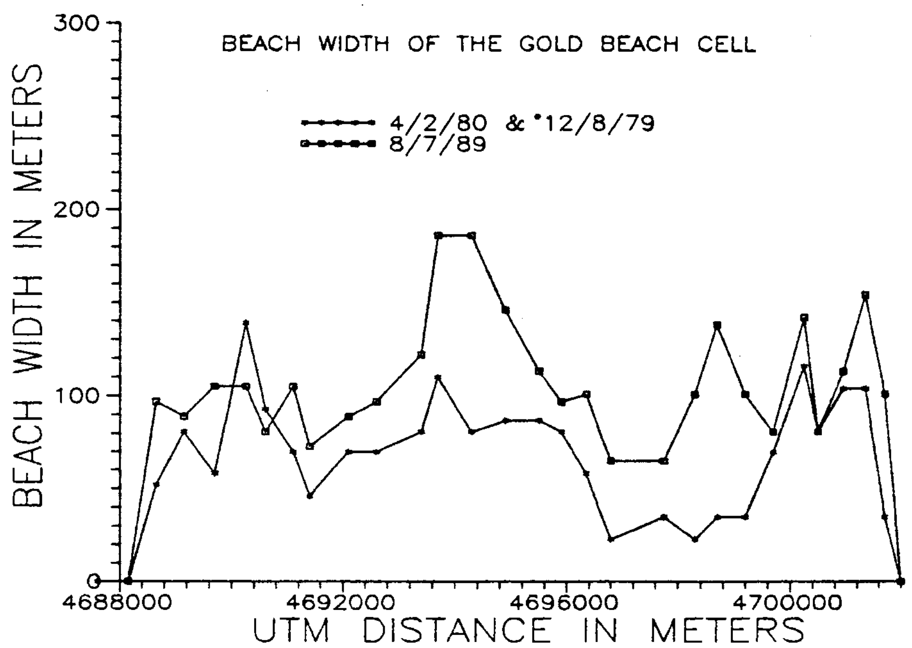


Figure 23. Beach width versus distance for the Gold Beach Cell.

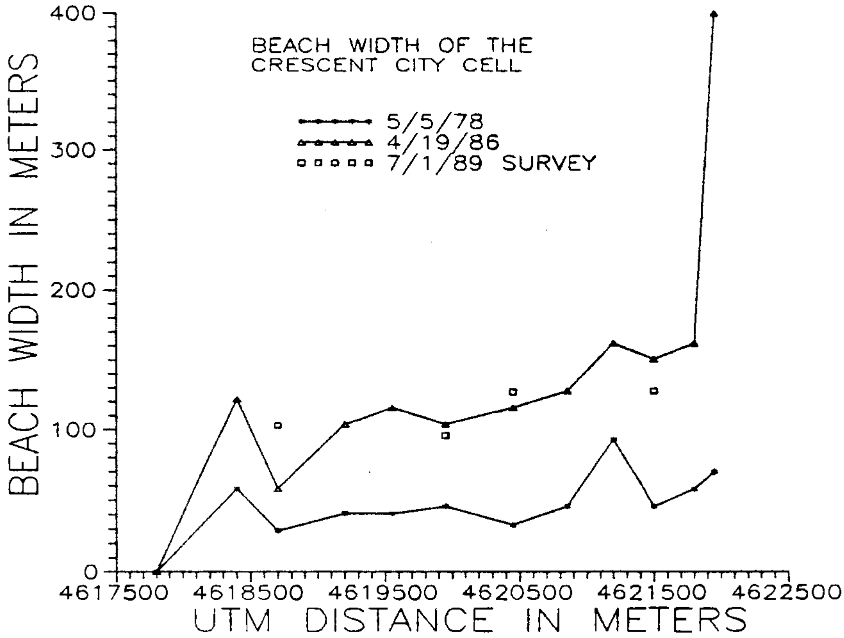


Figure 24. Beach width versus distance for the Crescent City Cell.

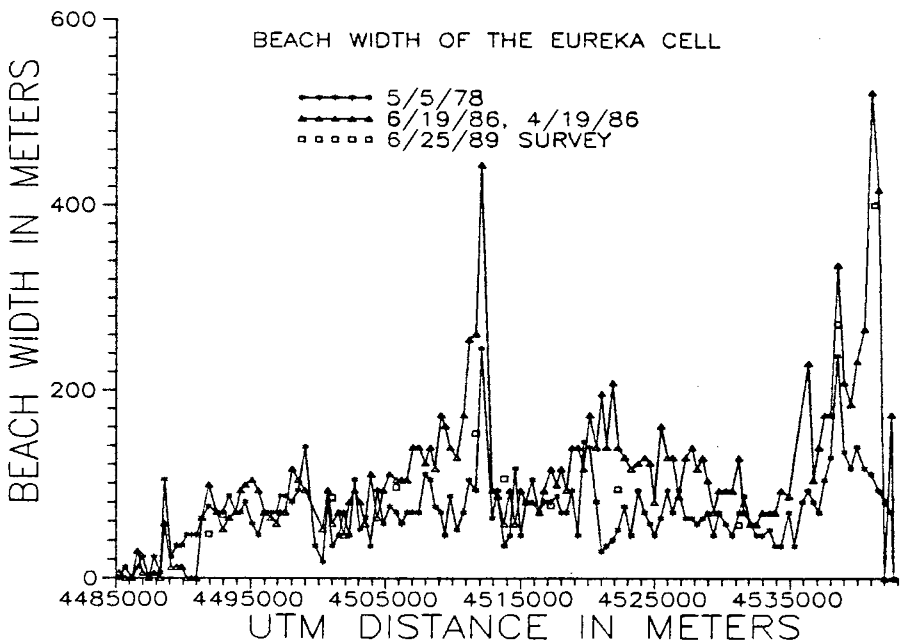
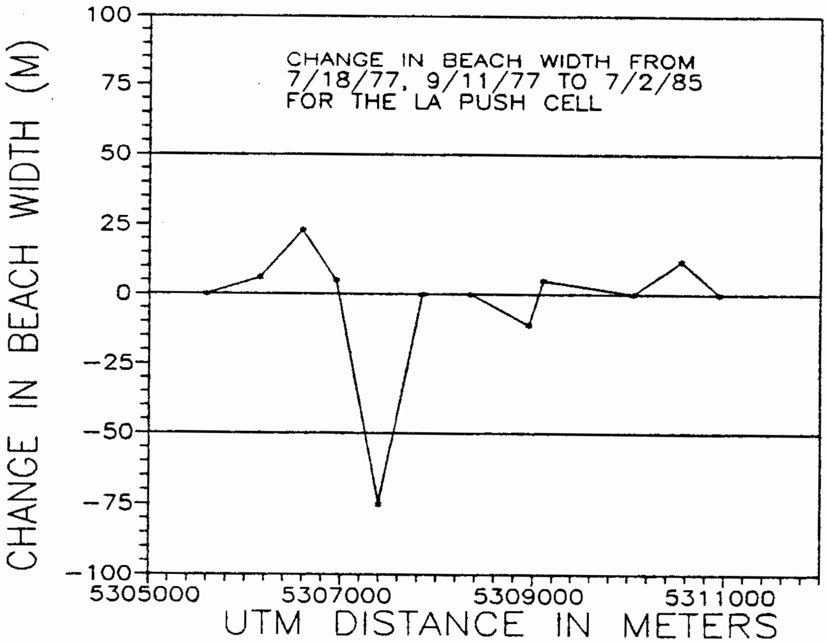
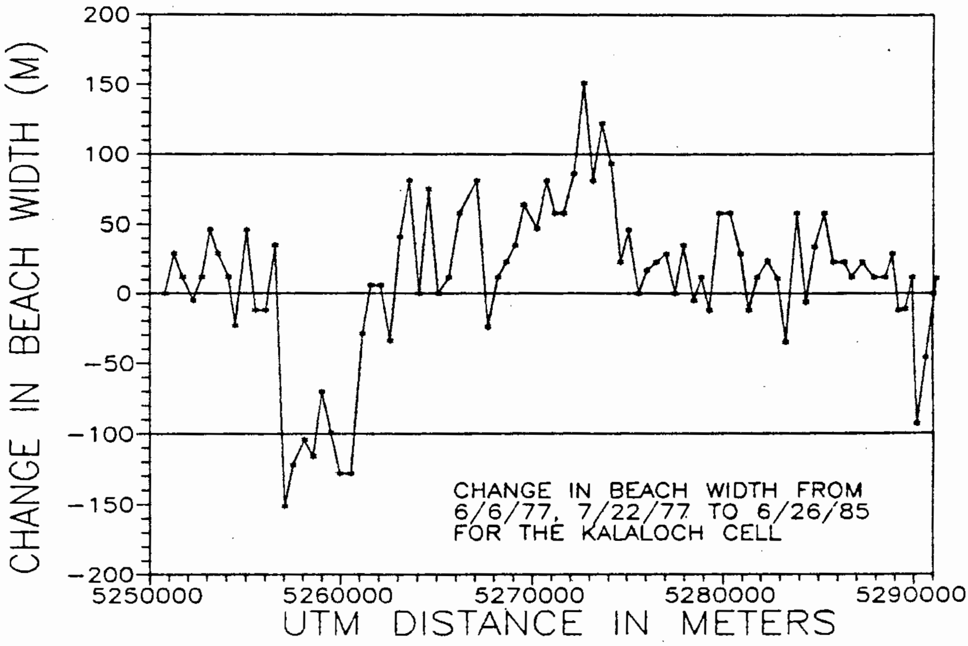


Figure 25. Beach width versus distance for the Eureka Cell.



<u>Figure 26.</u> Change in beach width during the 1983 El Niño for the La Push Cell.



<u>Figure 27.</u> Change in beach width during the 1983 El Niño for the Kalaloch Cell.

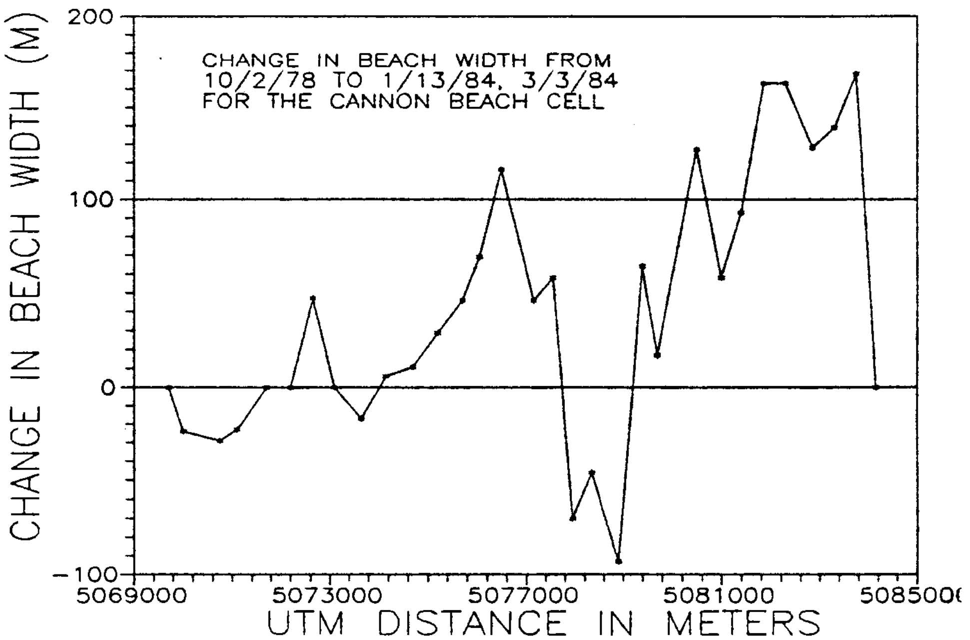


Figure 28. Change in beach width during the 1983 El Niño for the Cannon Beach Cell.

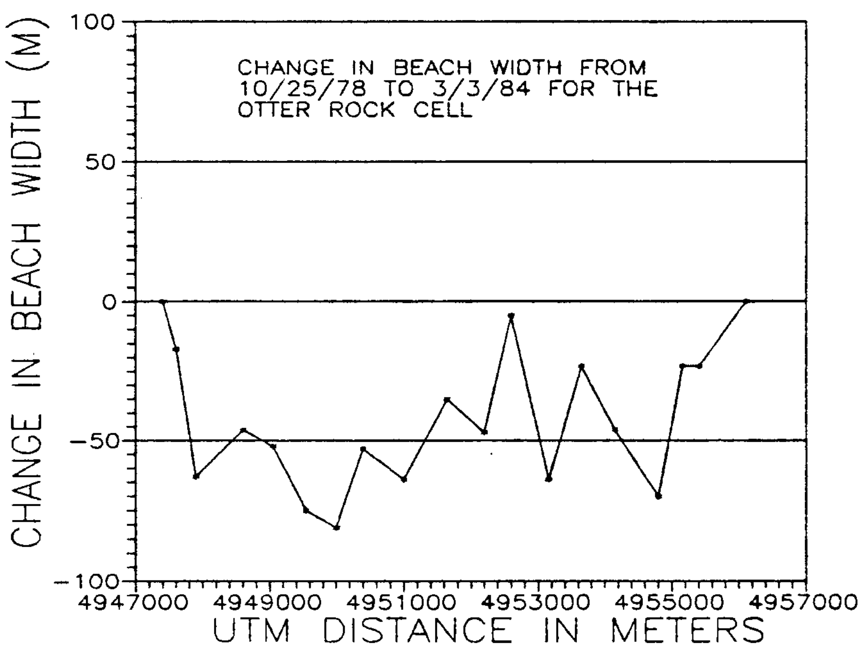


Figure 29. Change in beach width during the 1983 El Niño for the Otter Rock Cell.

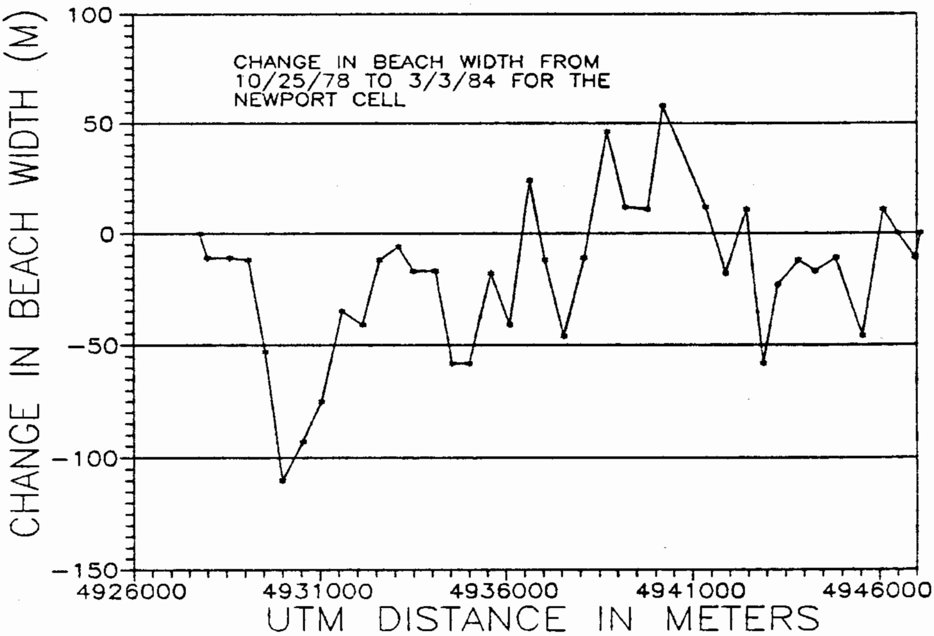


Figure 30. Change in beach width during the 1983 El Niño for the Newport Cell.

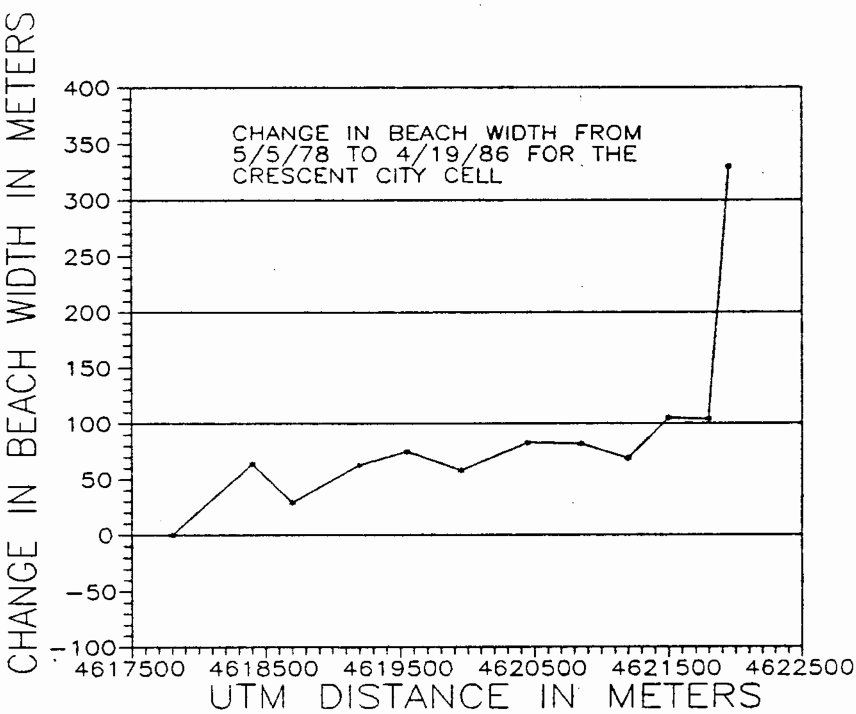


Figure 31. Change in beach width during the 1983 El Niño for the Crescent City Cell.

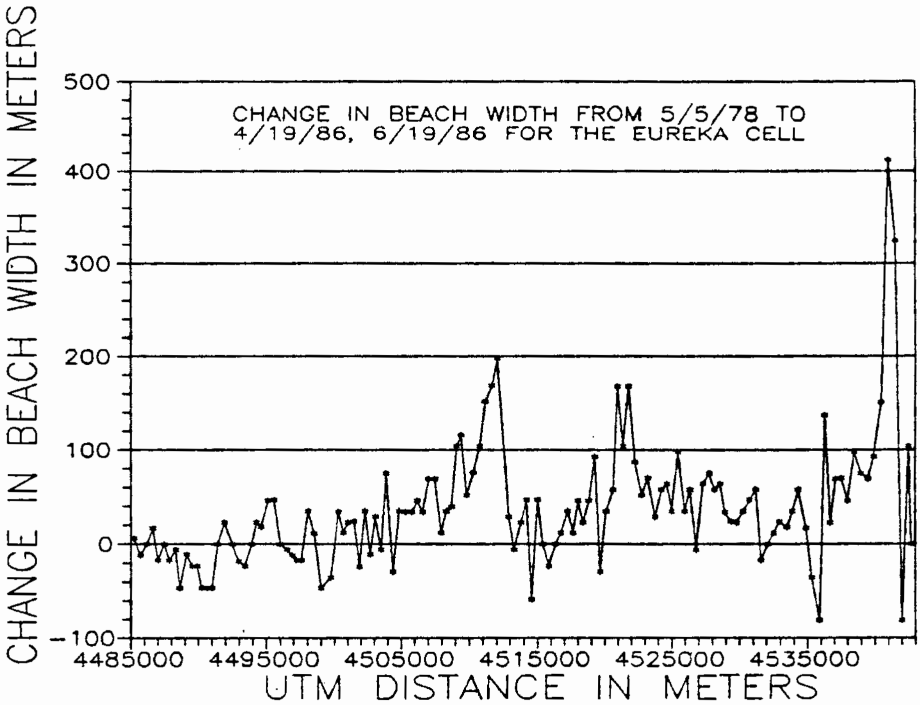


Figure 32. Change in beach width during the 1983 El Niño for the Eureka Cell.

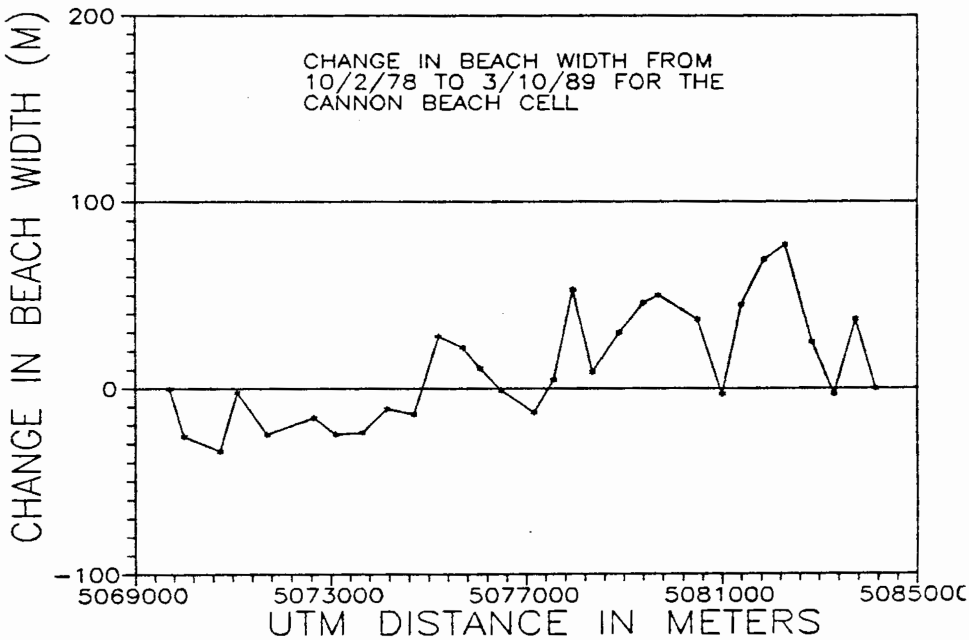


Figure 33. Change in beach width after the 1983 El Niño for the Cannon Beach Cell.

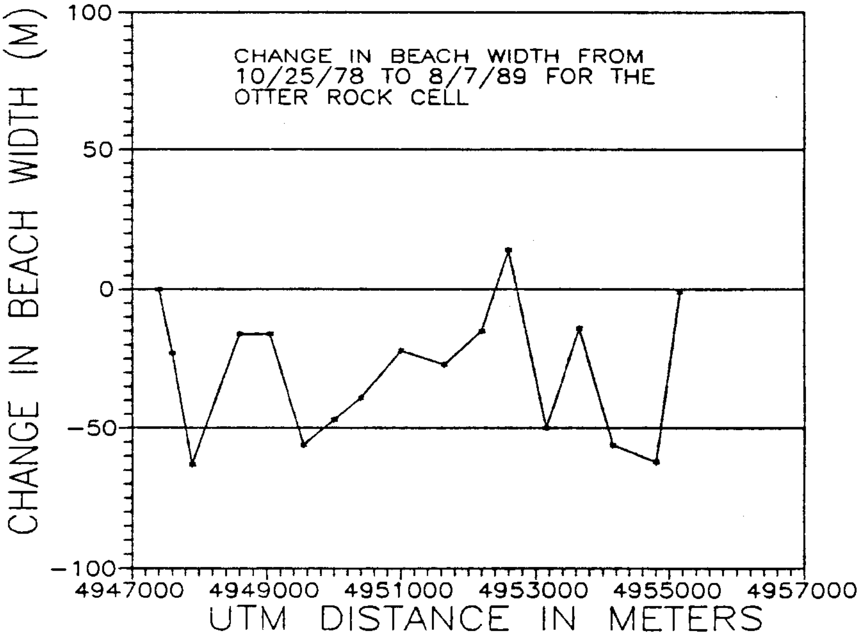


Figure 34. Change in beach width after the 1983 El Niño for the Otter Rock Cell.

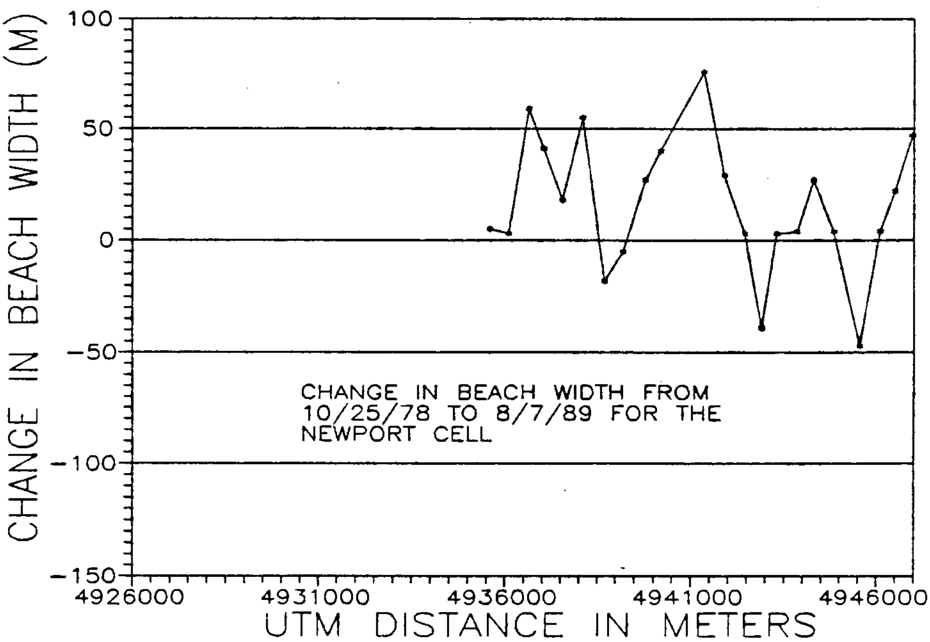


Figure 35. Change in beach width after the 1983 El Niño for the Newport Cell.

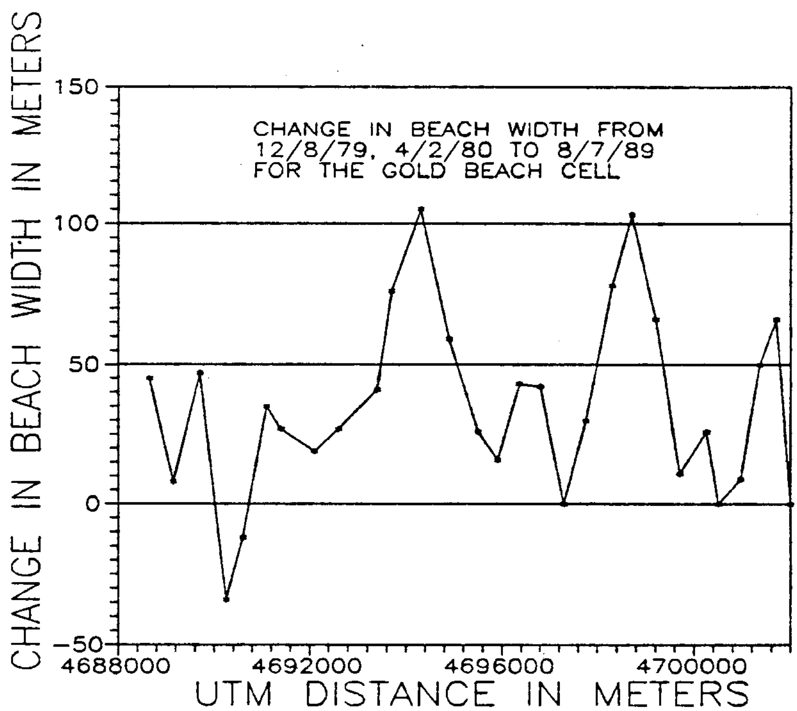


Figure 36. Change in beach width after the 1983 El Niño for the Gold Beach Cell.

variation in beach orientation with N-S UTM distance is shown for each cell in Figures 37 through 44. The average shoreline orientation varies from 229° Az for the Crescent City Cell to 291° Az for the Eureka Cell. The average shoreline orientation for the other six cells lies between 255° and 275° Az.

BEACH PROFILING/WAVE-CUT PLATFORM ANALYSIS

Beach profiling and depth to wave cut platform analysis was completed in order to calculate beach slopes and sand volumes for the selected cells. The results of beach profiling and wave-cut platform analysis are presented in Appendix II. The asterisks connected by the solid line represent the survey data while open squares without connecting lines represent the level of the wave cut platform at that point in the profile as determined by seismic refraction surveys or direct observation. All elevations are adjusted to mean tide level.

Beach slopes were measured at the mid-beachface position for comparison to beach grain size analysis and to corresponding position in cell. Beach slope estimates are presented in slope percent (rise/run multiplied by 100). The elevation of the wave-cut platform, at the point where MTL intersects the profile surface, was recorded for each beach surveyed in order to make comparisons to sand volumes. Average mid-beachface slopes, beach widths, and wave-cut

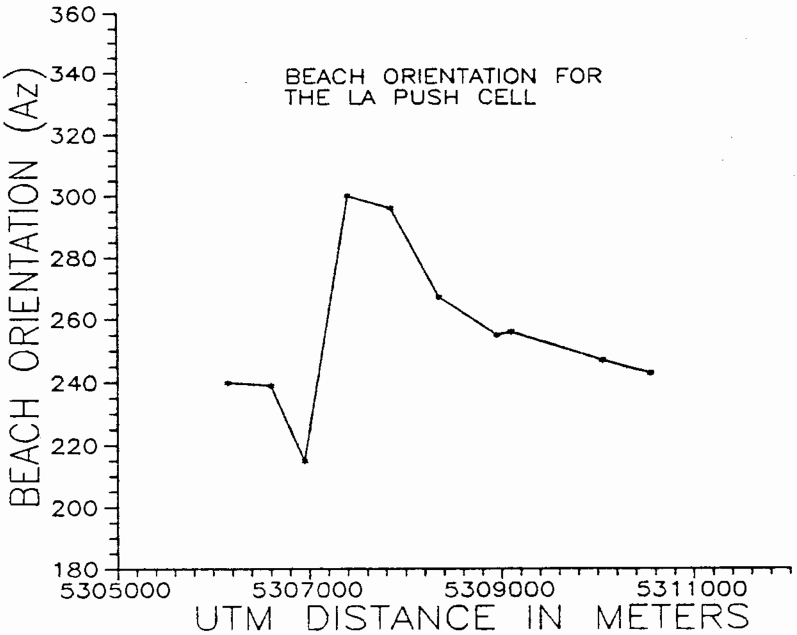


Figure 37. Shoreline orientation for the La Push Cell.

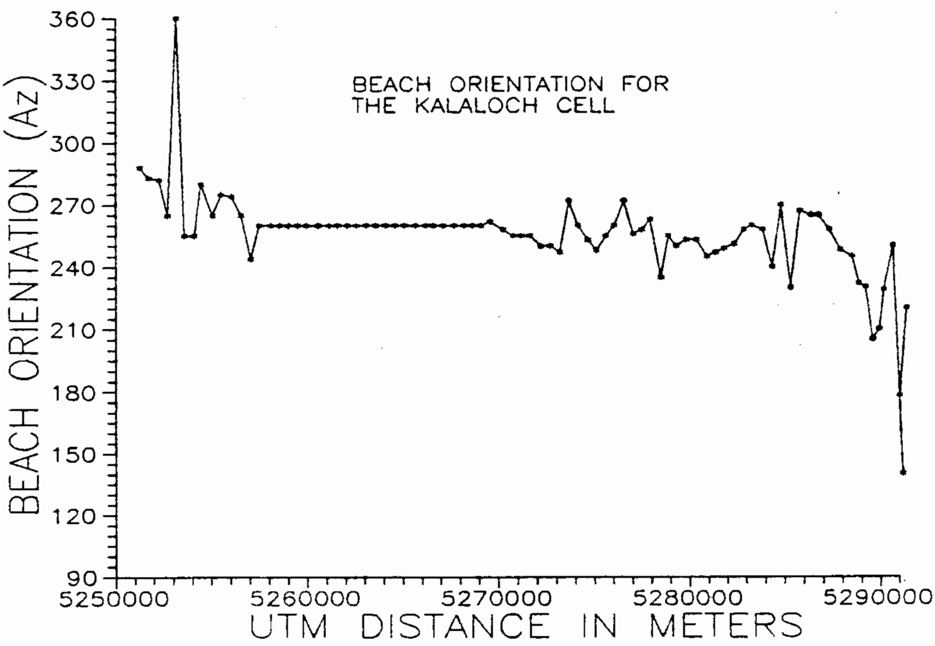


Figure 38. Shoreline orientation for the Kalaloch Cell.

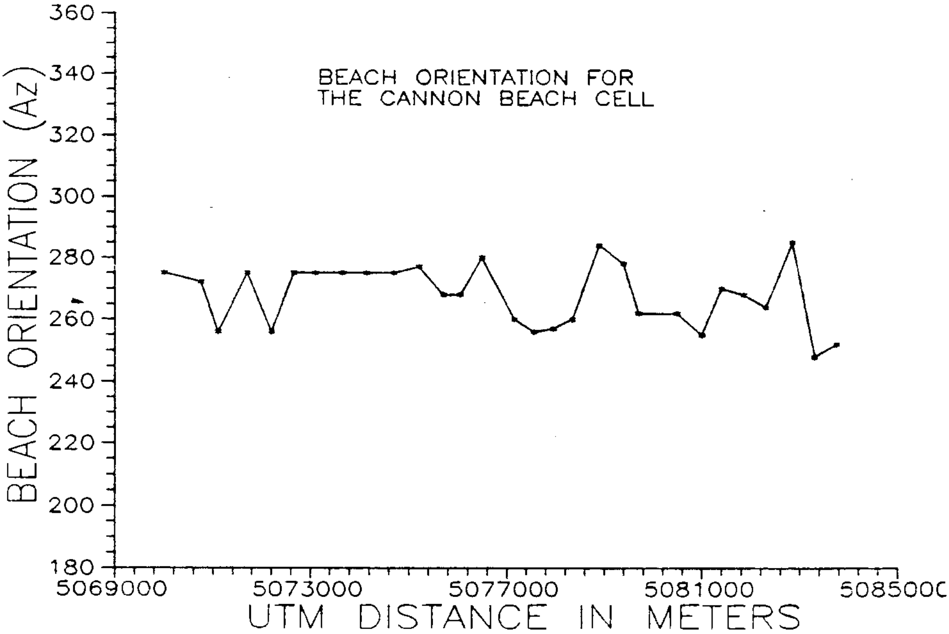


Figure 39. Shoreline orientation for the Cannon Beach Cell.

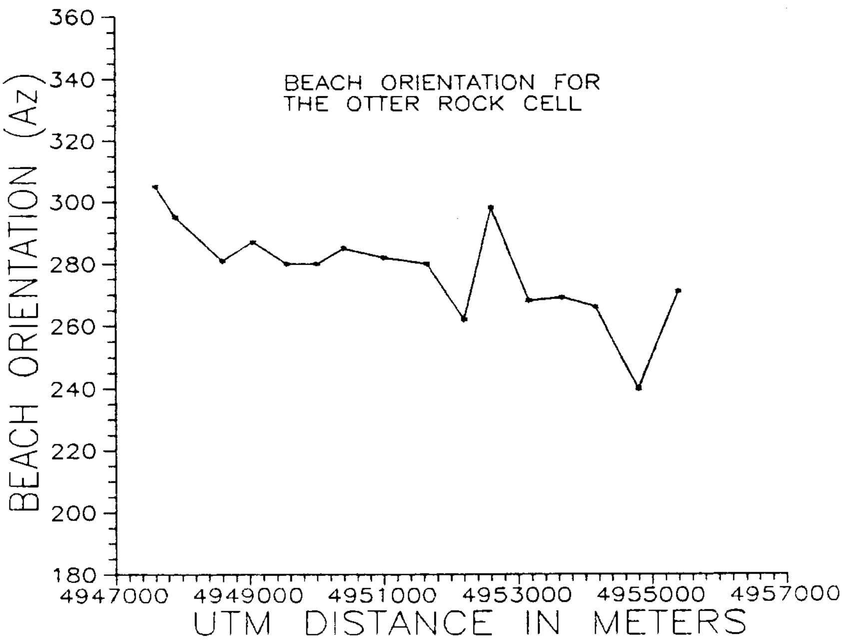
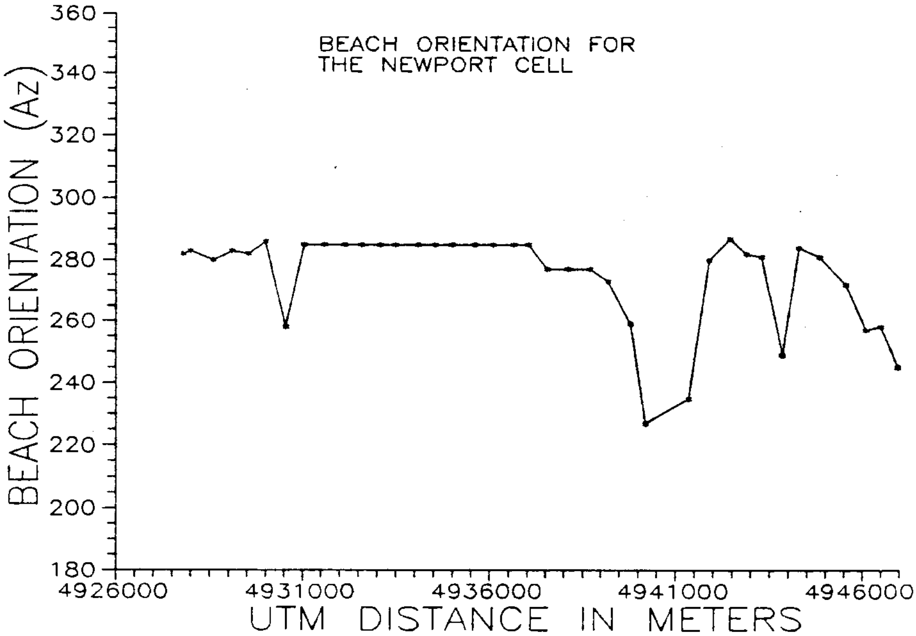
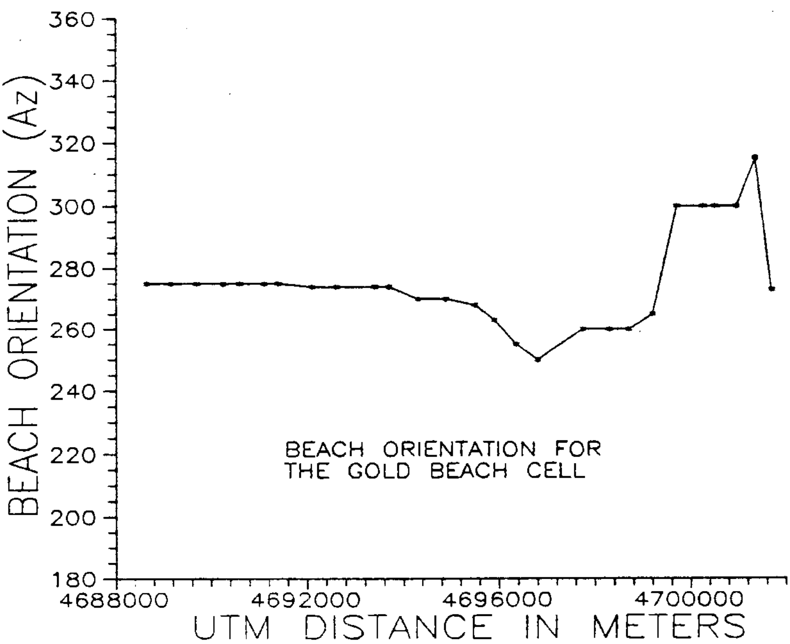


Figure 40. Shoreline orientation for the Otter Rock Cell.



<u>Figure 41.</u> Shoreline orientation for the Newport Cell.



<u>Figure 42.</u> Shoreline orientation for the Gold Beach Cell.

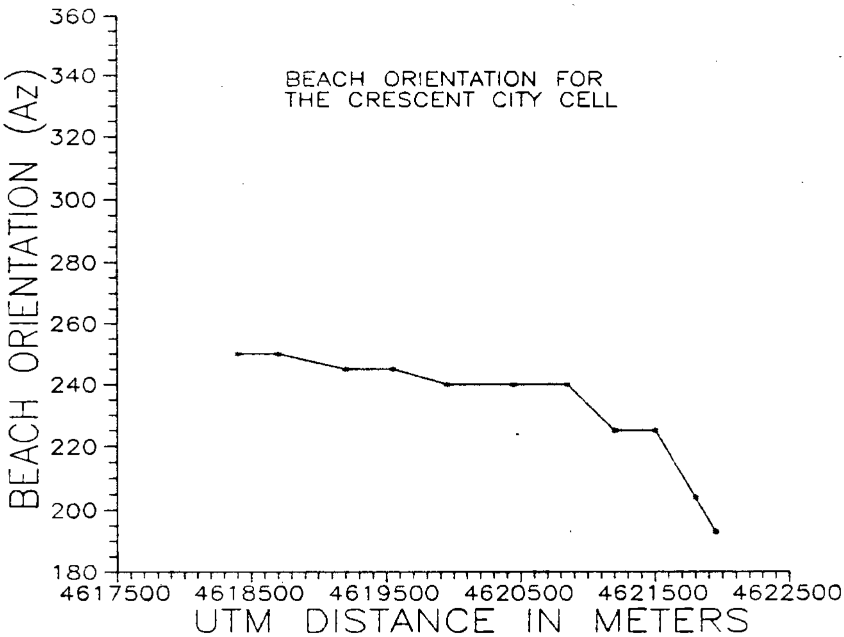


Figure 43. Shoreline orientation for the Crescent City Cell.

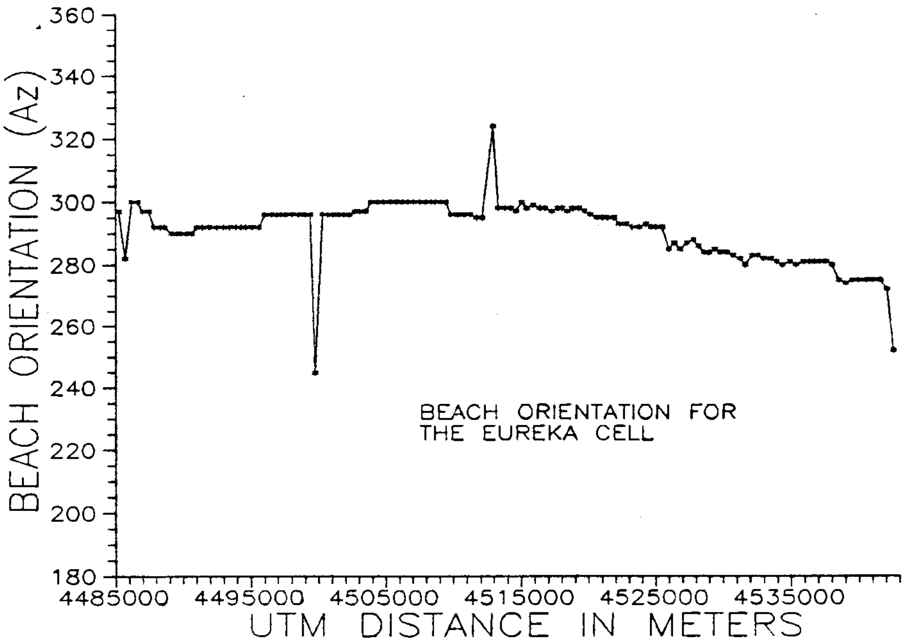


Figure 44. Shoreline orientation for the Eureka Cell.

platform depth below MTL for the beaches studied are given in Table I. Figures 45 through 52 show the relationship between mid-beachface slope and cell position for each selected littoral cell.

GRAIN SIZE ANALYSIS

Beach sand and terrace samples were analyzed for mean grain size and standard deviation from each profiled beach in the eight littoral cells. The results of these analyses are presented in Tables II and III below. The mean grain size for beaches within the study areas ranges between 0.113 and 1.729 mm with an average of 0.271 mm. The average grain size for all beaches sampled in the Pacific Northwest is 0.313 mm (Peterson and others, 1990b). Figures 53 through 60 show the relationships among beach grain size, terrace sand grain size, and position in the cell measured in S-N UTM distance for each cell. The mean grain size ranges between 0.164 and 0.753 mm in beach samples from the La Push Cell, with an average mean grain size of 0.548 mm. For the Kalaloch Cell, mean grain sized ranges from 0.122 to 1.729 mm, with an average mean grain size of 0.460 mm. The mean grain size ranges between 0.152 and 0.187 mm in the Cannon Beach Cell, with an average mean grain size of 0.172 mm. The average mean grain size of beach samples collected in the Otter Rock Cell is 0.232 mm with mean grain size ranging from 0.189 to 0.275 mm. The mean grain size ranges between

TABLE I

BEACH WIDTHS AND MID-BEACHFACE SLOPES DETERMINED FROM BEACH PROFILES IN SELECTED CELLS OF THE PNW

PROFILE	WIDTH	AVG.	Slope (M)	%M	Avg. %M
LaPush Cell					
N. Rialto Beach	54	47	0.0443	4.43	4.82
S. Rialto Beach	40		0.0521	5.21	
LaPush A	100	95	0.0146	1.46	2.09
LaPush B	90		0.0272	2.72	
Kalaloch Cell					
Ruby Beach B	48	51	0.0183	1.83	1.73
Ruby Beach A	53		0.0163	1.63	
Beach #4 A	57	51	0.0207	2.07	1.89
Beach #4 B	45		0.0171	1.71	
Kalaloch C	155	129	0.0162	1.62	1.62
Kalaloch A	100		0.0208	2.08	
Kalaloch B	131		0.0115	1.15	
South Beach B	84	66	0.0123	1.23	1.57
South Beach A	43		0.0111	1.11	
South Beach C	70		0.0238	2.38	
Whale Creek B	130	139	0.0183	1.83	1.71
Whale Creek A	158		0.0193	1.93	
Whale Creek C	130		0.0136	1.36	
Cannon Beach Cell					
Chapman B	240	225	0.0124	1.24	1.14
Chapman A	210		0.0104	1.04	
Tolovana C	148	176	0.0131	1.31	1.58
Tolovana A	150		0.0157	1.57	
Tolovana B	230		0.0187	1.87	
Arcadia A	158	155	0.0115	1.15	1.35
Arcadia B	171		0.0120	1.20	
Arcadia C	135		0.0169	1.69	

TABLE I

BEACH WIDTHS AND MID-BEACHFACE SLOPES DETERMINED FROM BEACH PROFILES IN SELECTED CELLS OF THE PNW (continued)

PROFILE	WIDTH	AVG.	Slope (M)	%M	Avg. %M
Arch Cape C	149	131	0.0113	1.13	1.39
Arch Cape A	145		0.0134	1.34	
Arch Cape B	100		0.0171	1.71	
Cove Beach B	77	49	0.0172	1.72	1.63
Cove Beach A	20		0.0154	1.54	
Otter Rock Cell					
Otter Rock	182	182	0.0125	1.25	1.25
Beverly Beach A	147	167	0.0166	1.66	1.43
Beverly Beach B	135		0.0137	1.37	
Beverly Beach C	219		0.0126	1.26	
Moolack B	100	117	0.0097	0.97	1.43
Moolack A	120		0.0180	1.80	
Moolack C	131		0.0151	1.51	
58th Street	45	45	0.0357	3.57	3.57
Newport Cell					
Agate Cove A	195	191	0.0121	1.21	1.18
Agate Cove B	187		0.0114	1.14	
Agate Wayside A	214	205	0.0116	1.16	1.32
Agate Wayside B	200		0.0148	1.48	
Agate Wayside C	202		0.0133	1.33	
Nye Beach A	140	144	0.0165	1.65	1.75
Nye Beach B	148		0.0184	1.84	
South Beach C	140	142	0.0169	1.69	1.73
South Beach A	145		0.0239	2.39	
South Beach B	140		0.0110	1.10	
Holiday Beach C	158	183	0.0149	1.49	1.32
Holiday Beach A	145		0.0115	1.15	
Holiday Beach B	245		0.0131	1.31	

TABLE I

BEACH WIDTHS AND MID-BEACHFACE SLOPES DETERMINED FROM BEACH PROFILES IN SELECTED CELLS OF THE PNW (continued)

PROFILE	WIDTH	AVG.	Slope (M)	%M	Avg. %M
Lost Creek C	170	167	0.0185	1.85	1.46
Lost Creek A	170		0.0095	0.95	
Lost Creek B	160		0.0157	1.57	
Seal Rock B	50	64	0.0117	1.17	1.37
Seal Rock A	78		0.0157	1.57	
Gold Beach Cell					
Otter Point B	178	170	0.0151	1.51	1.64
Otter Point A	160		0.0163	1.63	
Otter Point C	173		0.0179	1.79	
High Tide B	114	116	0.0260	2.60	2.28
High Tide A	115		0.0226	2.26	
High Tide C	119		0.0198	1.98	
Red House	199		0.0161	1.61	1.61
FairgroundsC	82	79	0.0317	3.17	3.75
Farigrounds A	90		0.0371	3.71	
Fairgrounds B	64		0.0438	4.38	
Big Rock B	95	101	0.0400	4.00	3.92
Big Rock A	119		0.0371	3.71	
Big Rock C	90		0.0406	4.06	
Boomer Rd. B	35	55	0.1000	10.00	10.19
Boomer Rd. A	99		0.1000	10.00	
Boomer Rd. C	30		0.1057	10.57	
Crescent City Cell					
Crescent City N. B	130	128	0.0156	1.56	1.36
Crescent City N. A	125		0.0115	1.15	
Dead Dog A	128	127	0.0161	1.61	1.56
Dead Dog B	126		0.0150	1.50	
Crescent Beach A	95	96	0.0218	2.18	1.82
Crescent Beach B	97		0.0145	1.45	

TABLE I

BEACH WIDTHS AND MID-BEACHFACE SLOPES DETERMINED FROM BEACH PROFILES IN SELECTED CELLS OF THE PNW (continued)

PROFILE	WIDTH	AVG.	Slope (M)	%M	Avg. %M
Crescent City S. A	100	103	0.0143	1.43	1.59
Crescent City S. B	106		0.0174	1.74	
Eureka Cell					
Moonstone	400	400	0.0059	0.59	0.59
Clam Beach B	296	272	0.0143	1.43	1.24
Clam Beach A	264		0.0156	1.56	
Clam Beach C	257		0.0072	0.72	
Mad River B	?		0.0211	2.11	2.53
Mad River A	65	57	0.0427	4.27	
Mad River C	48		0.0122	1.22	
Manila B	110	94	0.0330	3.30	3.49
Manila A	83		0.0414	4.14	
Manila C	90		0.0303	3.03	
Samoa	77		0.0360	3.60	3.60
North Jetty C	108	105	0.0454	4.54	3.47
North Jetty B	98		0.0300	3.00	
North Jetty A	110		0.0286	2.86	
South Jetty A	192	154	0.0180	1.80	1.81
South Jetty B	143		0.0192	1.92	
South Jetty C	126		0.0171	1.71	
Table Bluff 1c	98	96	0.0240	2.40	2.44
Table Bluff 1a	98		0.0234	2.34	
Table Bluff 1b	92		0.0258	2.58	
Table Bluff 2	85	85	0.0328	3.28	3.28
Centerville 2c	90	67	0.0458	4.58	5.25
Centerville 2a	60		0.0543	5.43	
Centerville 2b	50		0.0575	5.75	
Centerville 1b	55	47	0.0545	5.45	5.84
Centerville 1a	38		0.0623	6.23	

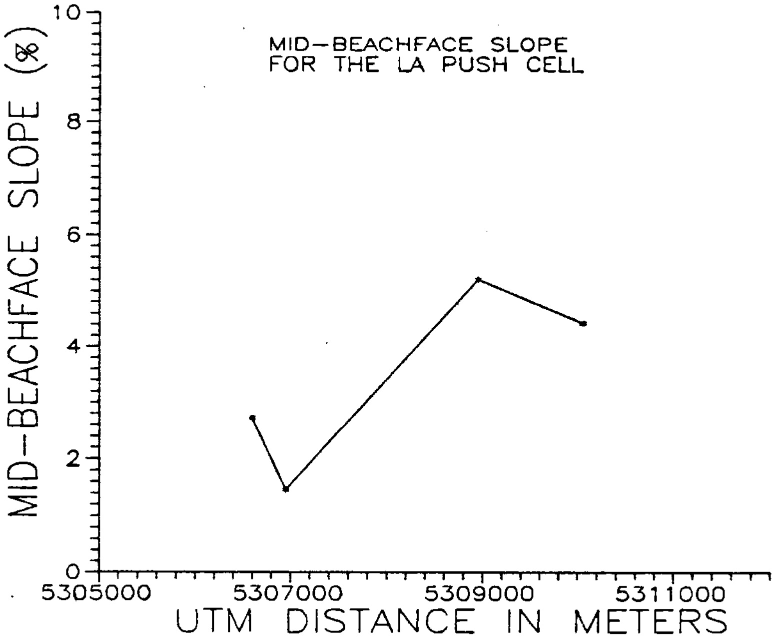


Figure 45. Mid-beachface slope versus distance for the La Push Cell.

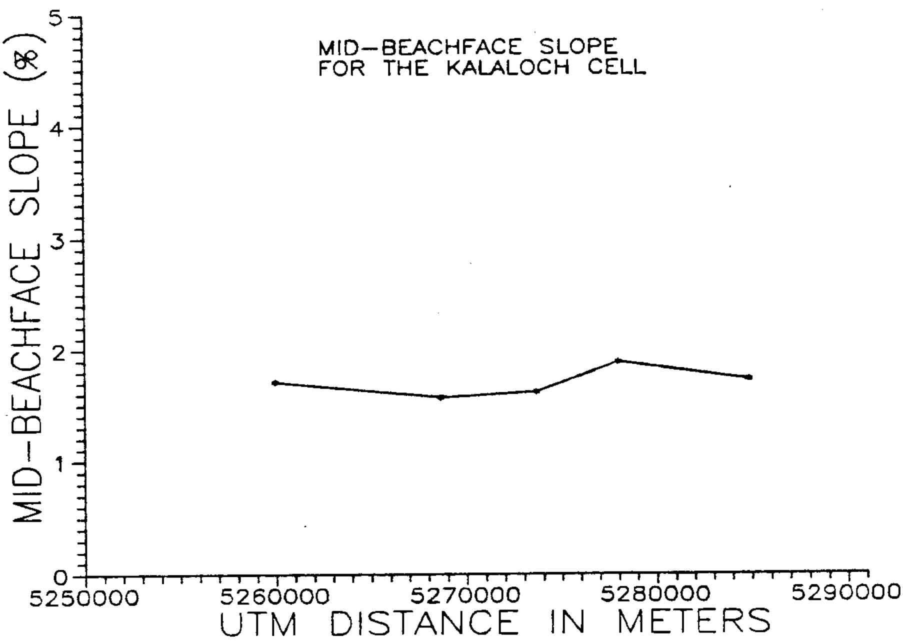


Figure 46. Mid-beachface slope versus distance for the Kalaloch Cell.

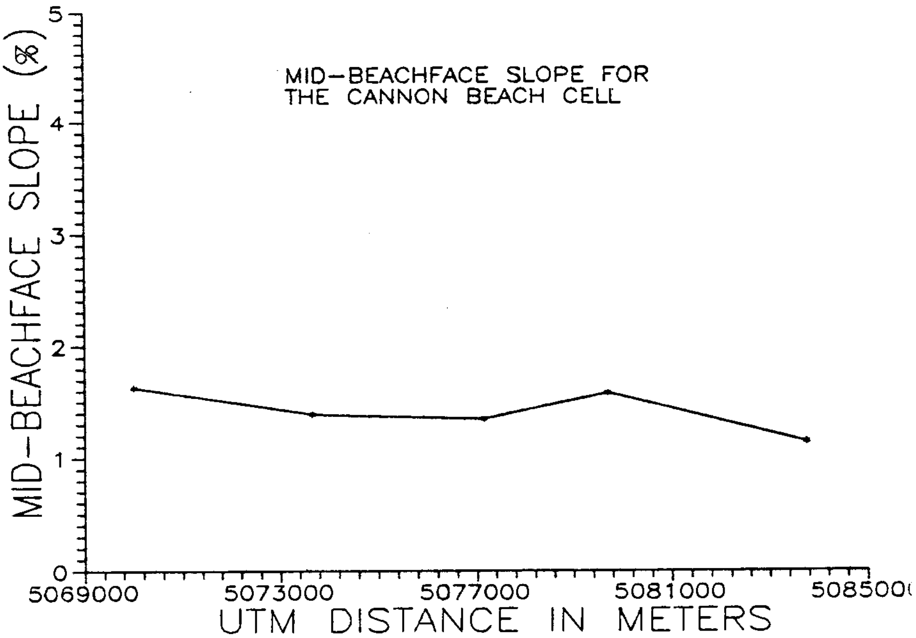


Figure 47. Mid-beachface slope versus distance for the Cannon Beach Cell.

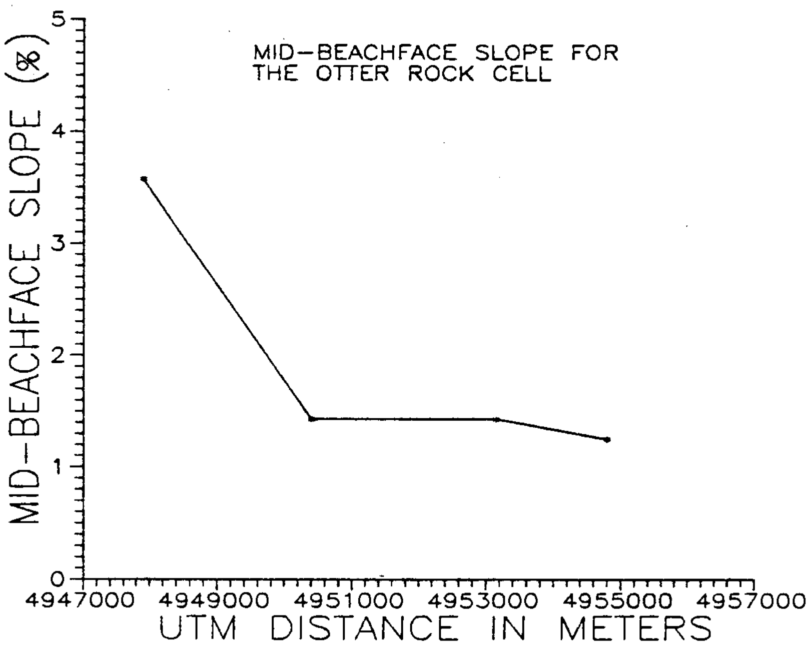


Figure 48. Mid-beachface slope versus distance for the Otter Rock Cell.

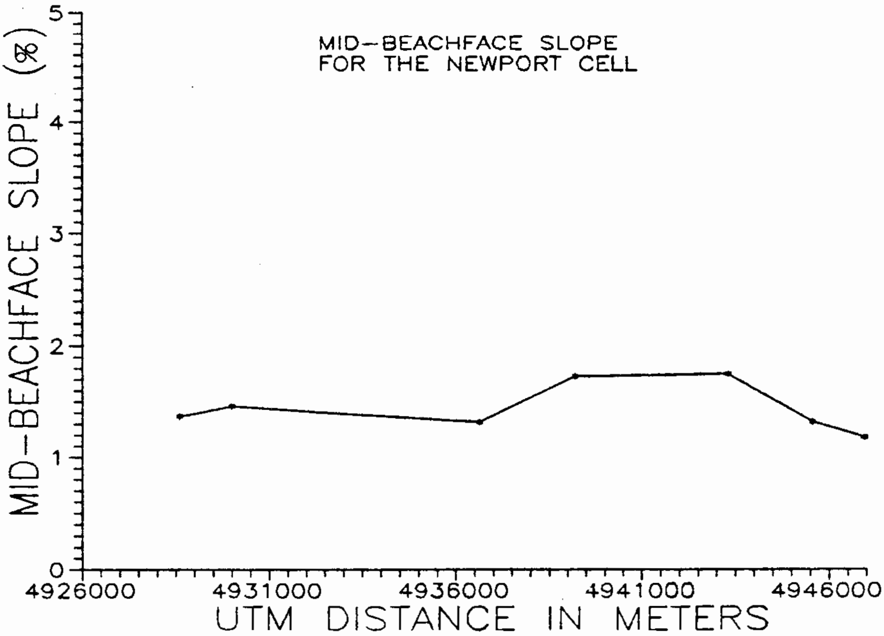


Figure 49. Mid-beachface slope versus distance for the Newport Cell.

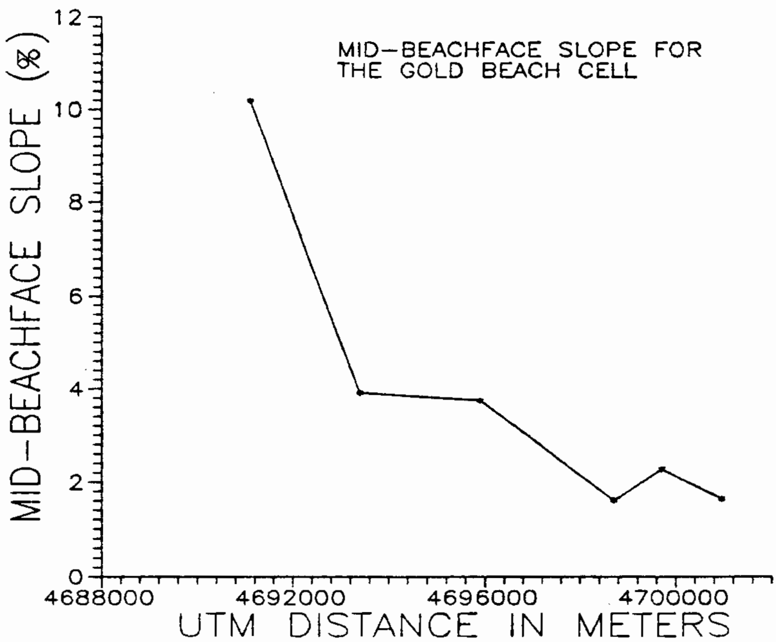


Figure 50. Mid-beachface slope versus distance for the Gold Beach Cell.

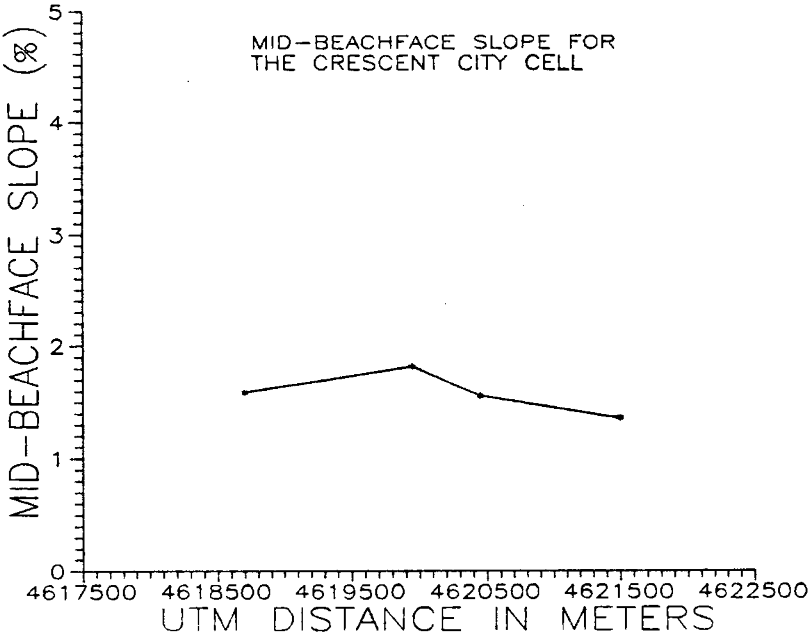


Figure 51. Mid-beachface slope versus distance for the Crescent City Cell.

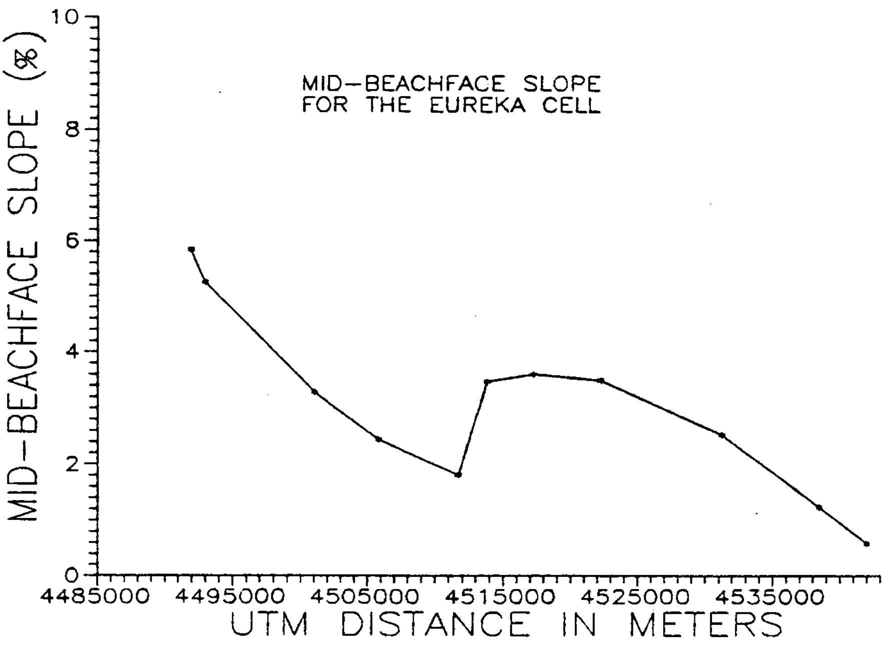


Figure 52. Mid-beachface slope versus distance for the Eureka Cell.

TABLE II

RESULTS OF GRAIN SIZE ANALYSIS OF SELECTED BEACHES IN THE PNW

LOCATION	SAMPLE	UTM N-S	UTM W-E	MEAN	STD. DEV.
		(meters)	(meters)	(mm)	(mm)
North Rialto (Ellen Creek) *	B125	5310050	377400	0.727	0.374
South Rialto*	B116	5308950	377600	0.753	0.297
LaPush South	B115	5306950	377650	0.164	0.790
Ruby Beach *	B119	5284800	393850	1.729	0.257
Beach #4 *	B114	5277950	395800	0.790	0.191
South Brown's Point	B118	5276050	396300	0.122	0.785
Kalaloch Beach	B117	5273650	396600	0.130	0.824
South Beach	B113	5268650	397600	0.158	0.796
Whale Creek	B124	5259950	398750	0.151	0.744
Little Hogsback Beach	B121	5254100	399150	0.140	0.807
Chapman Beach	B97	5083750	424100	0.166	0.841
Tolovana Beach	B93	5079700	425300	0.166	0.779
Arcadia Beach	B92	5077150	425400	0.187	0.818
North Arch Cape Beach	B88b	5073650	425150	0.187	0.824
Cove Beach	B99	5070000	424700	0.152	0.829
Otter Rock Beach	B79	4954800	416200	0.189	0.742
Beverly Beach	B77	4953150	416250	0.232	0.785
Moolack Beach	B76	4950400	415950	0.232	0.824
58th Street Beach	B78	4947900	415300	0.275	0.669
Agate Beach Cove	B63	4946950	415950	0.122	0.829
Agate Beach Wayside	B64	4945550	416150	0.147	0.801
Nye Beach	B65	4943300	415750	0.151	0.812
South Beach	B66	4939200	415500	0.147	0.841
Holiday Beach (Grant Cr.)	B69	4936650	415250	0.170	0.812
Ona Beach	B67	4932600	414750	0.151	0.824
Lost Creek Wayside	B68	4930000	414500	0.153	0.801
Seal Rocks Beach	B70	4928600	414150	0.153	0.796
Otter Point Beach	B43	4700950	382700	0.180	0.688
High Tide Beach	B42	4699700	382100	0.177	0.779
Red House Beach	B44	4698700	382100	0.204	0.737
Gold Beach Fairgrounds	B45a	4695900	382650	0.325	0.642
Hunters Creek	B30	4694300	382750	0.358	0.674
Big Rock Beach	B45b	4693400	382700	0.379	0.702
Boomer Road Beach	B46	4691100	382700	0.426	0.693

TABLE II

RESULTS OF GRAIN SIZE ANALYSIS OF SELECTED BEACHES IN THE PNW
(continued)

LOCATION	SAMPLE	UTM N-S	UTM W-E	MEAN	STD. DEV.
		(meters)	(meters)	(mm)	(mm)
Crescent City North	B38	4621500	403150	0.121	0.841
Dead Dog Beach	B40	4620450	403900	0.120	0.818
Crescent City Beach	B18	4619950	404150	0.113	0.812
Crescent City South	B39	4618700	404750	0.134	0.790
Endert's Beach	B17	4616950	405100	0.480	0.616
Moonstone Beach	B11a	4542000	406600	0.120	0.763
Clam Beach	B10	4538450	406100	0.133	0.818
Mad River Beach	B9	4531200	404300	0.162	0.774
Manila	B8	4522250	401000	0.183	0.779
Samoa	B7	4517250	399000	0.248	0.801
North Jetty Humbolt	B6	4513800	397300	0.243	0.768
South Jetty Humbolt	B4	4511700	395600	0.203	0.774
Table Bluff	B5	4505800	392300	0.241	0.790
North Eel River Beach	B3	4501050	389800	0.312	0.801
Centerville Beach	B2	4492950	386000	0.595	0.664

Note: * Indicates greater than 5% >2mm, sieve analysis performed.

TABLE III

RESULTS OF GRAIN SIZE ANALYSIS OF SELECTED TERRACES IN THE PNW

LOCATION	ID #	UTM N-S (meters)	UTM W-E (meters)	MEAN (phi)	STD. DEV. (phi)
Beach #4	T40a	5277950	395800	0.143	0.785
Beach #4	T40b	5277950	395800	0.191	0.722
Kalaloch	T41	5273650	396600	0.248	0.412
South Beach	T39	5268650	397600	0.503	0.470
Arcadia Beach	T35	5077150	425400	0.149	0.395
Arch Cape Beach	T34	5073650	425150	0.095	0.366
Cove Beach	T36	5070000	424700	0.067	0.599
Beverly Beach	T27	4953150	416250	0.203	0.818
Moolack Beach	T26	4950400	415950	NONE	
58th Street	T28a	4947900	415300	NONE	
58th Street	T28b	4947900	415300	0.219	0.807
Agate Cove	T15	4946950	415950	0.082	0.441
Agate Wayside	T16	4945550	416150	0.065	0.387
Nye	T17	4943300	415750	0.164	0.732
Holiday Beach	T20	4936650	415250	0.222	0.727
Ona Beach	T19	4932600	414750	0.192	0.812
Lost Creek Wayside	T18	4930000	414500	0.199	0.785
Seal Rocks	T21	4928600	414150	0.164	0.801
Otter Point	T9b	4700950	382700	0.184	0.599
Crescent City South	T10b	4618700	404750	0.233	0.304
Trinidad	T2	4545650	403400	0.209	0.603
Centerville	T1	4492950	386000	0.245	0.559

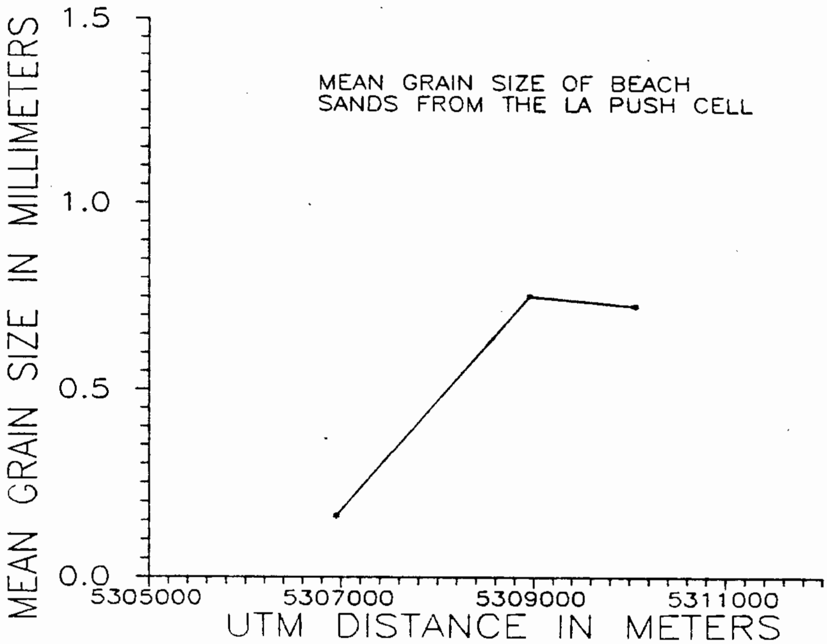


Figure 53. Beach and terrace grain size versus distance for the La Push Cell.

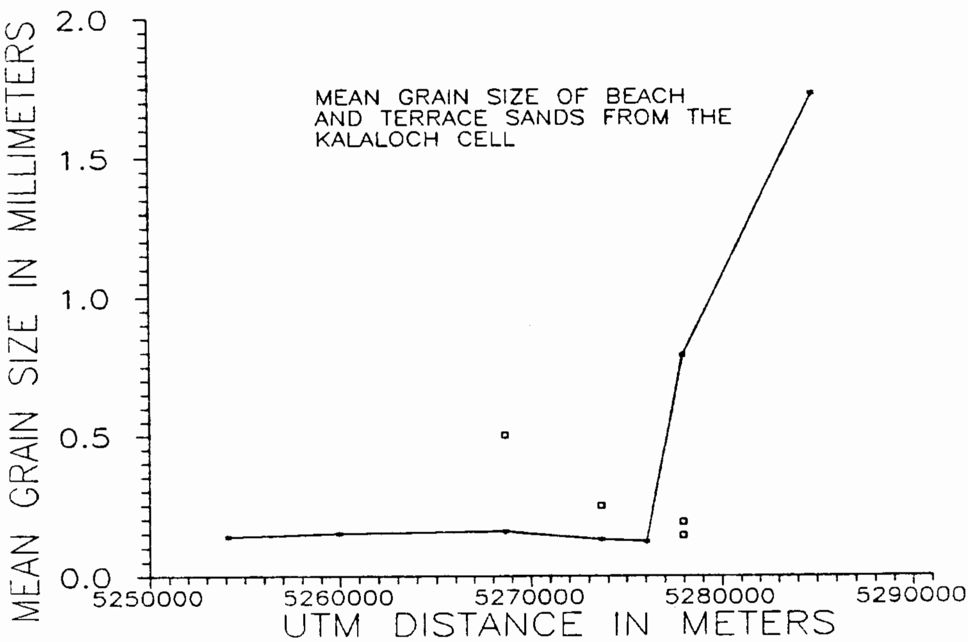


Figure 54. Beach and terrace grain size versus distance for the Kalaloch Cell.

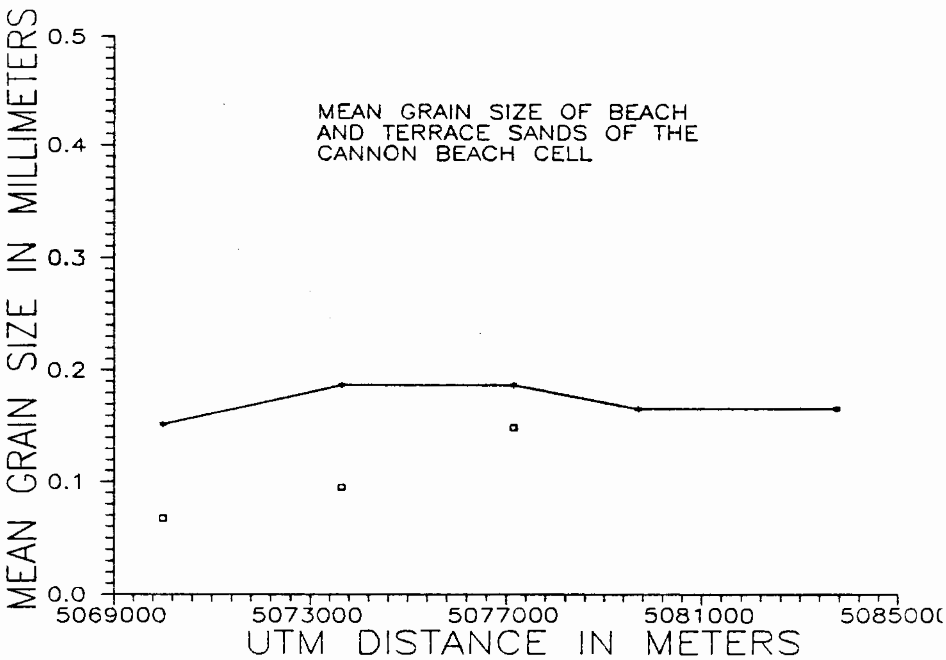


Figure 55. Beach and terrace grain size versus distance for the Cannon Beach Cell.

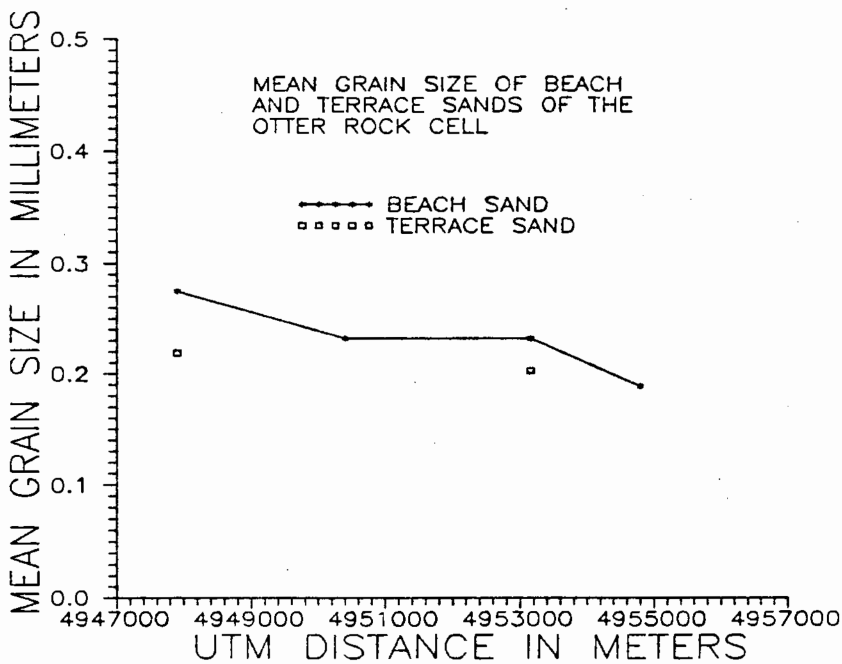


Figure 56. Beach and terrace grain size versus distance for the Otter Rock Cell.

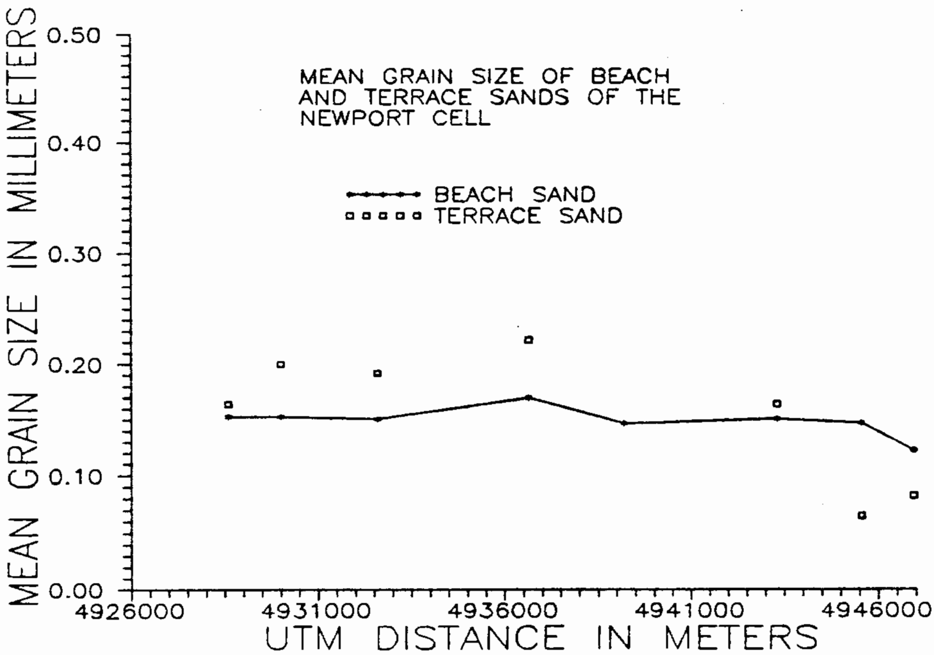


Figure 57. Beach and terrace grain size versus distance for the Newport Cell.

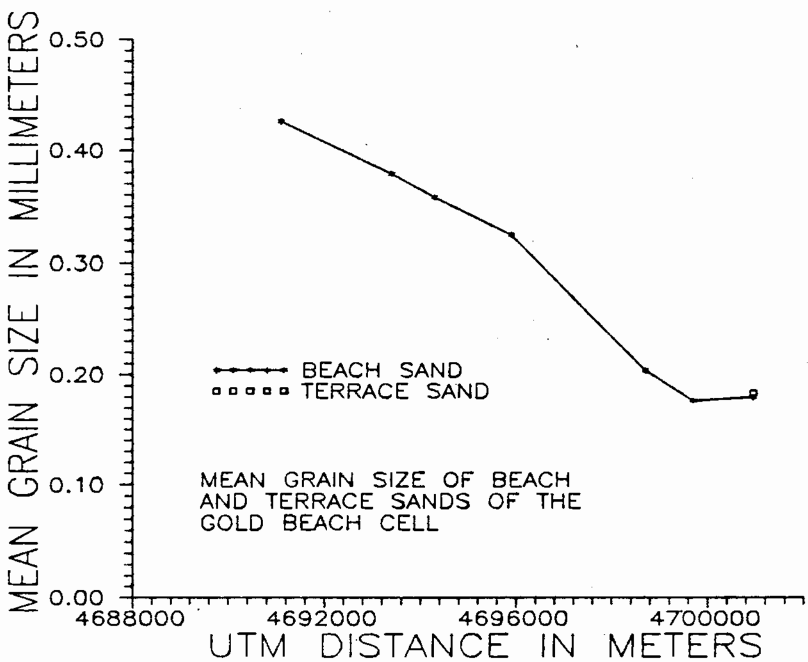


Figure 58. Beach and terrace grain size versus distance for the Gold Beach Cell.

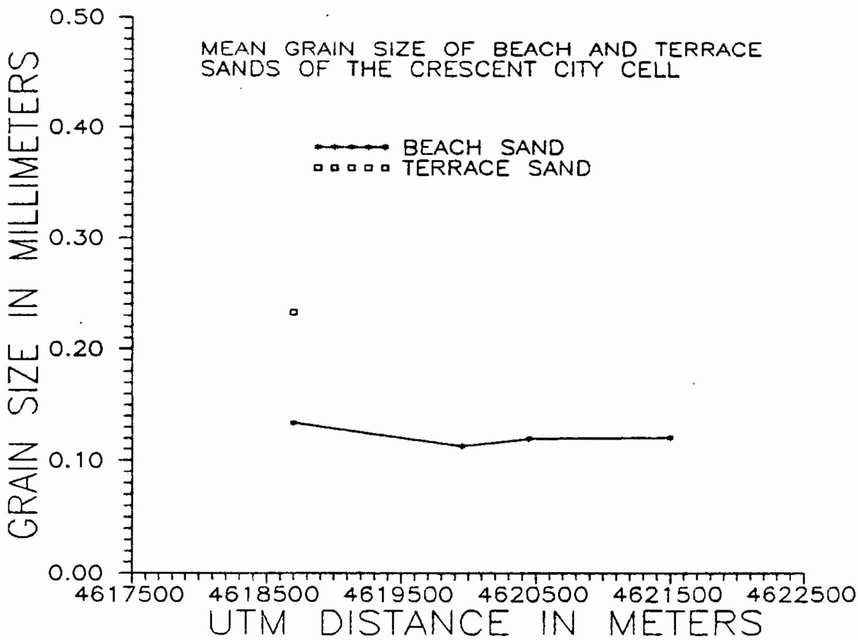


Figure 59. Beach and terrace grain size versus distance for the Crescent City Cell.

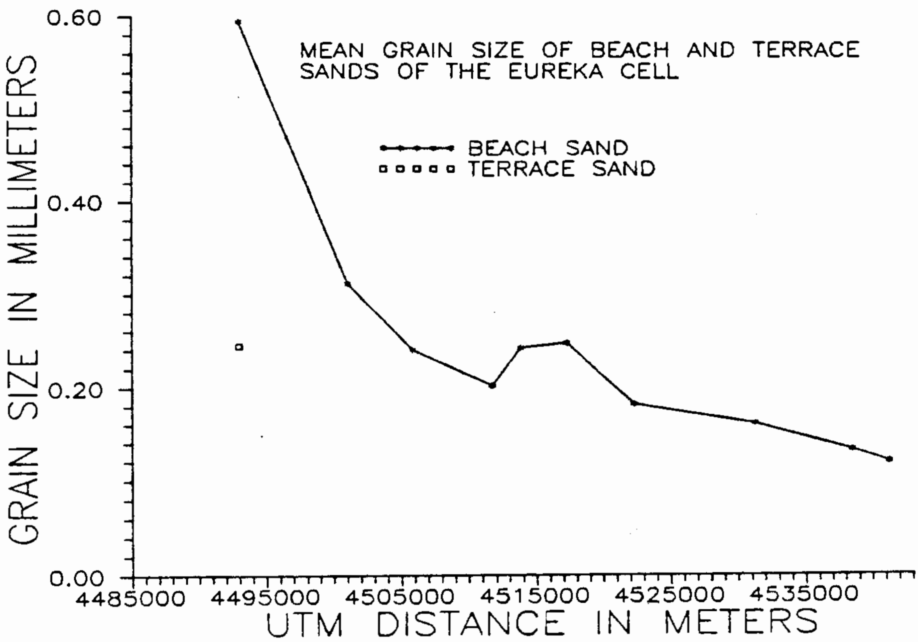


Figure 60. Beach and terrace grain size versus distance for the Eureka Cell.

0.122 and 0.170 mm in the Newport Cell, with an average mean grain size of 0.149 mm. For the Gold Beach Cell, mean grain size ranges between 0.177 and 0.426 mm, with an average mean grain size of 0.293. The average mean grain size of beach samples collected from the Crescent City Cell is 0.122 mm, with mean grain size ranging from 0.113 to 0.134 mm. The mean grain size of beach samples in the Eureka Cell ranges between 0.120 and 0.595 mm, with an average mean grain size of 0.244 mm.

The average mean grain size of terrace sand samples collected in the Kalaloch Cell is 0.271 mm with a range in mean grain size between 0.143 and 0.503 mm. Terrace samples of the Cannon Beach Cell have a mean grain size range of 0.067 to 0.149 mm with an average mean grain size of 0.104 mm. Of the terrace samples collected from the Otter Rock Cell, only two contained sand. The majority of sea cliff sites there are composed of mudstones. The mean grain size of these samples are 0.203 and 0.219 mm, for an average of 0.211 mm. The mean grain size of terrace samples from the Newport Cell ranges from 0.065 to 0.222 mm with an average mean grain size of 0.155. The single terrace sand sample collected at Otter Point in the Gold Beach Cell has a mean grain size of 0.184 mm. The mean grain size of the terrace exposed at the south end of the Crescent City Cell is 0.233 mm. Terrace samples were collected at Centerville Beach and Trinidad Head in the Eureka Cell. These samples have mean grain sizes of 0.245 and 0.209 mm respectively, for an average of 0.227 mm.

SAND CROSS-SECTIONAL AREA AND VOLUME ESTIMATION

The quantity of sand on a given beach determines to a large extent its ability to protect bluffs, dunes, and sea cliffs from erosion by storm surges and wave attack (Komar, 1976). The cross-sectional area of sand at each profile site was calculated by measuring the area between the upper beach surface (established by surveying) and the wave cut platform at depth (established through the seismic refraction survey). The stable vegetated dune or sea cliff base was used as the landward limit while the intersection of estimated MLLW position with the profile was used as the seaward limit. The three cross-sectional areas calculated for this study include: 1) the area of sand above MHHW, 2) the area of sand above MLLW, and 3) the total area of sand. The cross-sectional areas measured at each profile site, as well as an analysis of the degree to which the site selected represents the cell segment (based on beach width) are presented in Table IV. Figures 61 through 68 show the relationship between the three sand areas and longshore distance for each cell. Table IV also shows the longshore length of the cell sections and the estimated volumes of sand in those segments determined by multiplying the cell section lengths by the beach areas. Three volumes are

TABLE IV

BEACH SAND AREA AND VOLUME ESTIMATES FOR SELECTED BEACHES OF THE PNW

LOCATION	AERIAL PHOTO DATA (1989)					SURVEY DATA				
LA PUSH CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
N. Rialto	N/A					54	0.044	132	92	36
S. Rialto	N/A					40	0.052	140	140	33
LaPush North	N/A					100	0.015	82	82	53
LaPush South	N/A					90	0.027	80	80	73
						71	0.035	108.50	98.50	48.75
KALALOCH CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Ruby Beach	N/A					51	0.017	217	217	75
Beach #4	N/A					51	0.019	209	121	23
Kalaloch	N/A					129	0.016	1071	228	31
South Beach	N/A					66	0.016	108	100	20
Whale Creek	N/A					139	0.017	404	275	91
Little Hogsback*	N/A					20		15	15	0
						76	0.017	337.33	159.33	40.00
CANNON BEACH CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Chapman Beach	3/10/89	171.75	6.99	0.04	171	225	0.011	726	726	528
Tolovana Beach	3/10/89	135.29	16.13	0.12	137	176	0.016	226	216	15
Arcadia	3/10/89	96.14	25.86	0.27	109	155	0.014	383	287	31
Arch Cape	3/10/89	85.50	22.56	0.26	92	131	0.014	174	174	48
Cove Beach	3/10/89	33.25	12.47	0.38	44	49	0.016	267	112	30
		104.39				147	0.014	355.20	303.00	130.40
OTTER ROCK CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Otter Rock	8/7/89	55.00	4.58	0.08	54	182	0.013	115	115	27
Beverly Beach	8/7/89	72.00	12.00	0.17	66	167	0.014	139	139	17
Moolack Beach	8/7/89	54.75	12.09	0.22	60	117	0.014	48	48	9
58th Street	8/7/89	31.50	23.17	0.74	18	45	0.036	32	31	4
		53.31				128	0.019	83.50	83.25	14.25
NEWPORT CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Agate Beach Cove	8/7/89	117.00	21.00	0.18	93	191	0.012	329	235	35
Agate Beach Wayside	8/7/89	107.40	42.13	0.39	150	205	0.013	217	217	96
Nye Beach	8/7/89	100.20	50.09	0.50	84	144	0.018	142	133	10
South Beach	8/7/89	118.00	30.40	0.26	111	142	0.017	3425	838	358
Holiday Beach	8/7/89	96.75	15.76	0.16	105	152	0.013	276	211	36
Lost Creek	N/A					167	0.015	163	139	22
Seal Rocks	N/A					64	0.014	138	138	17
		107.87				152	0.014	670.00	273.00	82.00

TABLE IV

BEACH SAND AREA AND VOLUME ESTIMATES FOR SELECTED BEACHES OF THE PNW (continued)

LOCATION	AERIAL PHOTO DATA (1989)					SURVEY DATA				
GOLD BEACH CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Otter Point	8/7/89	122.67	27.79	0.23	113	170	0.016	580	355	209
High Tide Road	8/7/89	101.25	28.76	0.28	81	116	0.023	601	303	182
Red House Beach	8/7/89	101.25	29.80	0.29	138	199	0.016	394	369	213
Fairgrounds	8/7/89	104.40	29.25	0.28	97	79	0.038	691	372	239
Big Rock	8/7/89	137.67	42.45	0.31	122	101	0.039	670	412	254
Boomer Bend Road	8/7/89	93.00	12.09	0.13	105	55	0.102	216	216	192
		110.04				120	0.039	525.33	337.83	214.83
CRESCENT CITY CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Crescent City North	N/A					128	0.014	166	166	62
Dead Dog Beach	N/A					127	0.016	631	291	71
Crescent City Beach	N/A					96	0.018	218	131	33
Crescent City South	N/A					103	0.016	71	71	28
						113	0.016	271.50	164.75	48.50
EUREKA CELL	DATE	AVG. WIDTH	STD. DEV.	S.D./MEAN	Ap WIDTH	PROF. WIDTH	SLOPE	AREA	^MLLW	^MHHW
Moonstone Beach	N/A					400	0.006	716	716	179
Clam Beach	N/A					272	0.012	556	487	242
Mad River	N/A					57	0.025	1620	273	75
Manila	N/A					94	0.035	1516	310	127
Samoa	N/A					77	0.036	1240	234	69
N. Jetty Humbolt	N/A					105	0.035	1789	362	162
S. Jetty Humbolt	N/A					154	0.018	2856	454	398
Table Bluff	N/A					96	0.024	223	178	128
North Eel River	N/A					97	0.033	2647	757	339
Centerville 2	N/A					67	0.053	1301	346	161
Centerville 1	N/A					47	0.058	227	109	16
						133	0.030	1335.55	384.18	172.36

Notes: * Estimated profile.
' Interval contains some 3/3/84 data.
N/A - Data not available for normalization.

TABLE IV

BEACH SAND AREA AND VOLUME ESTIMATES FOR SELECTED BEACHES OF THE PNW (continued)

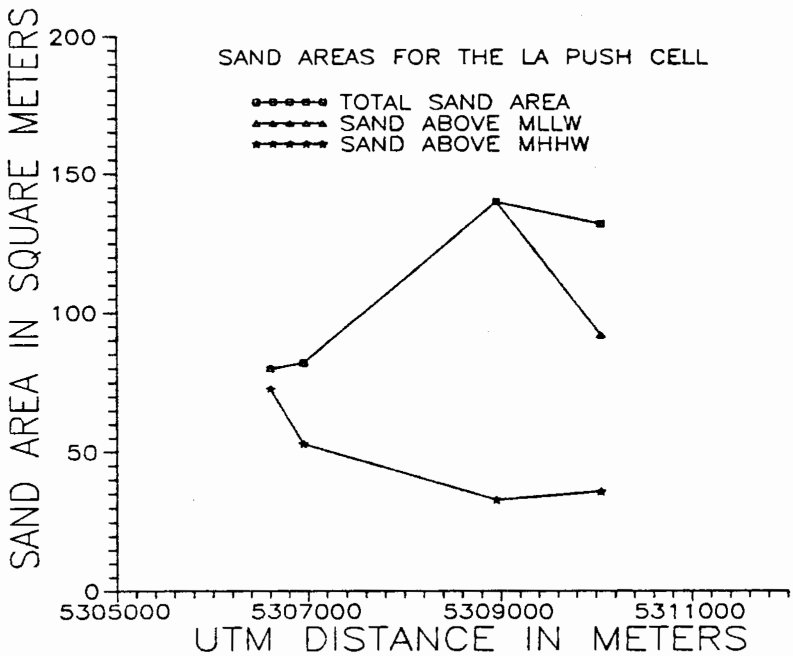
LOCATION	MAPS	NORMALIZATION		ADJUSTED AREAS			ADJUSTED VOLUMES		
LA PUSH CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
N. Rialto	1830	N/A		132	92	36	241560	168360	65880
S. Rialto	2075	N/A		140	140	33	290500	290500	68475
LaPush North	790	N/A		82	82	53	64780	64780	41870
LaPush South	730	N/A		80	80	73	58400	58400	53290
	5425			109	99	49	655240	582040	229515
KALALOCH CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Ruby Beach	1100	N/A		217	217	75	238700	238700	82500
Beach #4	8170	N/A		209	121	23	1707530	988570	187910
Kalaloch	5150	N/A		1071	228	31	5515650	1174200	159650
South Beach	6650	N/A		108	100	20	718200	665000	133000
Whale Creek	7350	N/A		404	275	91	2969400	2021250	668850
Little Hogsback*	6950	N/A		15	15	0	104250	104250	0
	35370			337	159	40	11253730	5191970	1231910
CANNON BEACH CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Chapman Beach	2075	3/10/89	1.00	729	729	530	1513057	1513057	1100405
Tolovana Beach	3630	3/10/89	1.01	223	213	15	810140	774293	53770
Arcadia	2835	3/10/89	1.13	338	253	27	957700	717650	77516
Arch Cape	3110	3/10/89	1.08	162	162	45	502907	502907	138733
Cove Beach	2195	3/10/89	1.32	202	85	23	442879	185777	49762
	13845		1.11	331	288	128	4226683	3693684	1420187
OTTER ROCK CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Otter Rock	1280	8/7/89	0.98	117	117	28	149926	149926	35200
Beverly Beach	2135	8/7/89	0.92	152	152	19	323744	323744	39595
Moolack Beach	2990	8/7/89	1.10	44	44	8	130962	130962	24555
58th Street	1350	8/7/89	0.57	56	54	7	75600	73238	9450
	7755		0.89	92	92	15	680232	677869	108800
NEWPORT CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Agate Beach Cove	1100	8/7/89	0.79	414	296	44	455294	325210	48435
Agate Beach Wayside	1680	8/7/89	1.40	155	155	69	261025	261025	115476
Nye Beach	3050	8/7/89	0.84	169	159	12	516626	483883	36382
South Beach	2680	8/7/89	0.94	3641	891	381	9757856	2387470	1019945
Holiday Beach	2865	8/7/89	1.09	254	194	33	728610	557017	95036
Lost Creek	3720	N/A		163	139	22	606360	517080	81840
Seal Rocks	3660	N/A		138	138	17	505080	505080	62220
	18755		1.01	705	282	82	12830851	5036764	1459335

TABLE IV

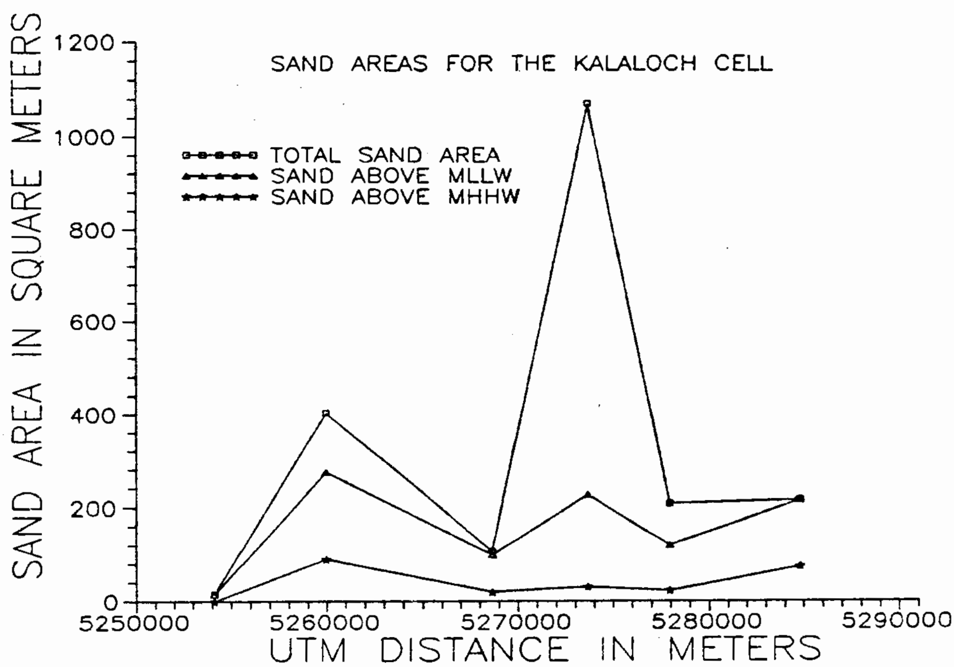
BEACH SAND AREA AND VOLUME ESTIMATES FOR SELECTED BEACHES OF THE PNW (continued)

LOCATION	MAPS	NORMALIZATION		ADJUSTED AREAS			ADJUSTED VOLUMES		
GOLD BEACH CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Otter Point	1525	8/7/89	0.92	630	385	227	960191	587703	346000
High Tide Road	1220	8/7/89	0.80	751	379	228	916525	462075	277550
Red House Beach	1890	8/7/89	1.36	289	271	156	546354	511687	295364
Fairgrounds	2315	8/7/89	0.93	744	400	257	1721701	926878	595494
Big Rock	2500	8/7/89	0.89	756	465	287	1890141	1162296	716561
Boomer Bend Road	3780	8/7/89	1.13	191	191	170	723168	723168	642816
	13230		1.00	560	349	221	6758081	4373807	2873785
CRESCENT CITY CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Crescent City North	1460	N/A		166	166	62	242360	242360	90520
Dead Dog Beach	1035	N/A		631	291	71	653085	301185	73485
Crescent City Beach	1100	N/A		218	131	33	239800	144100	36300
Crescent City South	1525	N/A		71	71	28	108275	108275	42700
	5120			272	165	49	1243520	795920	243005
EUREKA CELL	X L.S.	DATE USED	R1	=TOTAL	=^MLLW	=^MHHW	=TOTAL	=^MLLW	=^MHHW
Moonstone Beach	1645	N/A		716	716	179	1177820	1177820	294455
Clam Beach	5795	N/A		556	487	242	3222020	2822165	1402390
Mad River	9940	N/A		1620	273	75	16102800	2713620	745500
Manila	5795	N/A		1516	310	127	8785220	1796450	735965
Samoa	4760	N/A		1240	234	69	5902400	1113840	328440
N. Jetty Humbolt	3175	N/A		1789	362	162	5680075	1149350	514350
S. Jetty Humbolt	7460	N/A		2856	454	398	21305760	3386840	2969080
Table Bluff	915	N/A		223	178	128	204045	162870	117120
North Eel River	6100	N/A		2647	757	339	16146700	4617700	2067900
Centerville 2	8110	N/A		1301	346	161	10551110	2806060	1305710
Centerville 1	7250	N/A		227	109	16	1645750	790250	116000
	60945			1336	384	172	90723700	22536965	10596910

Notes: * Estimated profile.
' Interval contains some 3/3/84 data.
N/A - Data not available for normalization.



<u>Figure 61.</u> Beach sand areas versus distance for the La Push Cell.



<u>Figure 62.</u> Beach sand areas versus distance for the Kalaloch Cell.

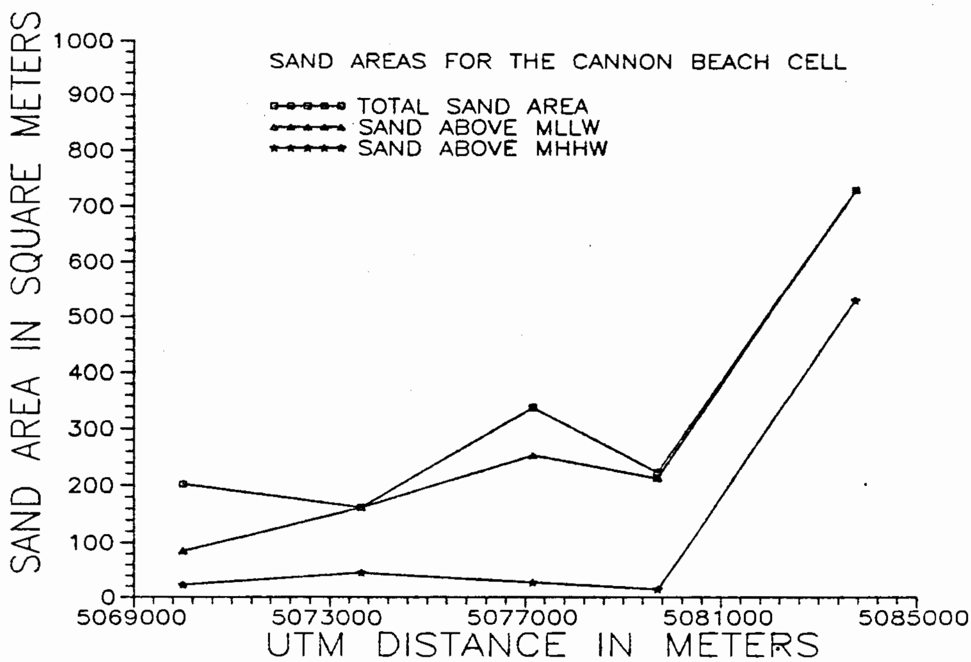


Figure 63. Beach sand areas versus distance for the Cannon Beach Cell.

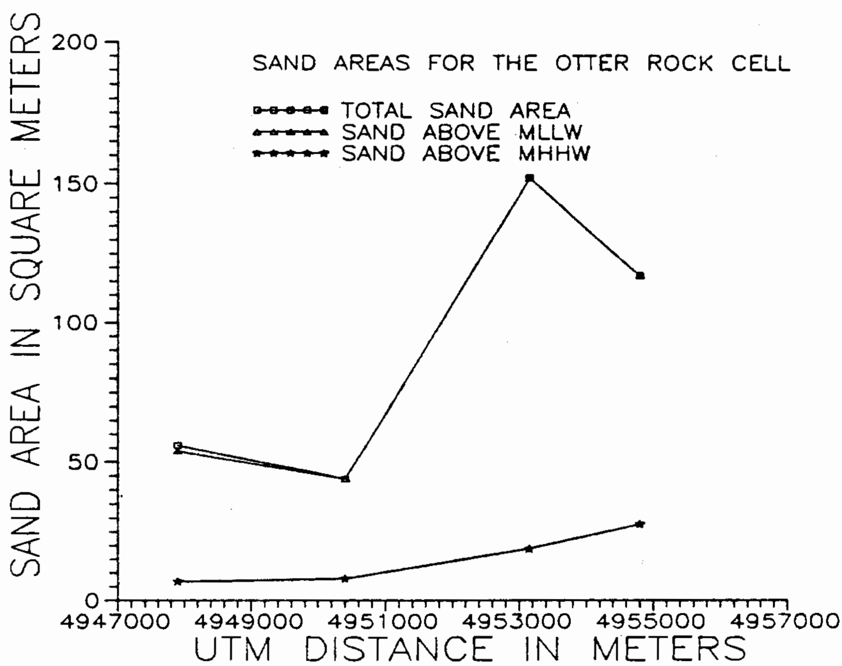
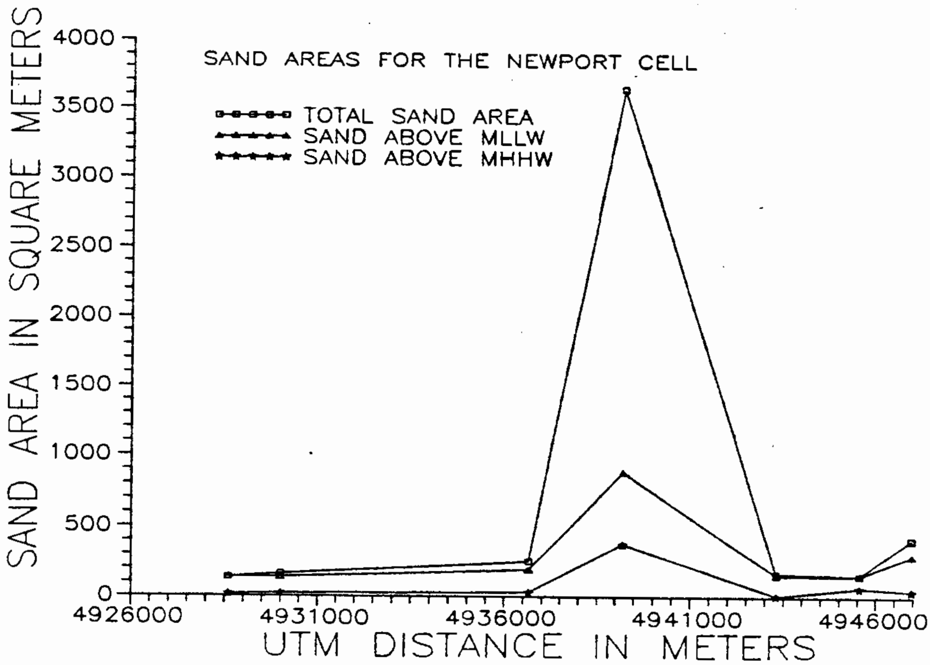
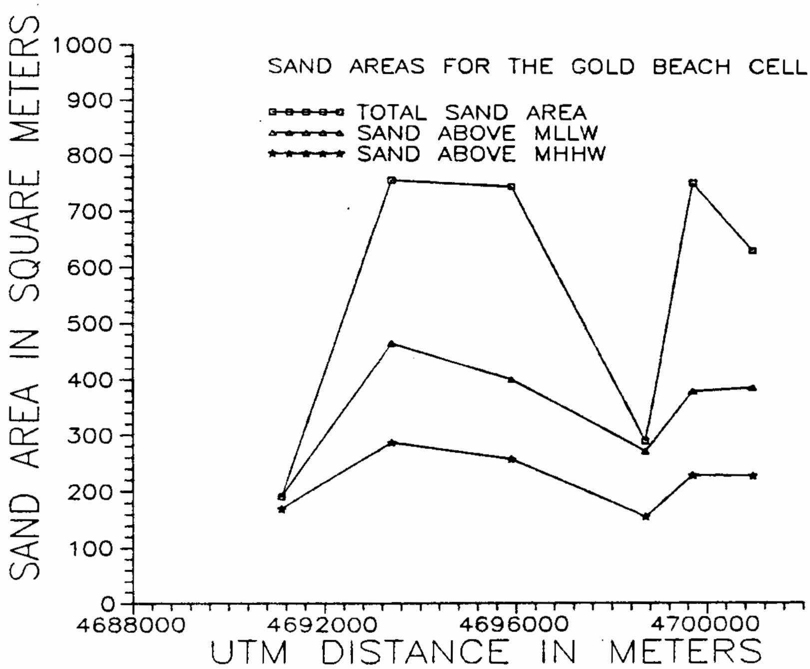


Figure 64. Beach sand areas versus distance for the Otter Rock Cell.



<u>Figure 65.</u> Beach sand areas versus distance for the Newport Cell.



<u>Figure 66.</u> Beach sand areas versus distance for the Gold Beach Cell.

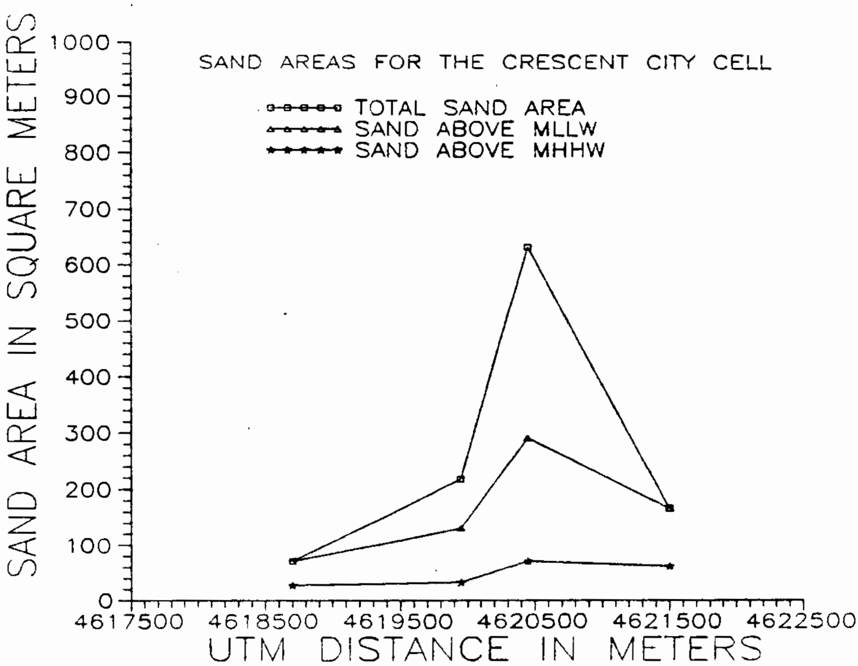


Figure 67. Beach sand areas versus distance for the Crescent City Cell.

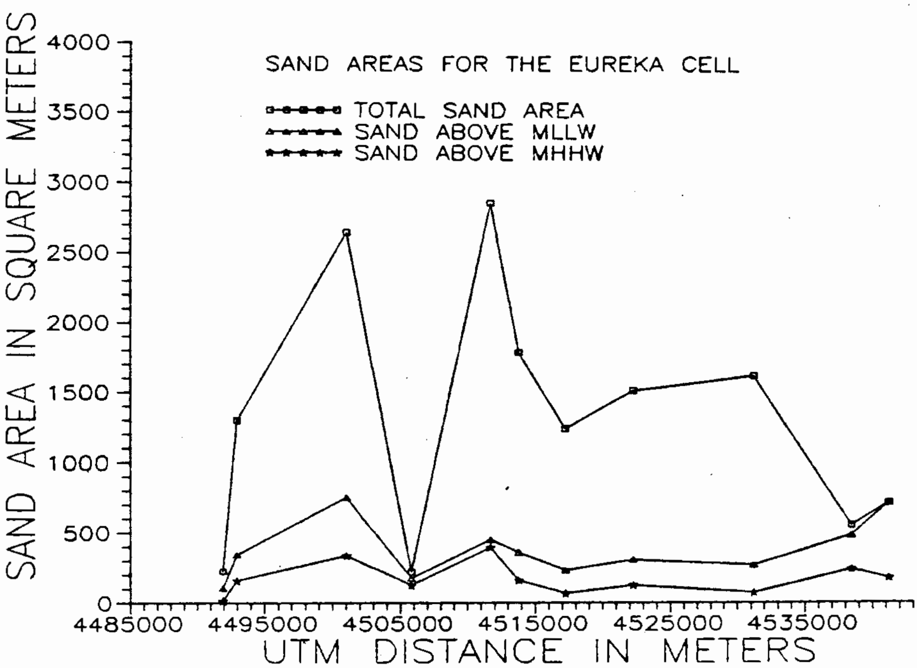


Figure 68. Beach sand areas versus distance for the Eureka Cell.

calculated: 1) the volume of sand above MHHW, 2) the volume of sand above MLLW, and 3) the total volume of sand in the cell segment. A summary table of sand volumes and other parameters for each cell is presented in Table V. The Eureka Cell contains the largest total volume of sand of the eight cells studied with more than 90 million cubic meters. The La Push Cell has the least total sand in storage with approximately 655,000 cubic meters. In order of total sand volume, the cells are ranked in the following order: the Eureka Cell, the Newport Cell, the Kalaloch Cell, the Gold Beach Cell, the Cannon Beach Cell, the Crescent City Cell, the Otter Rock Cell, and the La Push Cell.

TABLE V

SUMMARY OF CELL MEASURES FOR SELECTED CELLS OF THE PNW

CELL	La Push	Kalaloch	Cannon Beach	Otter Rock	Newport	Gold Beach	Crescent City	Eureka
N/S UTM CELL START (m)	5,311,600	5,291,000	5,084,150	4,955,400	4,947,100	4,702,000	4,621,950	4,542,700
CELL LENGTH (m)	5,425	35,370	13,845	7,755	18,755	13,230	5,120	60,945
AVG. ORIENTATION (Az)	267	257	268	274	275	275	229	291
AVG. BCH. SLOPE %	3.50	1.70	1.40	1.90	1.40	3.90	1.60	3.00
TOTAL SAND VOL. (m^3)	655,240	11,253,730	4,226,686	680,232	12,830,851	6,758,009	1,243,520	90,723,700
SAND ABOVE MLLW (m^3)	582,040	5,191,970	3,693,681	677,869	5,036,764	4,373,763	795,920	22,536,965
SAND ABOVE MHHW (m^3)	229,515	1,231,910	1,420,187	108,800	1,459,335	2,873,759	243,005	10,596,910
AVG. TOT. SAND VOL. /m	121	318	305	88	684	511	243	1,489
AVG. SAND VOL. ^MLLW /m	107	147	267	87	269	331	155	370
AVG. SAND VOL. ^MHHW /m	42	35	103	14	78	217	47	174

DISCUSSION (ANALYSIS OF SAND DISTRIBUTION)

There is considerable variability in the distribution of sand within (intracellular) and between (intracellular) littoral cells of the Pacific Northwest. In order to determine why sand is distributed in the configuration present in cells of the Pacific Northwest, an analysis of the factors which control sand distribution must be performed on a cell by cell basis. Once the factors which control sand distributions within cells are addressed, factors important to intercellular sand distributions will be examined.

INTRACELLULAR VARIABILITY OF SAND DISTRIBUTION

La Push Cell

Figure 61 shows the cross-sectional areas of beach sand as measured at each of the four profile sites in the La Push Cell. The La Push Cell shows a reversal in the quantity of sand within portions of the profile over the cell length. The total area of sand and the area of sand above MLLW decrease to the south within the cell ($r= 0.93$) while the sand above MHHW increases to the south ($r= -0.88$). Throughout most of the cell, the sand lies above MLLW. Only North Rialto Beach (N5310050) has a substantial amount of sand below MLLW as can be seen from the divergence of the lines representing MLLW and total sand volumes. This condition arises since the upper surface of the wave-cut platform lies at or above the MLLW level.

The mid-beachface slope (r= 0.82) and mean grain size of the beach sands (r= 0.95) decrease to the south within the cell (see Figures 45 and 53). The maximum mid-beach face slopes range between 4.43% and 5.21% at the north end of the cell where the mean grain size is greater than 0.7 mm. At the south end of the cell the slope ranges between 1.46% and 2.72% while mean grain size is approximately 0.164 mm.

Although sediment discharge rates and the hydraulic factor are not available for the Quillayute River, visual inspection of the river indicates that the Quillayute River estuary is dominated by the river which is actively supplying sand to the beaches nearest the river mouth. A comparison of beach width and terrace height for the La Push Cell shows that there is no obvious relationship (r= -0.37) between these two variables (Figure 69).

The orientation of the beach generally decreases from the Quateata headland north to the Quillayute River mouth (r= -0.99) and again from the river mouth to the north end of the cell (r= -0.93; Figures 5 and 37). Figure 37 shows that the orientation of the La Push Cell shoreline changes abruptly at the Quillayute River mouth (N5307000 to N5307200). This is due primarily to the deposition of sand

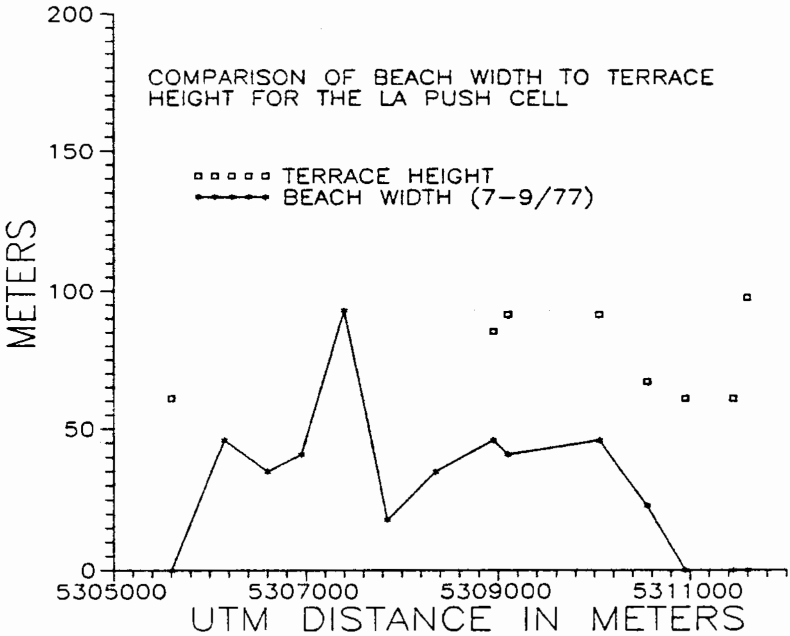


Figure 69. Beach width and terrace height versus distance for the La Push Cell.

supplied by the Quillayute River in the sheltered area behind the large sea stack (James Island) just offshore of the river mouth (see Figure 5).

The affects of the 1983 El Niño on the La Push Cell can be seen in Figures 18 and 26. A small change in beach width occurred between N5307000 to N5307900 and just south of the mouth of the Quillayute River. For the most part, there appears to be little change in beach width from 1977 to 1985 in the La Push Cell.

The La Push Cell is characterized by narrow, steep, coarse grained beaches in the north half of the cell, and wide, gently sloping, finer grained beaches in the southern half of the cell (Figures 45 and 53). The total sand volume per linear meter of shoreline decreases from north to south while the volume of sand above MHHW increases to the south. North of the Quillayute River mouth the beaches show signs of substantial erosion (Tom Terich, personal communication, 1989) while the southern half shows no evidence of recent erosion and contains a narrow dune field. The 1983 El Niño appears to have had little effect on the distribution of beach sands within the cell. The Quillayute River appears to be the major source of sand to the cell at present. Based on sand accumulation (location of zones of highest sand volume) and beach grain size, the net transport direction of sediments within the La Push Cell appears to be to the north and south away from the Quillayute River mouth.

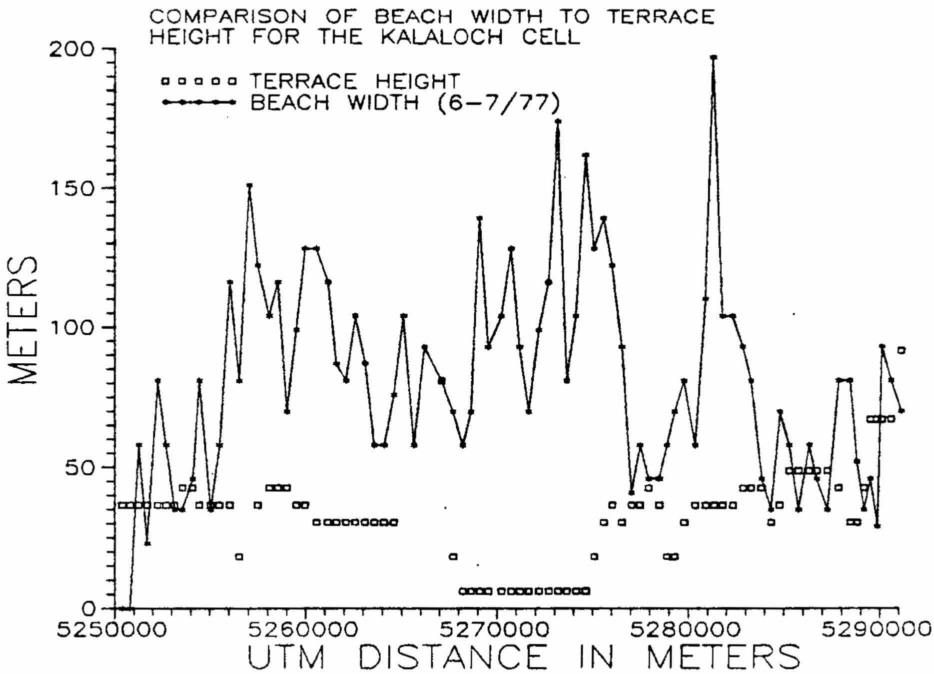
Kalaloch Cell

Figure 62 shows the distribution of sand volume per meter of shoreline for the Kalaloch Cell. Of the approximately 11 million cubic meters of sand present in the Kalaloch Cell, most of the variability in sand volume comes from the variation of the wave-cut platform depth. The Kalaloch Beach profile has the largest store of sand below MLLW within the cell (1071 cubic meters per meter shoreline). At the Kalaloch profile the wave cut platform reaches a depth of -7.5 m MTL (see Appendix II). The Little Hogsback profile has the least total sand with 15 cubic meters per meter of shoreline. The wave-cut platform is visible within the swash and surf zones during low tide. Excluding the Little Hogsback area, the Kalaloch Cell shows moderate variability in the volume of sand above MLLW and MHHW along shore. For example, the volume of sand per meter longshore ranges between 100 and 275 m^3 for sand above MLLW, and between 20 and 91 m^3 for sand above MHHW. The Little Hogsback profile shows a sand volume of 20 cubic meters above MLLW and there is essentially no sand above MHHW. This is also an area of dramatic sea cliff mass wasting, demonstrating qualitatively, the lack of correlation between sea cliff retreat and beach sand supply in this part of the cell.

The mid-beachface slope varies only slightly throughout the Kalaloch Cell, reaching a maximum of 1.89% at the Beach #4 profile (see Figure 46). The minimum value occurs at South Beach where the slope is 1.57%. In contrast to the relatively constant mid-beachface slope, the mean grain size of beach sands from the Kalaloch Cell increases greatly at the north end of the cell (see Figure 54), reaching a maximum of 1.79 mm at Ruby Beach (r= 0.97). The southern two-thirds of the cell varies only slightly (0.122 to 0.158 mm) and shows no apparent trends along shore (r= -0.48). Clearly, the large increase in mean grain size is not reflected in the mid-beachface slopes for the northern portion of the cell. Although the maximum slope a beach face can attain is related to the grain size of the sediments of which it is made, not all beaches in the Kalaloch Cell have attained the maximum possible slope. This is possibly due to the shallow wave cut platform depth and the lack of wave swash percolation in the swash zone.

The mean grain sizes of terrace sand in the Kalaloch Cell decrease to the north (r= -0.97), in direct contrast to the beach grain size (Figure 54). Were there a direct correlation between terrace grain size and adjacent beach grain size, one might speculate that the terraces were contributing some component of the beach sand present. The fact that there appears to be a negative correlation between beach and terrace grain size indicates that terraces are not large contributors of sand to the beaches at present. There is no correlation between beach width and terrace height within the Kalaloch Cell (r= -0.003; Figure 70). If there were a significant positive or negative correlation between beach width and terrace height, one might conclude that either the higher terraces had more sand material to contribute to the adjacent beaches or that the more resistant terraces which stand in relief are not able to contribute sands to the beaches. Another possibility is that longshore currents are effectively transporting any sands contributed to the beach and thus the system has been homogenized throughout much of the cell.

Visual inspection of the major drainage systems entering the Kalaloch Cell reveals that the Queets and Hoh Rivers are fluvially dominated. Aside from possible offshore sources of beach sand these rivers appear to be the only major potential sources of sediment to the beaches at present. Because the total volume of sand on a beach and even the amount of sand above MLLW is affected by the elevation of the wave-cut platform, the quantity of sand above MHHW can be a better indicator of the influence of various sand sources contribute. The volume of beach sand above MHHW is greatest in the area adjacent to the Queets River mouth, indicating that these beaches are being supplied only up to N5277000 by sand from these sources.



<u>Figure 70.</u> Beach width and terrace height versus distance for the Kalaloch Cell.

A progradation of beaches from approximately N5263000 to the north end of the cell (Figures 19 and 27) occurred during the 1983 El Niño. South of this point there is a zone of decrease in beach width (N5256500 to N5263000) suggesting that this was the source of anomalous sand supply to the north. The 1989 survey data tentatively (see Figure 19) suggests that the cell has readjusted to pre-El Niño beach widths.

The shoreline orientation is relatively constant throughout most of the cell (see Figure 38) averaging approximately 255 degrees azimuth. At the south and north ends (north of Brown's Point) of the cell the shoreline orientation becomes more variable and changes gradually to face more directly north and south respectively (see Figure 6).

The Kalaloch Cell is characterized by continuous, fine grained beaches of variable width throughout much of the cell, with narrow, coarse grain size beaches at the northern end of the cell. The mid-beachface slopes of beaches in the Kalaloch Cell vary little, even in the north end of the cell where the mean grain size is nearly 1.8 mm. Through comparison of terrace height to beach width and terrace mean grain size to beach mean grain size, it appears that the terraces, though present throughout much of the cell, have little effect on adjacent beaches in terms of sand supply. Based on beach sediment volumes per meter shoreline, the major sources of sediments to the Kalaloch Cell appear to be the Queets and Hoh Rivers. Orientation varies little throughout most of the cell and appears not to be a factor in controlling either beach width or volume. Based on beach grain size trends and sand accumulation (location of largest sand volumes), it appears that the northern third of the Kalaloch Cell may have a net southward transport of sediment, while the southern two-thirds of the cell shows net transport to the north. The abrupt change in grain size north of Brown's Point indicates that Brown's Point may be acting as a sub-cell boundary.

Cannon Beach Cell

The Cannon Beach Cell contains approximately 4 million cubic meters of sand of which nearly 30% presently resides in the northernmost 2 km at Chapman Beach (Figure 63). Beach volumes decrease sharply south to Tolovana Beach (see Figures 7 and 63). From Tolovana Beach to the south end of the cell, beach volumes are less variable. The total sand volumes in these profiles ranges between 338 and 162 cubic meters per meter shoreline. There is a decrease in the total volume of sand per meter shoreline to the south within the cell (r= -.78). The sand above MLLW decreases to the south within the cell (r= -0.85) from 729 at Chapman Beach to 85 cubic meters/meter at Cove Beach. Except at Chapman Beach, there is very little sand above MHHW in the Cannon Beach Cell (Figure 63). The amount of sand above MHHW ranges between 45 and 15 m^3/m for the Tolovana to Cove Beach cell segment.

Chapman Beach is the widest beach in the cell averaging 225 meters from 1989 survey data (see Figure 7 and Table I). Beach width decreases south of Chapman Beach to Cove Beach which averages 49 meters. The Cannon Beach Cell showed marked changes in beach width following the 1983 El Niño (see Figures 20 and 28). The area south of Silver Point and the Chapman Beach at the northern end of the cell showed increases in beach width while the area between Silver Point and Humbug Point, and the southern end of the cell showed decreases in beach width. From 1989 aerial photograph data it can be seen that beaches north of Hug Point have begun to readjust to more closely resemble their 1978 configurations. Although the northern beaches are generally still wider than in 1978, the sand has become more evenly distributed following the 1985 photo period. The Silver Point to Humbug Point segment which showed the most drastic removal of sand has completely recovered and is in fact wider than it was in 1978 (see Figure 28). South of Hug Point the beaches still have not attained their pre-1983 widths. It is possible that Hug Point is acting as a one-way valve to sediment transport in the Cannon Beach Cell. Sand is allowed to move around it to the north but less effectively to the south. During anomalous climatic periods, the sediment transport rate increases, causing rapid changes in beach width. A comparison of beach width and terrace height reveals no obvious correlations between these two variables (r= 0.05; Figure 71), even though a lack of rivers entering this cell implies total sand supply is from sea cliff sources.

The slope of the mid-beachface varies slightly from 1.63% at the south end of the cell to 1.14% at the north (Figure 47). The mean grain size of beach sands varies only slightly (0.152 to 0.187 mm) throughout the cell (Figure 55) while terrace grain size steadily increases from 0.067 mm at Cove Beach to 0.149 mm at Arcadia Beach (r= -0.99). If terraces are providing a significant portion of the sand on the beaches of the Cannon Beach Cell, then a significant portion of the finer fraction of these terrace sands are being removed from the system in order to produce the beach grain sizes seen at present. The lack of any significant streams entering this cell precludes any significant fluvial sand supply from such sources.

Orientation of the shoreline, although somewhat variable, averages approximately 270^{o} Az (Figure 39) and is consistent throughout the cell.

The Cannon Beach Cell is characterized by narrow, flat beaches throughout much of the cell with a general increase in beach width to the north. Sand volumes and beach widths are at a maximum at the extreme north end of the cell indicating sand is accumulating within this zone. Because

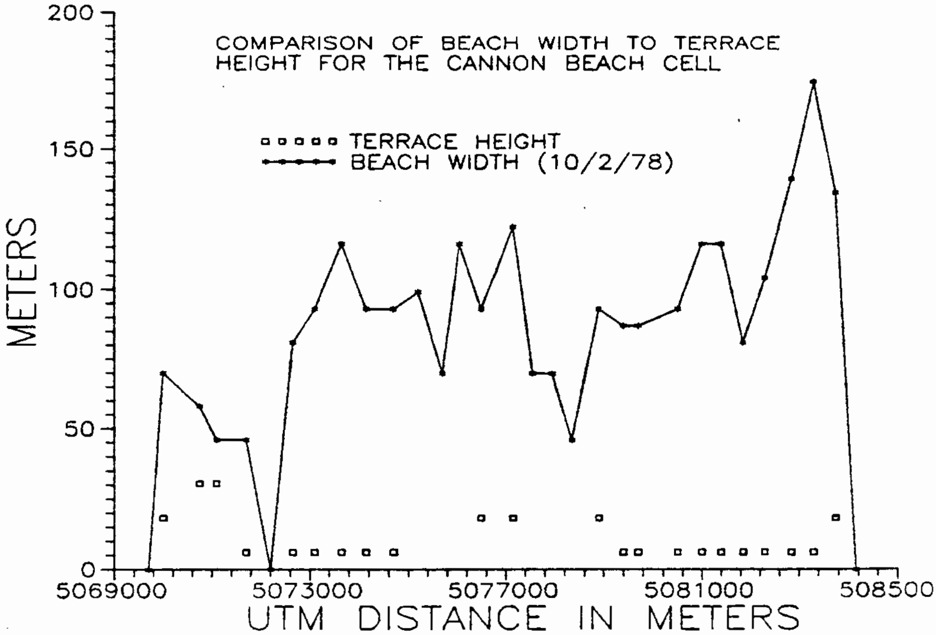


Figure 71. Beach width and terrace height versus distance for the Cannon Beach Cell.

this zone of accumulation is just south of the northernmost barrier to sediment transport, the predominant transport direction of sediment within this cell is likely to the north. At Chapman Beach there is a large dune complex which is actively growing at present. The rest of the cell has lower sand volumes. Erosion (beach sand removal and terrace retreat) is a persistent problem for most areas within the cell (except the Chapman Beach area) because changes in the shoreline results in damage to the heavily developed shoreline. The areas most affected by erosion are those areas with the least quantity of sand above MHHW within the cell. The Tolovana area, with only 15 cubic meters of sand above MHHW per meter shoreline, has been fortified with rip-rap revetments and low sea walls to prevent further landward erosion. The present sources of sands to the cell, if there are any, are unknown. There are no significant drainage systems entering the cell and there appears to be little contribution of sands by the erosion of the low terrace which runs the length of the cell. Diminished exposure of this terrace by shoreline protection structures will reduce future sand supply from remaining terrace deposits.

Otter Rock Cell

The Otter Rock Cell contains approximately 680,232 m^3 of total sand (Table V). Because the cell is formed atop a very shallow wave cut platform, virtually all of this sand is above MLLW (Figure 64). The quantity of sand above MLLW ranges between 44 and 54 m^3 per meter shoreline in the southern half of the cell and between 117 and 152 m^3 per meter shoreline in the northern half of the cell (Figure 64). The quantity of sand above MHHW gradually increases from south to north in the Otter Rock Cell (r= 0.95). 58th Street Beach and Moolack Beach in the southern half of the cell contain less than 10 m^3 per meter shoreline (Figures 8 and 64). At the northern end of the cell, Otter Rock Beach contains 28 m^3 per meter shoreline (Figure 64).

Beach widths determined during the 1989 survey show a consistent increase in the northward direction (Table I). This trend can also be seen in the 1978, 1984, and 1989 aerial photograph data (Figure 21). Beach widths do not vary in relation to terrace heights within the cell (r= 0.18; Figure 72). Indeed much of the terrace is a thin cap overlying Tertiary mudstones which provide little sand to this cell.

The slope of the mid-beachface is relatively constant at about 1.37% for the northern two-thirds of the cell (Figure 48). In the 58th Street area, the mid-beachface slope is 3.57%. There is an overall decrease in mid-beachface slope in the cell (r= -0.83). The mean grain size of beach sands generally decreases from 0.275 mm at the south end of the cell to 0.189 mm at the north (r= -0.93; Figure 56). The mean grain size of terrace sands sampled in

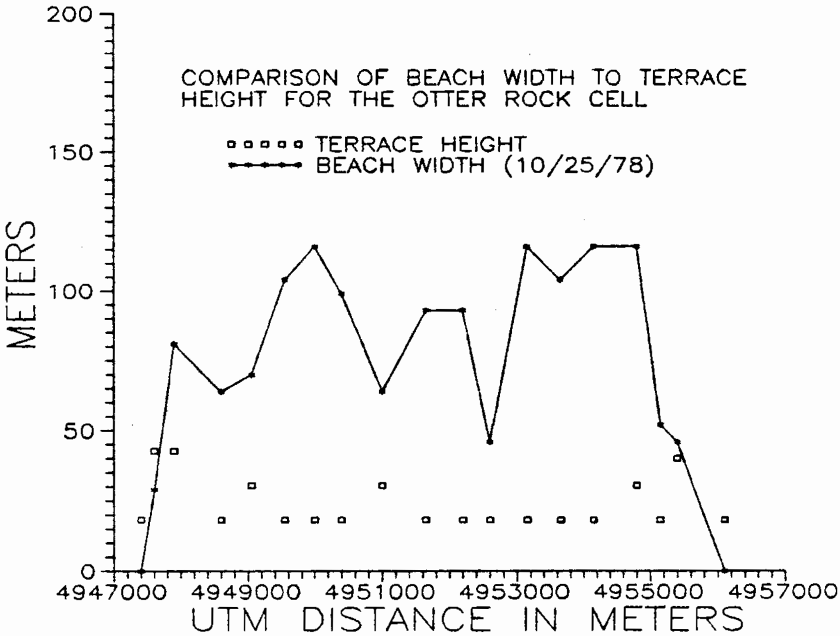


Figure 72. Beach width and terrace height versus distance for the Otter Rock Cell.

the Otter Rock Cell varies from 0.20 mm at Beverly Beach to 0.22 mm at Moolack Beach (Figure 56). There are no significant drainage systems entering the Otter Rock Cell. The source of the sands present in the Otter Rock Cell is most likely the terraces at the southern end of the cell which are actively eroding.

Orientation of the shoreline gradually decreases to the north from about 290° Az in the 58th Street Beach area to 270° Az in the Otter Rock area (Figure 40). The average shoreline orientation is 280° Az.

The Otter Rock Cell is characterized by narrow, steep beaches with little sediment volume at the southern end of the cell which gradually increase in width and volume to the north where the beaches become wider, flatter, and finer grained. The volume of sand above MHHW is quite low throughout the cell but is less than 10 m^3 per meter shoreline for the southern half of the cell which is experiencing substantial terrace retreat. The erosion of the terrace material which is finer than all but the northernmost beach sand in the cell appears to be the only source of sediments to the beaches at present. The fact that these terrace sands are finer grained than the beaches within the cell indicates that either the terraces are only providing a component of the beach sand present today or that the finer portion of the terrace sands are being carried offshore during erosion and transport. Transport of beach sediments in the Otter Rock Cell appears to be to the north based on the decreasing grain size trend and the increase in beach width and volume to the north in the cell.

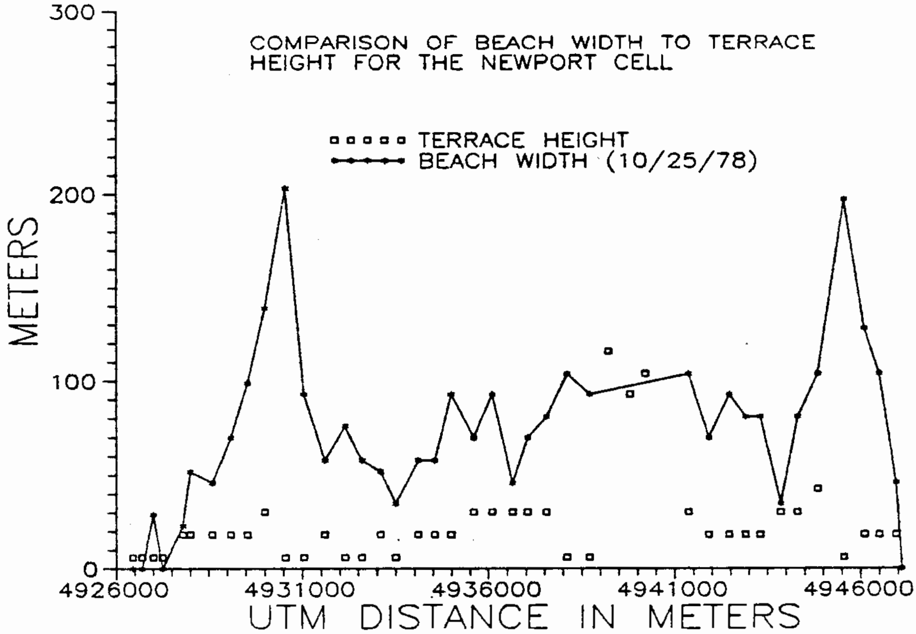
Newport Cell

Of the approximately 12.8 million m^3 of sand within the Newport Cell (Table V), approximately 75% of this sand is present in the South Beach area (Figures 9 and 65). Total sand volume is less than approximately 500 m^3 per meter shoreline for the Newport Cell except in the South Beach transect where total sand volume reaches 3641 m^3 per meter. The volume of sand above MLLW ranges between 891 m^3 at South Beach and 138 m^3 in the Seal Rocks area (Figure 65). There is a general dearth of sand above MHHW everywhere in the cell except South Beach where the volume is approximately 381 m^3 per meter shoreline. Elsewhere in the cell, the quantity of sand above MHHW ranges between 12 m^3 and 69 m^3 per meter shoreline. It appears that all volumes increase from the southern end of the cell near Seal Rocks northward to the South Jetty near South Beach (Figures 9 and 65). The correlation coefficient of this trend is r= 0.99 for the total volume of sand, the sand volume above MLLW, and for the sand volume above MHHW.

Beach width varies in a manner similar to the longshore volume of sand in the Newport Cell (Figure 22). This is not necessarily a insignificant point because depth to platform can also influence beach sand volume. There was a significant change in beach width throughout the southern half of the cell during the period 10/78 to 3/84 (Figure 30) with sand generally being transported from the southern portion of the cell northward toward South Beach. The 1989 aerial photographs available for this study only covered the northern half of the cell. Within this segment, most beaches showed no change in relative beach width from both 10/78 and 3/84 values. Beach width varies independently of terrace height in the Newport Cell (r= -0.23; Figure 73).

Mid-beachface slope ranged between 1.18% and 1.46% for most of the Newport Cell (Figure 49). In the South Beach to Nye Beach vicinity, the mid-beachface slope was 1.73% and 1.75% respectively. The mean grain size of beach sands is consistent throughout the cell, ranging from 0.170 mm at Holiday Beach to 0.122 mm at Agate Beach Cove (Figure 57). Terrace grain sizes are slightly coarser than the adjacent beaches throughout much of the cell (Figure 57). At the northern end of the cell, however, there is a decrease in both the mean grain size of the terrace and adjacent beach sands.

Shoreline orientation averages 285° Az in the southern half of the Newport Cell (Figure 41). In the northern half of the cell the orientation becomes more variable and fluctuates between 235° and 287° Az. The average



<u>Figure 73.</u> Beach width and terrace height versus distance for the Newport Cell.

orientation for the northern half of the cell is approximately 265° Az.

The only significant drainage system within the cell is the Yaquina River which enters through Yaquina Bay (Figure 9). Although the estimated bedload transport of this river is approximately 10^4 m^3 per year, the hydraulic factor for this estuary is relatively high at approximately H_F=50 (Figure 13). The ability of this river to contribute sediment to the beaches of the Newport Cell is doubtful and it is likely that Yaquina Bay is acting as a sediment sink to sediments (if any) transported across the bay mouth jetties (Kulm and Byrne, 1966). Beaver Creek, located at approximately N4930500 (Figure 9), is relatively small and provides little or no significant sand supply. Although beach widths are slightly wider in the area around the mouth of Beaver Creek, it is because of the topographic low created by the previous erosion of the Beaver Creek drainage and not the progradation of the beach due to continual sediment input. In fact, there is a step back in the shoreline position in this area which can be seen in aerial photographs and in the shoreline orientation data (Figure 41). The only other possible active sources of sediment to the cell are from erosion of the weakly cemented terrace which runs the length of the cell except where eroded by drainage systems.

The Newport Cell can be characterized generally by narrow, steep beaches with low volumes of sand at the south end of the cell, and north of the bay mouth gradually changing to wide, flat beaches with larger volumes of sand. Beach grain size is quite consistent throughout the cell. Either the terrace or an offshore sand source appear to be supplying the bulk of the sand to the Newport Cell at present because the major drainage system is tidally dominated and is reportedly acting as a trap to sediment transported alongshore within the cell. Although transport direction and rate likely varies seasonally and interannually (Peterson and others, 1990a), the dominant transport direction is apparently to the north in the Newport Cell based on beach sand accumulations on the south side of barriers to longshore transport.

The jetty system of Yaquina Bay is apparently acting as a headland in the Newport Cell, partially blocking longshore sand transport. The orientation of the jetties with respect to the shoreline have promoted the buildup of sand on the southern side of the jetties resulting in widening of the beaches. This sand buildup is also described for other jetty systems of Oregon by Komar and others (1976b). Nye Beach, located just north of the jetty system and bay mouth, has the lowest quantity of sand above MHHW in the cell and has continually experienced the highest rates of historic erosion (terrace retreat) in the Newport

Cell. The beach area just north of Seal Rocks area, the possible southern boundary of this cell, also has quite low quantities of sand above MHHW and is presently experiencing terrace retreat.

Gold Beach Cell

The Gold Beach Cell contains some 6.75 million m^3 of sand over a distance of 13.2 km (Table V). The various quantities of sand are relatively evenly distributed over the length of the cell except in the Red House Beach and Boomer Bend Road areas (Figures 10 and 66). Within these areas the sand quantities (total, above MLLW, and above MHHW) are lower, especially total sand which is less than half that found throughout the rest of the cell. Even with these areas of lower sand volumes, there appears to be a plentiful supply of sand throughout the cell. The lowest value for the quantity of sand above MLLW is 156 m^3 per meter shoreline (Figure 66).

Beach widths determined by aerial photo analysis (1979 & 1980 data) reveal no longshore trends in beach width within the Gold Beach Cell (Figure 23). Although no aerial photographs were available from the period immediately following the 1983 El Niño for the Southern Oregon area, a comparison of 12/79 and 4/80 aerial photographs to 8/89 aerial photographs reveals that most beaches in the Gold Beach Cell remained essentially the same over the time interval (Figure 36). Terrace height does not appear to influence beach width in the Gold Beach Cell (r= -0.03; Figure 74).

Both mid-beachface slope and average grain size for the beaches of the Gold Beach Cell showed a consistent decrease to the north with correlation coefficients of r= -0.87 and r= - 0.99 respectively (Figures 50 and 58). The greatest slope was found to average 10.19% at Boomer Bend Road Beach with a corresponding mean grain size of 0.426 mm. At the northern end of the cell, slopes ranged between 1.61% and 2.28% while mean grain size of the beaches ranged between 0.177 mm and 0.204 mm.

There are three possible sources of sand to the Gold Beach Cell at present: 1) sediment supplied to the beach by the Rogue River; 2) sediment made available by the erosion of the weakly-cemented, low terraces at the northern end of the cell; and 3) onshore sediment transport of shelf sands. The Rogue River, with a hydraulic factor of H_F=0.5 and an approximate bedload sediment output of 1,200,000 m^3 per year, is the most likely of these three possible sources to provide the bulk of the sand to the Gold Beach Cell (Figure 13).

The shoreline orientation of the Gold Beach Cell can be divided into three distinct zones. The first zone, extending from Cape Sebastian at the southern end of the cell to Big Rock Beach, has an orientation of about 275° Az

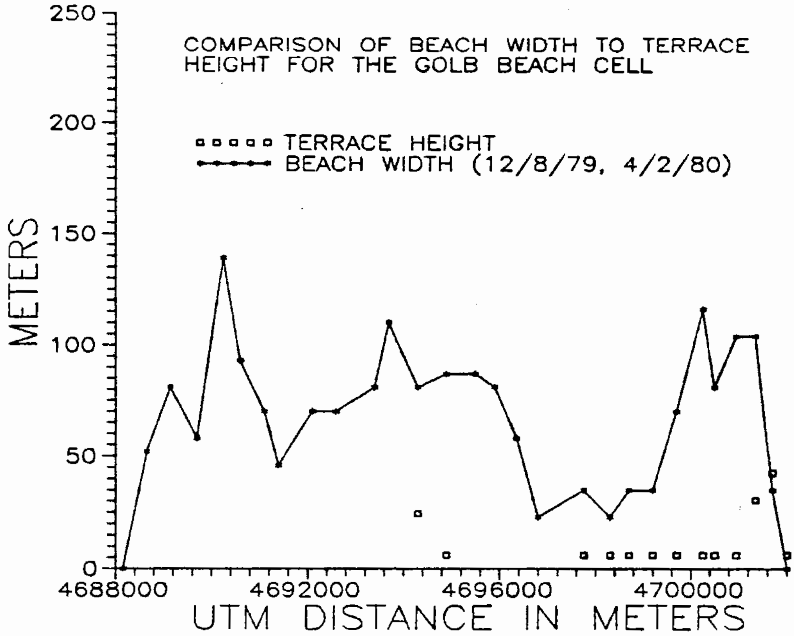


Figure 74. Beach width and terrace height versus distance for the Gold Beach Cell.

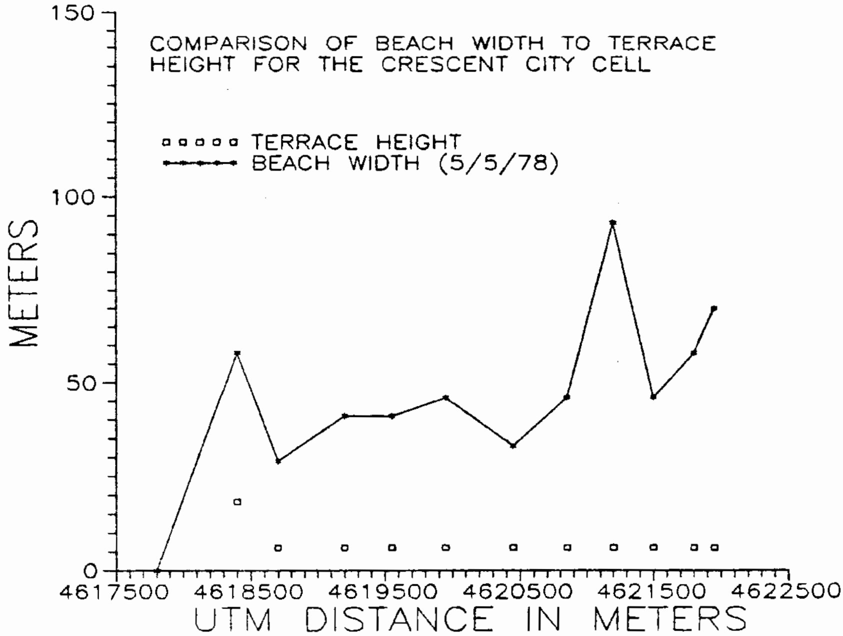
with little variation (Figure 42). The next zone extends from Big Rock Beach north to the Redhouse Beach area and has an approximate orientation of 260° Az and is somewhat variable. The northernmost zone extends from High Tide Beach north to Otter Point and has a shoreline orientation of 300° Az. Shoreline orientation appears to play a large role in the distribution of sand within the Gold Beach Cell. In the northern portion of the cell, beach volumes are at a minimum at the transition between the 260° Az cell segment and the 300° Az cell segment (Figures 10, 42, and 66). Although sand is able to move around this point freely, from this prominent bend in the shoreline sand volume increases both to the north and south. It appears that sand is restricted in its movement north from the Rogue River mouth by the 260° Az orientation of the shoreline and sand north of this subtle promontory is effectively driven north by southwest winter swells. During times of extreme southerly wave approach, sediment is possibly driven northward across this transition point. The largest portion of the sand in the Gold Beach Cell lies just south of the Rogue River mouth (Figure 66). The 260° Az orientation in the area north and south of the river mouth and possibly the 220° Az entrance of the river into the ocean might be responsible for the southward transport of sediments (Figures 10 and 42). South of Big Rock Beach, beach volumes and widths decrease and there is an increase in the mean grain size and slope of the mid-beachface. Distance from the source of sediment input and the change in shoreline orientation to 275° Az are the likely reasons for this change.

There is more than one dominant transport direction within the Gold Beach Cell. Based on the location of sand accumulation zones and on shoreline orientation, the dominant sediment transport direction appears to be to the north and south away from the abrupt change in shoreline orientation at about N4699250. From this point beach volumes and widths increase to the north and south. It is uncertain whether the transport direction is to the south or north in the area from Big Rock Beach south to the Cape Sebastian headland. Because of the tremendous abundance of sediment supplied by the Rogue River and the generally even longshore distribution of the beach sands, only two areas within the cell show even minor signs of erosion. These are the Redhouse Beach and Boomer Bend Road Beach areas which have the lowest volumes of sand above and below MHHW in the cell. Were the sediment supply from the river to be greatly diminished by damming or some other means or the sea level to rise rapidly, this cell would likely become split in two with the break falling at the change in orientation between High Tide Beach and Redhouse Beach.

Crescent City Cell

1978 and 1986 aerial photograph data as well as 1989 survey data show that beach width increases somewhat to the north (r= 0.57) within the Crescent City Cell (Figure 11). Although the beach is at its widest at the north end of the cell, the largest sand quantities are found in the Dead Dog Beach transect, located approximately 2 km from the northern cell boundary. The quantity of sand above MHHW is less variable throughout the cell and is also at a maximum in the Dead Dog transect (Figure 67). The lowest values are 28 and 32 m^3 per meter longshore distance and are found in the Crescent City South and Crescent Beach transects respectively.

A low terrace runs the length of the Crescent City Cell and is exposed increasingly with distance to the south. This terrace varies only slightly over the length of the cell while beach width is much more variable (Figure 75). The terrace has a mean grain size of 0.233 mm (Figure 59) and has an active erosional scarp. This terrace is the only apparent onshore source of sand to the Crescent City Cell because there are no significant drainage systems entering the cell. Because the cell overlies a shallow wave-cut terrace, there is a possibility that some onshore transport of sand has occurred. The mean grain size of the beaches of the Crescent City Cell is relatively constant, ranging between 0.134 and 0.120 mm over the 5.1 km cell length



<u>Figure 75.</u> Beach width and terrace height versus distance for the Crescent City Cell.

(Figure 59). The slope of the mid-beachface is also quite consistent within the cell ranging from 1.36% to 1.82% and decreasing to the north (Figure 51).

The shoreline orientation of the Crescent City Cell gradually changes from 250° Az at the southern end of the cell to 240° Az at Dead Dog Beach (r= -0.91; Figures 11 and 43). From Dead Dog Beach to the north cell end at the Crescent City Harbor, the orientation changes more abruptly from 240° Az to less than 200° Az in approximately 2 km of shoreline. It is at this location of the change in the shoreline orientation that the largest sand volumes in the cell occur. Based on beach width and sand volume estimates, the predominant sediment transport direction for the Crescent City Cell is to the north. As sediment is transported north within the cell, transport becomes less efficient in the area near the Dead Dog Beach transect, presumably due to the abrupt change in shoreline orientation. The fact that sediment transport appears to be predominantly to the north in this cell is curious given its general southwesterly orientation. The cause of this is likely to be the refraction of incident wave crests caused by shoaling around Pt. St. George as they approach the nearshore. Were refraction not considered, it would take a wave approach less than approximately 230° Az for a significant portion of the year to cause the sediment distribution patterns observed.

The sand distribution within the Crescent City Cell is largely controlled by the predominant northward transportation of sand whose probable present origin is the actively eroding terrace at the southern end of the cell. This area also has the lowest quantities of sand above and below MHHW for the cell. The abrupt change in shoreline orientation in the Dead Dog Beach area appears to be limiting the transport of sand north of this area. The sand distributions which have resulted from these forcing factors are characterized by narrow, gently sloping, fine-grained beaches with low quantities of sand in the southern end of the cell. Beaches in this cell gradually increase in width and sand volume to the north until the point where a change in shoreline orientation occurs.

Eureka Cell

The Eureka Cell is the longest cell studied at 60.9 km in length (Table V). The total sand volume of this cell is approximately 90 million m^3 of sand, averaging nearly 1500 m^3 per meter shoreline over the length of the cell. Again these volumes are determined using the intersection of MLLW with the shoreline and the stable dune crest or sea cliff base as the cross-shore limits of measurement. In profiles where bedrock was not reached, a maximum cutoff of -10 m depth is used. The spits enclosing Humboldt Bay and Eel River Valley extend over most of the length of the cell

(Figure 12). The platform depth in the area of these spits is greater than the -10 m cutoff for the purposes of this study. Because of this, the quantity of sand below MLLW is approximately 75% of the total sand in the cell. The lack of a shallow platform in front of Humboldt Bay confirm an excess of sand supply leading to the formation of a seaward barrier in this cell. The total sand volume for sites in the Eureka Cell range between 223 m^3 in the Table Bluff Beach transect to 2856 m^3 per meter shoreline in the South Jetty transect (see Figures 12 and 68). The total sand volumes for the cell are largely dependent on the depth to the wave cut platform, proximity to sand sources, and the presence of features which inhibit longshore transport. For example, total beach volumes are at a minimum in the area south of Centerville Beach and the Table Bluff Beach area where platform depth is less than three or four meters below the profile surface. While total sand volumes increase (r= 0.87) to the north in the area south of the Humboldt Bay jetty system (excluding the Table Bluff area), north of the bay total sand volumes decrease to the north (r= -0.78) and are generally lower than in the southern cell section. The quantities of sand above MLLW and MHHW vary much less throughout the length of the cell (Figure 68). The volume of sand above MLLW increases somewhat from the southern cell boundary to the South Jetty area (r= 0.85) and again from North Jetty to the Clam Beach area (r= 0.85). Because sea cliffs are only present in the Table Bluff and Centerville Beach areas within the Eureka Cell, profiles and volume measurements are from the foredune crest.

Beach widths determined from 1978 and 1986 aerial photographs show a northward increase from the False Cape area to the south jetty of Humboldt Bay (r= 0.95), and again from the north jetty to the Moonstone Beach area (r= 0.82; see Figures 12 and 25). Figure 32 shows that increases in beach width occurred for most areas of the Eureka Cell over this time period. Terraces are present only at the extreme north and south ends of the cell and do not appear to have an impact on sand distribution (Figure 76).

Mid-beachface slopes show a consistent trend of decrease to the north from (5.84%) at Centerville Beach to (1.81%) in the South Jetty area (r= -0.98) and again from (3.47%) at the North Jetty transect to (0.59%) at the Moonstone Beach transect (r= -0.97; Figure 52). The mean grain size of beach sands of the Eureka Cell shows a similar trend (Figure 60) with a northward decrease from the southern cell boundary to the mouth of Humboldt Bay (r= -0.94) and again from the bay mouth north to the Moonstone Beach area (r= -0.96). Similar results were obtained by Bodin (1982) for samples collected during the summer of 1979.

The average orientation of the shoreline changes gradually from about 290° Az in the False Cape area to 300°

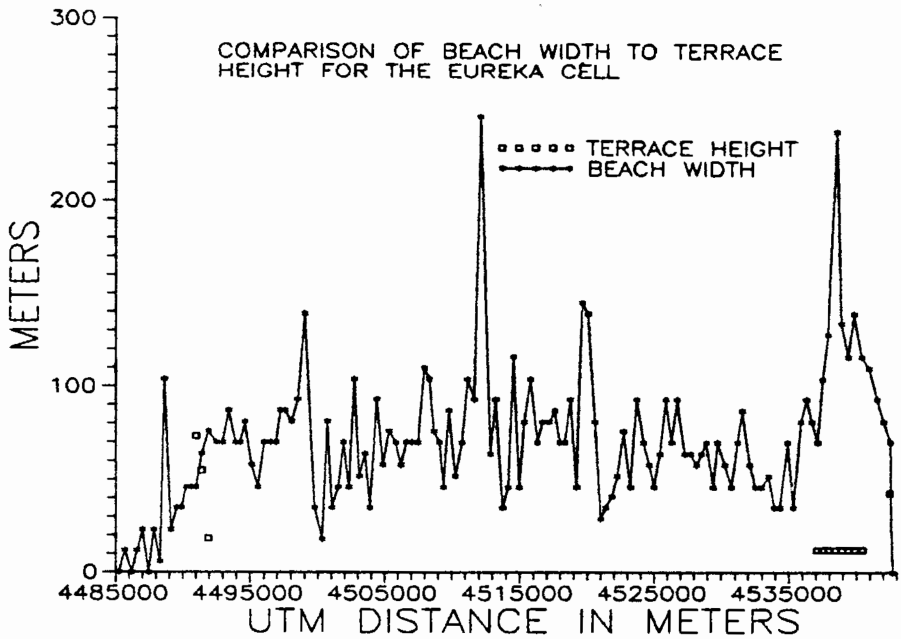


Figure 76. Beach width and terrace height versus distance for the Eureka Cell.

Az at South Jetty Beach (r= 0.87; Figure 12 and 44). From North Jetty Beach to Moonstone Beach at the north end of the cell, the orientation changes from approximately 300° Az to 275° Az (r= -0.89).

There are four possible sources of beach sand for the Eureka Cell at present. The Eel River, with a hydraulic factor of H_F= 1.5 and an estimated bedload transport rate of more than 10^5 m^3 per year, is undoubtedly the largest contributor to the cell (Figure 13). Bodin (1982) determined that although the Mad River is supplying some sand to the beaches in its vicinity, it is not an important source of sand for the cell. The large difference in grain size between the actively eroding terrace at the southern end of the cell and adjacent beach sands indicates that the terrace is supplying only a small component of the sand to these beaches (Figure 52).

Trends in grain size and the location of zones of sand accumulation in the Eureka Cell indicate that the net transport direction is to the north, with the Humboldt Bay jetty system acting as a barrier to sand transport. Any sediment which is transported across the bay mouth is likely swept into or away from the bay by ebb and flow tides. These findings agree well with those of Bodin (1982).

Even with the enormous volume of sand within the Eureka Cell, there are areas which have recently undergone erosion. The Centerville area at the south end of the cell has an actively eroding terrace, while Samoa Beach and Manila Beach north of the mouth of Humboldt Bay had three to four meter high erosional scarps at the leading edge of the stabilized dunes (Appendix II). These areas have the lowest quantities of sand above MHHW for the cell and are located just north of natural or man-made barriers to sand transport (see Figures 12 and 68).

FACTORS INFLUENCING INTRACELLULAR SAND DISTRIBUTION

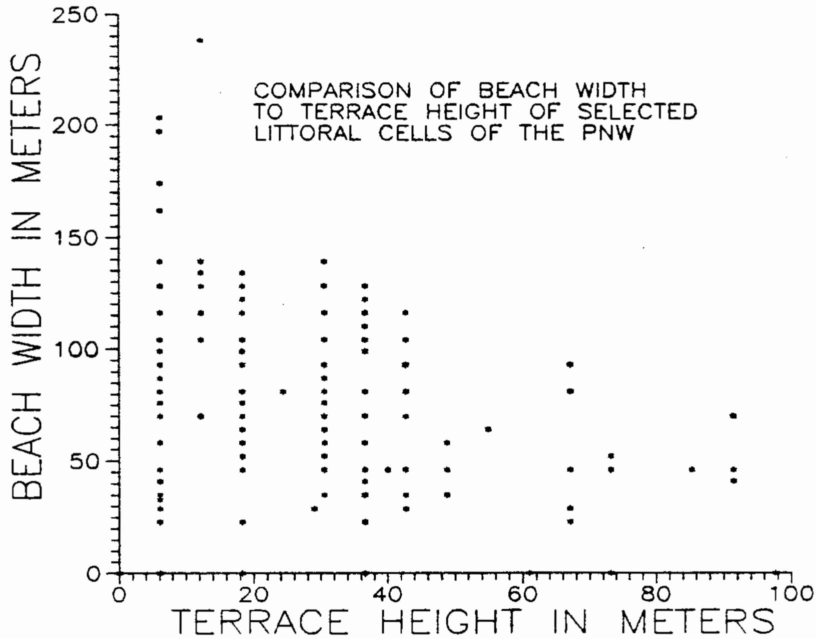
From the above discussion it is clear that longshore sand distribution is quite variable within the eight littoral cells chosen for this study. The distribution of these available sands are possibly related to such factors as: 1) proximity to sand sources such as rivers, terraces, shallow nearshore sand deposits, and the presence of relict sands; 2) location of sand sinks such as dune fields, nearshore submarine canyons, and estuaries; 3) shoreline orientation; 4) shoreline configuration; 5) the direction of net sediment transport within the littoral zone; and 6) the location of barriers to sand transport.

Proximity to Sediment Sources

For cells where the transport of sand away from active sediment sources is less than the available sediment supply, sand accumulations will form in areas adjacent to the source. The Quillayute River in the La Push Cell, the Queets River in the Kalaloch Cell, the Rogue River in the

Gold Beach Cell, and the Eel River in the Eureka Cell each have adjacent beaches which store large volumes of sand (see Figures 62, 66, and 68). Because most of the cells studied have net transport rates which exceed the local supply of sediment, such deposits are few and small in size. For cells in which transport of sand supplied by active sediment sources is greater than the sediment supply output, sand accumulations will result in areas where longshore sediment transport is restricted. The largest accumulations of sand in littoral cells of the Pacific Northwest occurs where headlands, jetties, or changes in shoreline orientation restrict the longshore transport of sand. The Chapman Beach area of the Cannon Beach Cell, the South Beach area of the Newport Cell, and the South Jetty area of the Eureka Cell are examples of such sand accumulations (see Figures 63, 65, and 68).

In order to see if the height of terraces affects the width of adjacent beaches because they should theoretically have more source to contribute, a comparison of beach width to terrace height for beaches which had terraces was performed for each cell and for the group of eight cells from data presented in Appendix I. The results of both the intracellular comparison (presented above) and the eight cell group (r= -0.32) showed poor correlation between beach width and terrace height (Figure 77). This is yet another indication that sediment transport rates generally exceed



<u>Figure 77.</u> A comparison of beach width to terrace height for selected littoral cells of the PNW.

sediment input from individual sources for the littoral cells studied.

There are no data available on the quantity of sediment transported onshore from nearshore sand deposits for the Pacific Northwest. This may be a source of sediment to some cells, especially ones bordered by a wide, shallow wave-cut platform such as the Otter Rock Cell.

The mean grain size of the sediments on beaches of the Pacific Northwest appear to be related to mid-beachface slope (r= 0.71). Figure 78 shows a comparison between median grain size of beaches in the Pacific Northwest and the average median grain size of beaches from the west and east coasts of the USA. From this figure it can be seen that samples collected from the mid-beachface in the Pacific Northwest do not substantially differ from those of the east and west coast averages. In addition, this figure shows that grain size is not the only factor controlling beach slope because some beaches with very large median grain sizes have very low slopes. Again, this is likely due to the depth of the wave-cut platform and the lack of wave swash percolation due to sediment saturation. There is a poor negative correlation between beach grain size and beach width for the sites studied (r= -0.42; Figure 79). Beach width does not appear to be strongly related to sand grain size.

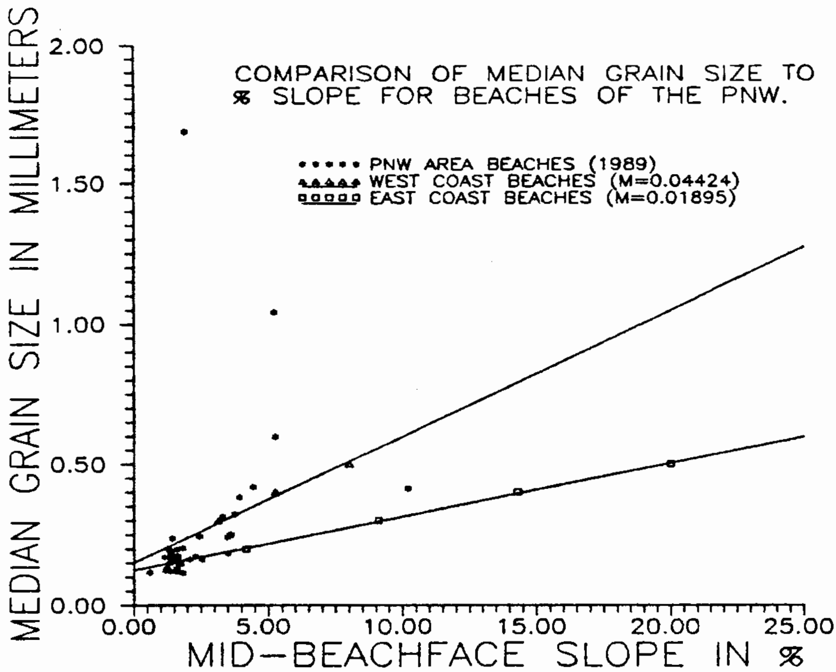


Figure 78. A comparison of median grain size to mid-beachface slope for selected littoral cells of the PNW.

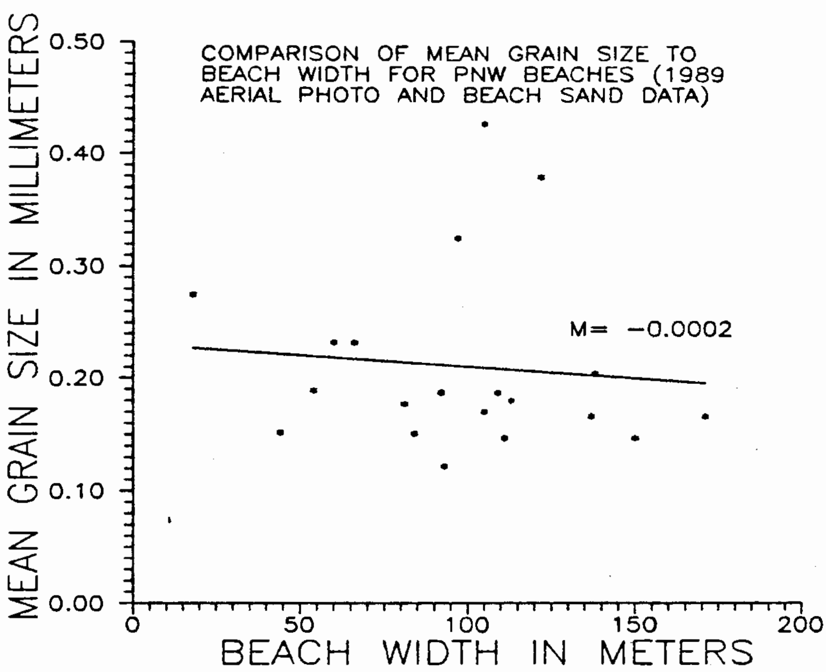


Figure 79. A comparison of mean grain size to beach width for selected littoral cells of the PNW.

Location of Sediment Sinks

Sand distribution may be influenced by the location of sediment sinks, such as tidally dominated estuaries or dune fields within the cell. Dune fields usually develop where an excess of sand is deposited above the beachface. This sand is then transported landward by onshore winds, thereby removing sediment from the beach itself. These deposits must occur where abundant sediment is available to replace the sand removed from the system. As a result, they tend to occur at the point where sediments being transported along shore encounter barriers to longshore transport. Examples of such dune fields can be found at South Beach (Newport Cell) and Chapman Beach (Cannon Beach Cell) as described previously (see Results). Although estuaries and dunes may be both long and short term sediment sinks, the sand may not be permanently lost from the cell once deposited in these sinks. If conditions change substantially (such as the occurrence of a long term reversal of sediment transport direction or the lowering of sea level) these sinks may become active sediment sources.

Tidally dominated estuaries such as Yaquina Bay (Newport Cell) may be acting as sinks of beach sand rather than sources (Kulm and Byrne, 1966). Humboldt Bay in the Eureka Cell may be removing sediment which is transported across the bay mouth as first suggested by Bodin (1982). These are the only two significant estuarine sinks of sand within the cells studied. But from Figure 13 it can be seen that similar estuaries may be acting as traps in other cells of the Pacific Northwest.

There is no information on the amount of sand removed from littoral cells by submarine canyon heads for the Pacific Northwest during Holocene time. However, Kulm and others (1968) do show substantial sand transport on various canyons of the Pacific Northwest including the Astoria Canyon during lower sea level stands. Of the cells studied, only the Eureka Cell has a prominent canyon head which lies offshore of the Eel River Mouth.

Other losses of beach sand might be regional in nature such as abrasion of weak grains and lithic fragments, or offshore transport of sediment not associated with submarine canyons.

Shoreline Orientation

Shoreline orientation is determined by the resistance of the rocks which make up the shoreline, the spatial relationships to headlands, offshore islands, and offshore topographic features (banks and reefs), and to the amount of sand available in an area to act as a buffer against wave attack.

Both the average shoreline orientation of a littoral cell and changes in shoreline orientation within a cell affect the longshore distribution of beach sand. The average shoreline orientation for segments within a cell largely determine the net sediment transport direction, especially in cells with simple offshore configurations. For example, the average shoreline orientation of 291° Az of the Eureka Cell results in a net northward transport of sediments because incident waves approach the shoreline obliquely (Figure 12). As mentioned previously (see Gold Beach in Discussion) the abrupt change in shoreline orientation just north of the Rogue River mouth in the Gold Beach Cell causes the net transport of sediment north and south away from the orientation inflection point (Figure 11).

Because shoreline orientation and sand transport are sometimes interrelated, a feed back loop might be formed in which shoreline orientation determines transport direction and sand accumulation which in turn influences shoreline orientation.

Shoreline Configuration

The configuration of the shoreline within a littoral cell, especially the elevation of the wave-cut platform, may have a large impact on the distribution of the total sand volume of a given area. Figures 80 through 87 show a comparison of total sand volume normalized to the average cell volume per meter of shoreline and platform depth at the MTL point. For the La Push (r= -0.94), Kalaloch (r= -0.99), Newport (r= -0.99), Gold Beach (r= -0.91), Crescent City (r=

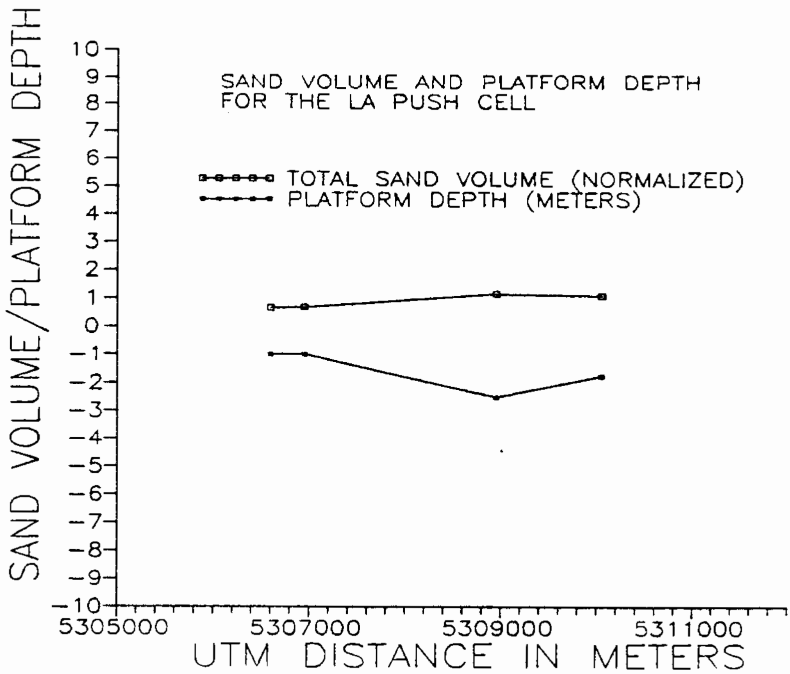


Figure 80. Normalized total beach volume and platform depth versus platform depth for the La Push Cell.

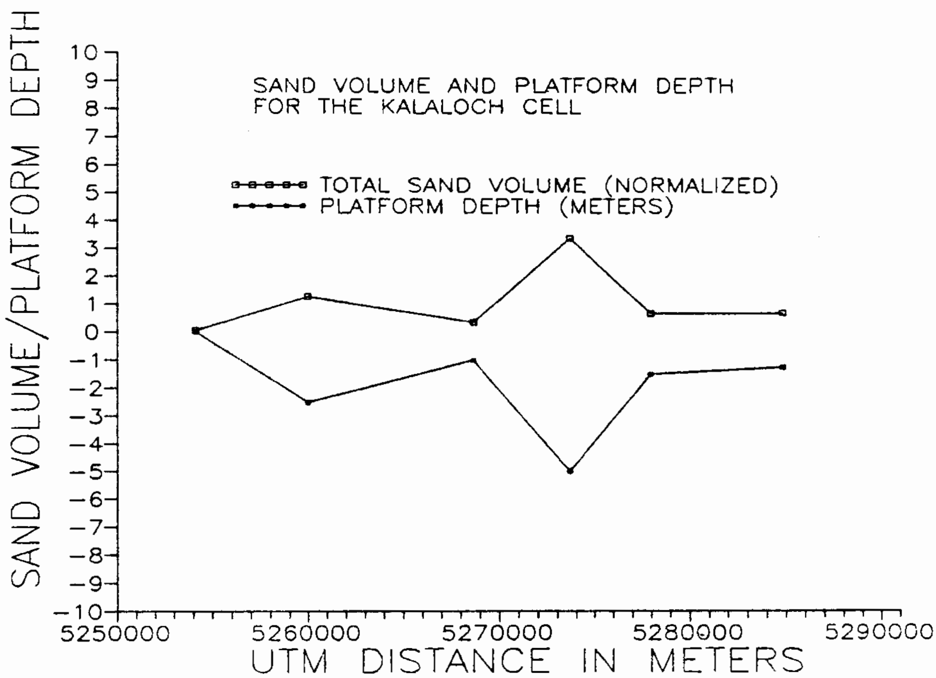


Figure 81. Normalized total beach volume and platform depth versus platform depth for the Kalaloch Cell.

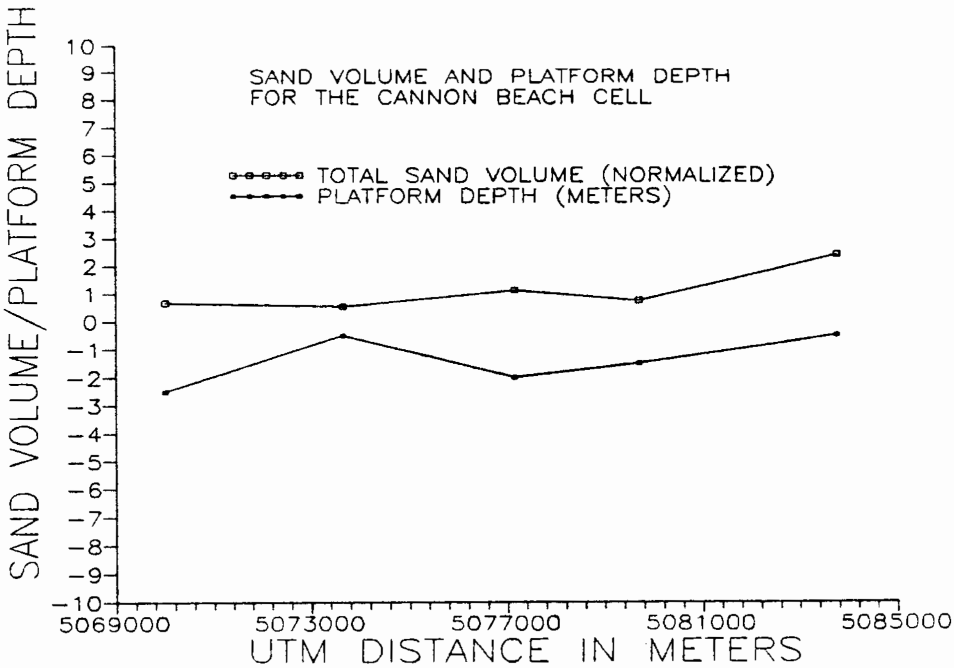


Figure 82. Normalized total beach volume and platform depth versus platform depth for the Cannon Beach Cell.

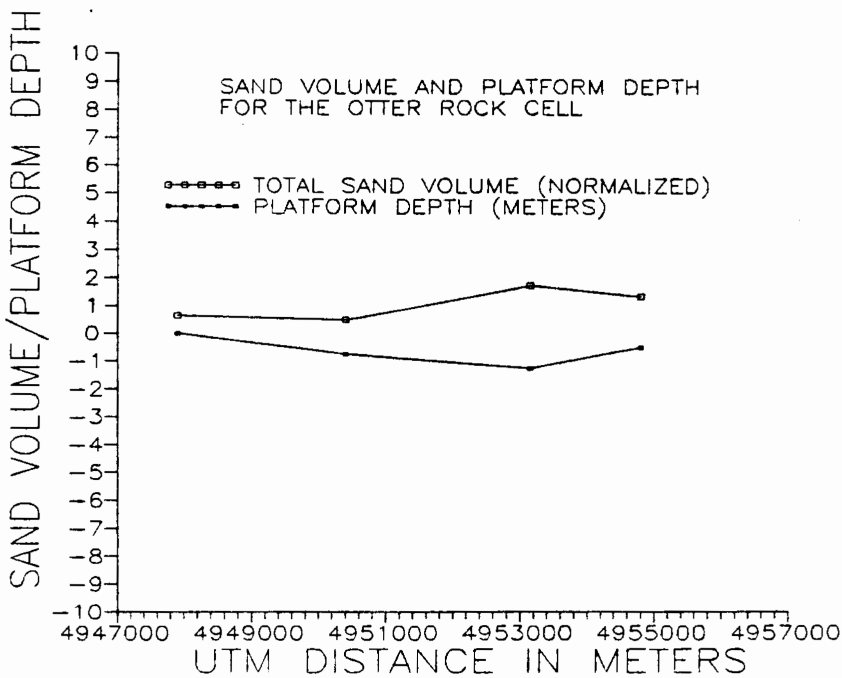


Figure 83. Normalized total beach volume and platform depth versus platform depth for the Otter Rock Cell.

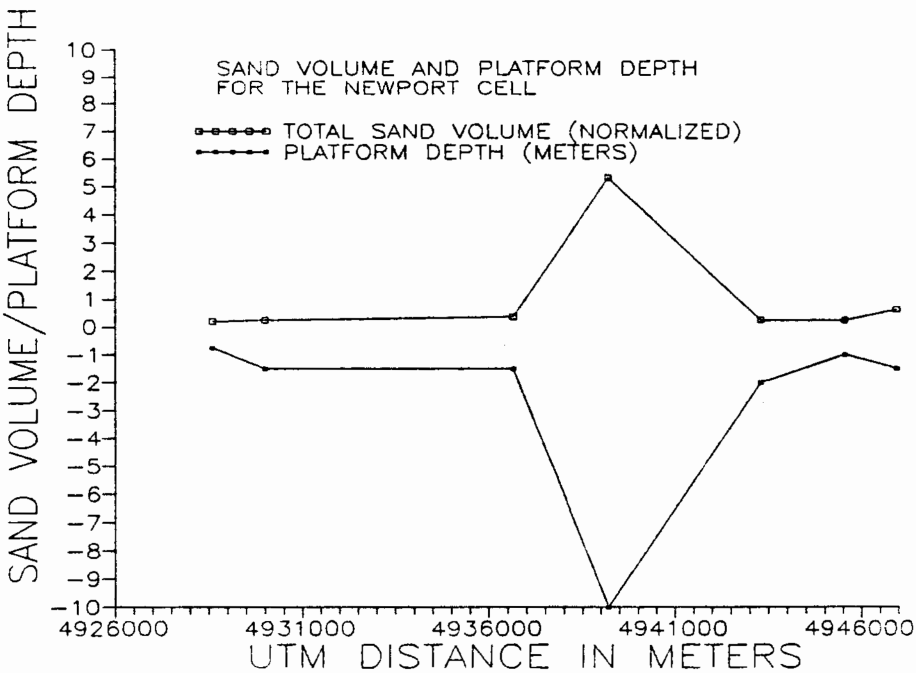


Figure 84. Normalized total beach volume and platform depth versus platform depth for the Newport Cell.

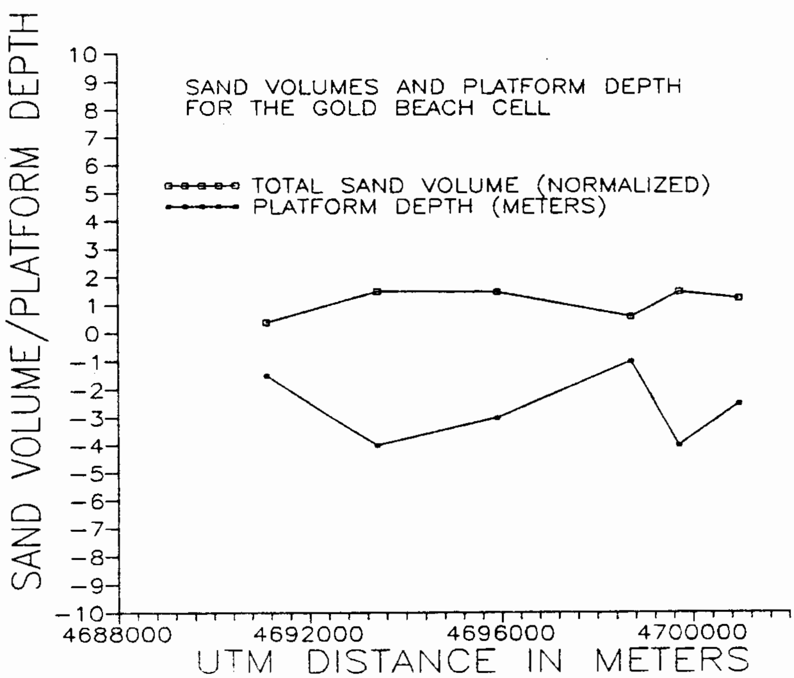


Figure 85. Normalized total beach volume and platform depth versus platform depth for the Gold Beach Cell.

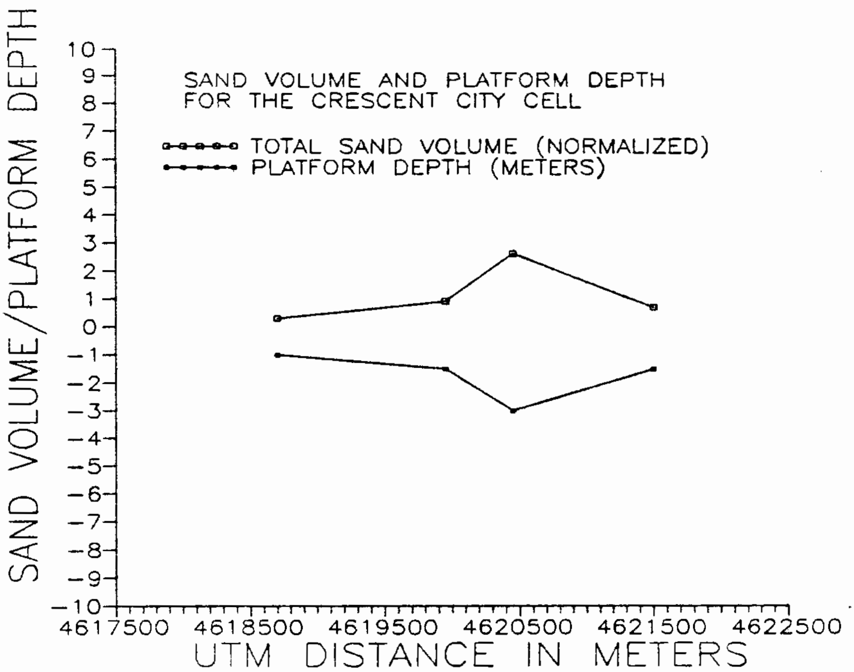


Figure 86. Normalized total beach volume and platform depth versus platform depth for the Crescent City Cell.

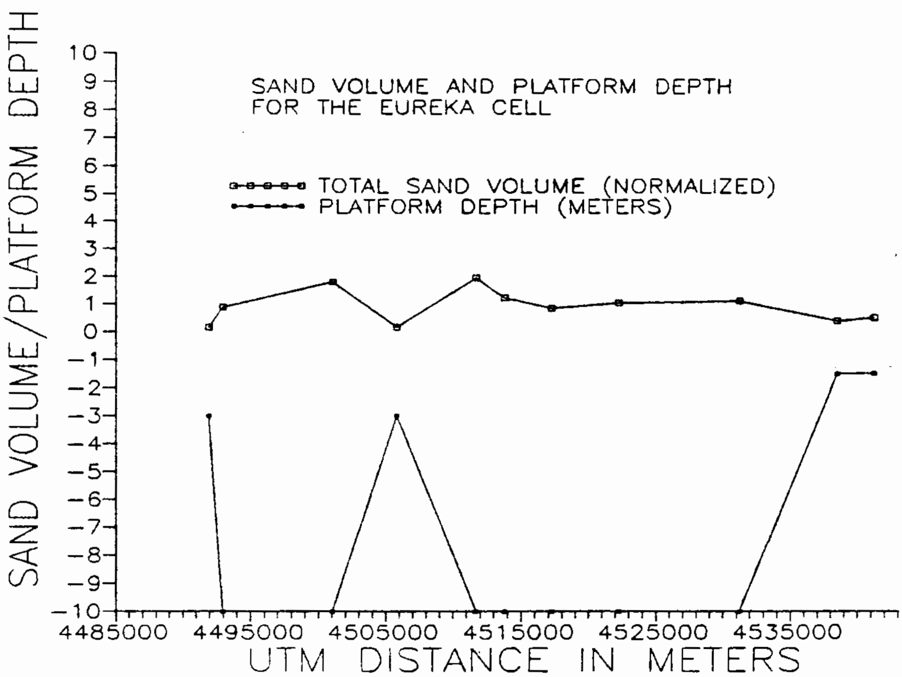


Figure 87. Normalized total beach volume and platform depth versus platform depth for the Eureka Cell.

-0.99), and Eureka (r= -0.79) cells, the total sand volume is strongly related to the depth of the wave-cut platform. The Cannon Beach and Otter Rock cells do not show a statistically significant correlation between these two variables. In most cells, the distribution of total sand volume in an area is governed by the depth of the wave-cut platform rather than beach width. As platform depth increases, there is more of a basin for sediments to collect in, and thus the total sand volume in storage increases. In those beaches where total sand does not correspond to platform depth, there is necessarily an increase in either beach width or the sand above MLLW.

There is a poor negative correlation (r= -0.49) between beach width and mid-beachface slope for most of the beaches studied (Figure 88).

Although the total quantity of sand in a given area is largely related to the depth of the wave-cut platform and not to the beach width, for the volume of sand above MHHW, it is the width of a beach which controls the sand volume in some analyzed cells (see Figures 89 through 96). The La Push, Otter Rock, and Crescent City cells have a good positive correlation between these two variables with coefficients of r= 0.82, r= 0.87, and r= 0.94 respectively. This relation exists because beaches build only to a maximum possible height before dune development occurs. In order to store large quantities of sand above MHHW on a beach, either

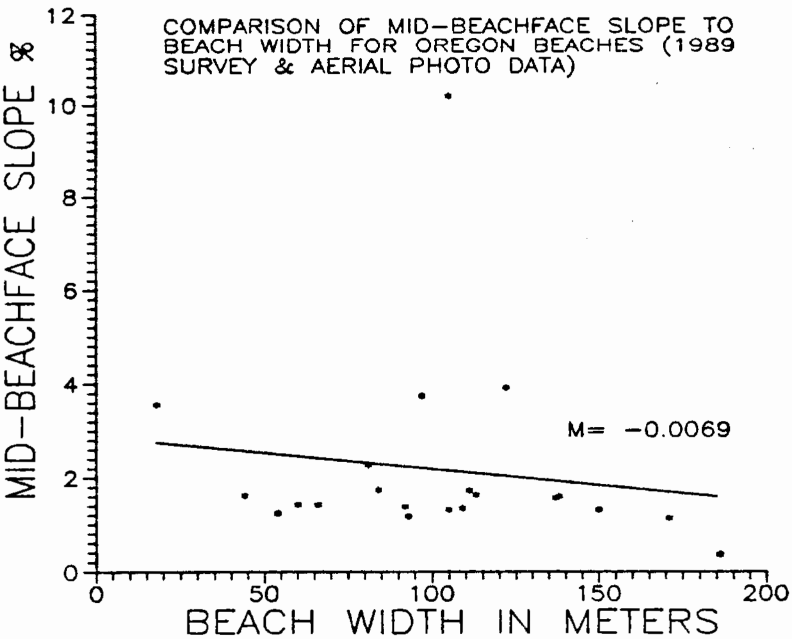


Figure 88. A comparison of mid-beachface slope to beach width for selected littoral cells of the PNW.

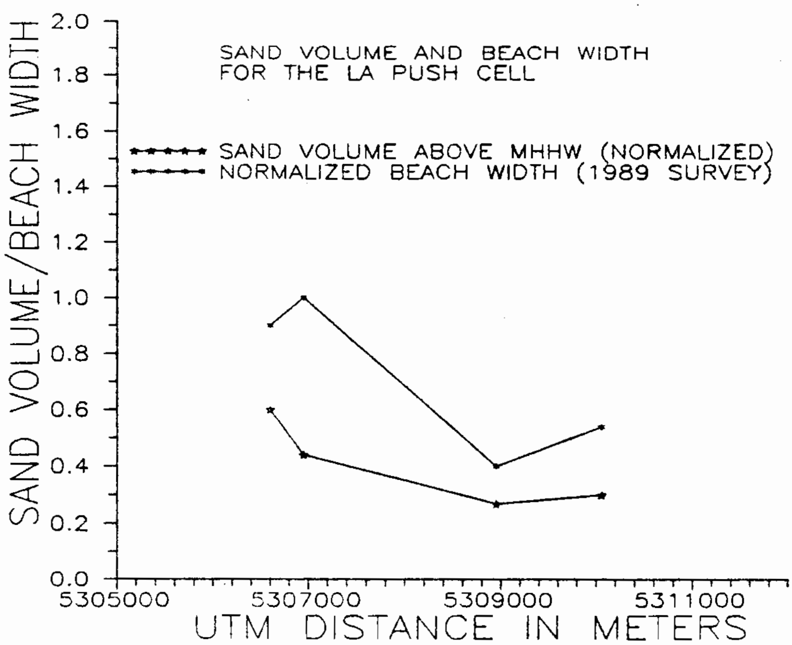


Figure 89. Normalized sand volume above MHHW and beach width versus distance for the La Push Cell.

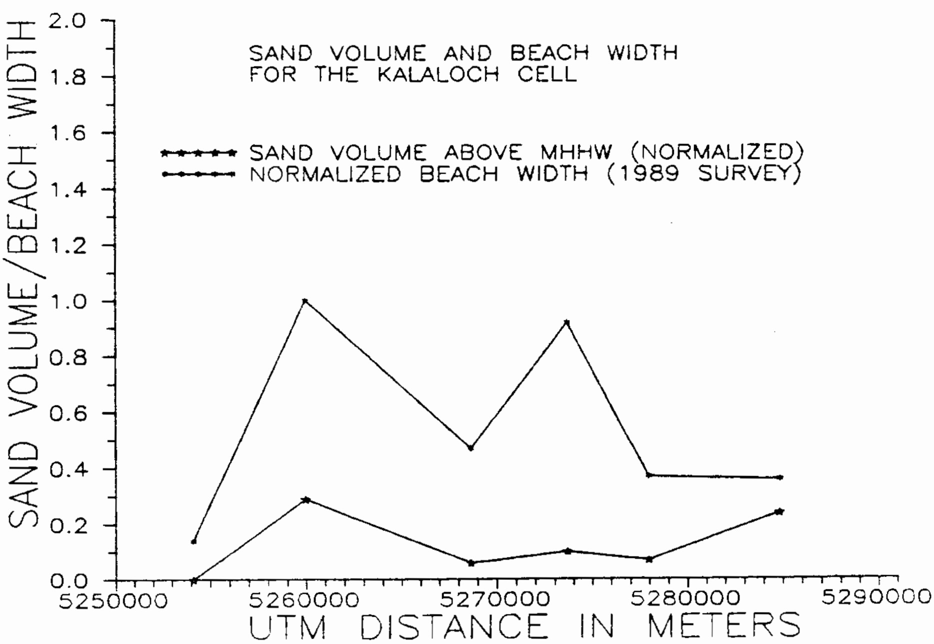


Figure 90. Normalized sand volume above MHHW and beach width versus distance for the Kalaloch Cell.

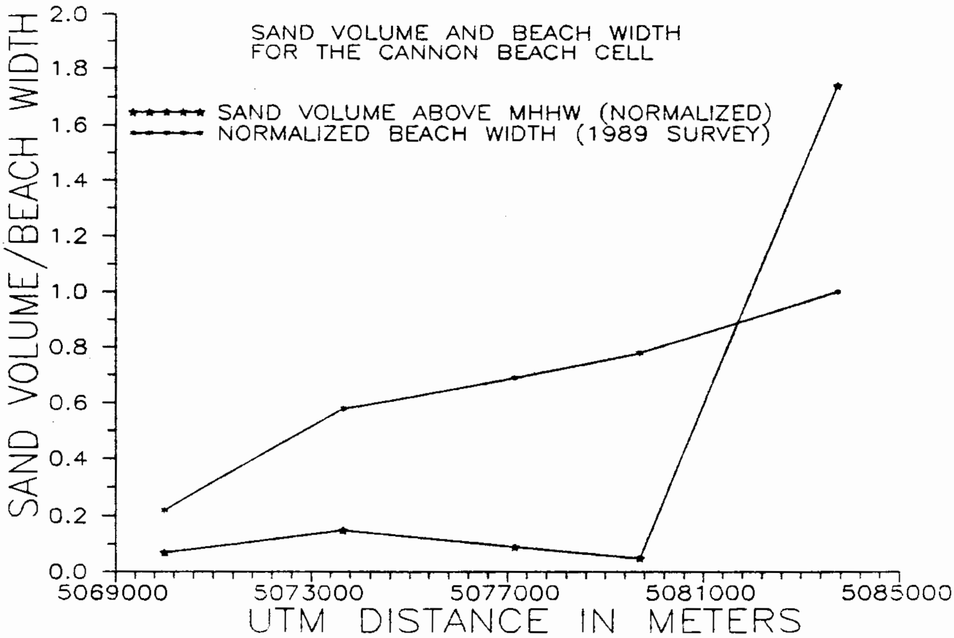


Figure 91. Normalized sand volume above MHHW and beach width versus distance for the Cannon Beach Cell.

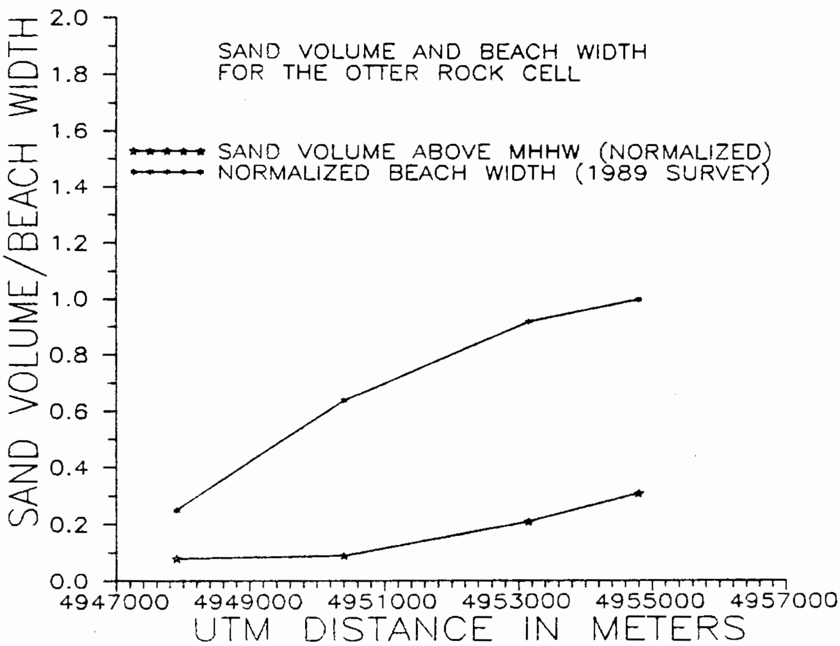


Figure 92. Normalized sand volume above MHHW and beach width versus distance for the Otter Rock Cell.

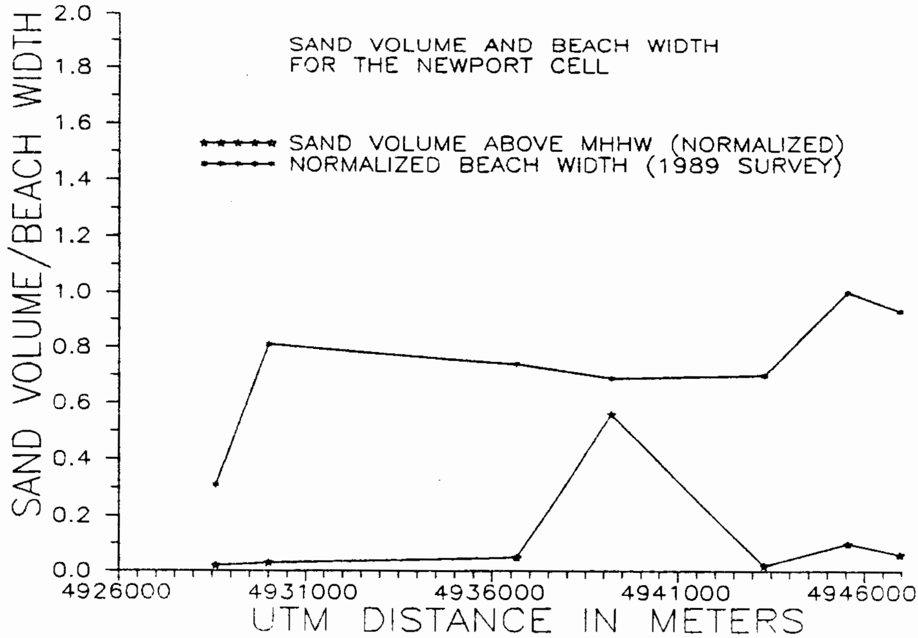


Figure 93. Normalized sand volume above MHHW and beach width versus distance for the Newport Cell.

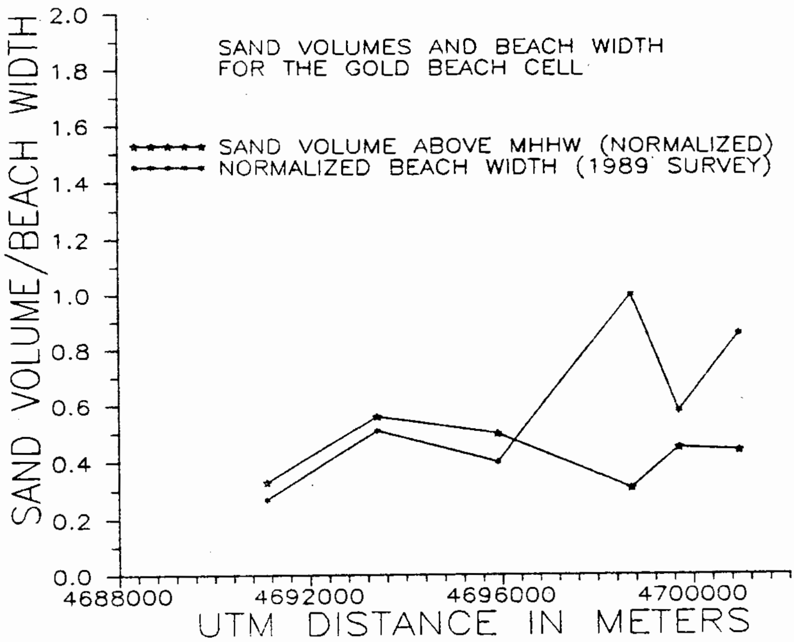
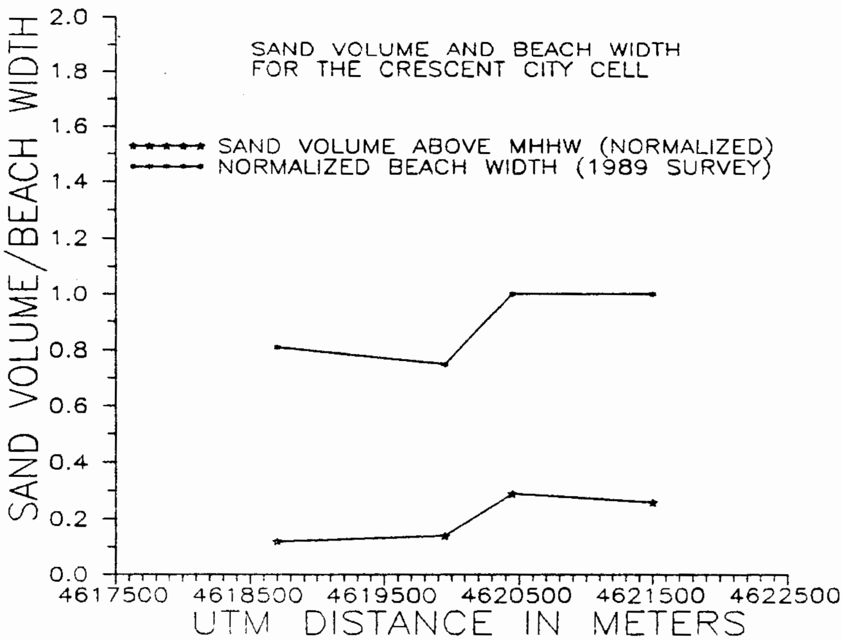
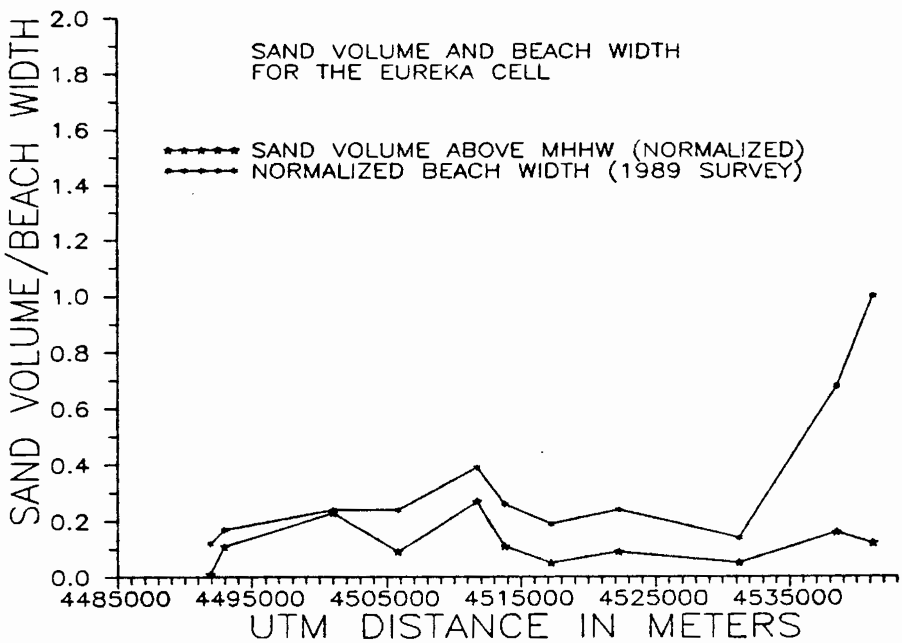


Figure 94. Normalized sand volume above MHHW and beach width versus distance for the Gold Beach Cell.



<u>Figure 95.</u> Normalized sand volume above MHHW and beach width versus distance for the Crescent City Cell.



<u>Figure 96.</u> Normalized sand volume above MHHW and beach width versus distance for the Eureka Cell.

the width of the beach must increase or sand must be stacked higher within the profile (dune building) or a combination of the two. The increase in volume above MHHW in the Chapman Beach area of the Cannon Beach Cell (see Figures 7 and 82) has resulted from the combination of both a large beach width and a significant dune complex. Conversely, some areas show significant quantities of sand above MHHW with narrow beach widths or extremely wide beaches without a large storage of sand above MHHW. Where sand volumes increase without a commensurate increase in beach width as is the case in the South Beach area of the Newport Cell (see Figures 9 and 93), it is due to a stacking of sand in the foredune complex. The Clam Beach and Moonstone Beach areas of the Eureka Cell have extremely wide beaches without significant increases in sand volume above MHHW. This is due to the fact that the beach profiles for these areas, although extremely wide, do not rise significantly above MHHW.

The definition of the sand volumes used in this study are based on variables such as platform depth, beach width, and tidal datum. Therefore, it is not surprising that comparisons between total sand volume and platform depth and between beach width and sand volume above MHHW correspond for most areas studied. Rather, it is surprising that they do not correspond everywhere, and it is these areas which represent the extremes of shoreline configuration. For example, the stacking of sand in the stabilized dune field of South Beach in the Newport creates the disparity between beach width and volume in this cell (Figure 93).

Direction of Net Sediment Transport

The direction of net sediment transport is a function of wave climate, shoreline configuration, and the physical properties of the sediment being transported, each of which constantly change with time. As mentioned above, if the rate of sediment transport exceeds a source's ability to provide sand to the beach, the distribution of sand within a cell will be influenced largely by the presence of barriers to longshore transport. Most beaches show that transport rate predominates over input of sand by the various sources and there is a net movement of sediments within the cells studied because sand does not accumulate to significant amounts adjacent to point sediment sources. Of the cells studied, the net transport direction (though probably changing with time) is to the north in the Cannon Beach, Otter Rock, Newport, Crescent City, and Eureka Cells. Net transport might be to the south in the La Push Cell, possibly due to the unusually complex morphology at the Quillayute River mouth in this small cell. Gold Beach shows a variable transport direction due to extreme changes in beach orientation. The net transport direction of the Kalaloch Cell appears to be to the south in the northern end of the cell, while the southern two-thirds show a preferred transport direction to the north.

Because wave climate is greatly affected by climatic disturbances such as the 1983 ENSO, such occurrences can drastically affect the distribution of sands within littoral cells. During the 1983 El Niño, the more southerly approach of incident wave energy caused an increase in the efficiency of sediment transportation to the north in most of the cells studied (see Results; see Figures 26 through 32). The result was the displacement of sand from the northern sides of southern cell boundaries and to the south sides of northern cell and sub-cell boundaries. Sand was also displaced on the north sides of barriers to longshore transport, such as the Humbolt Bay jetty system in the Eureka Cell, where sand sources to the south were not available or cut off.

Location of Barriers to Longshore Transport

Each cell in this study has as its end points a headland which protrudes into the ocean such as Yaquina Head which separates the Newport and Otter Rock Cells, or a series of small barriers such as Seal Rocks in the Newport Cell. These barriers compartmentalize the movement of sand in an area and thus define a littoral cell. These primary barriers at the ends of a cell may influence the distribution of the available sands, especially where no other barriers exist within the cell. For example, sand above MHHW generally is in greater abundance south of northern cell boundaries. For cells in which barriers exist within the cell sand distributions are influenced by the positions of local barriers to longshore transport. These barriers may be natural shoreline protrusions such as Hug Point in the Cannon Beach Cell, man-made obstructions such as jetties or groins, or large changes in shoreline orientation such as the High Tide to Redhouse Beach area within the Gold Beach Cell, each of which has affected the distribution of sand within its cell.

While shoreline configuration is largely responsible for the distribution of total sand within a profile, it is the direction of net sediment transport and the location of barriers to longshore transport which appear to control the quantity of sand above MHHW. Sand volumes above MHHW in the active beachface are at a minimum within the cells studied in areas such as Nye Beach (Newport Cell) where sediment transport is to the north, and the beach lies just north of a barrier to sand transport (in this case a jetty enclosing a harbor mouth). The same can be seen at Samoa Beach (Eureka Cell) where the area lies just north of the Humboldt Bay jetty system (see Figures 12 and 68). South of these barriers, sand has accumulated, forming the largest quantities of sand above MHHW in these cells. Similar sand distributions also occur in each of the littoral cells or sub-cells studied.

The two most important factors influencing intracellular sand distributions appear to be: 1) the net transport direction, which is related to shoreline orientation/configuration and local wave climate; and 2) the location of barriers to longshore transport in relation to the net direction of sediment transport. By comparison, other factors such as the location of sand sources and sinks do not appear to have a major effect on sand distributions in the cells studied. From these relations it is clear that rates of longshore sand transport and redistribution must exceed rates of local sediment supply to the cells.

INTERCELLULAR VARIABILITY OF SAND DISTRIBUTION

The amount of sand present within the littoral cells chosen for this study ranges from approximately 655,000 m^3 for the La Push Cell to over 90 million m^3 for the Eureka Cell. Figure 97 shows a comparison of total sand volume to length for the eight selected littoral cells. This figure shows that there is a positive correlation between the length of a littoral cell and the total quantity of sand within the cell ($r= 0.91$). The distribution of sand volumes between littoral cells chosen for this study is presented in figure 98 below. Although the total quantity of sand is related to the cell length, the quantities of sand above MLLW and MHHW do not vary in relation to total sand quantity. Figure 99 shows the distribution of sand between

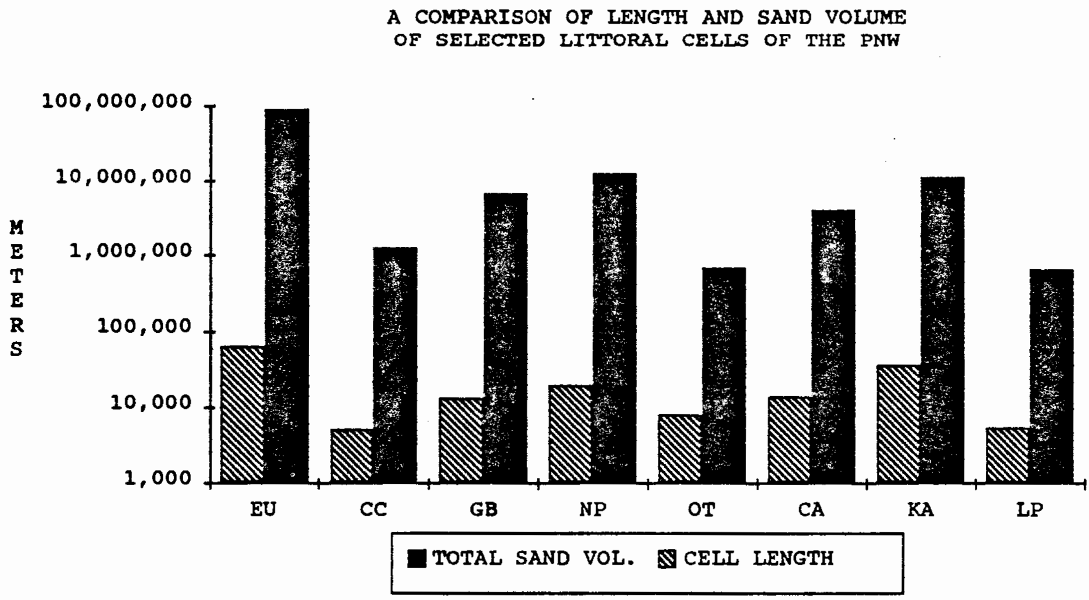


Figure 97. Variation in total sand volume and cell length for eight selected littoral cells of the PNW.

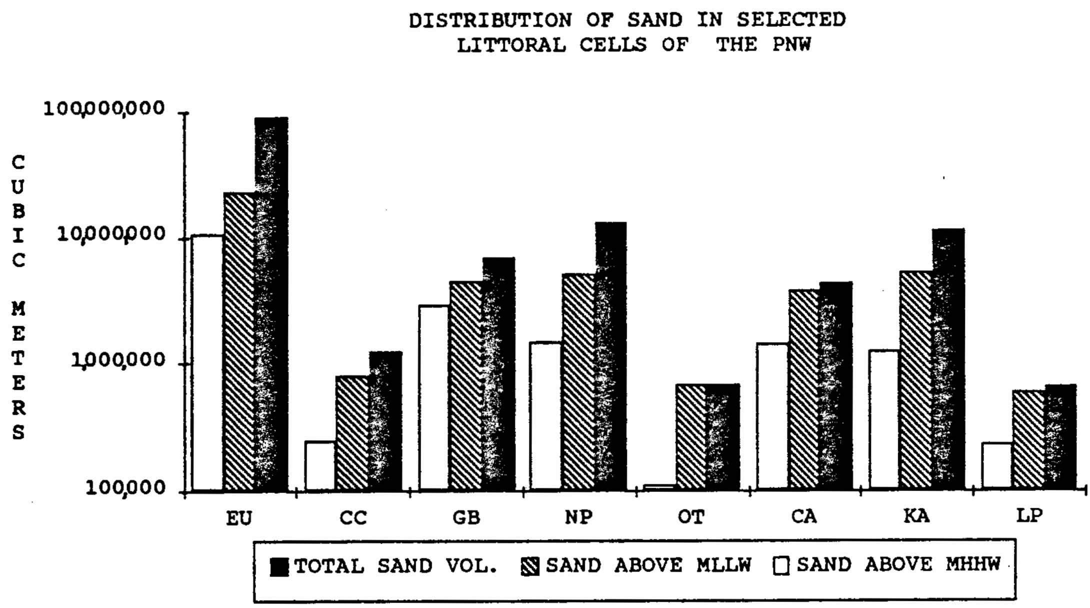


Figure 98. Variation in sand volumes for eight selected littoral cells of the PNW.

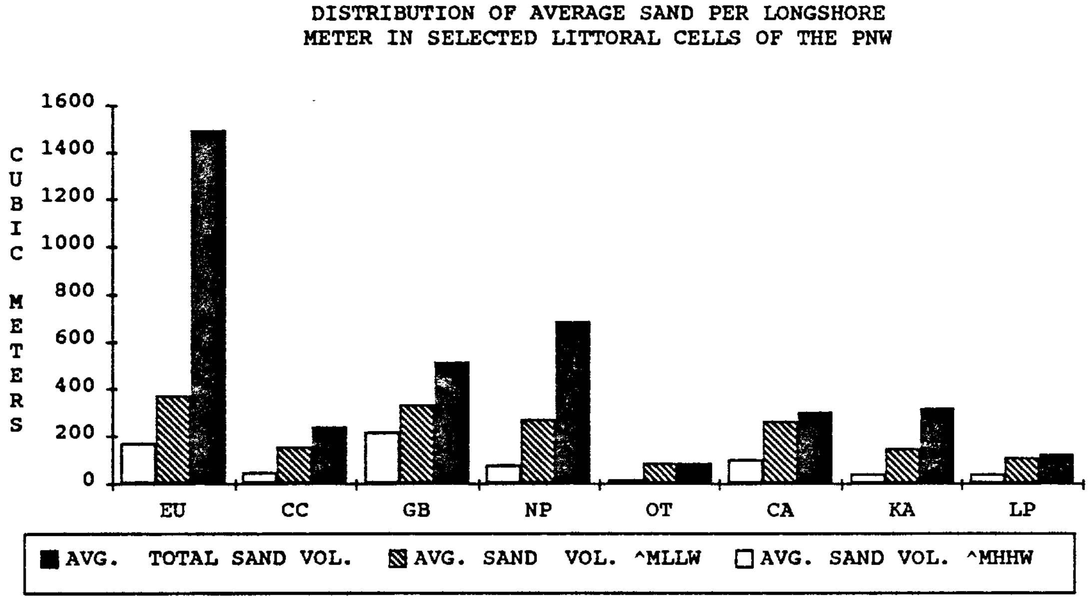


Figure 99. Variation in total sand volume normalized to cell length for eight selected littoral cells of the PNW.

selected littoral cells normalized by the length of the littoral cell. Of the four cells with the highest total volume of sediments and the highest average volume of sediments per longshore meter, the Newport Cell stands out as the only cell without a major drainage system entering its littoral zone. In fact, the Yaquina River enters the Newport Cell through Yaquina Bay which is reported to be a sink of sand. The fact that this cell ranks second in total sand volume indicates that either its major active source of sediments (most likely the rapidly eroding terraces which run its length) are capable of supplying an enormous amount of sediment, or most of the sand in the cell is relict. In contrast, the La Push Cell has a significant drainage system which enters its littoral zone (the Quillayute River), and yet it ranks last in total volume of sediment and next to last in total volume of sediment per meter longshore. The other three lowest ranking in sand volume (Otter Rock, Crescent City, and Cannon Beach) have no significant drainage systems entering their littoral zones. The reason for the low sand volume of the La Push Cell is unclear. The Quillayute River may be supplying less sediment to the La Push Cell than are the terrace sources in the other three cells at present. It is also possible that the La Push Cell is losing sand to offshore sediment sinks and/or to longshore transport around bounding headlands. Based on a comparison of grain size between these three cells, the later of these two alternatives is the most likely. Of these cells only the Cannon Beach has an active dune field which acts as an onshore sink of littoral sediments.

FACTORS INFLUENCING INTERCELLULAR SAND DISTRIBUTION

The distribution of sand between littoral cells of the Pacific Northwest is thought to be related primarily to the presence or absence of sand sources and sinks. Possible sources of sands include (in apparent order of importance in the study areas): 1) sediment transported into the coastal zone by rivers and streams; 2) actively eroding terraces and dune complexes bordering the coastal zone; 3) onshore transport of nearshore sediments; and 4) the presence of relict sands. The importance of sands supplied by offshore deposits is unknown for the Pacific Northwest. Possible sinks of sand include: 1) trapping in estuaries; 2) storage in dune fields; and 3) loss of sand to the offshore. A qualitative assessment of each estuaries ability to supply or withdraw sand from its cell has been discussed for each cell (see La Push, Kalaloch, Newport, Gold Beach, and Eureka sections of Intracellular Variability in Discussion above). The importance of sand loss to submarine canyon heads and/or offshore transport to the inner shelf is unknown for the Pacific Northwest.

The quantity of sand in a littoral cell appears to be related to the length of the littoral cell (Figure 97).

However, beaches within small cells with an over abundance of sand supply may prograde to the point where adjacent cells are linked as sand is allowed to bypass a headland. Such a process could be responsible for the distribution of sand evenly over successively larger distances. Table Bluff for example, probably formed a headland at some time in the history of the Eel River, and possibly divided the present day Eureka Cell into two distinct cells. As Eel River sediments filled the river valley, the development of a barrier spit allowed sediment to bypass Table Bluff and eventually the spits would grow to enclose Humboldt Bay. The largest cells in the Pacific Northwest (the Astoria and Eureka Cells) have but a single dominant sediment source within the limits of the cell. The cell length in these cells is dependent primarily on the abundance of the sediment supply.

Based on the distribution of sand within the Cannon Beach, Otter Rock, Newport, and Crescent City Cells and the apparent lack of a major sediment source, it appears that relict sands, trapped within these littoral cells by the post-glacial sea-level rise, comprise a large percentage of the sand present in these cells. Because of the lack of active sand input to these cells, such cells are limited in the size they can attain. These cells are also more likely to experience erosion because they are limited in the quantity of beach sand presently in storage.

The distribution of sand between littoral cells of the Pacific Northwest is related primarily to the presence (or absence) of major river sediment sources. Cells without such sources must rely on erosion of sand sources (terraces and dunes) or onshore sand transport in order to provide new sands to the littoral zone.

IMPLICATIONS FOR SHORELINE STABILITY

The distribution of sand within a cell is as important as the total quantity of sand present in the cell in preventing erosion. The Newport Cell, for example, has an average of 684 m^3 of total sand volume per meter shoreline while the Gold Beach Cell has only 511 m^3. Yet most of the sand in the Newport Cell is tied up in the wide beach and dune complex of the South Beach area. The rest of the cell has a relative dearth of sand. For example, of the sand above MHHW, the Newport Cell has an average of 78 m^3 per meter shoreline while the Gold Beach Cell has 217 m^3. While the Gold Beach Cell shows little sign of erosional activity, virtually the entire Newport Cell (except South Beach) is under attack by erosion. So the distribution of sands along shore and within the profile itself is as important as the quantity of sand in the cell in protection against erosion.

The Eureka Cell is the longest cell studied at 60.9 km in length (Table V). Its total sand volume is approximately seven times that of the Newport Cell (the next largest in total sand volume) while it is only 3.2 times as long. Even with the apparent abundance of sand in the Eureka Cell, portions of the cell shoreline have recently experienced dramatic erosion. Samoa Beach in the Eureka Cell has 1240

m^3 of total sand per longshore meter. When compared to other beaches within the cell, this appears to be an average amount of sand. And yet this beach has an active erosional surface which has recently cut landward into the stabilized dunes, while other beaches with similar values show no signs of erosion. The large amount of total sand arises from the fact that the beach is part of a spit system whose base is greater than 10 m below MTL. When the amount of sand above MHHW in this area (69 m^3) is compared to other beaches within the cell, it can be seen that it has one of the lowest values for the cell. The only other beach in this cell which is lower in sand above MHHW is Centerville Beach (16 m^3) which is also experiencing erosion (terrace retreat). Samoa Beach is located just north of a major subcell boundary, in this case the Humbolt Bay Jetty system. A similar example is the Nye Beach area which is located just north of the Yaquina Bay Jetty system in the Newport Cell. The presence of jetties and other barriers to longshore transport appears to have an affect on sand supply and the erosional susceptibility of shorelines.

The quantity of sand above MHHW varies between 15 and 45 m^3 meters of sand per meter shoreline for at least the southern two-thirds of the Cannon Beach Cell. Within this cell segment, measures are being taken to stop the advancement of erosion by building sea-walls and revetments. To the north there is more than 500 m^3 of sand per meter shoreline and the residents are taking measures to stop the active growth of the large dune complex. The distribution of sand above MHHW within a cell therefore appears to be a good indicator of local shoreline susceptibility to erosion.

The quantity and distribution of beach sand in Pacific Northwest littoral cells determines the cells' ability to buffer the erosive energy imparted to the coastline during surf conditions. Although few areas of the Pacific Northwest coast show no signs of previous or ongoing erosion, there is a strong relationship between areas within a cell experiencing active erosion and those which have the least amount of sand distributed above MHHW. Unfortunately, because each cell is unique with respect to the combined affects of such factors as orientation, latitude, geomorphology, and sand sources, a single value of sufficient sand quantity cannot be chosen for all cells. Each cell, and possibly areas within cells might have different requirements for sand quantities which will sufficiently buffer erosion.

Due to the limited quantities of sand available to act as a buffer within most of the cells studied, planning is critical to the continued use of the coastal zone by all. Because erosion of sea cliffs and terraces supplies sand to littoral cells (in some cases the only source) caution must be used when attempting to prevent landward erosion through the construction of sea walls and rip-rap revetments. The effectiveness of such measures is much in debate (Thompson, 1987). Although sea walls may provide a temporary protection to landward structures, it is usually at the expense of the adjacent beach. Where significant portions of the shoreline have been armored by sea walls and rip-rap, the result has been the loss of significant portions of the sand on the beach (Ringle, 1987). Likewise, the construction of barriers to longshore transport such as jetties and groins will alter the distribution of buffering sands, causing some areas to be more susceptible to erosion while other areas show sand accumulation. Because of the reversing nature of transport direction within littoral cells, the mining of beach sand (even in areas with an apparent abundance) may cause deleterious effects elsewhere in the cell.

With the continued rise in sea level, there will be less sand available on beaches in the Pacific Northwest to buffer against erosion. Because of this, it will become increasingly important to plan effectively for the maintenance of shorelines. Preferred alternatives for shoreline maintenance should include the use of beach replenishment through the placement of artificial fill sands as opposed to armoring of the shoreline, limitations on the further construction of barriers to sand transport, and the establishment of zoning systems which take into account the role of sea cliffs and terraces as a primary sand source in some cells.

RECOMMENDATIONS FOR FURTHER STUDY

The quantity of sand above MHHW appears to be a good indicator of an areas ability to withstand erosion. The next step in understanding the effect of sand distribution on erosion is to understand why the amount necessary to act as a sufficient barrier varies from cell to cell and possibly even within each cell. Once this is accomplished, it may be possible to determine what sand distributions are necessary to inhibit erosion for each cell in the Pacific Northwest. Those areas within cells which are found to be drastically lacking in sufficient sand quantities could then be delineated for coastal planning purposes or possibly targeted for beach enrichment.

Early in the course of this project, it became clear that coastal analysis would be greatly enhanced if data were collected in a more consistent manner than it has in the past. Although aerial photographs were available for most of the Pacific Northwest coast, the variation in tide level between flight dates and times added an unnecessary complication with respect to analysis. For this reason, aerial photographs were taken during the 1989 field season when the tide was at MTL for the Oregon cells. If all aerial photographs of the coastal zone were taken during times of MTL, a consistent data base could be constructed which would greatly enhance results of analysis. Secondly, aerial photograph dates should be scheduled more often and at consistent dates year to year. This would reduce the apparent change in the coastline which results from seasonal changes in sand transport.

Because it is the quantity of sand above MHHW which appears to be the most direct indicator of an areas potential to withstand erosion, future studies of cells for which static sand budgets have already been calculated may shift concentration from determining total sand quantities in an area to the sand which lies above MHHW. This would greatly simplify data acquisition because reliance on geophysical techniques to determine platform depth could be scaled down or eliminated entirely.

The importance of sediment transport from the offshore and the quantities of relict sands present within littoral cells of the Pacific Northwest are largely unknown. These areas need to be investigated in order to fully assess the dynamics of littoral processes in the Pacific Northwest.

CONCLUSIONS

1) Estimates of the total quantity of sand present in the active portion of the beach (MLLW to dune crest/sea cliff base) varies between the littoral cells studied: La Push- 655,240 m^3, Kalaloch- 11,253,730 m^3, Cannon Beach- 4,226,686 m^3, Otter Rock- 680,232 m^3, Newport- 12,830,851 m^3, Gold Beach- 6,758,009 m^3, Crescent City- 1,243,520 m^3, and Eureka- 90,723,700 m^3.

2) The distribution of sand between littoral cells of the Pacific Northwest is apparently related to the presence or absence of sand sources. Rivers are the dominant source of sand to littoral cells of the Pacific Northwest. Cells without major drainage systems which enter the littoral zone or those in which sediment is trapped in estuaries before reaching the littoral zone generally have small volumes of sand in storage and have shorter cell lengths. Such cells rely primarily on erosion of terrace deposits as the only active sand sources and it is likely that a large component of the sand present within these cells is sand which is relict.

3) The distribution of available sand within littoral cells of the Pacific Northwest is related to the net transport direction (a function of shoreline orientation/

configuration and local wave climate) and the location of barriers to longshore transport in relation to the net sediment transport direction.

4) The distribution of sands above MHHW in a cell segment does not always vary in relation to the total sand present in the segment. For example, the volume of sand above MHHW increases to the south in the La Push Cell while the total volume increases to the north.

5) Total sand volume of a cell segment is largely determined by the depth of the wave-cut platform and not the width of the beach for the cells studied.

6) The sand volume above MHHW varies directly with beach width for some of the beaches studied and is controlled primarily by the location of barriers to longshore transport. This conclusion is supported by evidence from the 1983 El Niño. The more southerly approach of incident wave energy caused by the 1983 ENSO event caused an increase in the efficiency of sediment transportation to the north in most of the cells studied. This caused the displacement of sand at southern cell boundaries and on the north sides of longshore transport barriers (man-made and naturally occurring) where sand sources to the south were not available or cut off. Sand in the cells studied had apparently returned to pre-El Niño longshore distributions prior to field work conducted in this study.

7) Based on sand distributions and grain size trends, the net transport direction of sediment is to the north within the Cannon Beach, Otter Rock, Newport, Crescent City, and Eureka Cells. The net transport direction is to the south for the northern third of the Kalaloch Cell, while the southern two-thirds show net transport to the north. The Gold Beach Cell has shows both north and south transportation of sediments away from the abrupt change in shoreline orientation associated with the Redhouse Beach to High Tide Beach area. The net littoral drift of the La Push Cell appears to be to the north and south from the Quillayute River mouth near the middle of the cell.

8) The ability of a beach to protect the shoreline from erosion is largely related to the quantity of sand in storage on a beach because this sand distributes and disperses the wave energy. More importantly than the total quantity of sand on a given beach is the distribution of that sand within the beach profile. From the cells studied, it can be seen that beaches within a cell which have the least sand in storage above MHHW are those which are presently or have recently experienced erosion.

9) Sand redistribution and associated exposure to erosion occurs on shorter time scales than does sand supply. Artificial changes in sand supply or along shore transport will have immediate effects on local shoreline erosion/accretion in littoral cells of the Pacific Northwest.

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APPENDIX A

BEACH DATA FOR SELECTED LITTORAL CELLS OF THE PNW

	A	B	C	D	E	F	G	H	I
1	CELL DATA FOR EIGHT SELECTED CELLS								
2									
3	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
4									
5		5311600	376050			T?2	97.6	7/18/77	0
6		5311450	376500	0.1		T?2	61	7/18/77	0
7		5310950	376800	0.6		T?2	61	7/18/77	0
8	N. RIALTO	5310550	377100	1.1	243	T?2	67.1	7/18/77	23
9		5310050	377400	1.6	247	T1D?	91.5	7/18/77	46
10		5309100	377500	2.1	256	T?2	91.5	9/11/77	41
11		5308950	377600	2.6	255	T?2	85.4	9/11/77	46
12	S. RIALTO	5308350	377650	3.1	267	T1D		9/11/77	35
13		5307850	377600	3.6	296	T1D		9/11/77	18
14		5307400	377350	4.1	300	T1D		9/11/77	93
15	Quillayute R. Mouth								
16		5306950	377650	4.6	215	D		9/11/77	41
17	LA PUSH	5306600	378358	5.1	239	D		9/11/77	35
18		5306150	378350	5.6	260	D		9/11/77	46
19	Quateata	5305600	378000			T2	61	9/11/77	0
20									
21									
22	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
23									
24		5291350	390100		220	U2		7/22/77	0
25		5291000	390550		178	U2		7/22/77	0
26	End of Hoh Head								
27		5291150	390900	0.1	140	T?2	91.5	7/22/77	70
28		5290650	391350	0.8	250	T?2	67.1	7/22/77	81
29		5290150	391550	1.3	229	T?2	67.1	7/22/77	93
30		5289900	391850	1.8	210	T?2	67.1	7/22/77	29
31		5289550	392150	2.3	205	T?1D	67.1	7/22/77	46
32		5289200	392450	2.8	230	T?1D	42.7	7/22/77	35
33		5288850	392850	3.3	233	T2	30.5	7/22/77	52
34		5288500	393000	3.8	245	T2	30.5	7/22/77	81
35		5287900	393300	4.3	248	T2	42.7	7/22/77	81
36		5287300	393500	4.8	258	T2	48.8	7/22/77	35
37		5286750	393550	5.3	265	T2	48.8	7/22/77	46
38		5286350	393650	5.8	265	T2	48.8	7/22/77	58
39		5285800	393700	6.3	267	T2	48.8	7/22/77	35
40	Abby Island								
41		5285300	393700	6.8	230	T2	48.8	7/22/77	58
42	Ceder Creek								
43	RUBY BEACH	5284800	393850	7.3	270	T2	36.6	7/22/77	70
44		5284350	393950	7.8	240	T2	30.5	7/22/77	35
45		5283850	394000	8.3	258	T2	42.7	7/22/77	46
46		5283300	394050	8.8	260	T2	42.7	7/22/77	81
47		5282850	394150	9.3	258	T2	42.7	7/22/77	93
48		5282350	394250	9.8	251	T2	36.6	7/22/77	104
49		5281800	394500	10.3	249	T2	36.6	7/22/77	104
50	Steamboat Creek	5281350	394650	10.8	247	T2		7/22/77	197
51		5280900	394900	11.3	245	T2	36.6	7/22/77	110
52		5280350	395100	11.8	253	T2	36.6	7/22/77	58
53		5279800	395300	12.3	253	T2	30.5	7/22/77	81
54		5279300	395450	12.8	250	T2	18.3	7/22/77	70
55		5278900	395550	13.3	255	T2	18.3	7/22/77	58
56		5278500	395600	13.8	235	T2	36.6	7/22/77	46
57	BEACH #4	5277950	395800	14.3	263	T2	42.7	7/22/77	46
58		5277500	395900	14.8	258	T2	36.6	7/22/77	58
59		5277050	395950	15.3	256	T2	36.6	7/22/77	41
60		5276550	396100	15.8	272	T2	30.5	7/22/77	93
61									
62		5276050	396300	16.3	260	T2	36.6	7/22/77	122
63		5275600	396350	16.8	255	T2	30.5	7/22/77	139

	A	B	C	D	E	F	G	H	I
64		5275100	396500	17.3	248	T2	18.3	7/22/77	128
65		5274650	396500	17.8	253	T2	6.1	7/22/77	162
66		5274150	396550	18.3	260	T2	6.1	7/22/77	104
67	KALALOCH	5273650	396600	18.8	272	T2	6.1	7/22/77	81
68		5273200	396700	19.3	247	T2	6.1	7/22/77	174
69		5272700	396850	19.8	250	T2	6.1	7/22/77	116
70		5272200	396950	20.3	250	T2	6.1	7/22/77	99
71		5271650	397100	20.8	255	T2	6.1	7/22/77	70
72		5271200	397200	21.3		T2	6.1	6/6/77	93
73		5270750	397300	21.8	255	T2	6.1	6/6/77	128
74		5270250	397400	22.3	258	T2	6.1	6/6/77	104
75		5269550	397500	22.8	262	T2	6.1	6/6/77	93
76		5269100	397500	23.3	260	T2	6.1	6/6/77	139
77	SOUTH BEACH	5268650	397600	23.8	260	T1D	6.1	6/6/77	70
78		5268200	397650	24.3	260	T1D	6.1	6/6/77	58
79		5267700	397700	24.8	260	T1D	18.3	6/6/77	70
80		5267100	397750	25.3	260	T1D		6/6/77	81
81	Queets River Mouth	5266600	397850	25.8	260			6/6/77	
82		5266200	397950	26.3	260	T1D		6/6/77	93
83		5265650	398050	26.8	260	T1D		6/6/77	58
84		5265100	398150	27.3	260	T1D		6/6/77	104
85		5264600	398200	27.8	260	T2	30.5	6/6/77	76
86		5264100	398250	28.3	260	T2	30.5	6/6/77	58
87		5263600	398300	28.8	260	T2	30.5	6/6/77	58
88		5263100	398400	29.3	260	T2	30.5	6/6/77	87
89		5262600	398400	29.8	260	T2	30.5	6/6/77	104
90		5262100	398450	30.3	260	T2	30.5	6/6/77	81
91		5261600	398500	30.8	260	T2	30.5	6/6/77	87
92		5261150	398550	31.3	260	T2	30.5	6/6/77	116
93	Whale Creek								
94		5260550	398600	31.8	260	T1D	30.5	6/6/77	128
95	WHALE CREEK	5259950	398750	32.3	260	T1D	36.6	6/6/77	128
96		5259500	398750	32.8	260	T2	36.6	6/6/77	99
97		5259000	398800	33.3	260	T2	42.7	6/6/77	70
98		5258550	398800	33.8	260	T2	42.7	6/6/77	116
99		5258100	398860	34.3	260	T2	42.7	6/6/77	104
100		5257500	398850	34.8	260	T2	36.6	6/6/77	122
101	Tunnel Island								
102		5257050	398850	35.3	244	T1D		6/6/77	151
103		5256550	399000	35.8	265	T2	18.3	6/6/77	81
104		5256050	399000	36.3	274	T2	36.6	6/6/77	116
105		5255500	399100	36.8	275	T2	36.6	6/6/77	58
106	Hogsback								
107		5255050	399100	37.3	265	T2	36.6	6/6/77	35
108		5254450	399050	37.8	280	T2	36.6	6/6/77	81
109	LITTLE HOGSBACK	5254100	399150	38.3	255	T2	42.7	6/6/77	46
110		5253550	399200	38.8	255	T2	42.7	6/6/77	35
111		5253150	399200	39.3	270	T2	36.6	6/6/77	35
112		5252700	399100	39.8	265	T2	36.6	6/6/77	58
113		5252250	399200	40.3	282	T2	36.6	6/6/77	81
114		5251700	399050	40.8	283	T2	36.6	6/6/77	23
115		5251250	399100	41.3	288	T2	36.6	6/6/77	58
116	Pratt	5250800	399350			T2	36.6	6/6/77	0
117	Cliff	5250400	399600			T2	36.6	6/6/77	0
118									
119									
120									
121	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
122									
123		5084150	424900			U2		10/2/78	0
124	CHAPMAN BEACH	5083750	424100	0.4	252	T1D	18.3	10/2/78	134
125		5083300	425200	0.9	248	T1D	6.1	10/2/78	174
126	Ecola Creek								

	A	B	C	D	E	F	G	H	I
127		5082850	425200	1.4	285	T1	6.1	10/2/78	139
128		5082300	425200	1.9	264	T1	6.1	10/2/78	104
129		5081850	425200	2.4	268	T1	6.1	10/2/78	81
130		5081400	425200	2.9	270	T2	6.1	10/2/78	116
131		5081000	425300	3.4	255	T2	6.1	10/2/78	116
132		5080500	425400	3.9	262	T1	6.1	10/2/78	93
133	TOLOVANA BEACH	5079700	425300	4.4	262	T1	6.1	10/2/78	87
134		5079400	425300	4.9	278	T1	6.1	10/2/78	87
135		5078900	425250	5.4	284	T2	18.3	10/2/78	93
136		5078350	425200	5.9	260	U2		10/2/78	46
137		5077950	425250	6.4	257	U2		10/2/78	70
138		5077550	425400	6.9	256	U2		10/2/78	70
139	Humbug Pt.								
140	ARCADIA BEACH	5077150	425400	7.4	260	T2	18.3	10/2/78	122
141		5076500	425350	7.9	280	T2	18.3	10/2/78	93
142		5076050	425350	8.4	268	U2		10/2/78	116
143	Hug Pt.	5075700	425300	8.9	268	U2		10/2/78	70
144		5075200	425300	9.4	277	U2		10/2/78	99
145		5074700	425200	9.9	275	T2	6.1	10/2/78	93
146		5074150	425200	10.4	275	T2	6.1	10/2/78	93
147	N. ARCH CAPE	5073650	425150	10.9	275	T2	6.1	10/2/78	116
148		5073100	425050	11.4	275	T2	6.1	10/2/78	93
149		5072650	424950	11.9	275	T2	6.1	10/2/78	81
150	Arch Cape	5072200	424850	12.4	256	U2		10/2/78	0
151		5071700	424800	12.9	275	T2	6.1	10/2/78	46
152		5071100	424800	13.4	256	T2	30.5	10/2/78	46
153		5070750	424800	13.9	272	T2	30.5	10/2/78	58
154	COVE BEACH	5070000	424700	14.4	275	T2	18.3	10/2/78	70
155		5069700	424650			U2		10/2/78	0
156									
157	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
158									
159		4956100	415800			T2	18.3	10/25/78	0
160	Otter Crest	4955400	415900		271	T2	40	10/25/78	46
161		4955150	415900	0.1	195	T2	18.3	10/25/78	52
162	OTTER ROCK	4954800	416200	0.6	240	T2	30.5	10/25/78	116
163		4954150	416300	1.1	266	T2	18.3	10/25/78	116
164		4953650	416200	1.6	269	T2	18.3	10/25/78	104
165	BEVERLY BEACH	4953150	416250	2.1	268	T2	18.3	10/25/78	116
166		4952600	416200	1.6	298	T2	18.3	10/25/78	46
167		4952200	416200	3.1	262	T2	18.3	10/25/78	93
168		4951650	416100	3.6	280	T2	18.3	10/25/78	93
169		4951000	416000	4.1	282	T2	30.5	10/25/78	64
170	MOOLACK BEACH	4950400	415950	4.6	285	T2	18.3	10/25/78	99
171		4950400	415950	4.6	285	T2	18.3	10/25/78	99
172		4950000	415900	5.1	280	T2	18.3	10/25/78	116
173		4949550	415700	5.6	280	T3	18.3	10/25/78	104
174		4949050	415600	6.1	287	T3	30.5	10/25/78	70
175		4948600	415500	6.6	281	T3	18.3	10/25/78	64
176	58th STREET	4947900	415300	7.1	295	T3	42.7	10/25/78	81
177		4947600	415200	7.6	305	T3	42.7	10/25/78	29
178	Yaquina Head	4947400	414500			T2	18.3	10/25/78	0
179		4947050	414700			U2		10/25/78	0
180		4947000	415350			U2		10/25/78	0
181		4947100	415800			U2		10/25/78	0
182	Yaquina Head								
183	AGATE COVE	4946950	415950	0.2	245	T2	18.3	10/25/78	46
184		4946500	416100	0.7	258	T2	18.3	10/25/78	104
185		4946100	416200	1.2	257	T2	18.3	10/25/78	128
186	AGATE WAYSIDE	4945550	416150	1.7	272	T1	6.1	10/25/78	197
187		4944850	416050	2.2	281	T2	42.7	10/25/78	104
188		4944300	416000	2.7	284	T3	30.5	10/25/78	81
189		4943850	415850	3.2	249	T3	30.5	10/25/78	35

	A	B	C	D	E	F	G	H	I
190	NYE BEACH	4943300	415750	3.7	281	T2	18.3	10/25/78	81
191		4942900	415450	4.2	282	T2	18.3	10/25/78	81
192		4942450	415600	4.7	287	T2	18.3	10/25/78	93
193		4941900	415450	5.2	280	T2	18.3	10/25/78	70
194		4941350	415650	5.7	235	T1D	30.5	10/25/78	104
195		4941250	415650	6.1					
196	Yaquina Bay								
197		4940350	415200	7					
198		4940200	415300	7.1	227	T1D		10/25/78	104
199		4939800	415450	7.6	259	T1D		10/25/78	93
200	SOUTH BEACH	4939200	415500	8.1	273	T1D		10/25/78	116
201		4938700	415400	8.6	277	T1D	6.1	10/25/78	93
202		4938100	415400	9.1	277	T1	6.1	10/25/78	104
203		4937550	415250	9.6	277	T2	30.5	10/25/78	81
204		4937050	415250	10.1	285	T3	30.5	10/25/78	70
205	HOLIDAY BEACH	4936650	415250	10.6	285	T2	30.5	10/25/78	46
206		4936100	415200	11.1	285	T2	30.5	10/25/78	93
207		4935600	415100	11.6	285	T2	30.5	10/25/78	70
208		4935000	415100	12.1	285	T2	18.3	10/25/78	93
209		4934550	415000	12.6	285	T2	18.3	10/25/78	58
210		4934100	414900	13.1	285	T2	18.3	10/25/78	58
211		4933500	414850	13.6	285	T2	6.1	10/25/78	35
212	LOST CREEK?	4933100	414300	14.1	285	T2	18.3	10/25/78	52
213		4932600	414750	14.6	285	T2	6.1	10/25/78	58
214		4932150	414700	15.1	285	T2	6.1	10/25/78	76
215		4931600	414650	15.6	285	T2	18.3	10/25/78	58
216		4931050	414650	16.1	285	T1	6.1	10/25/78	93
217		4930550	414650	16.6	258	T1	6.1	10/25/78	203
218		4930000	414500	17.1	286	T2	30.5	10/25/78	139
219		4929550	414400	17.6	282	T2	18.3	10/25/78	99
220		4929100	414250	18.1	283	T2	18.3	10/25/78	70
221	SEAL ROCKS	4928600	414150	18.6	280	T2	18.3	10/25/78	46
222		4928000	414050	19.1	283	T2	18.3	10/25/78	52
223		4927800	413850	19.6	282	T2	18.3	10/25/78	23
224	Seal Rock N. Headland								
225		4927250	413850			T2	6.1	10/25/78	0
226		4927000	413900			T2	6.1	10/25/78	29
227		4926700	413900			T2	6.1	10/25/78	0
228		4926450	413850			T2	6.1	10/25/78	0
229	Seal Rock S. Headland								
230									
231									
232	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
233							6.1		
234	Otter Point	4702000	382800			T2	6.1		0
235		4701700	383100	0.1	273	T2	42.7	4/2/80	35
236		4701350	382900	0.6	315	T2	30.5	4/2/80	104
237	OTTER POINT	4700950	382700	1.1	300	T1D	6.1	4/2/80	104
238		4700500	382500	1.6	300	T1D	6.1	4/2/80	81
239		4700250	382300	2.1	300	T1D	6.1	4/2/80	116
240	HIGH TIDE	4699700	382100	2.6	300	T1D	6.1	4/2/80	70
241		4699200	382000	3.1	265	T1D	6.1	4/2/80	35
242	REDHOUSE	4698700	382100	3.6	260	T1D	6.1	4/2/80	35
243		4698300	382100	4.1	260	T1D	6.1	4/2/80	23
244		4697750	382350	4.6	260	T1D	6.1	4/2/80	35
245		4697300	382300	5.1				4/2/80	-
246		4696800	382500	5.6	250	T1D		4/2/80	23
247		4696350	382600	6.1	255	T1D		4/2/80	58
248	GOLD BEACH	4695900	382650	6.6	263	T1D		4/2/80	81
249		4695500	382650	7.1	268	T1D		4/2/80	87
250		4694900	382700	7.6	270	T1D	6.1	12/8/79	87
251	HUNTERS CREEK	4694300	382750	8.1	270	T1D	24.4	12/8/79	81
252		4693700	382750	8.6	274	T1D		12/8/79	110

	A	B	C	D	E	F	G	H	I
253	BIG ROCK	4693400	382700	9.1	274	T1D		12/8/79	81
254		4692600	382700	9.6	274	T1D		12/8/79	70
255		4692100	382700	10.1	274	T1D		12/8/79	70
256		4691400	382650	10.6	275	T1D		12/8/79	46
257	BOOMER ROAD	4691100	382700	11.1	275	T1D		12/8/79	70
258		4690600	382650	11.6	275	U2		12/8/79	93
259		4690250	382650	12.1	275	U2		12/8/79	139
260		4689700	382600	12.6	275	T1D		12/8/79	58
261		4689150	382550	13.1	275	U2		12/8/79	81
262		4688650	382500	13.6	275	T1D		12/8/79	52
263	Cape Sebastian								
264		4688150	382450			U2		12/8/79	0
265		4687600	382350			U2		12/8/79	0
266									
267									
268	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
269									
270		4622150	400000		225	T1D	6.1	5/5/78	35
271		4621950	400300		302	T2	6.1	5/5/78	35
272									
273		4621950	402250	0.1	193	T1	6.1	5/5/78	70
274		4621800	402650	0.6	204	T1D	6.1	5/5/78	58
275	CRESCENT CITY N.	4621500	403150	1.1	225	T1D	6.1	5/5/78	46
276		4621200	403450	1.6	225	T1D	6.1	5/5/78	93
277		4620850	403700	2.1	240	T1D	6.1	5/5/78	46
278	DEAD DOG	4620450	403900	2.6	240	T1D	6.1	5/5/78	33
279	CRESCENT CITY	4619950	404150	3.1	240	T1D	6.1	5/5/78	46
280		4619550	404350	3.6	245	T1D	6.1	5/5/78	41
281		4619200	404550	4.1	245	T1D	6.1	5/5/78	41
282	CRESCENT CITY S.	4618700	404750	4.6	250	T1	6.1	5/5/78	29
283		4618400	404850	5.1	250	T2	18.3	5/5/78	58
284		4617800	404900			U2		5/5/78	0
285									
286	Del Norte	4617400	405000		278	U2		5/5/78	6
287		4616950	405100		255	U2		5/5/78	29
288									
289	Feature Name	UTM N/S	UTM E/W	Distance NH	Orientation	Platform	Ter. Ht.	Flight B	Bch. W. B
290									
291		4544100	405700			T2	73.2	5/5/78	0
292	Jepona Pt.	4543600	405750			T2	73.2	5/5/78	0
293		4543100	405900		273	T2	73.2	5/5/78	52
294		4542700	406200			U2		5/5/78	0
295		4542500	406500	0.3	252	T2	42.7	5/5/78	70
296		4542000	406600	0.8	272	T1D		5/5/78	81
297	MOONSTONE	4541500	406550	1.3	275	T1D		5/5/78	93
298		4540950	406450	1.8	275	T1D		5/5/78	110
299		4540450	406400	2.3	275	T1D	12.2	5/5/78	116
300		4539900	406300	2.8	275	T1D	12.2	5/5/78	139
301		4539450	406200	3.3	275	T1D	12.2	5/5/78	116
302		4538950	406200	3.8	274	T1D	12.2	5/5/78	134
303	CLAM BEACH	4538450	406100	4.3	275	T1D	12.2	5/5/78	238
304		4537950	406000	4.8	280	T1D	12.2	5/5/78	128
305		4537500	405900	5.3	281	T1D	12.2	5/5/78	104
306		4537100	405750	5.8	281	T1D	12.2	5/5/78	70
307		4536700	405650	6.3	281	T1D		5/5/78	81
308		4536300	405550	6.8	281	T1D		5/5/78	93
309		4535900	405450	7.3	281	T1D		5/5/78	81
310		4535300	405250	7.8	280	T1D		5/5/78	35
311	Mad River								
312		4534900	405200	8.3	281	T1D		5/5/78	70
313		4534300	405100	8.8	280	T1D		5/5/78	35
314		4533900	404900	9.3	281	T1D		5/5/78	35
315		4533500	404800	9.8	282	T1D		5/5/78	52

	A	B	C	D	E	F	G	H	I
316		4532950	404750	10.3	282	T1D		5/5/78	46
317		4532500	404600	10.8	283	T1D		5/5/78	46
318		4532100	404500	11.3	283	T1D		5/5/78	58
319		4531600	404400	11.8	280	T1D		5/5/78	87
320	MAD RIVER	4531200	404300	12.3	282	T1D		5/5/78	70
321		4530700	404200	12.8	283	T1D		5/5/78	46
322		4530250	404050	13.3	284	T1D		5/5/78	58
323		4529750	403900	13.8	284	T1D		5/5/78	70
324		4529350	403800	14.3	285	T1D		5/5/78	46
325		4528900	403700	14.8	284	T1D		5/5/78	70
326		4528550	403600	15.3	284	T1D		5/5/78	64
327		4528150	403400	15.8	286	T1D		5/5/78	58
328		4527750	403300	16.3	288	T1D		5/5/78	64
329		4527300	403150	16.8	287	T1D		5/5/78	64
330		4526800	403000	17.3	285	T1D		5/5/78	93
331		4526350	402800	17.8	287	T1D		5/5/78	70
332		4525950	402600	18.3	285	T1D		5/5/78	93
333		4525450	402450	18.8	292	T1D		5/5/78	64
334		4525000	402000	19.3	292	T1D		5/5/78	46
335		4524650	401850	19.8	292	T1D		5/5/78	58
336		4524250	401650	20.3	293	T1D		5/5/78	70
337		4523750	401500	20.8	292	T1D		5/5/78	93
338		4523250	401300	21.3	292	T1D		5/5/78	46
339		4522750	401150	21.8	293	T1D		5/5/78	76
340	MANILA	4522250	401000	22.3	293	T1D		5/5/78	52
341		4521850	400850	22.8	295	T1D		5/5/78	41
342		4521400	400650	23.3	295	T1D		5/5/78	35
343		4521000	400500	23.8	295	T1D		5/5/78	29
344		4520600	400300	24.3	295	T1D		5/5/78	81
345		4520100	400150	24.8	296	T1D		5/5/78	139
346		4519650	400000	25.3	297	T1D		5/5/78	145
347		4519250	399850	25.8	298	T1D		5/5/78	46
348		4518800	399700	26.3	298	T1D		5/5/78	93
349		4518400	399500	26.8	297	T1D		5/5/78	70
350		4518000	399350	27.3	298	T1D		5/5/78	70
351		4517650	399200	27.8	298	T1D		5/5/78	87
352	SAMOA	4517250	399000	28.3	297	T1D		5/5/78	81
353		4516750	398850	28.8	298	T1D		5/5/78	81
354		4516350	398700	29.3	298	T1D		5/5/78	70
355		4515850	398500	29.8	299	T1D		5/5/78	104
356		4515400	398350	30.3	298	T1D		5/5/78	81
357		4515000	398200	30.8	300	T1D		5/5/78	46
358		4514600	397900	31.3	297	T1D		5/5/78	116
359		4514200	397600	31.8	298	T1D		5/5/78	46
360	N. JETTY	4513800	397300	32.3	298	T1D		5/5/78	35
361		4513300	397000	32.8	298	T1D		5/5/78	93
362		4512900	396700	33.3	324	T1D		5/5/78	64
363	Humbolt Bay	4512500	396400	33.8		T1D		5/5/78	
364		4512100	395900	34.3	295	T1D		5/5/78	246
365	S. JETTY	4511700	395600	34.8	295	T1D		5/5/78	93
366		4511200	395300	35.3	296	T1D		5/5/78	104
367		4510800	395100	35.8	296	T1D		5/5/78	70
368		4510300	394900	36.3	296	T1D		5/5/78	52
369		4509800	394600	36.8	296	T1D		5/5/78	87
370		4509400	394400	37.3	300	T1D		5/5/78	46
371		4509100	394200	37.8	300	T1D		5/5/78	70
372		4508700	394000	38.3	300	T1D		5/5/78	76
373		4508350	393850	38.8	300	T1D		5/5/78	104
374		4507950	393600	39.3	300	T1D		5/5/78	110
375		4507500	393400	39.8	300	T1D		5/5/78	70
376		4507050	393100	40.3	300	T1D		5/5/78	70
377		4506600	392850	40.8	300	T1D		5/5/78	70
378		4506200	392600	41.3	300	T1D		5/5/78	58

	A	B	C	D	E	F	G	H	I
379	TABLE BLUFF	4505800	392300	41.8	300	T1D		5/5/78	70
380		4505300	392000	42.3	300	T1D		5/5/78	76
381		4504850	391700	42.8	300	T1D		5/5/78	58
382		4504400	391500	43.3	300	T1D		5/5/78	93
383		4503900	391200	43.8	300	T1D		5/5/78	35
384		4503500	391000	44.3	297	T1D		5/5/78	64
385		4503100	390800	44.8	297	T1D		5/5/78	52
386		4502700	390600	45.3	297	T1D		5/5/78	104
387		4502300	390400	45.8	296	T1D		5/5/78	46
388		4501900	390200	46.3	296	T1D		5/5/78	70
389		4501500	390000	46.8	296	T1D		5/5/78	46
390	N. EEL RIVER	4501050	389800	47.3	296	T1D		5/5/78	35
391		4500700	389600	47.8	296	T1D		5/5/78	81
392		4500300	389400	48.3	296	T1D		5/5/78	18
393		4499750	389200	48.8	245	T1D		5/5/78	35
394		4499400	388900	49.3	296	T1D		5/5/78	
395		4499000	388700	49.8	296	T1D		5/5/78	139
396		4498500	388500	50.3	296	T1D		5/5/78	93
397		4498050	388250	50.8	296	T1D		5/5/78	81
398		4497550	388100	51.3	296	T1D		5/5/78	87
399		4497200	387850	51.8	296	T1D		5/5/78	87
400		4496900	387700	52.3	296	T1D		5/5/78	70
401		4496500	387500	52.8	296	T1D		5/5/78	70
402		4496000	387300	53.3	296	T1D		5/5/78	70
403		4495550	387050	53.8	292	T1D		5/5/78	46
404		4495100	386900	54.3	292	T1D		5/5/78	58
405		4494600	386700	54.8	292	T1D		5/5/78	81
406		4494250	386550	55.3	292	T1D		5/5/78	70
407		4493900	386400	55.8	292	T1D		5/5/78	70
408		4493400	386250	56.3	292	T1D		5/5/78	87
409	CENTERVILLE 2	4492950	386000	56.8	292	T1D		5/5/78	70
410		4492500	385850	57.3	292	T1D		5/5/78	70
411	CENTERVILLE 1	4491900	385650	57.8	292	T1D	18.3	5/5/78	76
412		4491400	385400	58.3	292	T2	54.9	5/5/78	64
413		4491000	385200	58.8	292	T2	73.2	5/5/78	46
414		4490650	385100	59.3	290	U2		5/5/78	46
415		4490250	384950	59.8	290	U2		5/5/78	46
416		4489900	384800	60.3	290	U2		5/5/78	35
417		4489550	384700	60.8	290	U2		5/5/78	35
418		4489100	384550	61.3	290	U2		5/5/78	23
419		4488600	384350	61.8	292	U2		5/5/78	104
420		4488300	384150	62.3	292	U2		5/5/78	6
421		4487850	384000	62.8	292	U2		5/5/78	23
422		4487450	383800	63.3	297	U2		5/5/78	0
423		4487000	383500	63.8	297	U2		5/5/78	23
424		4486600	383300	64.3	300	U2		5/5/78	12
425		4486200	383000	64.8	300	U2		5/5/78	0
426		4485700	382850	65.3	282	U2		5/5/78	12
427	False Cape	4485250	382650		297	U2		5/5/78	0

	J	K	L	M	N	O	P	Q
1								
2								
3	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
4								
5	7/2/85	0						
6	7/2/85	0						
7	7/2/85	0						
8	7/2/85	35						
9	7/2/85	46				North Rialto(Ellen Creek)	125	0.727
10	7/2/85	46						
11	7/2/85	35				LaPush North(S. Rialto)	116	0.753
12	7/2/85	35						
13	7/2/85	18						
14	7/2/85	18						
15								
16	7/2/85	46			93	LaPush South	115	0.164
17	7/2/85	58			56	First Beach	126	0.157
18	7/2/85	52			35			
19	7/2/85	0						
20								
21								
22	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
23								
24	6/26/85	0						
25	6/26/85	0						
26								
27	6/26/85	81						
28	6/26/85	35						
29	6/26/85	0						
30	6/26/85	41						
31	6/26/85	35			58			
32	6/26/85	23			46			
33	6/26/85	81						
34	6/26/85	93						
35	6/26/85	93						
36	6/26/85	58						
37	6/26/85	58						
38	6/26/85	81						
39	6/26/85	58						
40								
41	6/26/85	116						
42								
43	6/26/85	104			6	Ruby Beach	119	1.729
44	6/26/85	29						
45	6/26/85	104						
46	6/26/85	46						
47	6/26/85	104						
48	6/26/85	128						
49	6/26/85	116						
50	6/26/85	185						
51	6/26/85	139						
52	6/26/85	116						
53	6/26/85	139						
54	6/26/85	58						
55	6/26/85	70						
56	6/26/85	41						
57	6/26/85	81				Beach #4	114	0.79
58	6/26/85	58						
59	6/26/85	70						
60	6/26/85	116						
61								
62	6/26/85	139			23	South Brown 's Point	118	0.122
63	6/26/85	139			12			

	J	K	L	M	N	O	P	Q
64	6/26/85	174						
65	6/26/85	185						
66	6/26/85	197						
67	6/26/85	203				Kalaloch Beach	117	0.13
68	6/26/85	255						
69	6/26/85	267						
70	6/26/85	185						
71	6/26/85	128						
72	6/26/85	151						
73	6/26/85	209						
74	6/26/85	151						
75	6/26/85	157			6			
76	6/26/85	174			12			
77	6/26/85	93			18	South Beach	113	0.158
78	6/26/85	70			12			
79	6/26/85	46			35			
80	6/26/85	162			70			
81	6/26/85							
82	6/26/85	151			81			
83	6/26/85	70			81			
84	6/26/85	104			151			
85	6/26/85	151						
86	6/26/85	58						
87	6/26/85	139						
88	6/26/85	128						
89	6/26/85	70						
90	6/26/85	87						
91	6/26/85	93						
92	6/26/85	87						
93								
94					58			
95					12	Whale Creek	124	0.151
96								
97								
98								
99								
100								
101								
102					200			
103	6/26/85	116						
104	6/26/85	104						
105	6/26/85	46						
106								
107	6/26/85	81						
108	6/26/85	58						
109	6/26/85	58				Little Hogsback Beach	121	0.14
110	6/26/85	64						
111	6/26/85	81						
112	6/26/85	70						
113	6/26/85	76						
114	6/26/85	35						
115	6/26/85	87						
116	6/26/85	0						
117	6/26/85	0						
118								
119								
120								
121	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
122								
123	1/13/84	0	3/10/89	0				
124	1/13/84	302	3/10/89	171		Chapman Beach	97	0.166
125	1/13/84	313	3/10/89	171				
126								

	J	K	L	M	N	O	P	Q
127	1/13/84	267	3/10/89	164				
128	1/13/84	267	3/10/89	181				
129	1/13/84	244	3/10/89	150				
130	1/13/84	209	3/10/89	161				
131	1/13/84	174	3/10/89	113				
132	1/13/84	220	3/10/89	130				
133	1/13/84	104	3/10/89	137		Tolovana Beach	93	0.166
134	1/13/84	151	3/10/89	133				
135	3/3/84	93	3/10/89	123				
136	3/3/84	23	3/10/89	55				
137	3/3/84	35	3/10/89	123				
138	1/13/84	128	3/10/89	75				
139								
140	1/13/84	168	3/10/89	109		Arcadia Beach	92	0.187
141	1/13/84	209	3/10/89	92				
142	1/13/84	185	3/10/89	127				
143	1/13/84	116	3/10/89	92				
144	1/13/84	128	3/10/89	127				
145	1/13/84	104	3/10/89	79				
146	1/13/84	99	3/10/89	82				
147	1/13/84	99	3/10/89	92		North Arch Cape Beach	88b	0.187
148	1/13/84	93	3/10/89	68				
149	1/13/84	128	3/10/89	65				
150	1/13/84	0						
151	1/13/84	46	3/10/89	21				
152	1/13/84	23	3/10/89	44				
153	1/13/84	29	3/10/89	24				
154	1/13/84	46	3/10/89	44		Cove Beach	99	0.152
155	1/13/84	0	3/10/89	0				
156								
157	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
158								
159	3/3/84	0						
160	3/3/84	23						
161	3/3/84	29	8/7/89	51				
162	3/3/84	46	8/7/89	54		Otter Rock Beach	79	0.189
163	3/3/84	70	8/7/89	60				
164	3/3/84	81	8/7/89	90				
165	3/3/84	52	8/7/89	66		Beverly Beach	77	0.232
166	3/3/84	41	8/7/89	60				
167	3/3/84	46	8/7/89	78				
168	3/3/84	58	8/7/89	66				
169	3/3/84	0	8/7/89	42				
170	3/3/84	46	8/7/89	60		Moolack	76	0.232
171	3/3/84	46				Moolack Beach	76	0.232
172	3/3/84	35	8/7/89	69				
173	3/3/84	29	8/7/89	48				
174	3/3/84	18	8/7/89	54				
175	3/3/84	18	8/7/89	48				
176	3/3/84	18	8/7/89	18		58 th. Street Beach	78	0.275
177	3/3/84	12	8/7/89	6				
178	3/3/84	0	8/7/89	0				
179	3/3/84	0	8/7/89	0				
180	3/3/84	0	8/7/89	0				
181	3/3/84	0	8/7/89	0				
182								
183	3/3/84	35	8/7/89	93		Agate Beach Cove	63	0.122
184	3/3/84	104	8/7/89	126				
185	3/3/84	139	8/7/89	132				
186	3/3/84	151	8/7/89	150		Agate Beach Wayside	64	0.147
187	3/3/84	93	8/7/89	108				
188	3/3/84	64	8/7/89	108				
189	3/3/84	23	8/7/89	39				

	J	K	L	M	N	O	P	Q
190	3/3/84	58	8/7/89	84		Nye Beach	65	0.151
191	3/3/84	23	8/7/89	42				
192	3/3/84	104	8/7/89	96				
193	3/3/84	52	8/7/89	99				
194	3/3/84	116	8/7/89	180	104			
195								
196								
197								
198	3/3/84	162	8/7/89	144	200			
199	3/3/84	104	8/7/89	120	200			
200	3/3/84	128	8/7/89	111	200	South Beach	66	0.147
201	3/3/84	139	8/7/89	75	200			
202	3/3/84	93	8/7/89	159				
203	3/3/84	35	8/7/89	99				
204	3/3/84	58	8/7/89	111				
205	3/3/84	70	8/7/89	105		Holiday Beach	69	0.17
206	3/3/84	52	8/7/89	96				
207	3/3/84	52	8/7/89	75				
208	3/3/84	35						
209	3/3/84	0						
210	3/3/84	41						
211	3/3/84	18						
212	3/3/84	46						
213	3/3/84	46				Ona Beach	67	0.151
214	3/3/84	35						
215	3/3/84	23						
216	3/3/84	18						
217	3/3/84	110						
218	3/3/84	29				Lost Creek Wayside	68	0.153
219	3/3/84	46						
220	3/3/84	58						
221	3/3/84	35				Seal Rocks Beach	70	0.153
222	3/3/84	41						
223	3/3/84	23						
224								
225	3/3/84	12						
226	3/3/84	35						
227	3/3/84	0						
228	3/3/84	0						
229								
230								
231								
232	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
233								
234								
235			8/7/89	101				
236			8/7/89	154				
237			8/7/89	113	46	Otter Point Beach	43	0.18
238			8/7/89	81	35			
239			8/7/89	142	81			
240			8/7/89	81		High Tide Beach	42	0.177
241			8/7/89	101				
242			8/7/89	138	116	Red House Beach	44	0.204
243			8/7/89	101	151			
244			8/7/89	65	200			
245			8/7/89	0				
246			8/7/89	65	200			
247			8/7/89	101	151			
248			8/7/89	97	93	Gold Beach Fairgrounds	45a	0.325
249			8/7/89	113	116			
250			8/7/89	146	116			
251			8/7/89	186	104	Hunters Creek	30	0.358
252			8/7/89	186	58			

	J	K	L	M	N	O	P	Q
253			8/7/89	122	29	Big Rock Beach	45b	0.379
254			8/7/89	97	93			
255			8/7/89	89	104			
256			8/7/89	73	70			
257			8/7/89	105	58	Boomer Road Beach	46	0.426
258			8/7/89	81				
259			8/7/89	105				
260			8/7/89	105	35			
261			8/7/89	89				
262			8/7/89	97	23			
263								
264								
265								
266								
267								
268	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
269								
270	4/19/86	46			23			
271	4/19/86	68						
272								
273	4/19/86	400						
274	4/19/86	162			12			
275	4/19/86	151			12	Crescent City North	38	0.121
276	4/19/86	162			12			
277	4/19/86	128			12			
278	4/19/86	116			12	Dead Dog Beach	40	0.12
279	4/19/86	104			12	Crescent City Beach	18	0.113
280	4/19/86	116			12			
281	4/19/86	104			6			
282	4/19/86	58				Crescent City South	39	0.134
283	4/19/86	122						
284	4/19/86	0						
285								
286	4/19/86	23						
287	4/19/86	41				Enderts Beach	17	0.48
288								
289	Flight A	Bch. W. A	Flight P	Bch. W. P	Dune W. B	Profile Name	Beach #	Mean Size
290								
291	4/19/86	0						
292	6/19/86	0						
293	6/19/86	116						
294	6/19/86	0						
295	6/19/86	174						
296	6/19/86	0			200	Moonstone Beach	11a	0.12
297	6/19/86	417			200			
298	6/19/86	522			200			
299	6/19/86	267			185			
300	6/19/86	232			116			
301	6/19/86	185			116			
302	6/19/86	209			174			
303	6/19/86	336			46	Clam Beach	10	0.133
304	6/19/86	174			139			
305	6/19/86	174			174			
306	6/19/86	139			197			
307	6/19/86	104			200			
308	6/19/86	230			200			
309					200			
310					200			
311								
312	6/19/86	87			139			
313	6/19/86	93			185			
314	6/19/86	70			185			
315	6/19/86	70			174			

	J	K	L	M	N	O	P	Q
316	6/19/86	70			185			
317	6/19/86	58			162			
318	6/19/86	58			174			
319	4/19/86	70			200			
320	4/19/86	128			200	Mad River Beach	9	0.162
321	4/19/86	93			200			
322	4/19/86	93			200			
323	4/19/86	93			200			
324	4/19/86	70			200			
325	4/19/86	104			200			
326	4/19/86	128			200			
327	4/19/86	116			200			
328	4/19/86	139			200			
329	4/19/86	128			200			
330	4/19/86	87			200			
331	4/19/86	128			200			
332	4/19/86	128			200			
333	4/19/86	162			200			
334	4/19/86	81			200			
335	4/19/86	122			200			
336	4/19/86	128			200			
337	4/19/86	122			200			
338	4/19/86	116			200			
339	4/19/86	128			200			
340	4/19/86	139			200	Manila	8	0.183
341	4/19/86	209			200			
342	4/19/86	139			200			
343	4/19/86	197			200			
344	4/19/86	139			200			
345	4/19/86	174			200			
346	4/19/86	116			200			
347	4/19/86	139			200			
348	4/19/86	139			200			
349	4/19/86	93			200			
350	4/19/86	116			200			
351	4/19/86	99			200			
352	4/19/86	116			200	Samoa	7	0.248
353	4/19/86	93			200			
354	4/19/86	70			200			
355	4/19/86	81			200			
356	4/19/86	81			200			
357	4/19/86	93			200			
358	4/19/86	58			200			
359	4/19/86	93			200			
360	4/19/86	58			200	North Jetty Humbolt	6	0.243
361	4/19/86	87			200			
362	4/19/86	93			200			
363	4/19/86				200			
364	4/19/86	444			200			
365	4/19/86	262			200	South Jetty Humbolt	4	0.203
366	4/19/86	256			200			
367	4/19/86	174			200			
368	4/19/86	128			200			
369	4/19/86	139			200			
370	4/19/86	162			200			
371	4/19/86	174			200			
372	4/19/86	116			185			
373	4/19/86	139			200			
374	4/19/86	122			185			
375	4/19/86	139			200			
376	4/19/86	139			151			
377	4/19/86	104			174			
378	4/19/86	104			116			

	J	K	L	M	N	O	P	Q
379	4/19/86	104			70	Table Bluff	5	0.241
380	4/19/86	110			139			
381	4/19/86	93			134			
382	4/19/86	64			162			
383	4/19/86	110			139			
384	4/19/86	58			151			
385	4/19/86	81			128			
386	4/19/86	93			197			
387	4/19/86	81			200			
388	4/19/86	46			200			
389	4/19/86	70			185			
390	4/19/86	58			168	North Eel River Beach	3	0.312
391	4/19/86	93			185			
392	4/19/86	52			200			
393	4/19/86				200			
394	4/19/86							
395	4/19/86	93			104			
396	4/19/86	104			200			
397	4/19/86	116			174			
398	4/19/86	70			162			
399	4/19/86	70			139			
400	4/19/86	58			41			
401	4/19/86	64			200			
402	4/19/86	70			200			
403	4/19/86	93			185			
404	4/19/86	104			174			
405	4/19/86	99			185			
406	4/19/86	93			151			
407	4/19/86	70			128			
408	4/19/86	64			128			
409	4/19/86	52			128	Centerville Beach	2	0.595
410	4/19/86	70			122			
411	4/19/86	99			76	Centerville (backshore)	1	0.398
412	4/19/86	64						
413	4/19/86	0						
414	4/19/86	0						
415	4/19/86	0						
416	4/19/86	12						
417	4/19/86	12						
418	4/19/86	12						
419	4/19/86	58						
420	4/19/86	0						
421	4/19/86	6						
422	4/19/86	0						
423	4/19/86	6						
424	4/19/86	29						
425	4/19/86	0						
426	4/19/86	0						
427	4/19/86	6						

	R	S	T	U
1				
2				
3	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
4				
5				
6				
7				
8				
9	0.374			
10				
11	0.297			
12				
13				
14				
15				
16	0.79			
17	0.818			
18				
19				
20				
21				
22	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				
41				
42				
43	0.257			
44				
45				
46				
47				
48				
49				
50				
51				
52				
53				
54				
55				
56				
57	0.191	40a	0.143	0.785
58		40b	0.191	0.722
59				
60				
61				
62	0.785			
63				

	R	S	T	U
64				
65				
66				
67	0.824	41	0.248	0.412
68				
69				
70				
71				
72				
73				
74				
75				
76				
77	0.796	39	0.503	0.47
78				
79				
80				
81				
82				
83				
84				
85				
86				
87				
88				
89				
90				
91				
92				
93				
94				
95	0.774			
96				
97				
98				
99				
100				
101				
102				
103				
104				
105				
106				
107				
108				
109	0.807			
110				
111				
112				
113				
114				
115				
116				
117				
118				
119				
120				
121	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
122				
123				
124	0.841			
125				
126				

	R	S	T	U
127				
128				
129				
130				
131				
132				
133	0.779			
134				
135				
136				
137				
138				
139				
140	0.818	35	0.149	0.395
141				
142				
143				
144				
145				
146				
147	0.824	34	0.095	0.366
148				
149				
150				
151				
152				
153				
154	0.829	36	0.067	0.599
155				
156				
157	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
158				
159				
160				
161				
162	0.742			
163				
164				
165	0.785	27	0.203	0.818
166				
167				
168				
169				
170	0.28	26		
171	0.824	26		1
172				
173				
174				
175				
176	0.669	28a		1
177		28b	0.219	0.807
178				
179				
180				
181				
182				
183	0.829	15	0.082	0.441
184				
185				
186	0.801	16	0.065	0.387
187				
188				
189				

	R	S	T	U
190	0.812	17	0.164	0.732
191				
192				
193				
194				
195				
196				
197				
198				
199				
200	0.841			
201				
202				
203				
204				
205	0.812	20	0.222	0.727
206				
207				
208				
209				
210				
211				
212				
213	0.824	19	0.192	0.812
214				
215				
216				
217				
218	0.801	18	0.2	0.785
219				
220				
221	0.796	21	0.164	0.801
222				
223				
224				
225				
226				
227				
228				
229				
230				
231				
232	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
233				
234				
235				
236				
237	0.688	9b	0.184	0.599
238				
239				
240	0.779			
241				
242	0.737			
243				
244				
245				
246				
247				
248	0.642			
249				
250				
251	0.674			
252				

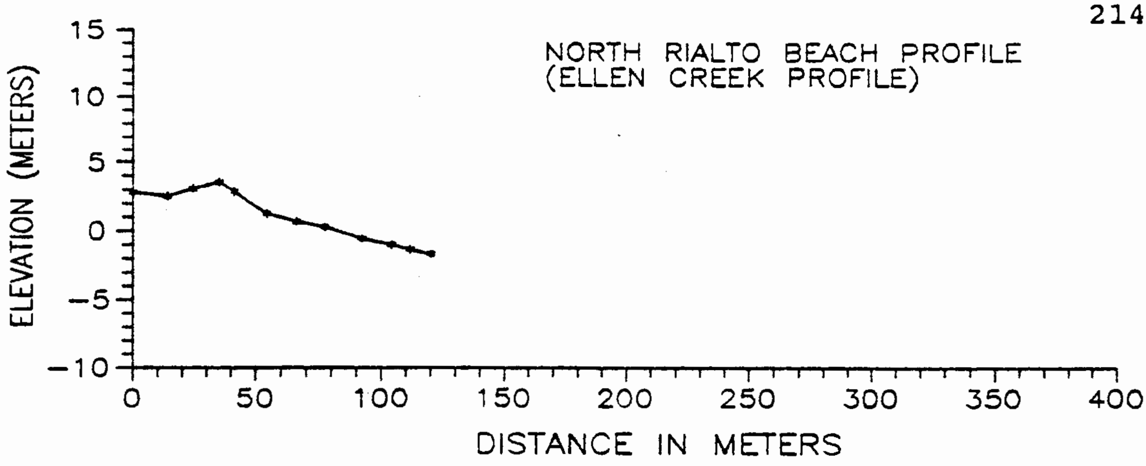
	R	S	T	U
253	0.702			
254				
255				
256				
257	0.693			
258				
259				
260				
261				
262				
263				
264				
265				
266				
267				
268	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
269				
270				
271				
272				
273				
274				
275	0.841			
276				
277				
278	0.818			
279	0.812			
280				
281				
282	10b	0.233	0.304	
283				
284				
285				
286				
287	0.616			
288				
289	Stand. Dev.	Terrace #	Mean Size	Stand. Dev.
290				
291				
292				
293				
294				
295				
296	0.763			
297				
298				
299				
300				
301				
302				
303	0.818			
304				
305				
306				
307				
308				
309				
310				
311				
312				
313				
314				
315				

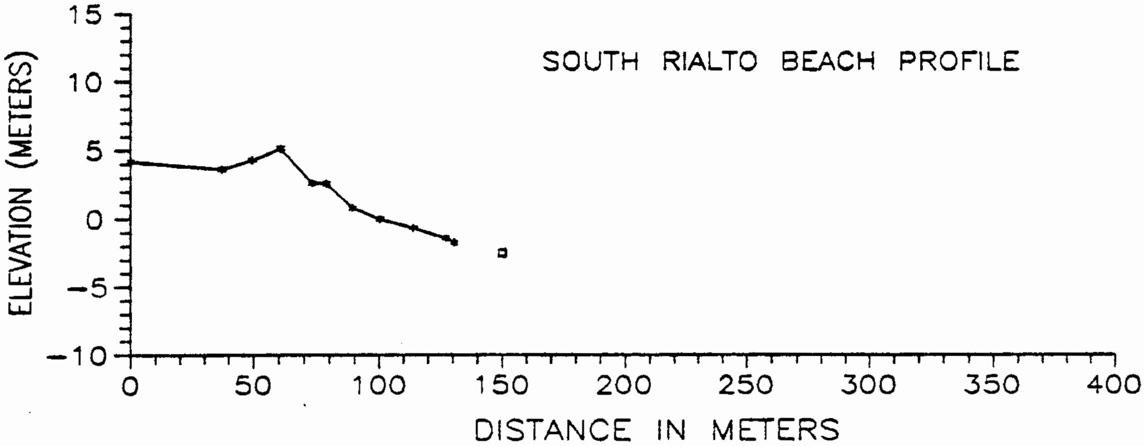
	R	S	T	U
316				
317				
318				
319				
320	0.774			
321				
322				
323				
324				
325				
326				
327				
328				
329				
330				
331				
332				
333				
334				
335				
336				
337				
338				
339				
340	0.779			
341				
342				
343				
344				
345				
346				
347				
348				
349				
350				
351				
352	0.801			
353				
354				
355				
356				
357				
358				
359				
360	0.768			
361				
362				
363				
364				
365	0.774			
366				
367				
368				
369				
370				
371				
372				
373				
374				
375				
376				
377				
378				

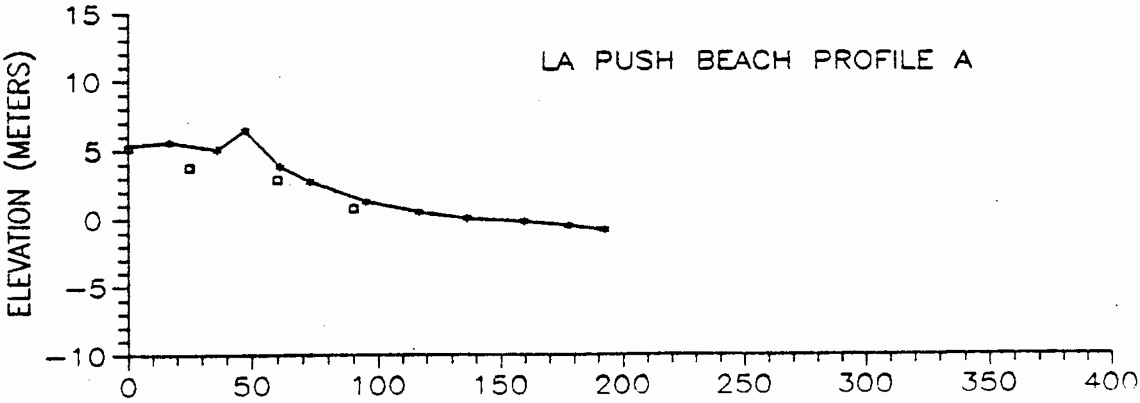
	R	S	T	U
379	0.79			
380				
381				
382				
383				
384				
385				
386				
387				
388				
389				
390	0.801			
391				
392				
393				
394				
395				
396				
397				
398				
399				
400				
401				
402				
403				
404				
405				
406				
407				
408				
409	0.664	1	0.245	0.559
410				
411	0.79			
412				
413				
414				
415				
416				
417				
418				
419				
420				
421				
422				
423				
424				
425				
426				
427				

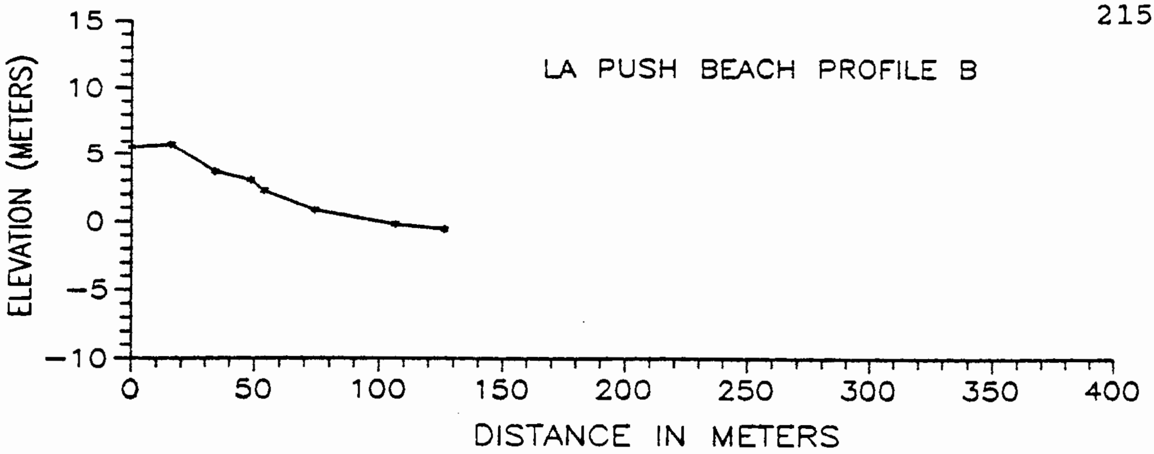
APPENDIX B

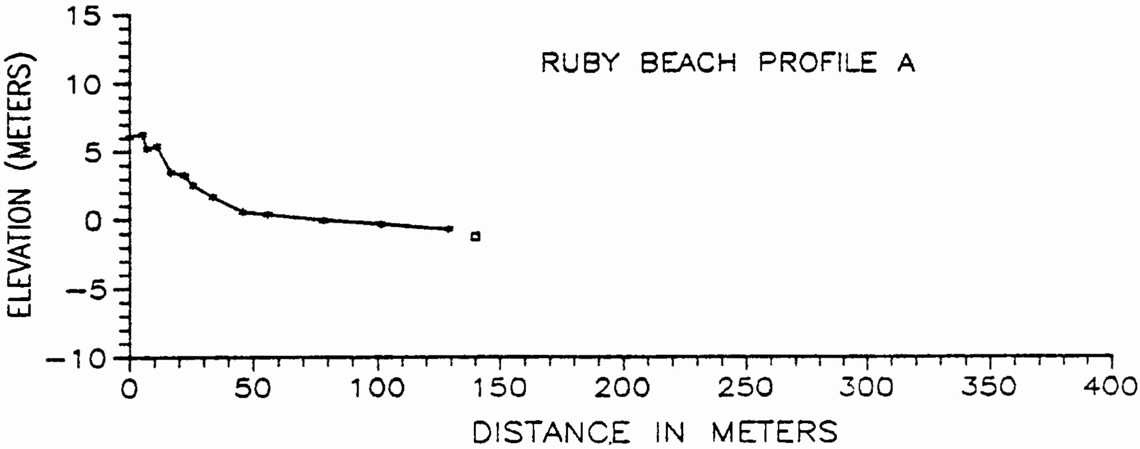
BEACH PROFILES FOR BEACHES IN SELECTED LITTORAL CELLS OF THE PNW

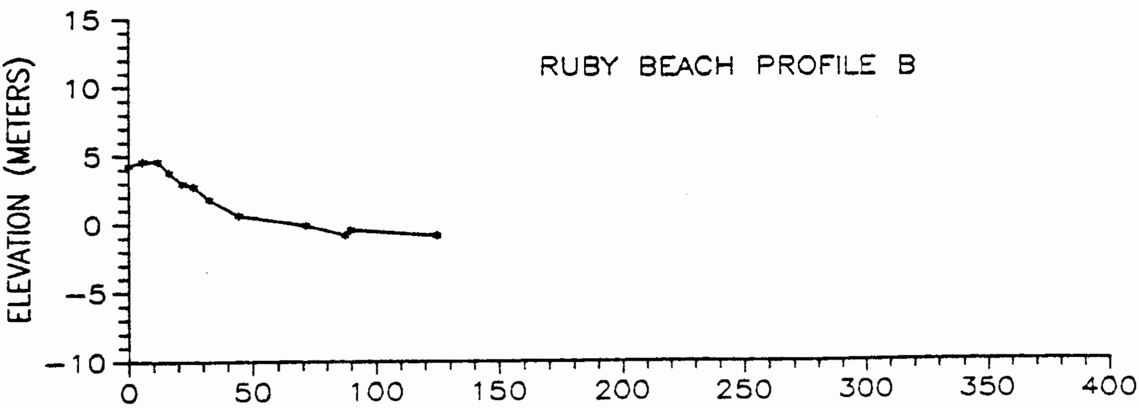

NORTH RIALTO BEACH PROFILE
(ELLEN CREEK PROFILE)
ELEVATION (METERS)
DISTANCE IN METERS
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400

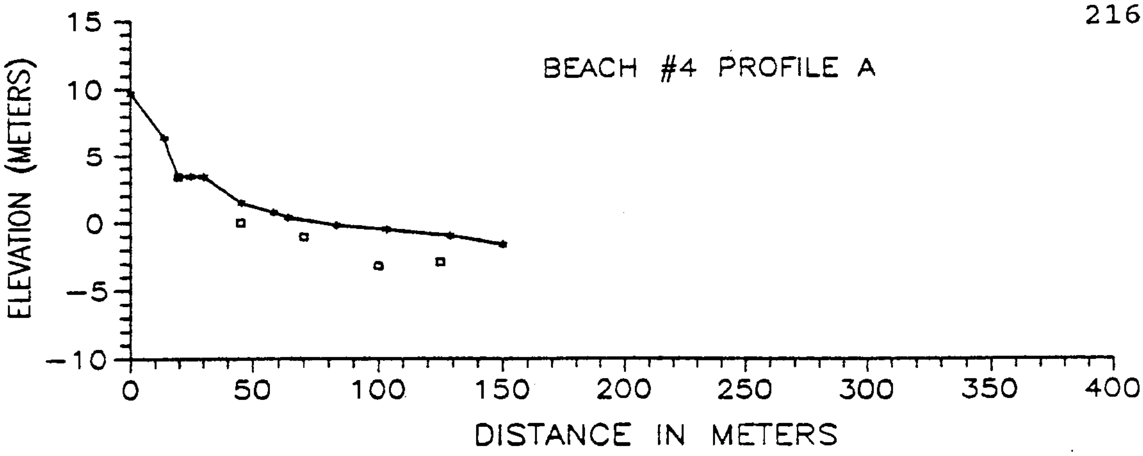

SOUTH RIALTO BEACH PROFILE
ELEVATION (METERS)
DISTANCE IN METERS
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400

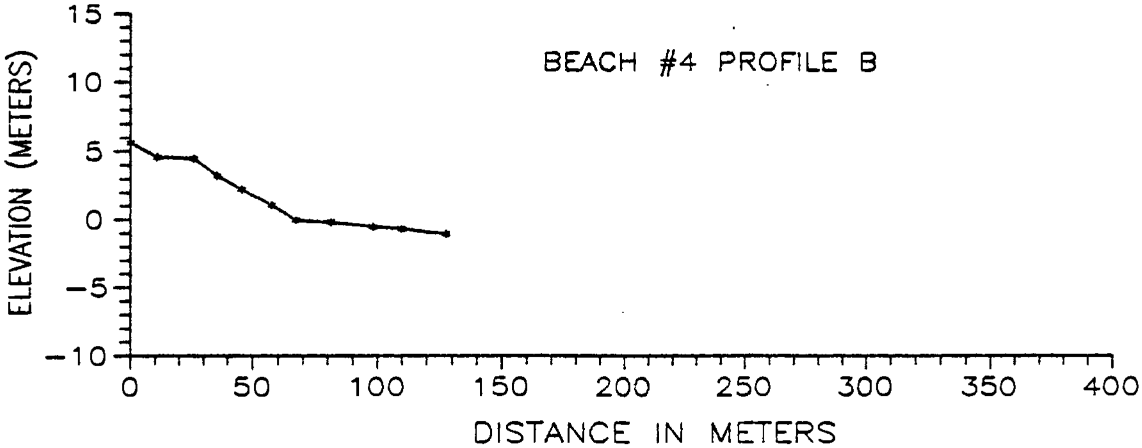

LA PUSH BEACH PROFILE A
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400


LA PUSH BEACH PROFILE B
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


RUBY BEACH PROFILE A
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


RUBY BEACH PROFILE B
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400


BEACH #4 PROFILE A
ELEVATION (METERS)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


BEACH #4 PROFILE B
ELEVATION (METERS)
15
10
5
0
-5
-10
0
50
100
150
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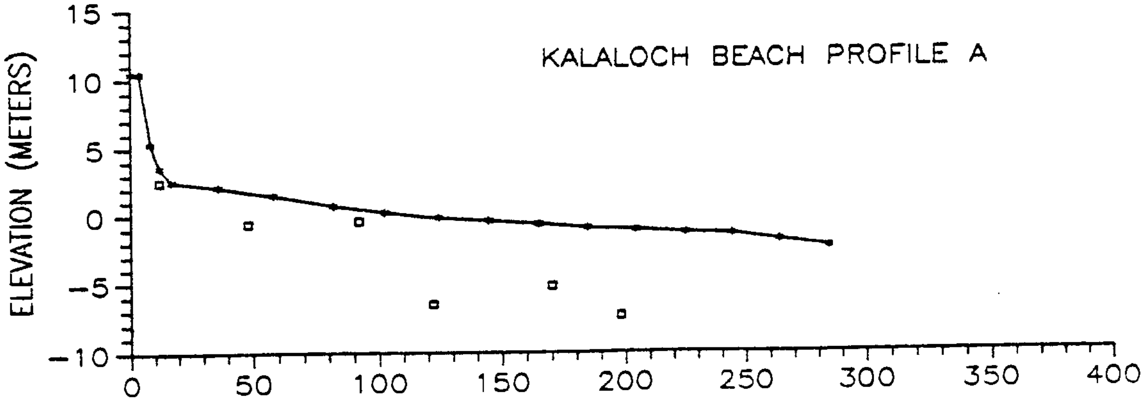
DISTANCE IN METERS


KALALOCH BEACH PROFILE A
ELEVATION (METERS)
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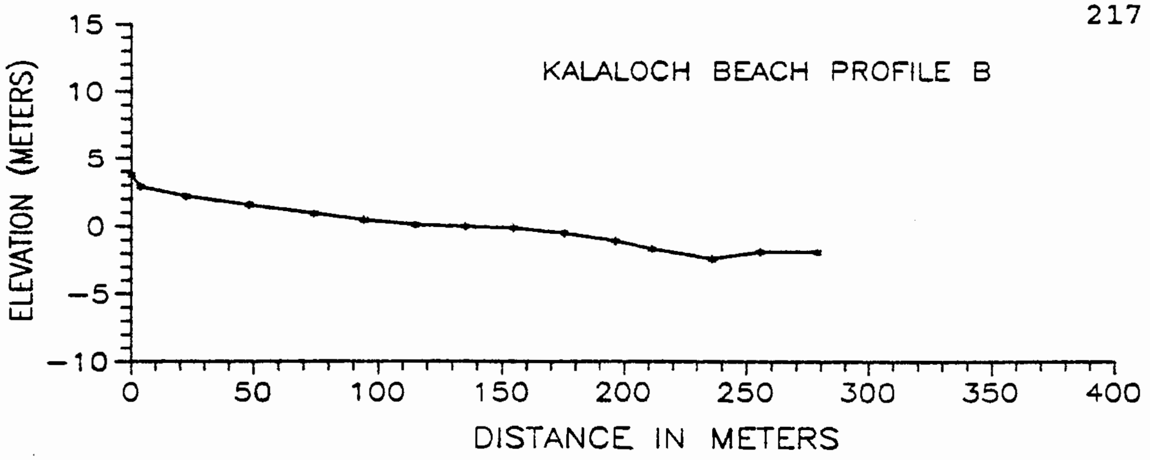
KALALOCH BEACH PROFILE B
ELEVATION (METERS)
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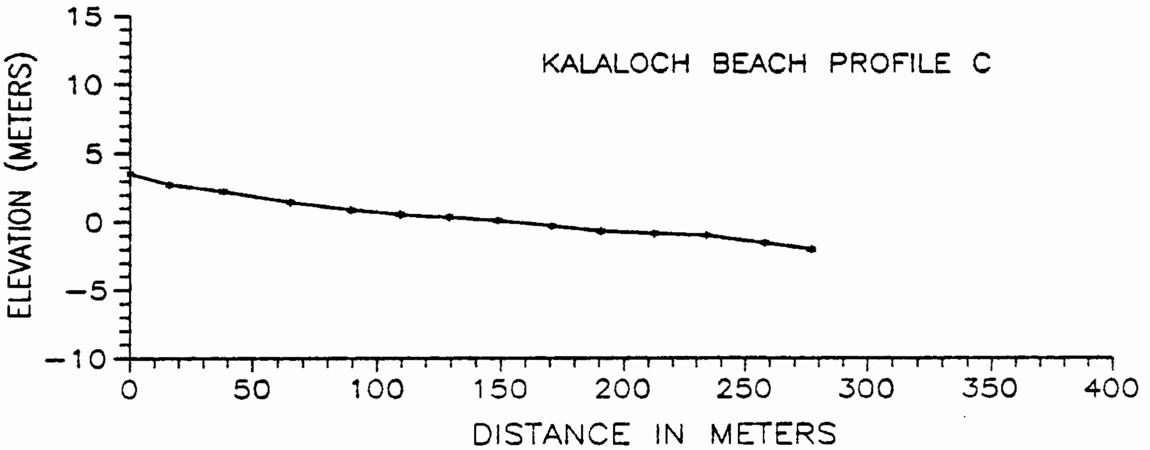
DISTANCE IN METERS


KALALOCH BEACH PROFILE C
ELEVATION (METERS)
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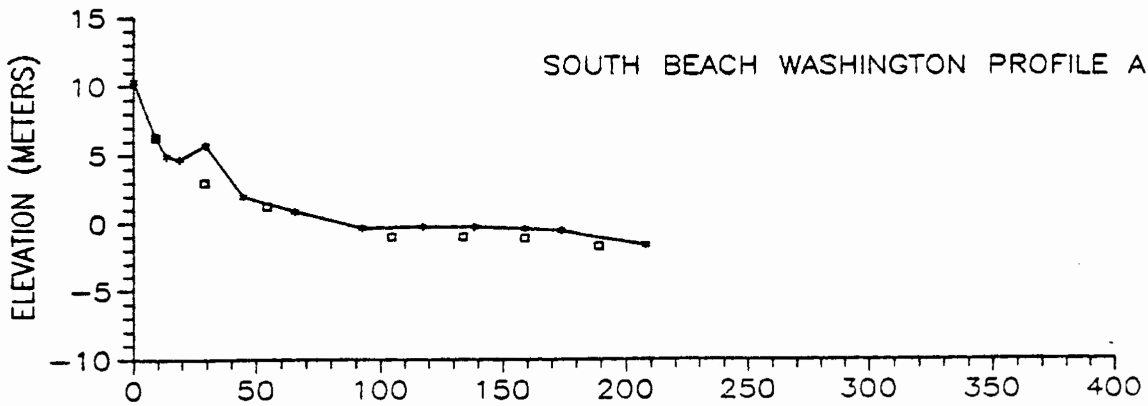
DISTANCE IN METERS


SOUTH BEACH WASHINGTON PROFILE A
ELEVATION (METERS)
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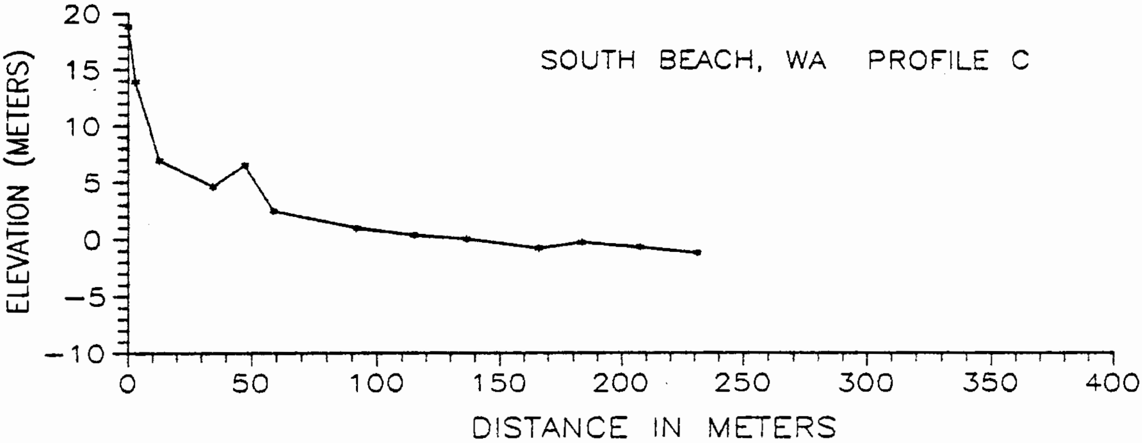

SOUTH BEACH, WA PROFILE C
ELEVATION (METERS)
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5
0
-5
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200
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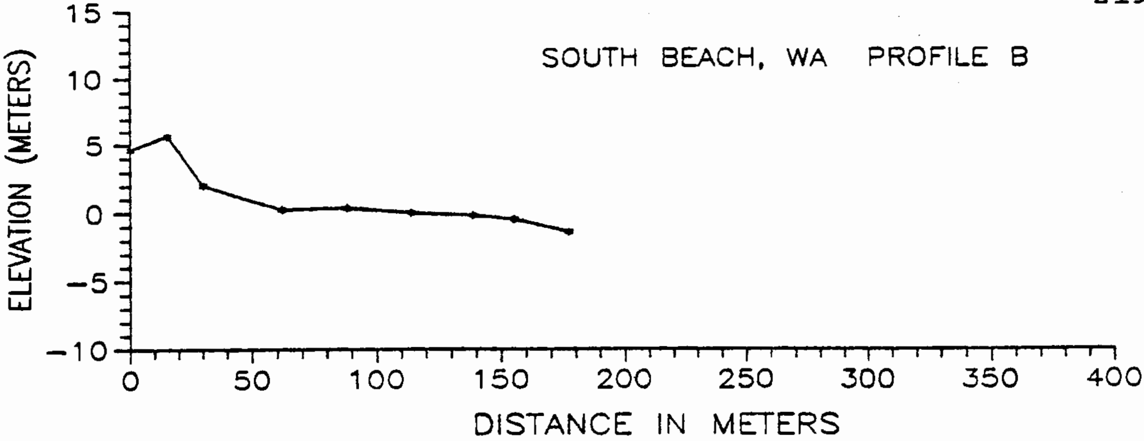
350
400
DISTANCE IN METERS


SOUTH BEACH, WA PROFILE B
ELEVATION (METERS)
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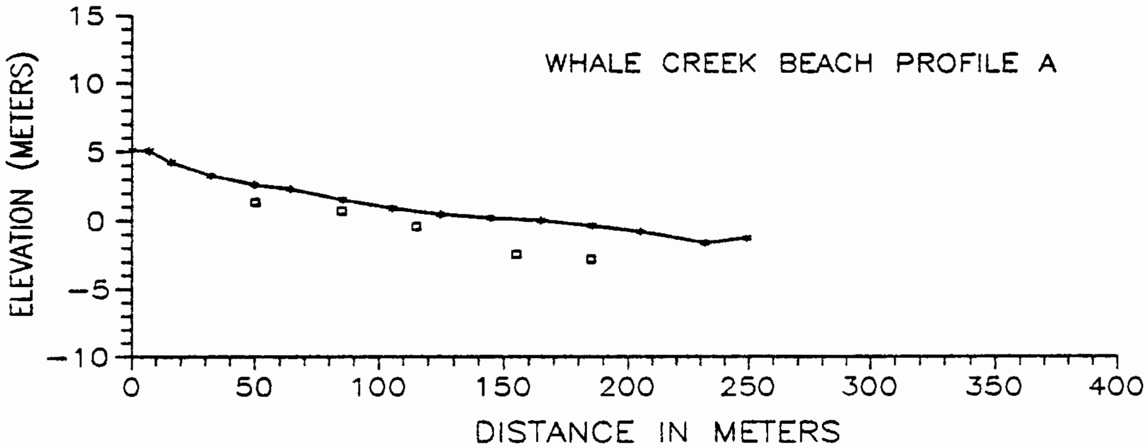
DISTANCE IN METERS


WHALE CREEK BEACH PROFILE A
ELEVATION (METERS)
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−10
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350
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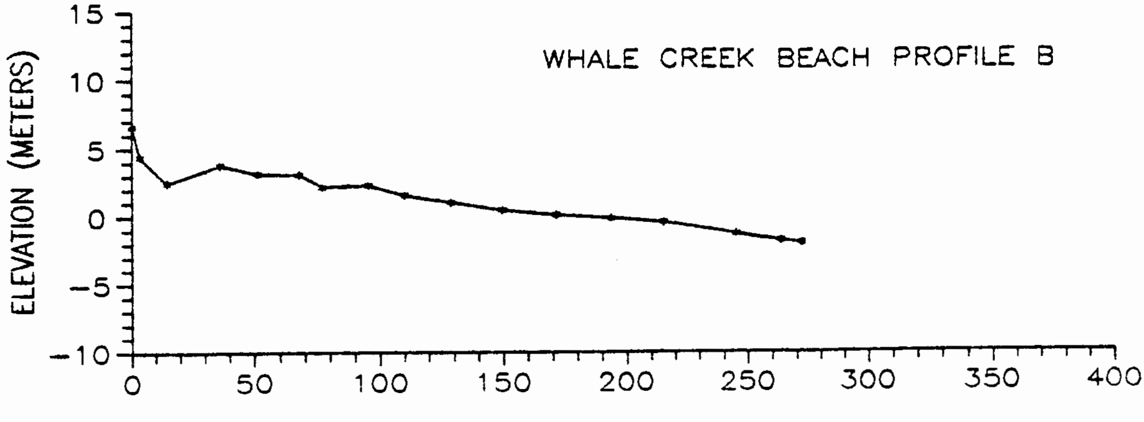
DISTANCE IN METERS


WHALE CREEK BEACH PROFILE B
ELEVATION (METERS)
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10
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−10
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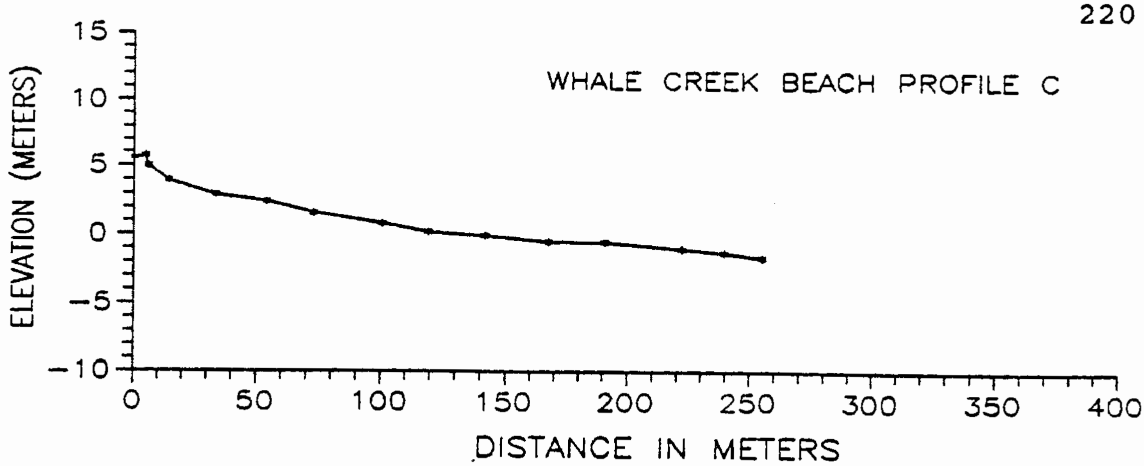
WHALE CREEK BEACH PROFILE C
ELEVATION (METERS)
15
10
5
0
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−10
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200
250
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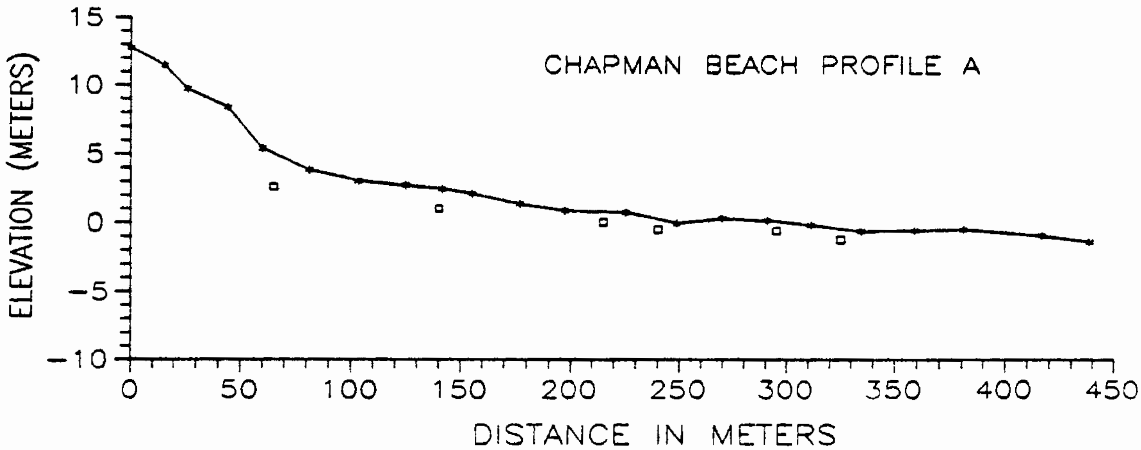
350
400
DISTANCE IN METERS


CHAPMAN BEACH PROFILE A
ELEVATION (METERS)
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−5
−10
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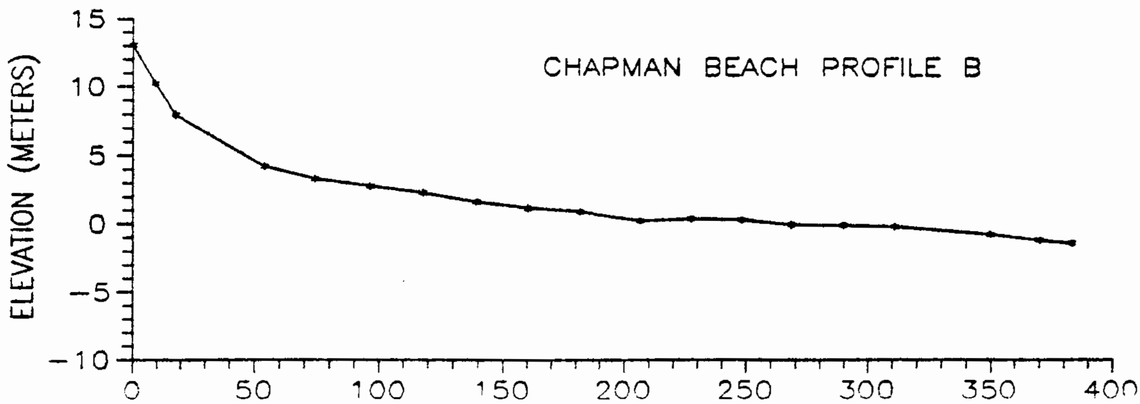
400
450
DISTANCE IN METERS


CHAPMAN BEACH PROFILE B
ELEVATION (METERS)
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10
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350
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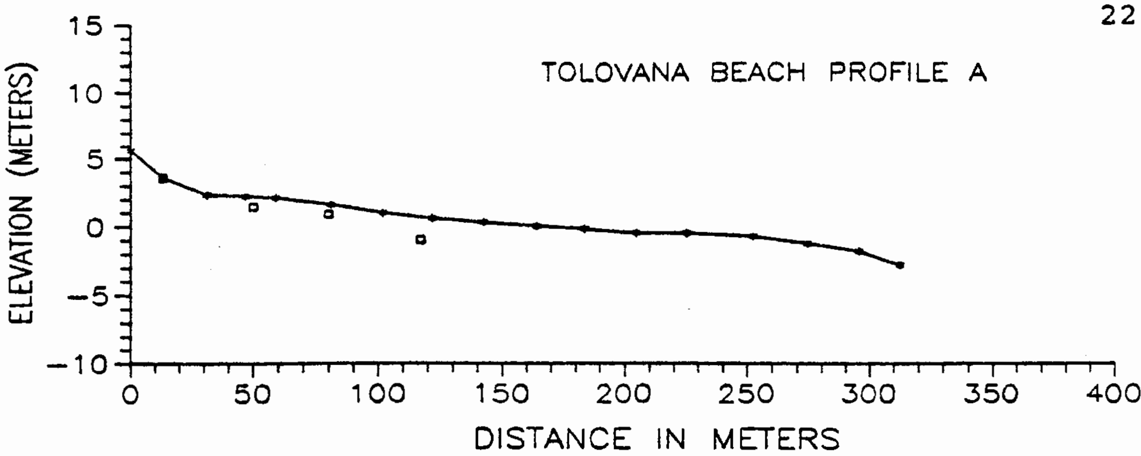
TOLOVANA BEACH PROFILE A
ELEVATION (METERS)
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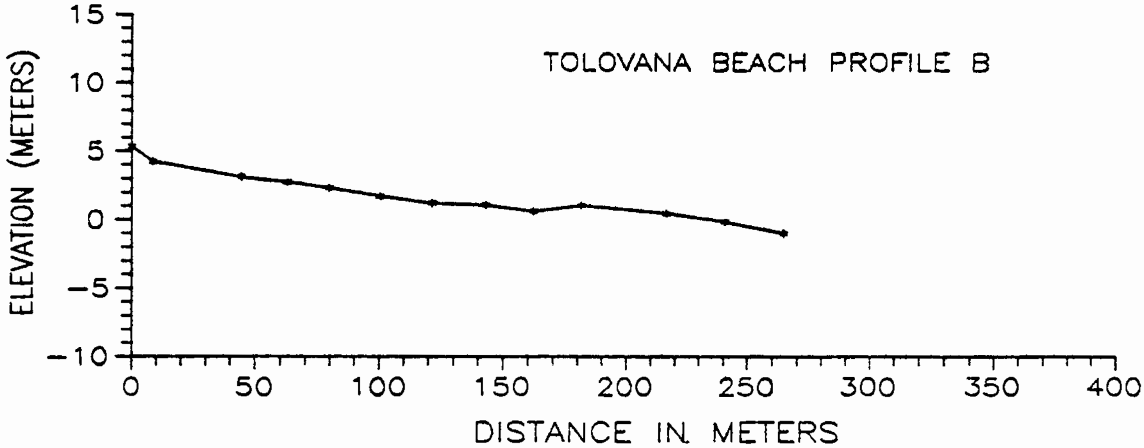
400
DISTANCE IN METERS


TOLOVANA BEACH PROFILE B
ELEVATION (METERS)
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-10
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150
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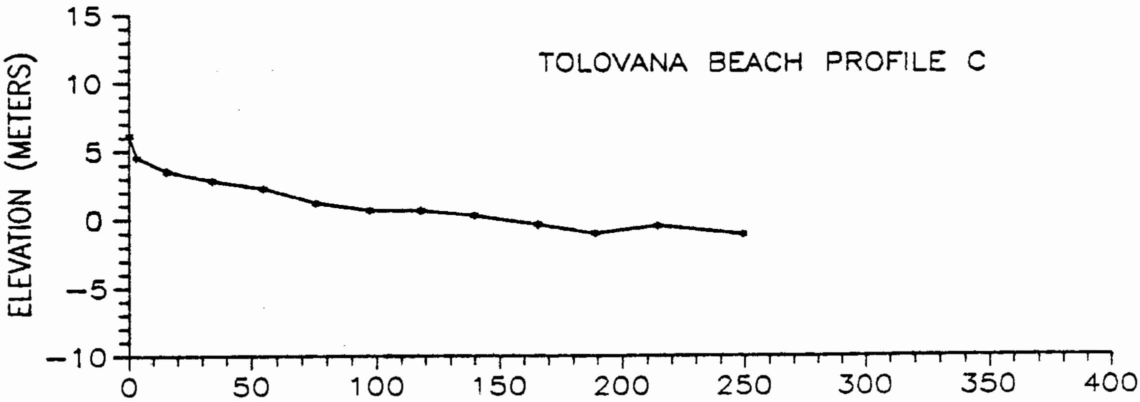
350
400
DISTANCE IN METERS


TOLOVANA BEACH PROFILE C
ELEVATION (METERS)
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10
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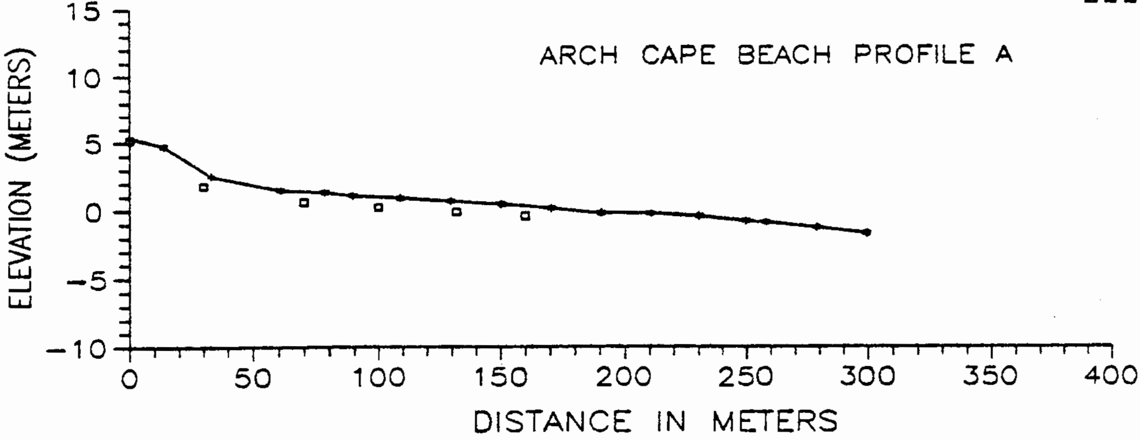
ARCH CAPE BEACH PROFILE A
ELEVATION (METERS)
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5
0
-5
-10
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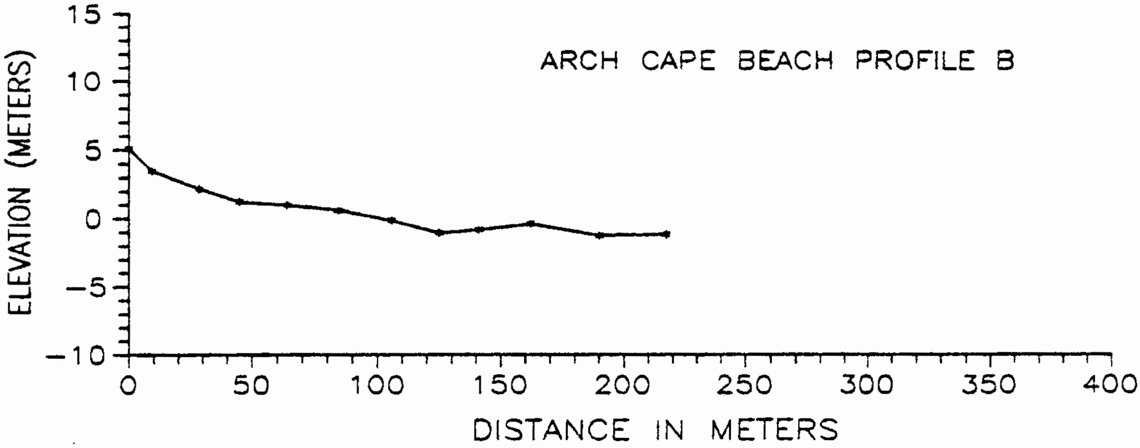
350
400
DISTANCE IN METERS


ARCH CAPE BEACH PROFILE B
ELEVATION (METERS)
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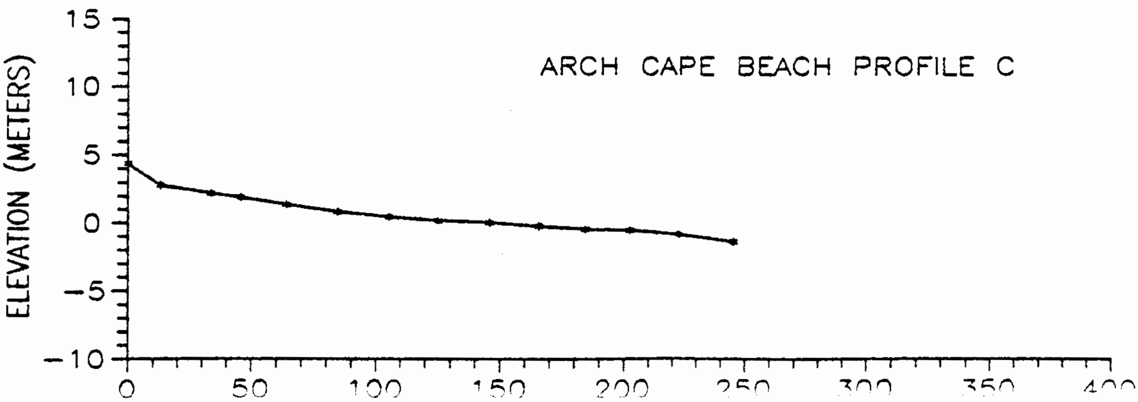
400
DISTANCE IN METERS


ARCH CAPE BEACH PROFILE C
ELEVATION (METERS)
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-5
-10
0
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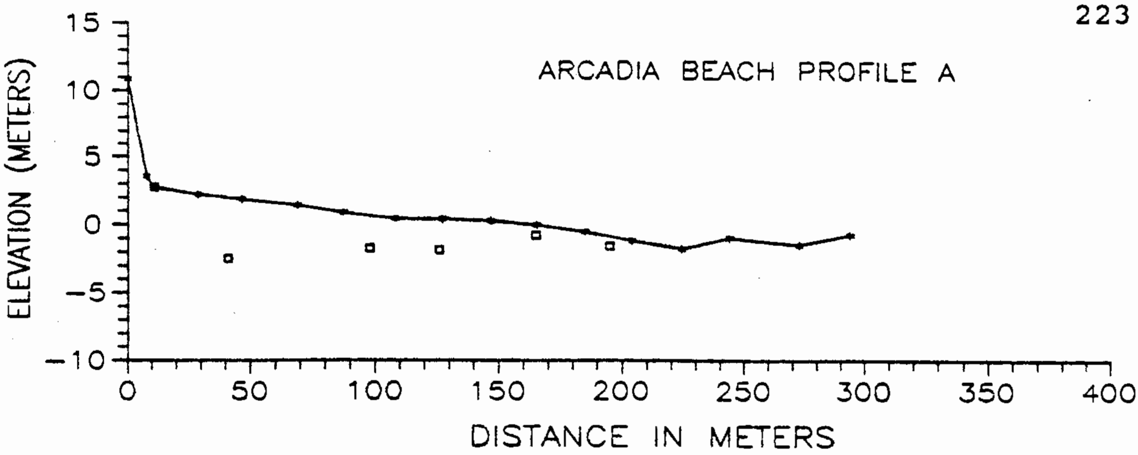
ARCADIA BEACH PROFILE A
ELEVATION (METERS)
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−5
−10
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150
200
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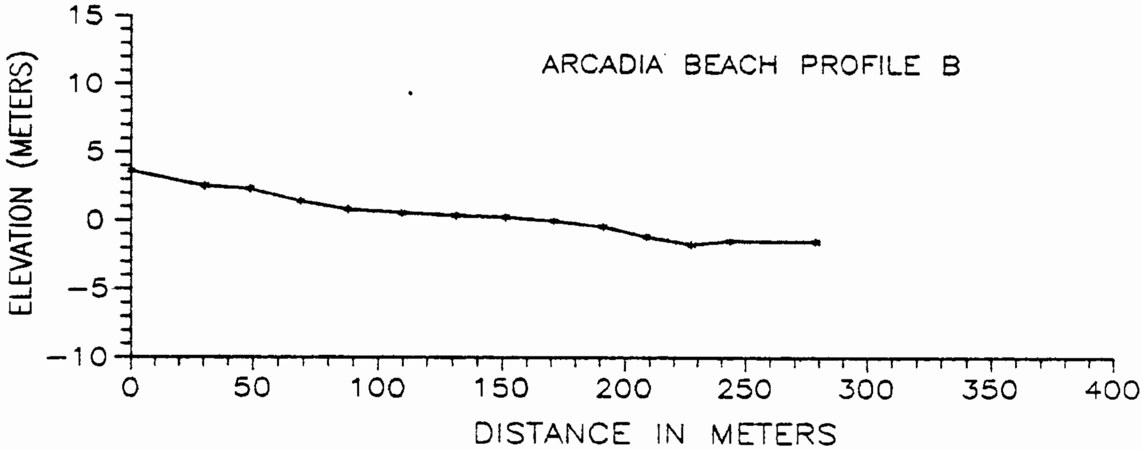
350
400
DISTANCE IN METERS


ARCADIA BEACH PROFILE B
ELEVATION (METERS)
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0
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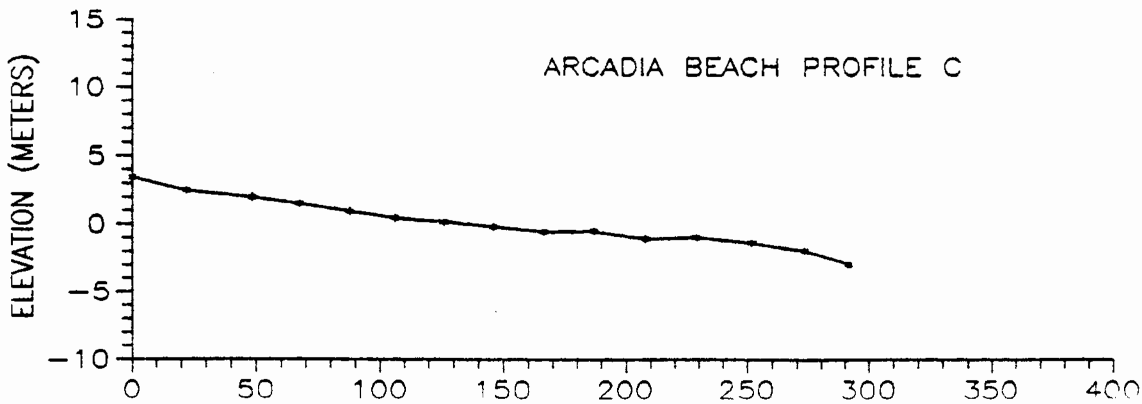
350
400
DISTANCE IN METERS


ARCADIA BEACH PROFILE C
ELEVATION (METERS)
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10
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−10
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50
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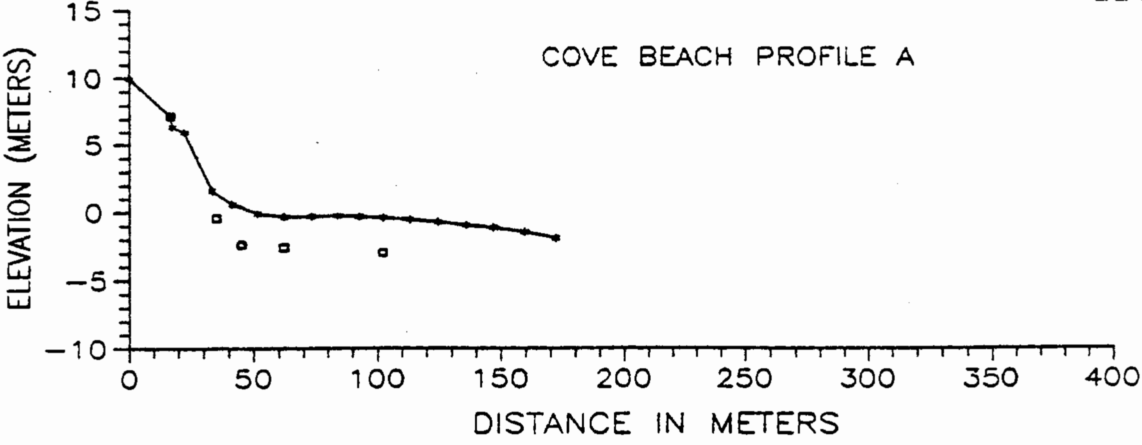
350
400


COVE BEACH PROFILE A
ELEVATION (METERS)
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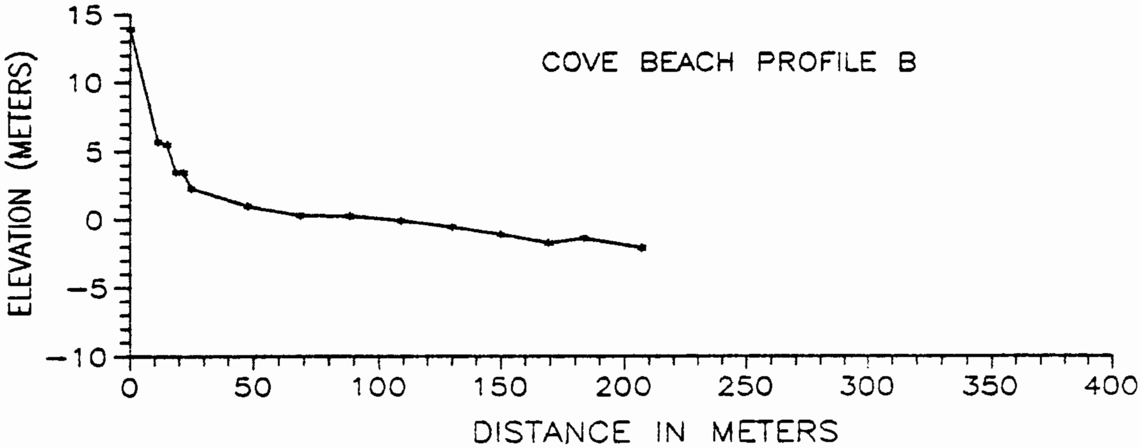
400
DISTANCE IN METERS


COVE BEACH PROFILE B
ELEVATION (METERS)
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150
200
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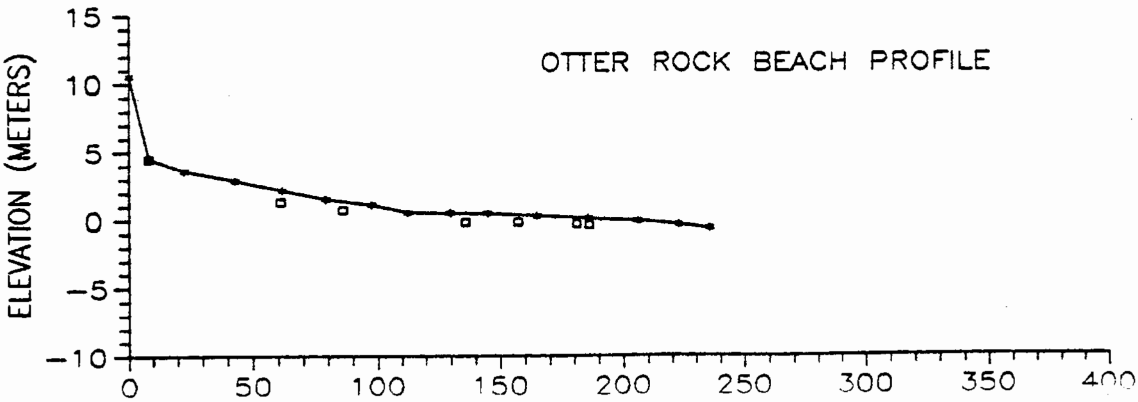
300
350
400
DISTANCE IN METERS


OTTER ROCK BEACH PROFILE
ELEVATION (METERS)
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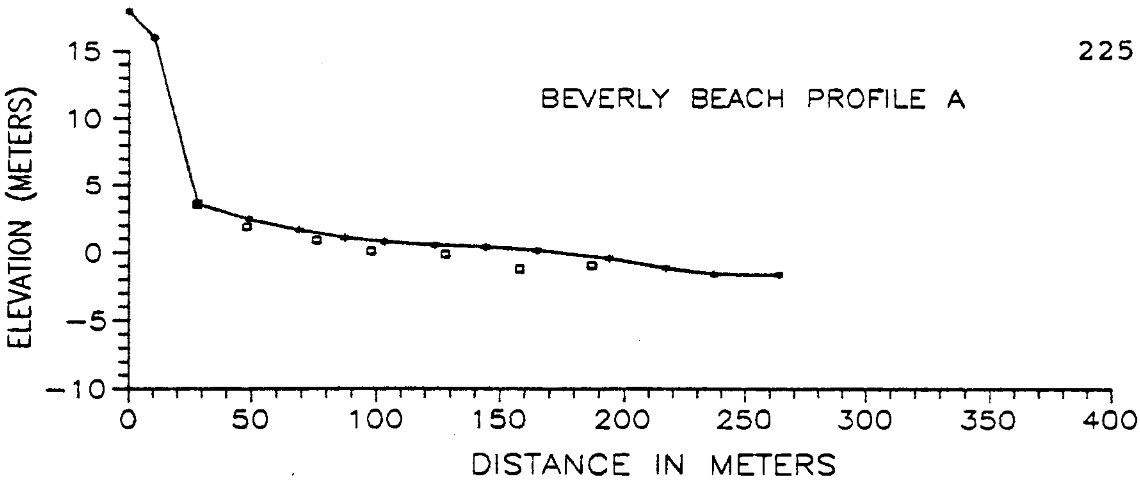
BEVERLY BEACH PROFILE A
ELEVATION (METERS)
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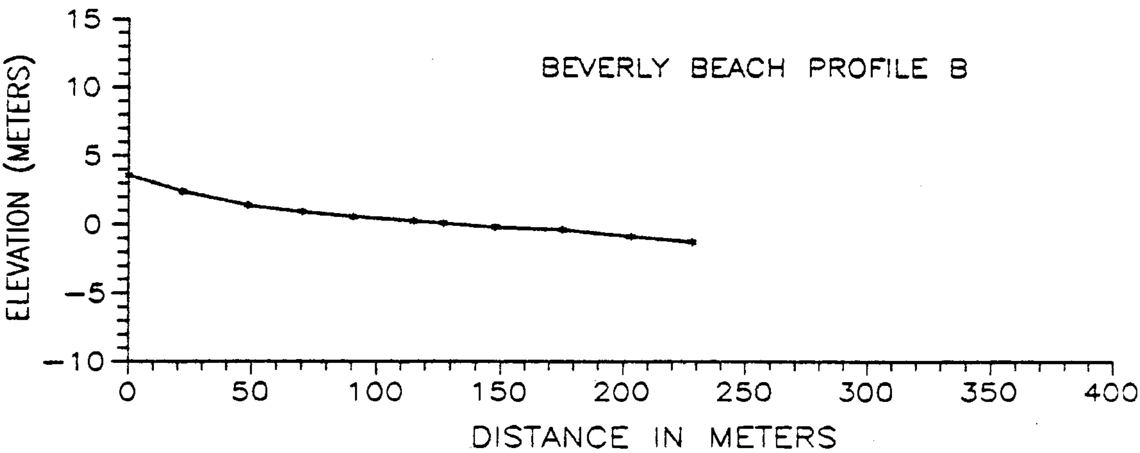
350
400
DISTANCE IN METERS


BEVERLY BEACH PROFILE B
ELEVATION (METERS)
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−5
−10
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50
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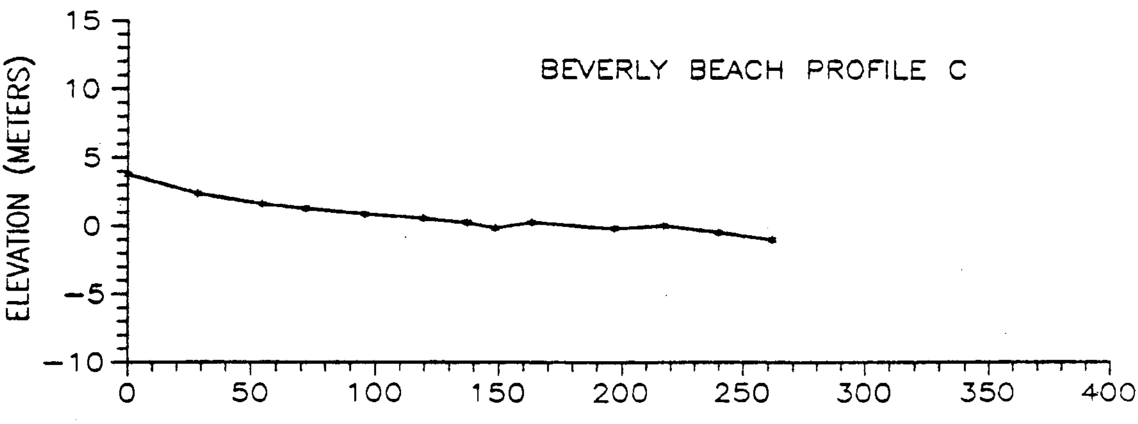
150
200
250
300
350
400
DISTANCE IN METERS


BEVERLY BEACH PROFILE C
ELEVATION (METERS)
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−10
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50
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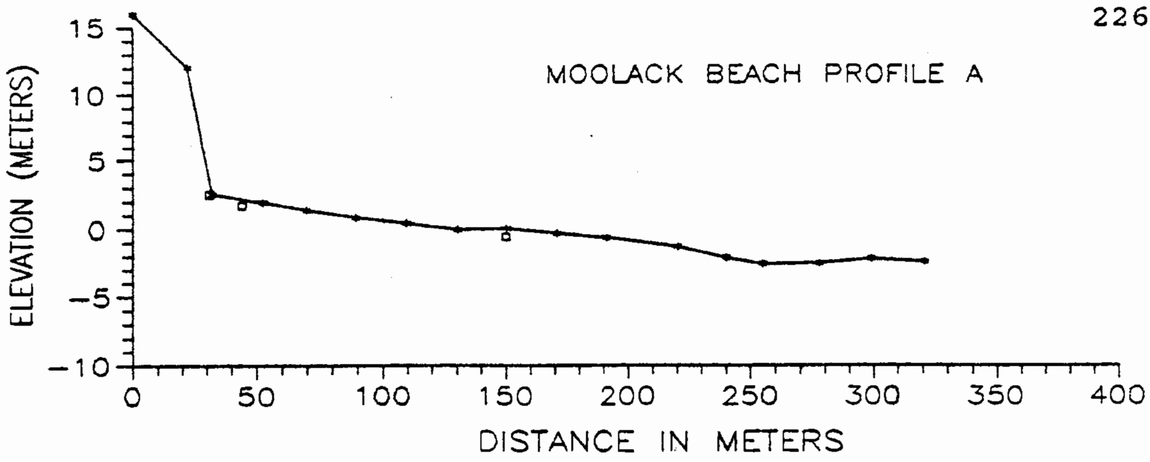
150
200
250
300
350
400


MOOLACK BEACH PROFILE A
ELEVATION (METERS)
DISTANCE IN METERS
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−5
−10
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50
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350
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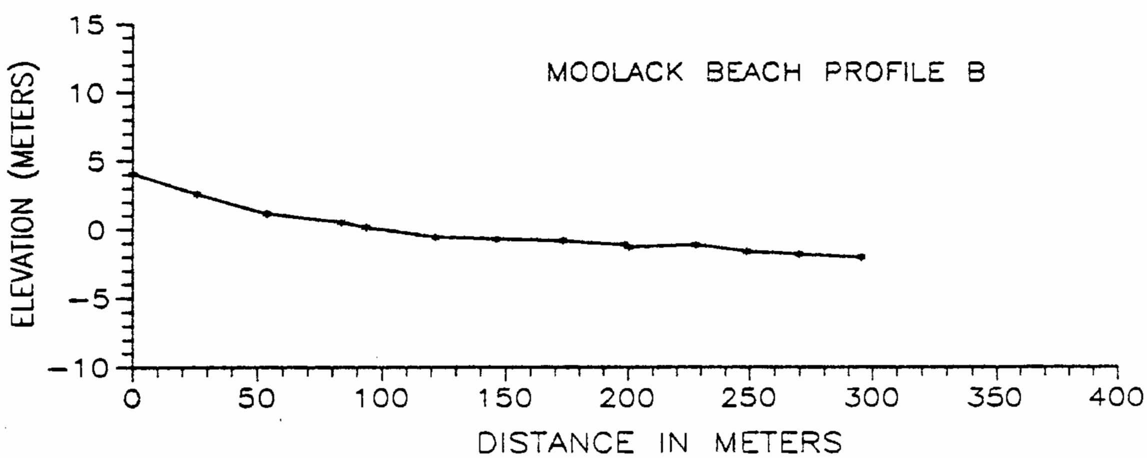
MOOLACK BEACH PROFILE B
ELEVATION (METERS)
DISTANCE IN METERS
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0
−5
−10
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50
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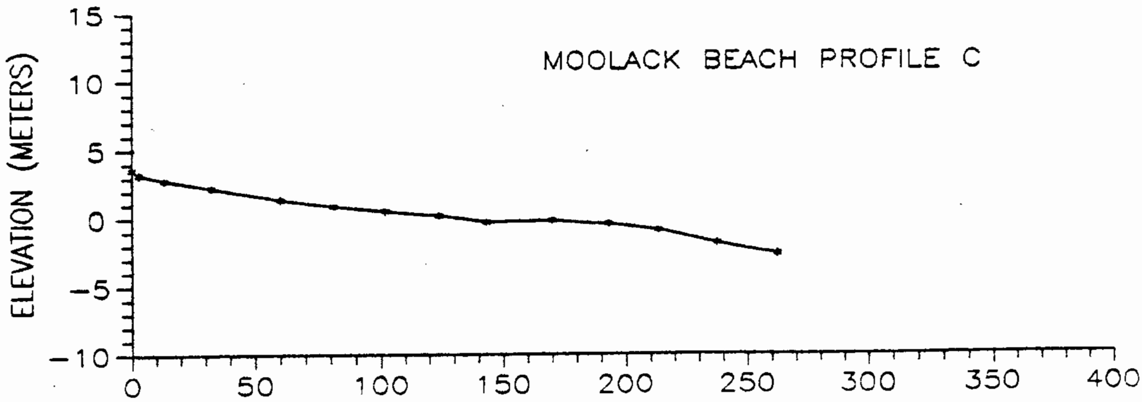
MOOLACK BEACH PROFILE C
ELEVATION (METERS)
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−10
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50
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350
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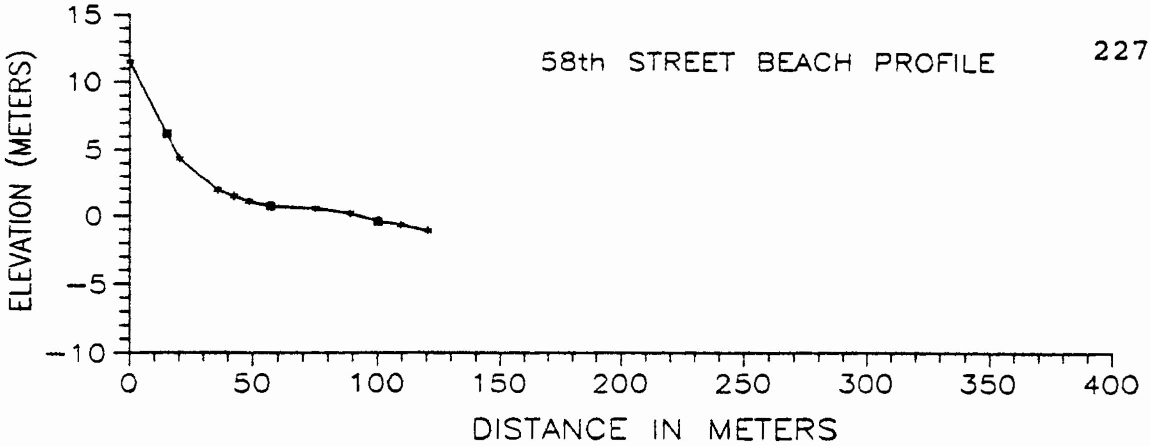
58th STREET BEACH PROFILE
ELEVATION (METERS)
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350
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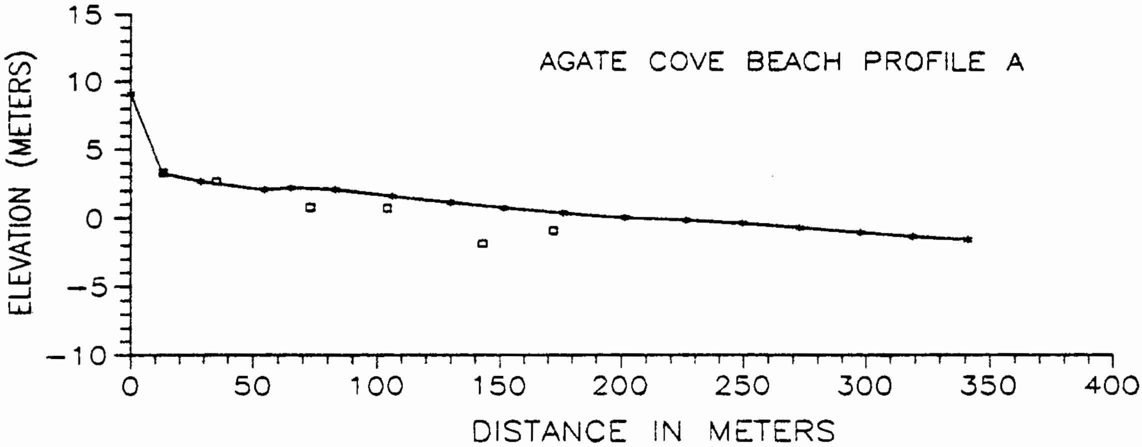
DISTANCE IN METERS


AGATE COVE BEACH PROFILE A
ELEVATION (METERS)
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-10
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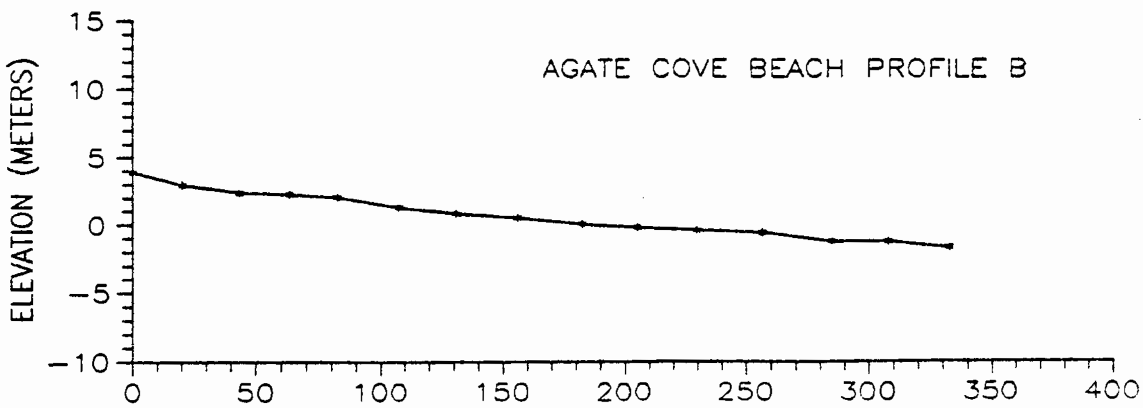
350
400
DISTANCE IN METERS


AGATE COVE BEACH PROFILE B
ELEVATION (METERS)
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-5
-10
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350
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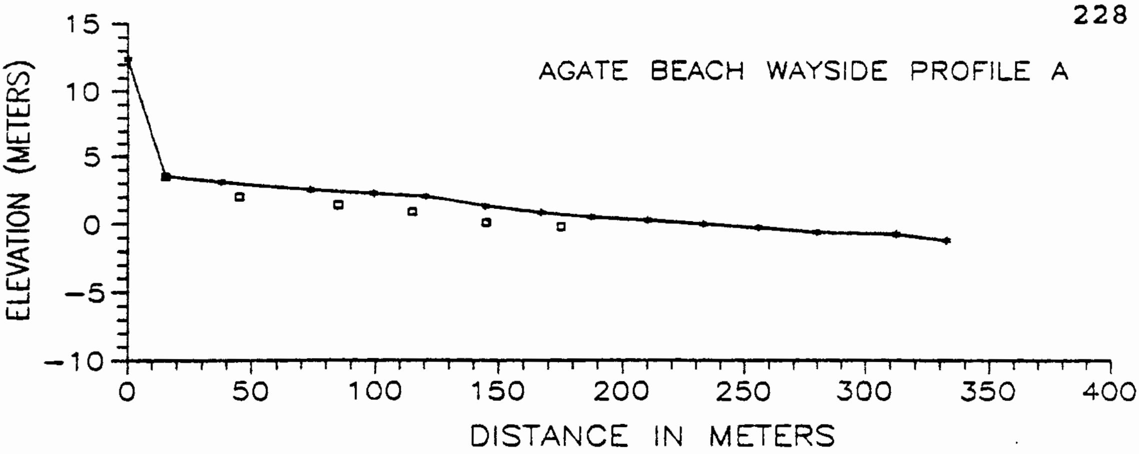
AGATE BEACH WAYSIDE PROFILE A
ELEVATION (METERS)
DISTANCE IN METERS
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−5
−10
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50
100
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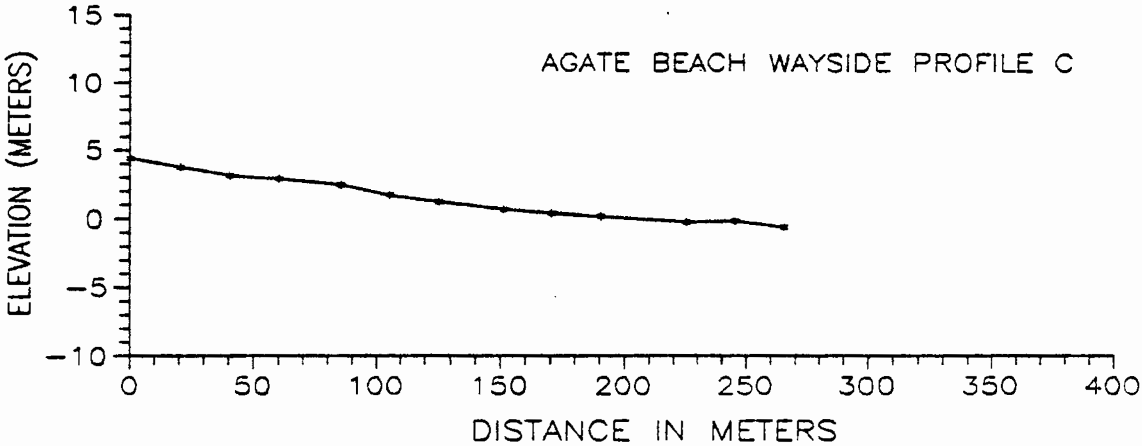
350
400


AGATE BEACH WAYSIDE PROFILE C
ELEVATION (METERS)
DISTANCE IN METERS
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0
−5
−10
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50
100
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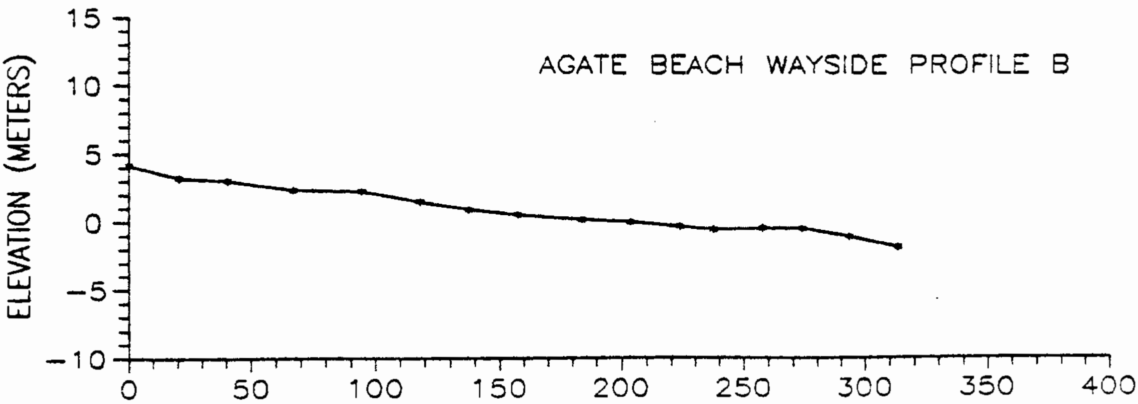
AGATE BEACH WAYSIDE PROFILE B
ELEVATION (METERS)
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−10
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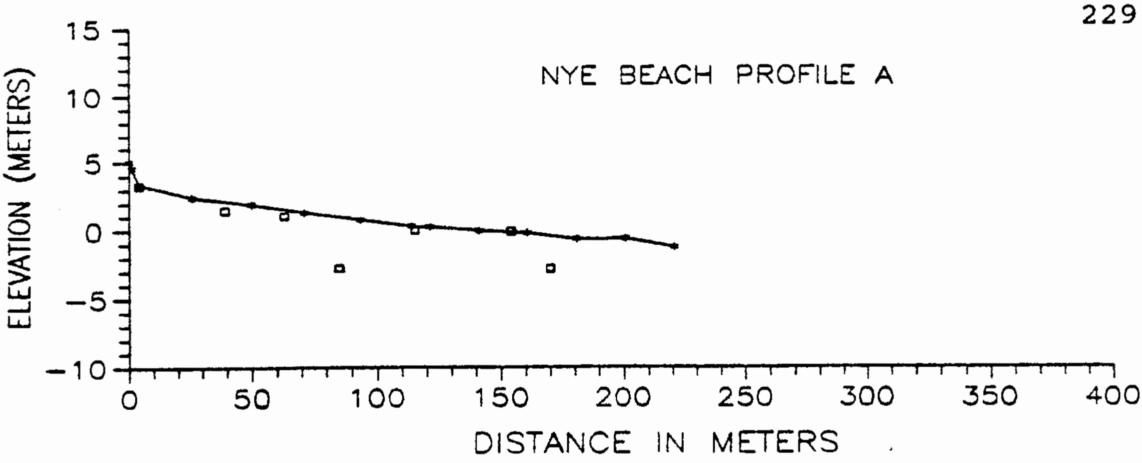
NYE BEACH PROFILE A
ELEVATION (METERS)
DISTANCE IN METERS
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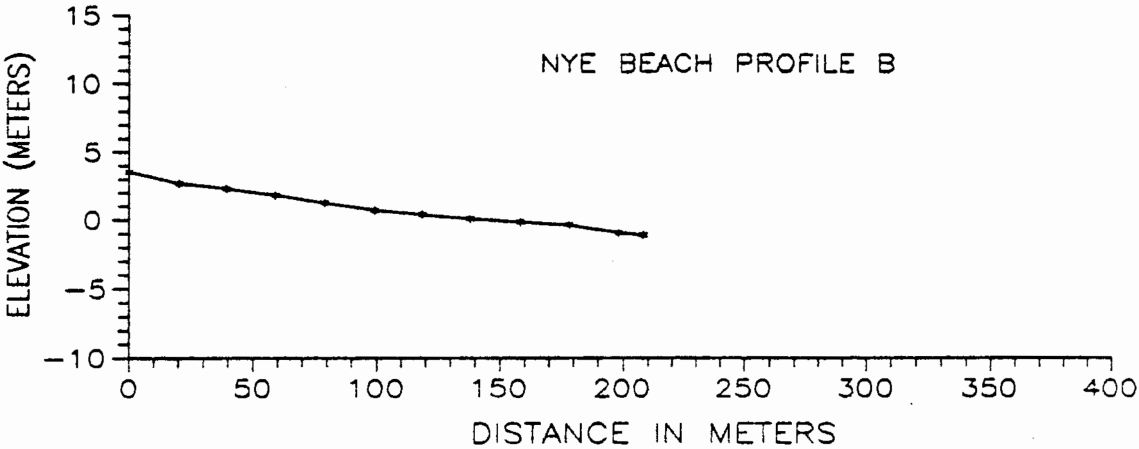
350
400


NYE BEACH PROFILE B
ELEVATION (METERS)
DISTANCE IN METERS
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−5
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100
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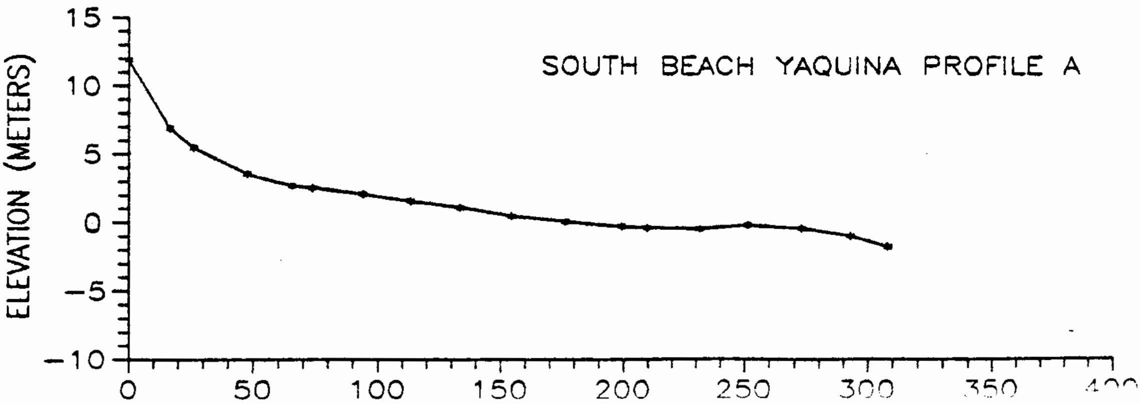
SOUTH BEACH YAQUINA PROFILE A
ELEVATION (METERS)
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−10
0
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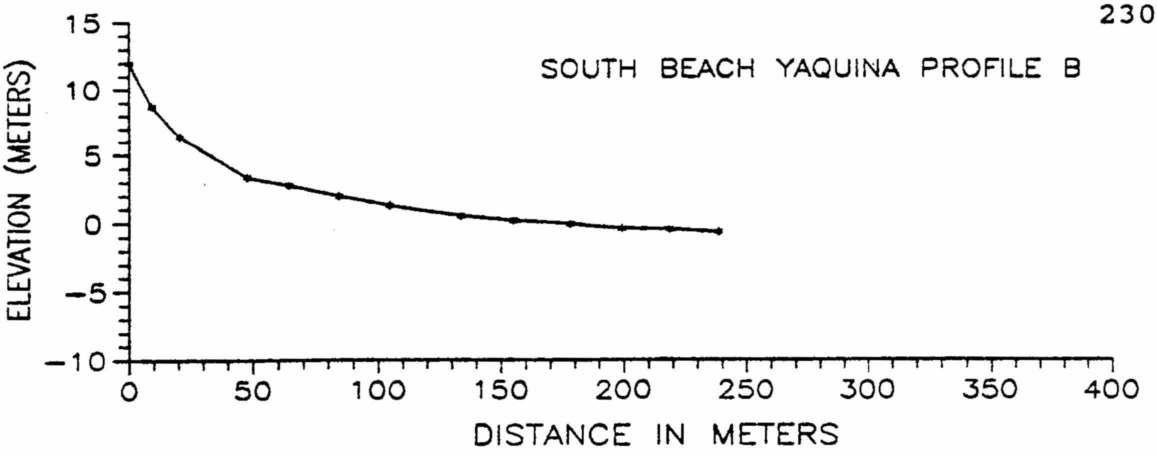
100
150
200
250
300



SOUTH BEACH YAQUINA PROFILE B
ELEVATION (METERS)
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200
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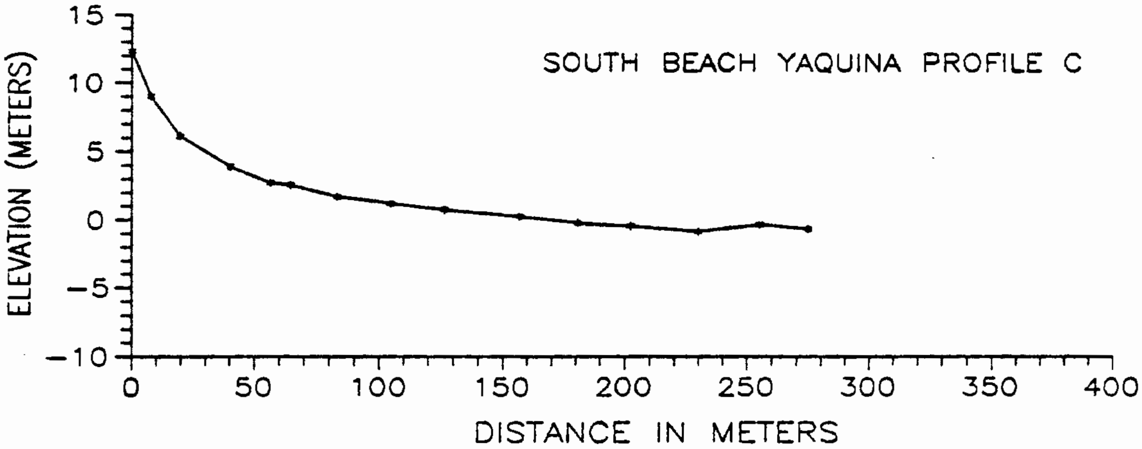
350
400
DISTANCE IN METERS



SOUTH BEACH YAQUINA PROFILE C
ELEVATION (METERS)
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-10
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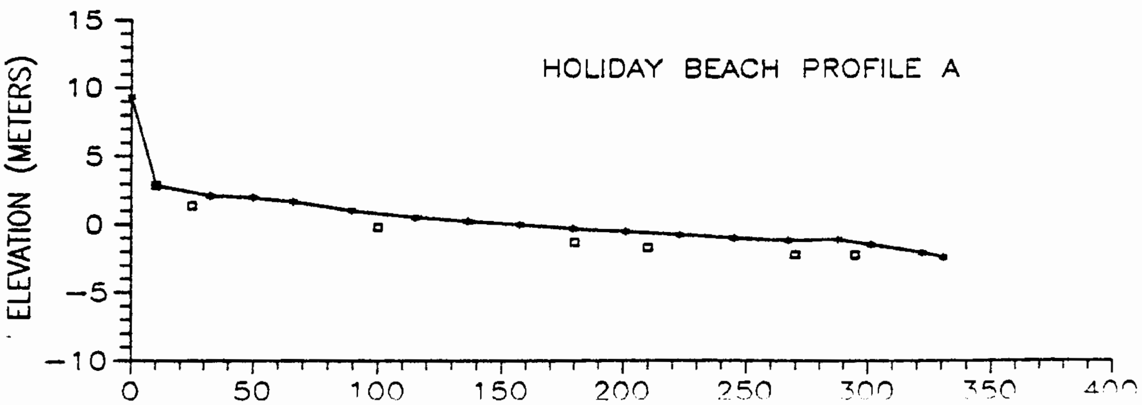
150
200
250
300
350
400
DISTANCE IN METERS



HOLIDAY BEACH PROFILE A
ELEVATION (METERS)
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-10
0
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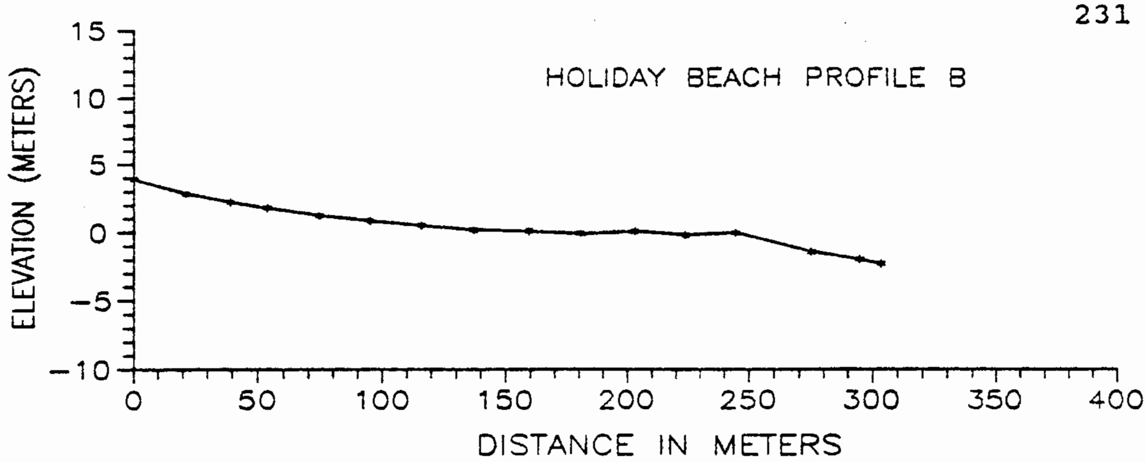
200
250
300


HOLIDAY BEACH PROFILE B
ELEVATION (METERS)
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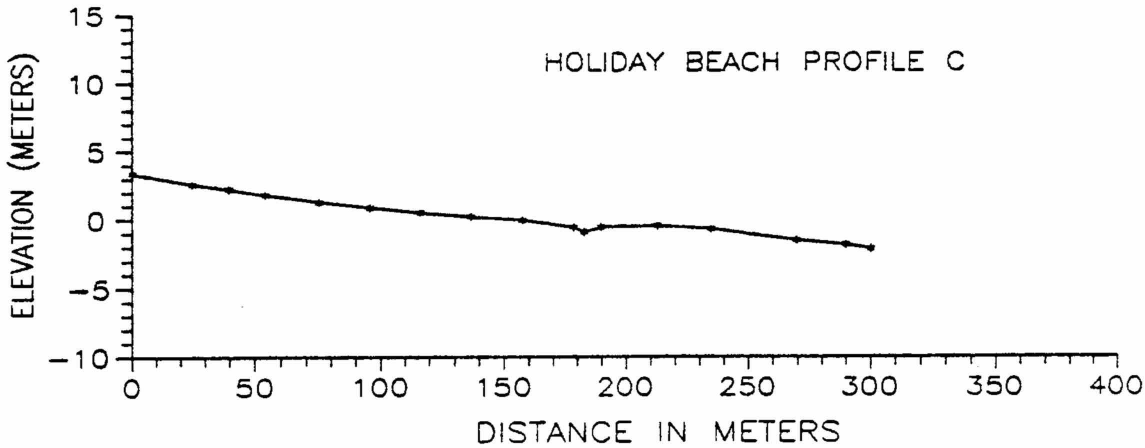
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


HOLIDAY BEACH PROFILE C
ELEVATION (METERS)
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−10
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250
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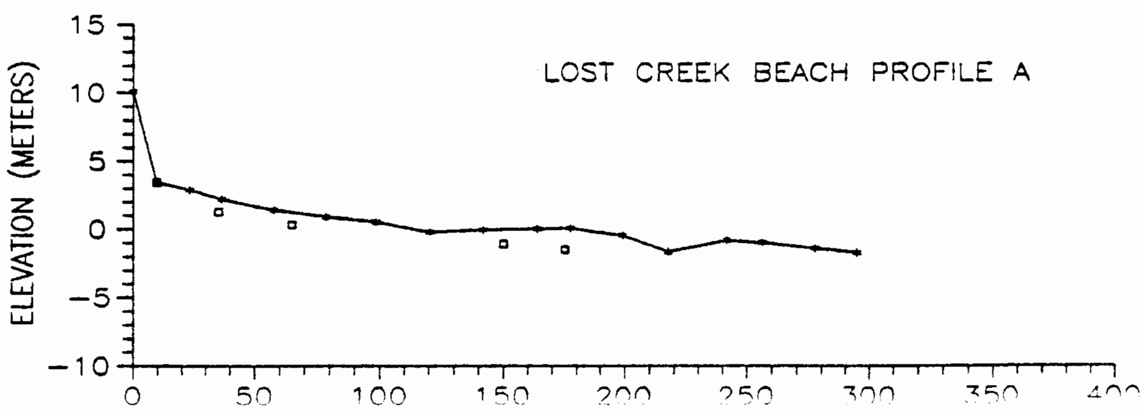
350
400
DISTANCE IN METERS


LOST CREEK BEACH PROFILE A
ELEVATION (METERS)
15
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0
−5
−10
0
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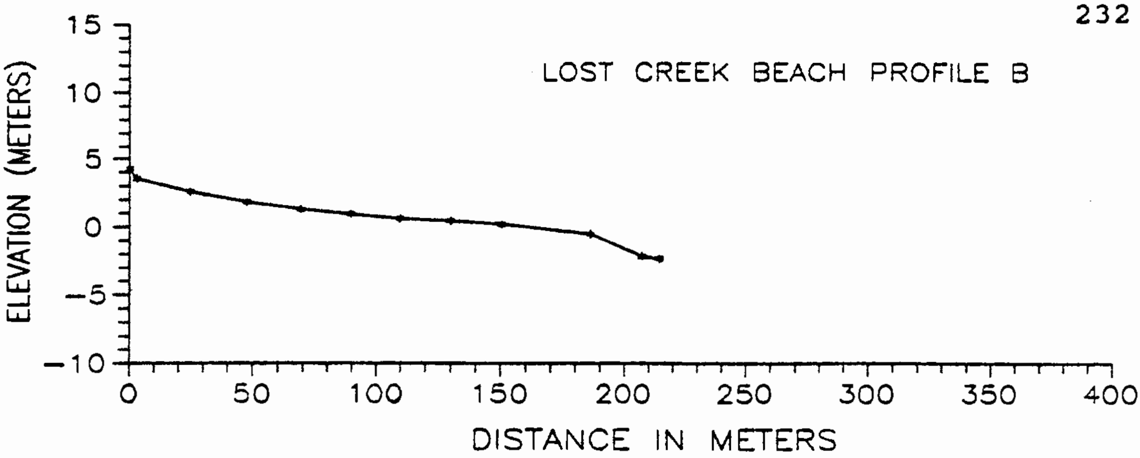
100
150


LOST CREEK BEACH PROFILE B
ELEVATION (METERS)
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0
−5
−10
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150
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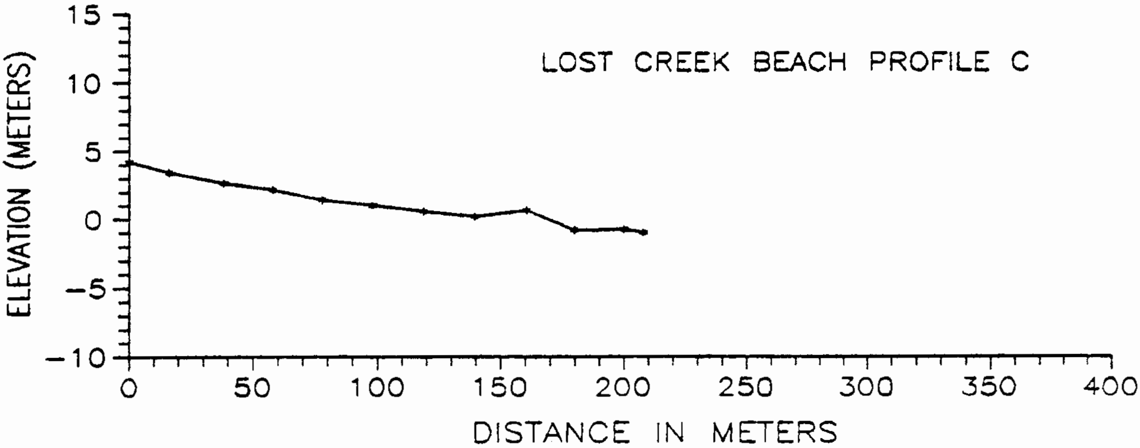
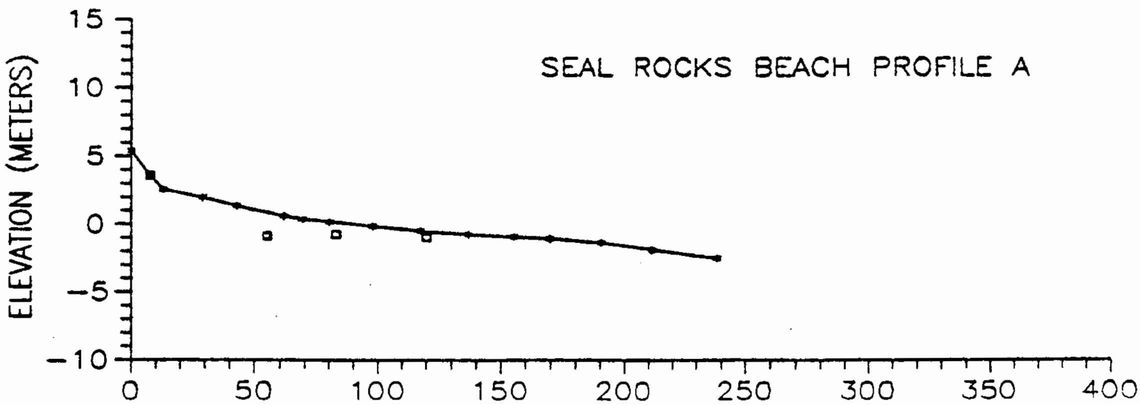
250
300
350
400
DISTANCE IN METERS


LOST CREEK BEACH PROFILE C
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


SEAL ROCKS BEACH PROFILE A
ELEVATION (METERS)
15
10
5
0
−5
−10
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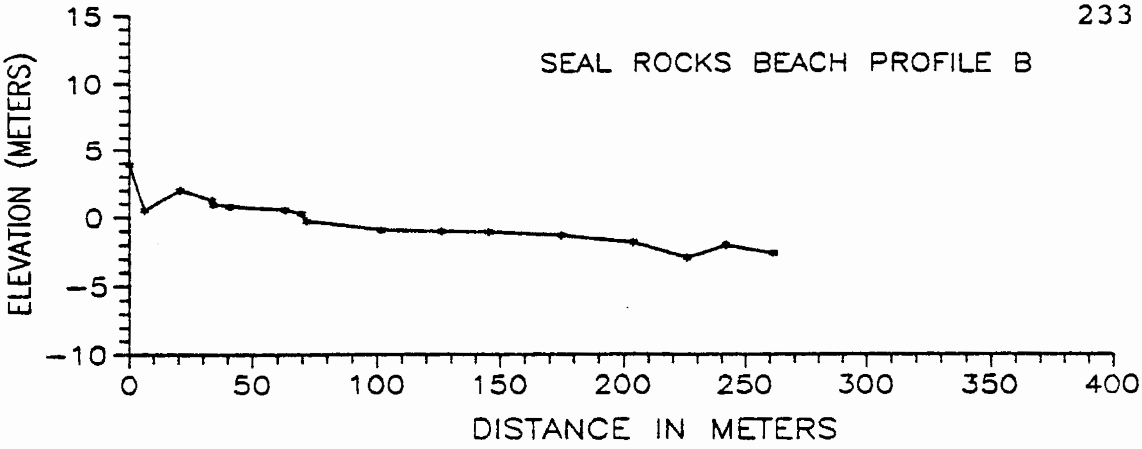
SEAL ROCKS BEACH PROFILE B
ELEVATION (METERS)
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0
-5
-10
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150
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250
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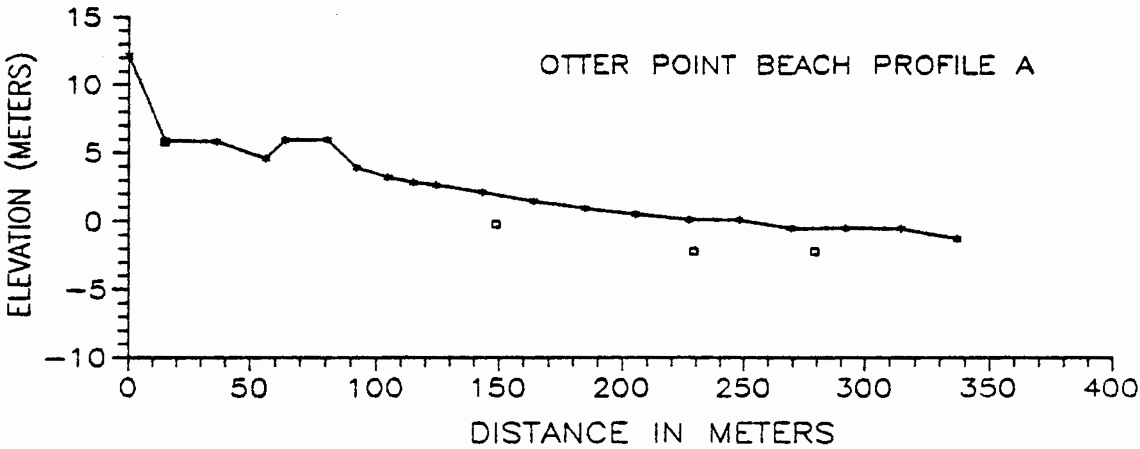
350
400
DISTANCE IN METERS


OTTER POINT BEACH PROFILE A
ELEVATION (METERS)
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5
0
-5
-10
0
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150
200
250
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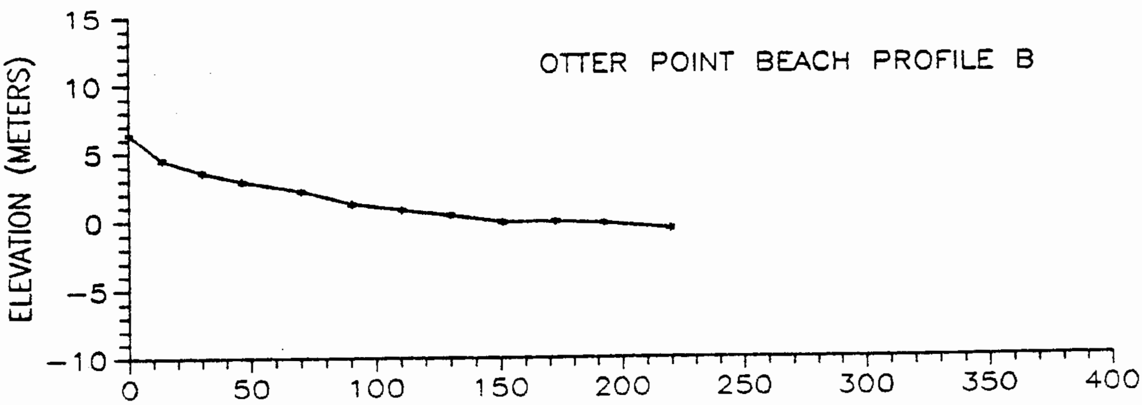
350
400
DISTANCE IN METERS


OTTER POINT BEACH PROFILE B
ELEVATION (METERS)
15
10
5
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-5
-10
0
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100
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300
350
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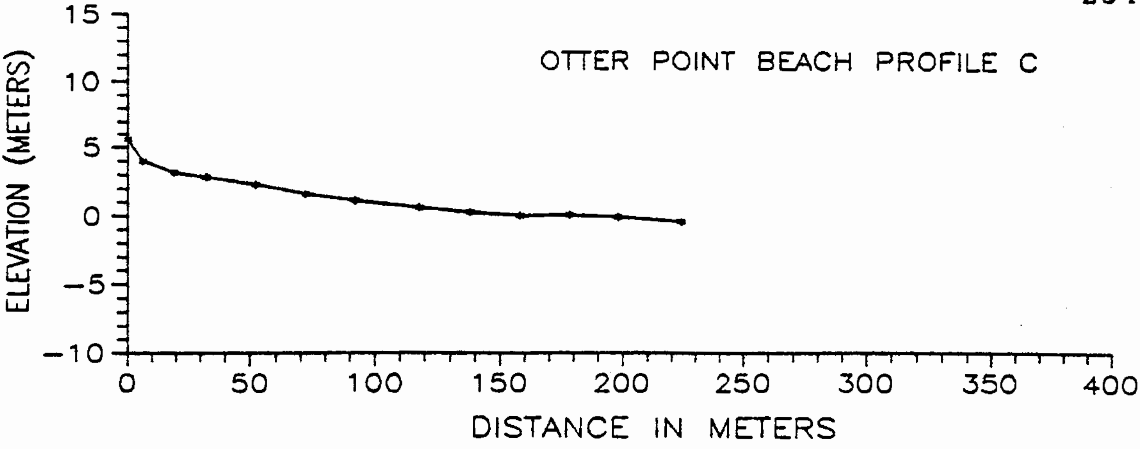
OTTER POINT BEACH PROFILE C
ELEVATION (METERS)
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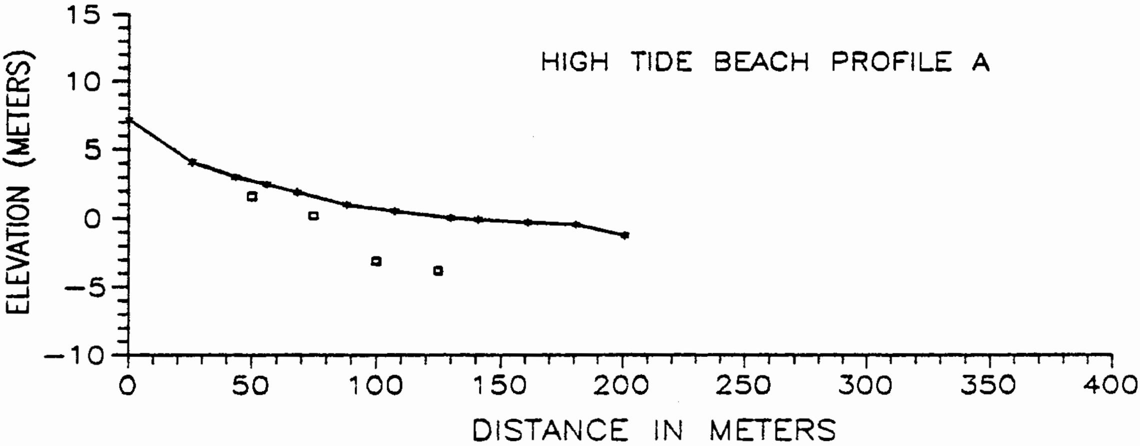
5
0
-5
-10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


HIGH TIDE BEACH PROFILE A
ELEVATION (METERS)
15
10
5
0
-5
-10
0
50
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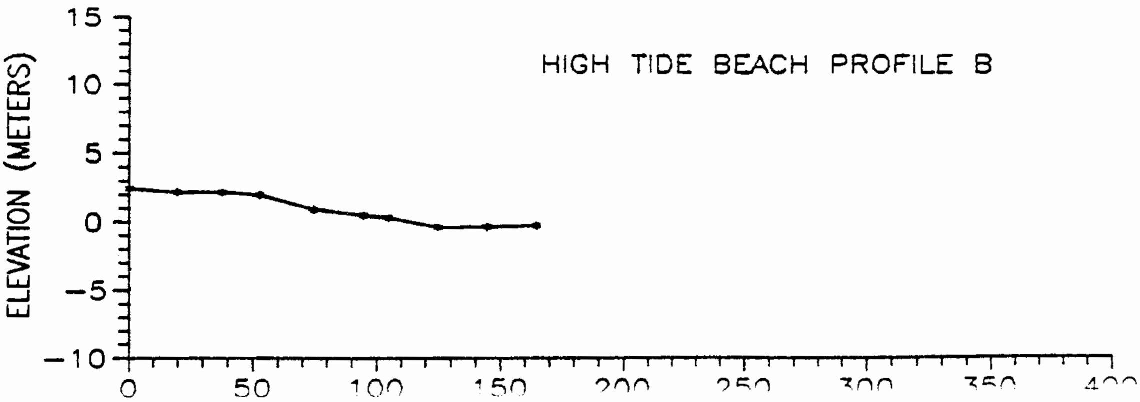
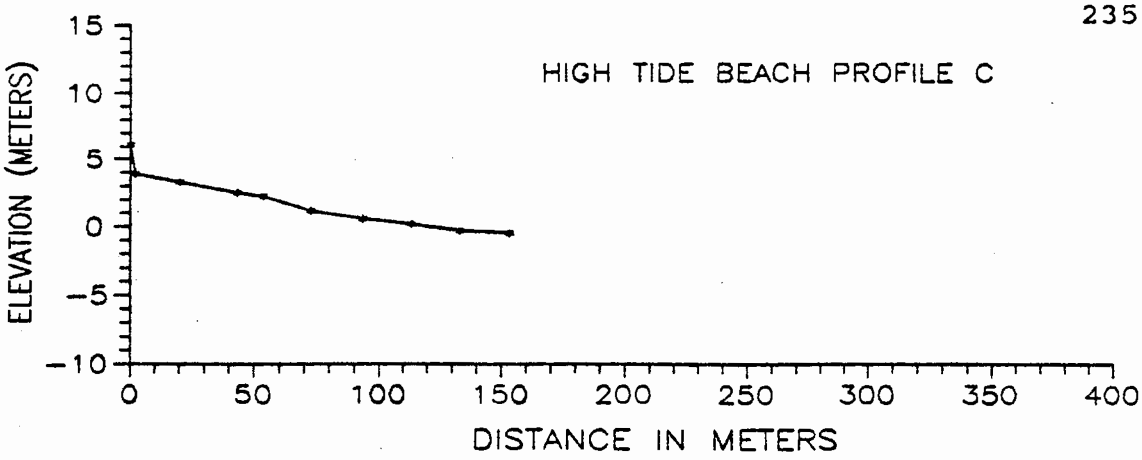
150
200
250
300
350
400
DISTANCE IN METERS


HIGH TIDE BEACH PROFILE B
ELEVATION (METERS)
15
10
5
0
-5
-10
0
50



HIGH TIDE BEACH PROFILE C
ELEVATION (METERS)
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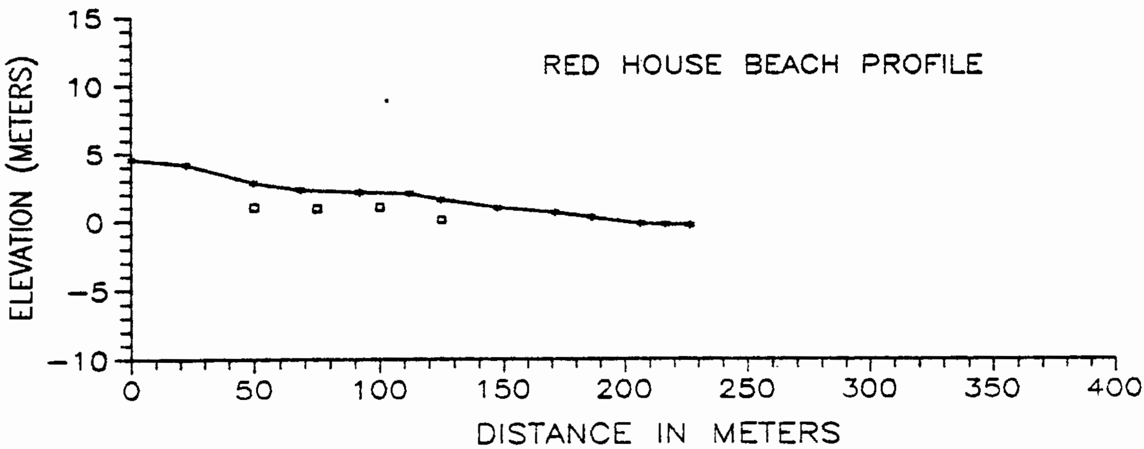
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS



RED HOUSE BEACH PROFILE
ELEVATION (METERS)
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0
−5
−10
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200
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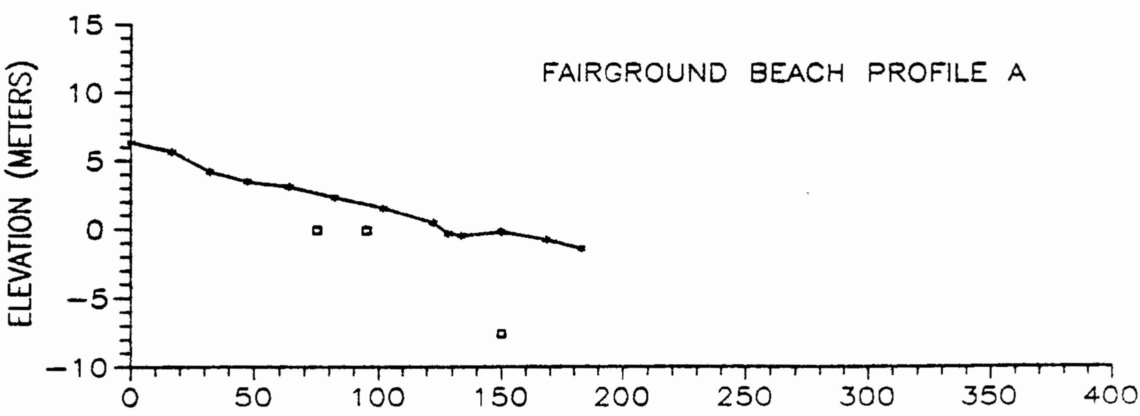
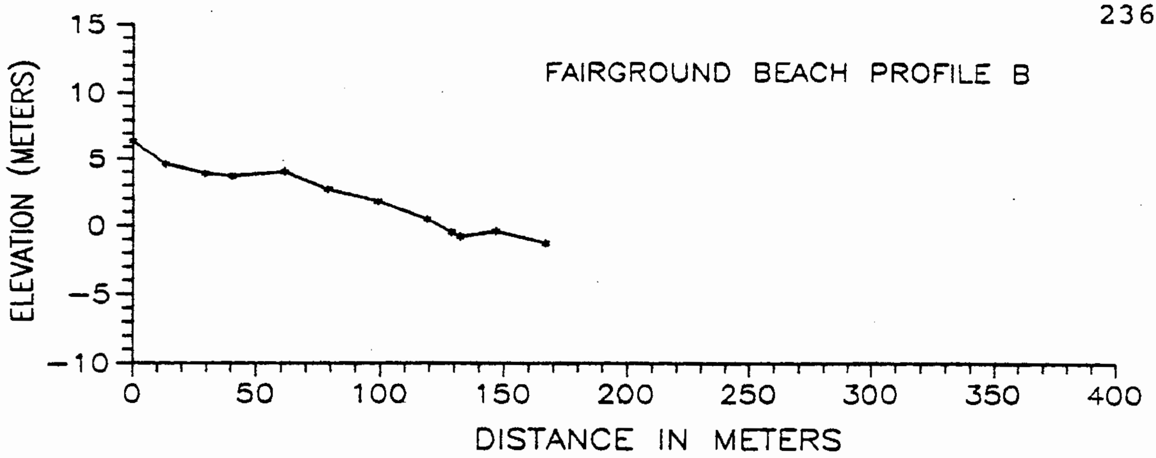
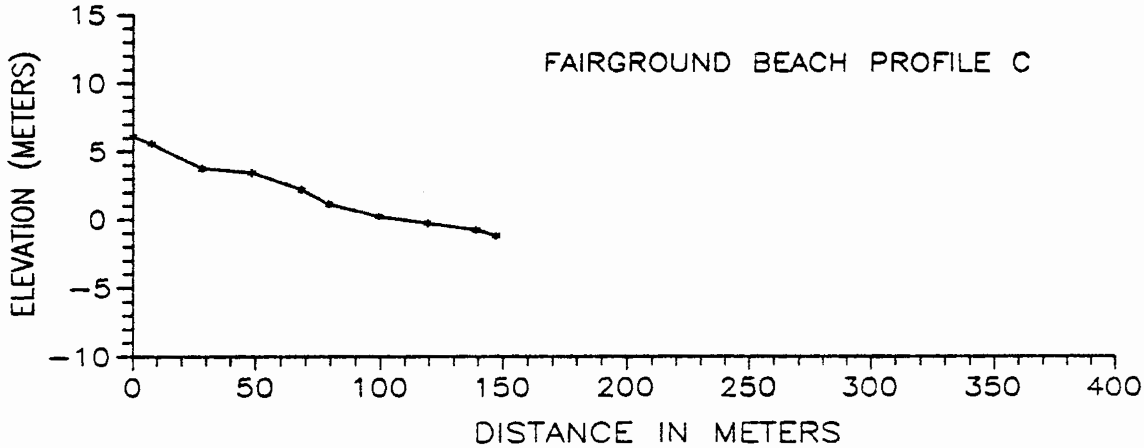
350
400
DISTANCE IN METERS



FAIRGROUND BEACH PROFILE A
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400


FAIRGROUND BEACH PROFILE B
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


FAIRGROUND BEACH PROFILE C
ELEVATION (METERS)
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−5
−10
0
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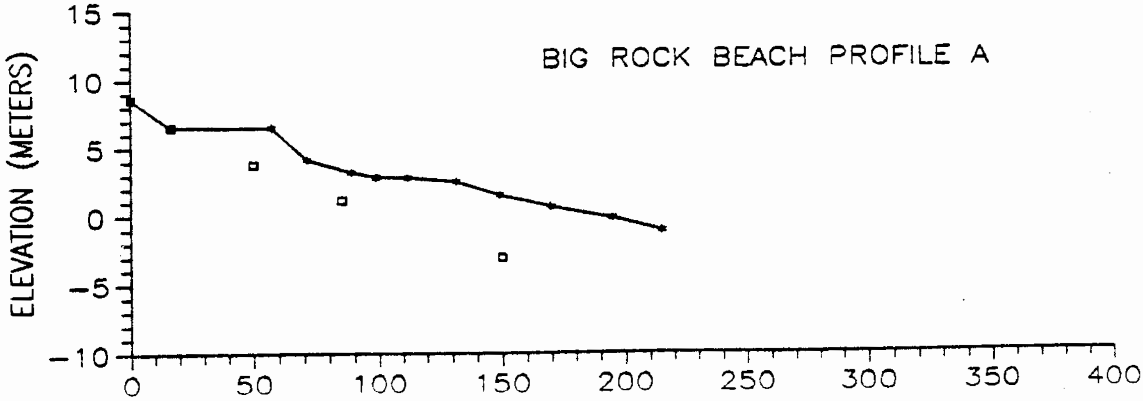
150
200
250
300
350
400
DISTANCE IN METERS


BIG ROCK BEACH PROFILE A
ELEVATION (METERS)
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10
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−5
−10
0
50
100
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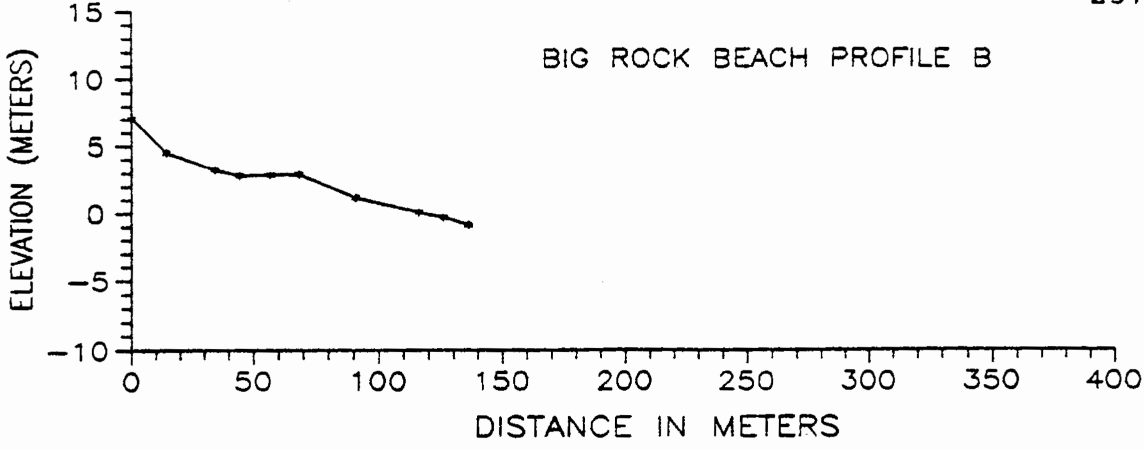
250
300
350
400



BIG ROCK BEACH PROFILE B
ELEVATION (METERS)
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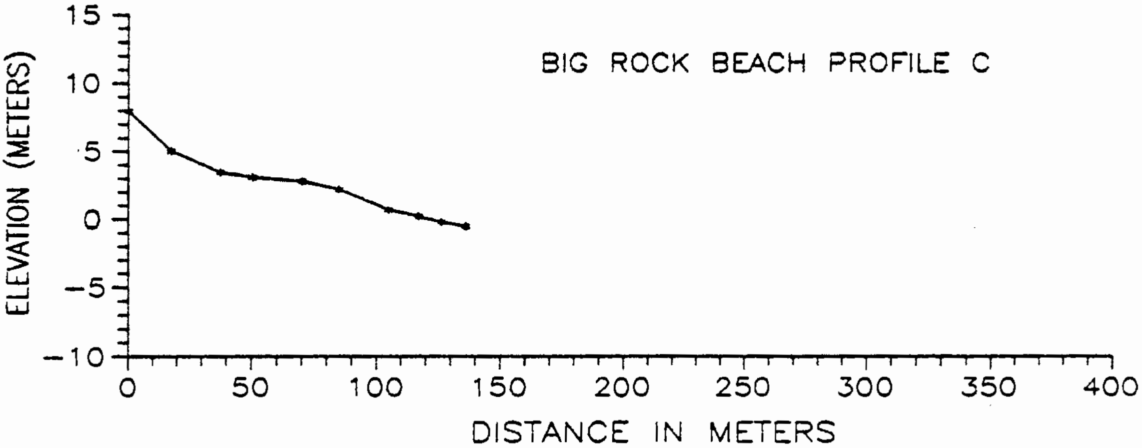
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS



BIG ROCK BEACH PROFILE C
ELEVATION (METERS)
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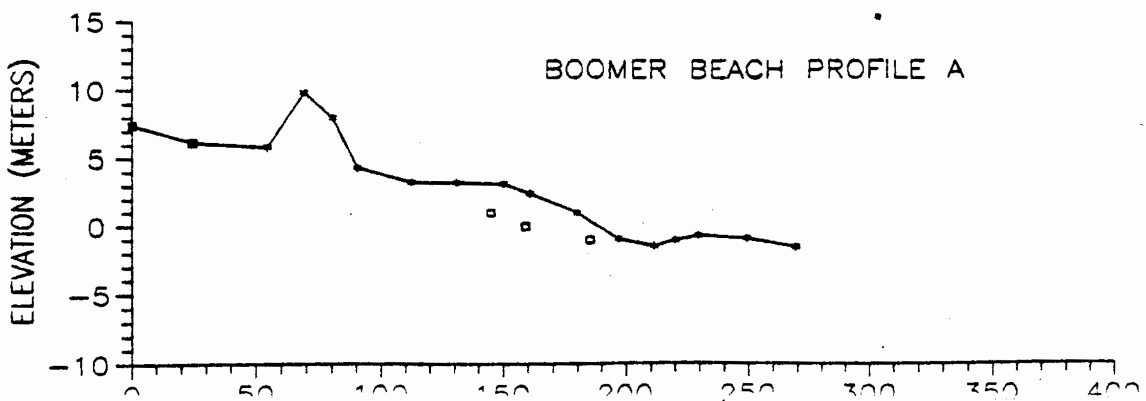
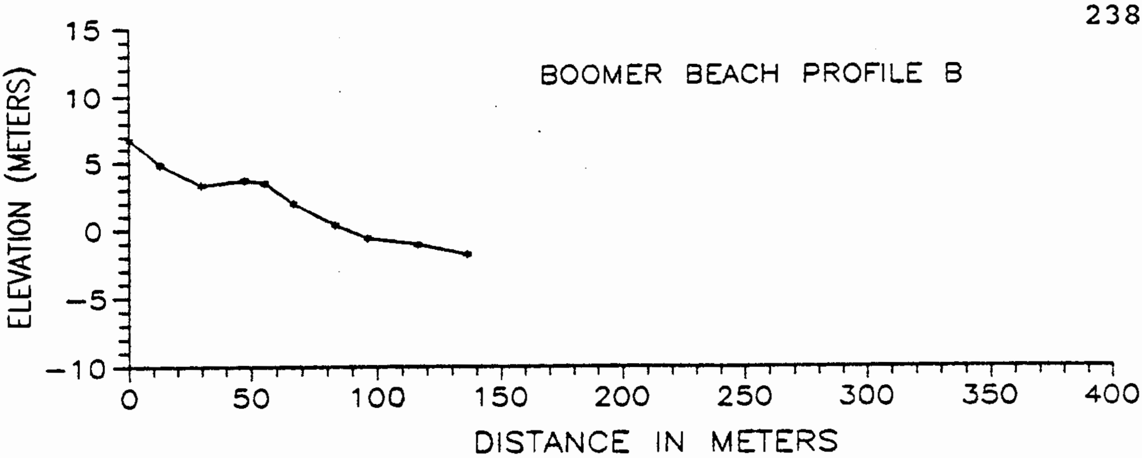
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS



BOOMER BEACH PROFILE A
ELEVATION (METERS)
15
10
5
0
−5
−10


BOOMER BEACH PROFILE B
ELEVATION (METERS)
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5
0
−5
−10
0
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150
200
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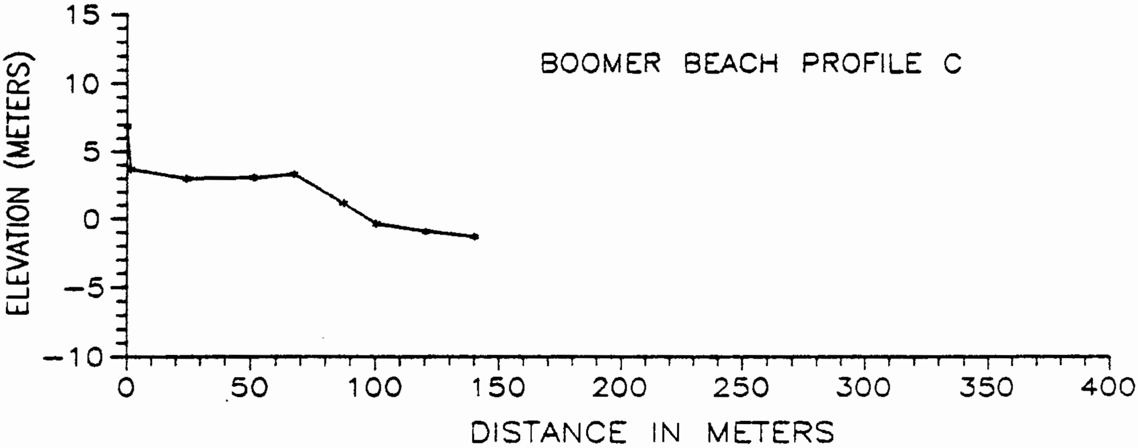
300
350
400
DISTANCE IN METERS


BOOMER BEACH PROFILE C
ELEVATION (METERS)
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−5
−10
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150
200
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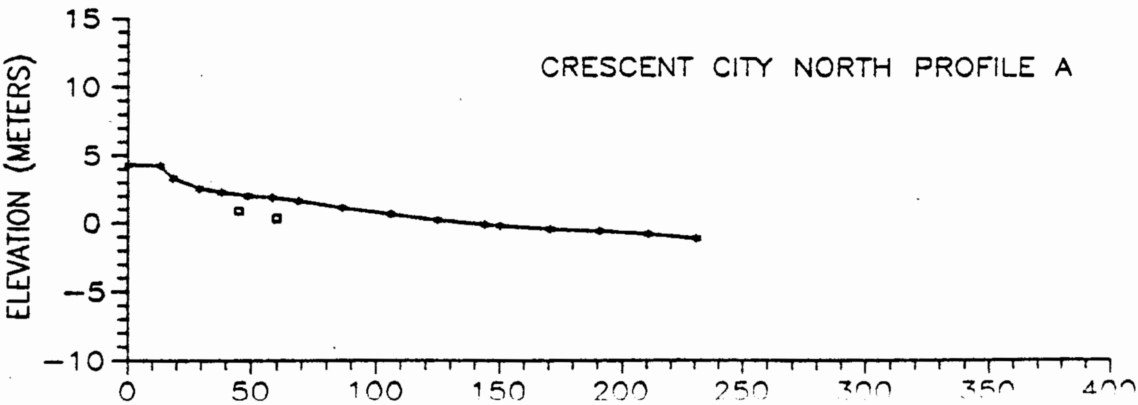
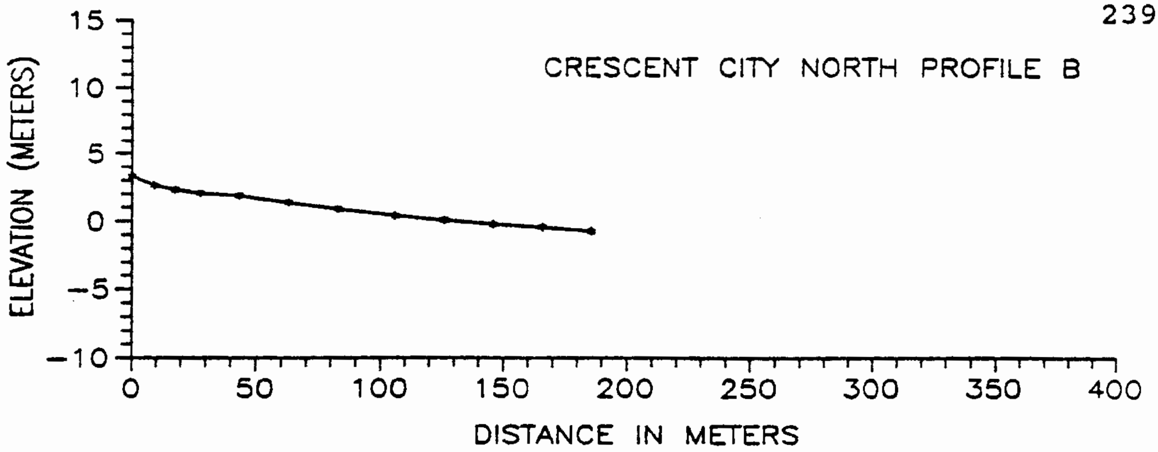
350
400
DISTANCE IN METERS


CRESCENT CITY NORTH PROFILE A
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200


CRESCENT CITY NORTH PROFILE B
ELEVATION (METERS)
15
10
5
0
−5
−10
0
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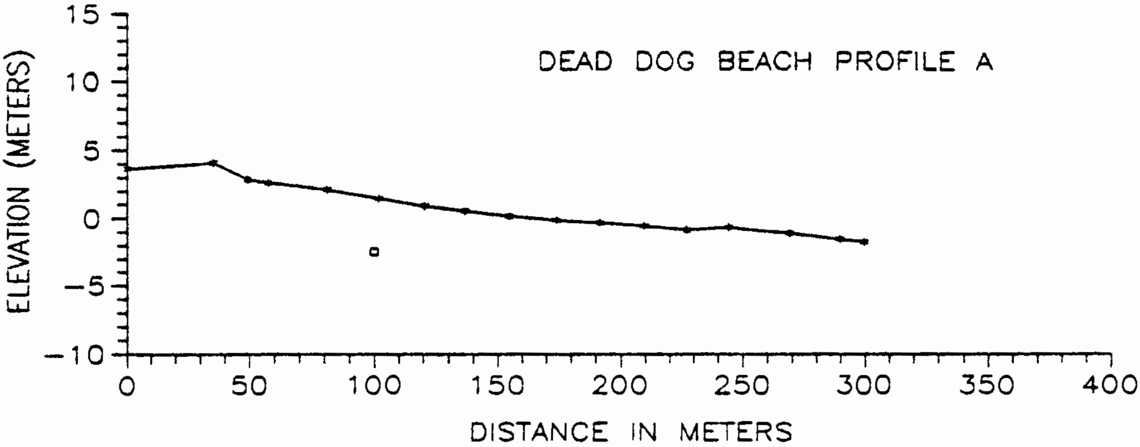
100
150
200
250
300
350
400
DISTANCE IN METERS


DEAD DOG BEACH PROFILE A
ELEVATION (METERS)
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0
−5
−10
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150
200
250
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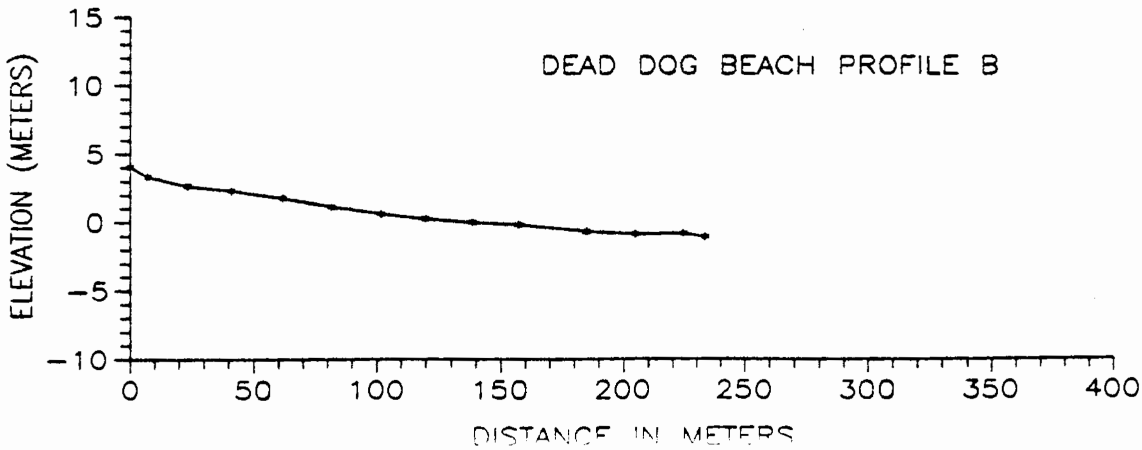
350
400
DISTANCE IN METERS


DEAD DOG BEACH PROFILE B
ELEVATION (METERS)
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10
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0
−5
−10
0
50
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350
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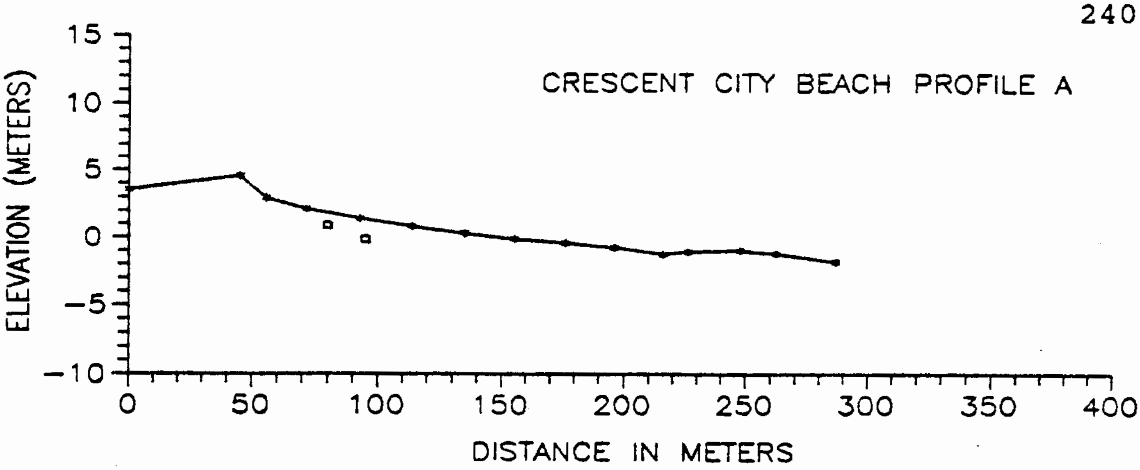
CRESCENT CITY BEACH PROFILE A
ELEVATION (METERS)
DISTANCE IN METERS
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10
5
0
−5
−10
0
50
100
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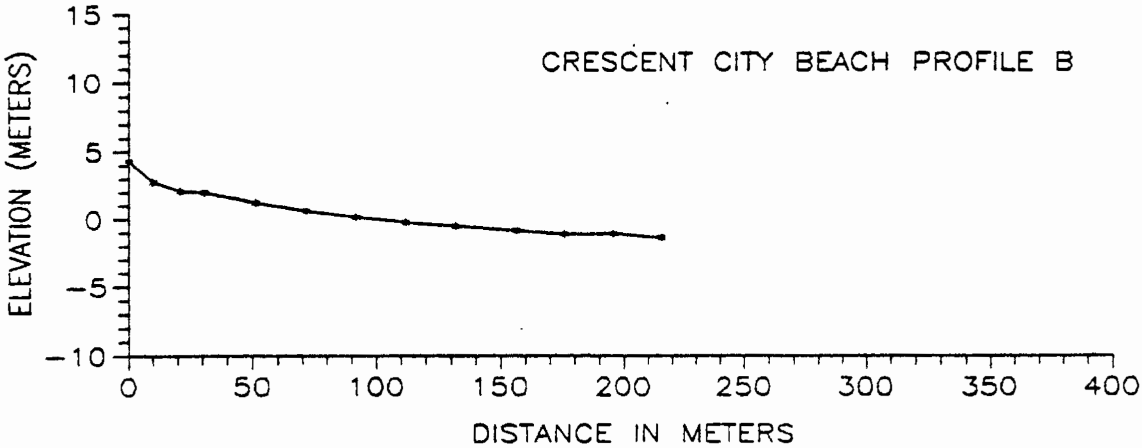
200
250
300
350
400


CRESCENT CITY BEACH PROFILE B
ELEVATION (METERS)
DISTANCE IN METERS
15
10
5
0
−5
−10
0
50
100
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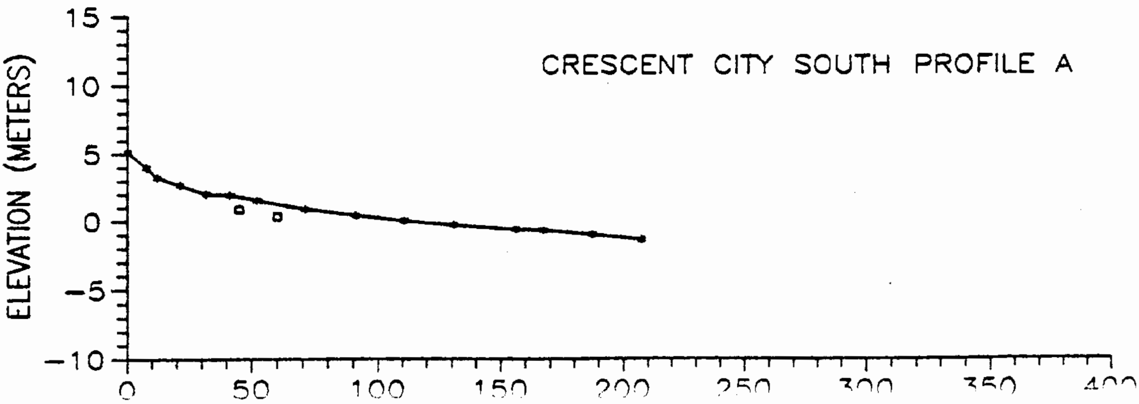
200
250
300
350
400


CRESCENT CITY SOUTH PROFILE A
ELEVATION (METERS)
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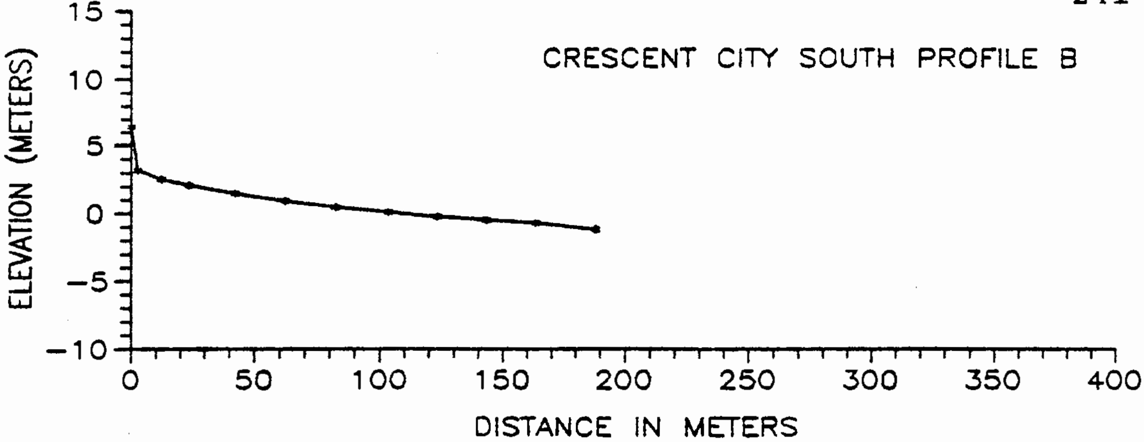
10
5
0
−5
−10
0
50
100


CRESCENT CITY SOUTH PROFILE B
ELEVATION (METERS)
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0
−5
−10
0
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100
150
200
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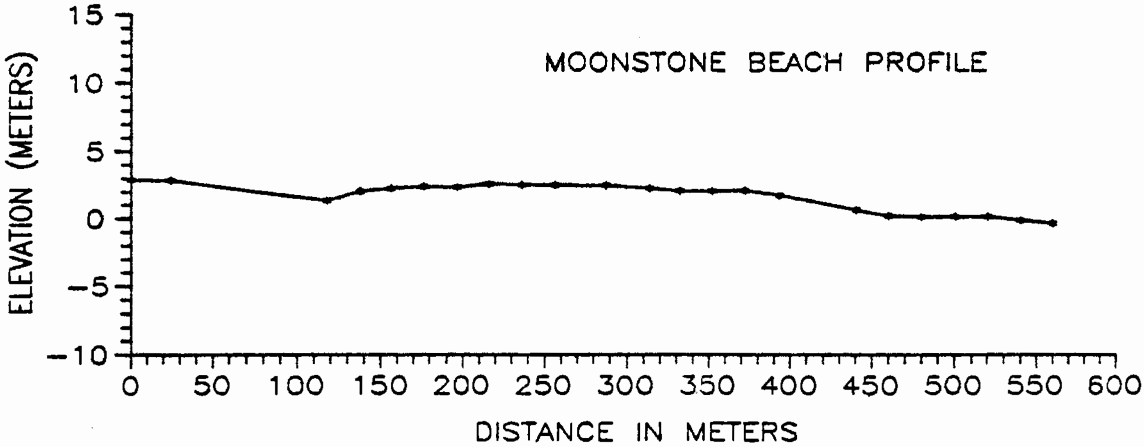
300
350
400
DISTANCE IN METERS


MOONSTONE BEACH PROFILE
ELEVATION (METERS)
15
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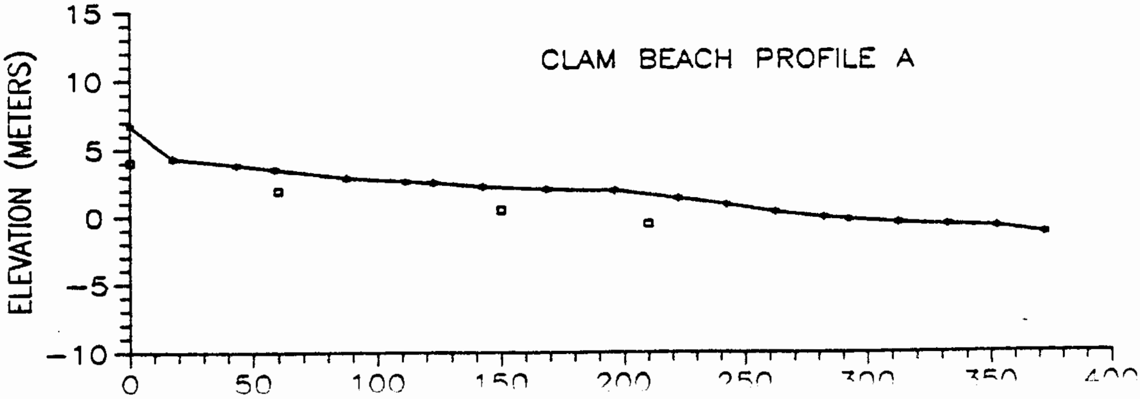
−5
−10
0
50
100
150
200
250
300
350
400
450
500
550
600
DISTANCE IN METERS


CLAM BEACH PROFILE A
ELEVATION (METERS)
15
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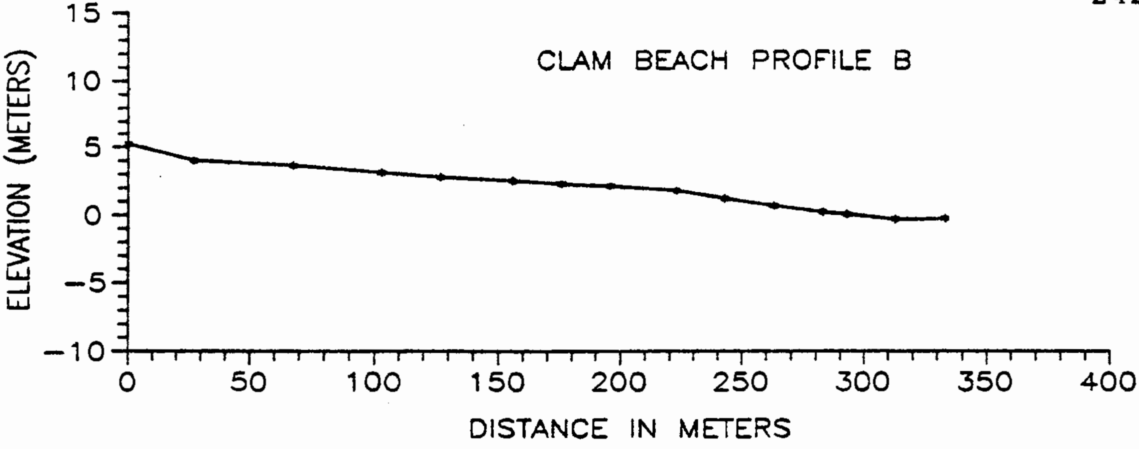
5
0
−5
−10
0
50
100


CLAM BEACH PROFILE B
ELEVATION (METERS)
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0
−5
−10
0
50
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150
200
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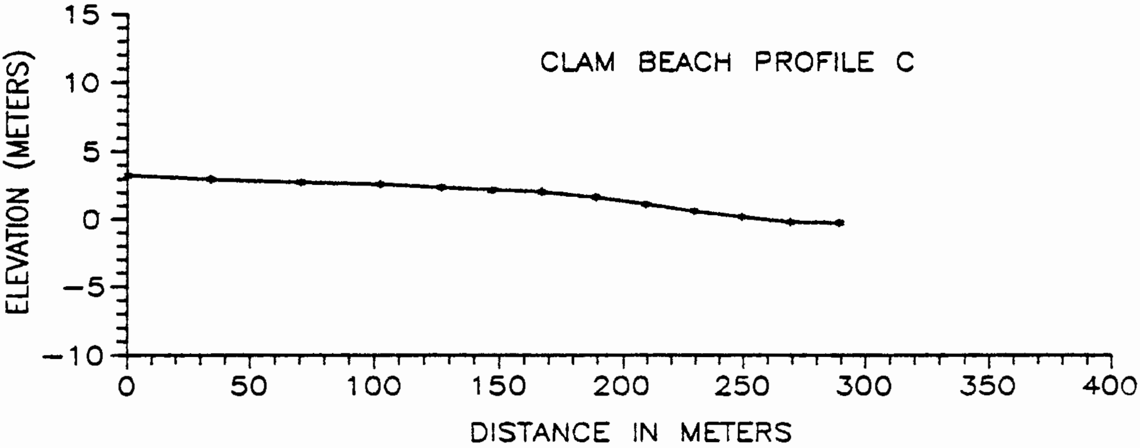
300
350
400
DISTANCE IN METERS


CLAM BEACH PROFILE C
ELEVATION (METERS)
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−10
0
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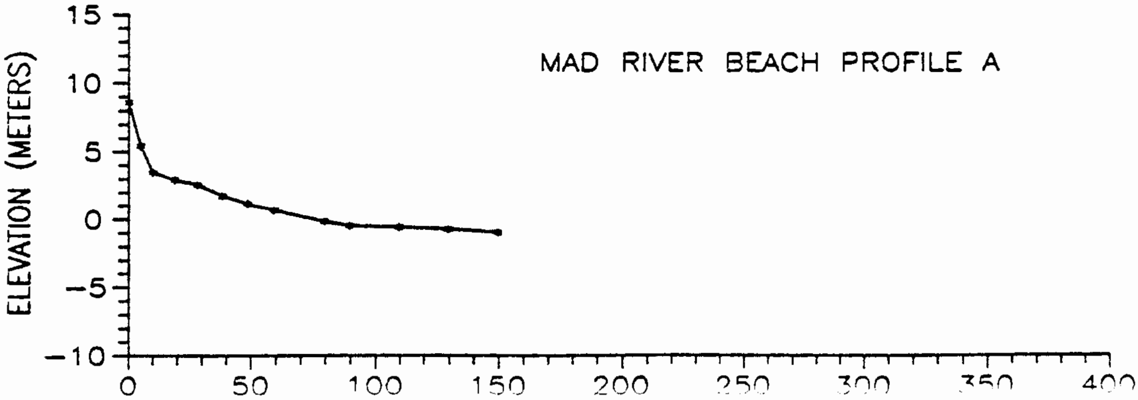
150
200
250
300
350
400
DISTANCE IN METERS


MAD RIVER BEACH PROFILE A
ELEVATION (METERS)
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−5
−10
0
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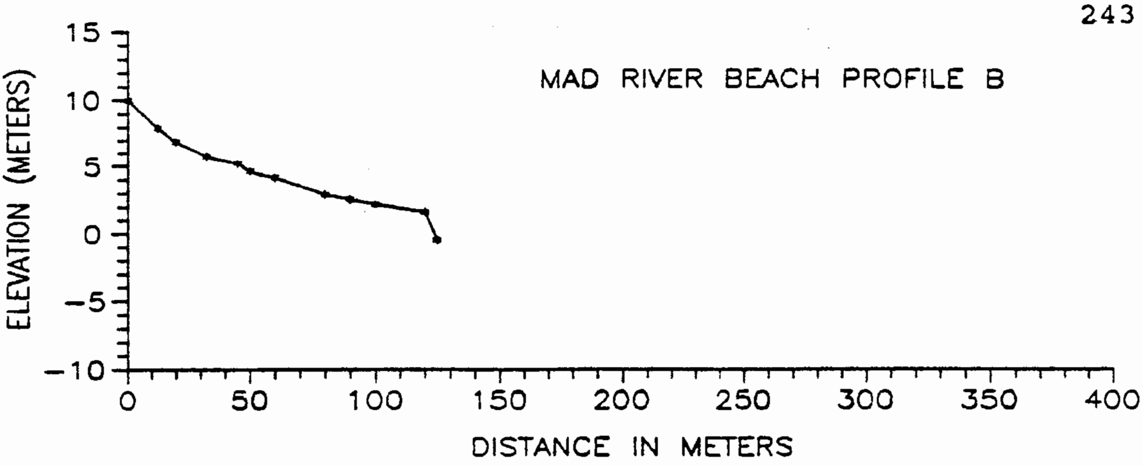
150
200


MAD RIVER BEACH PROFILE B
ELEVATION (METERS)
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−10
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150
200
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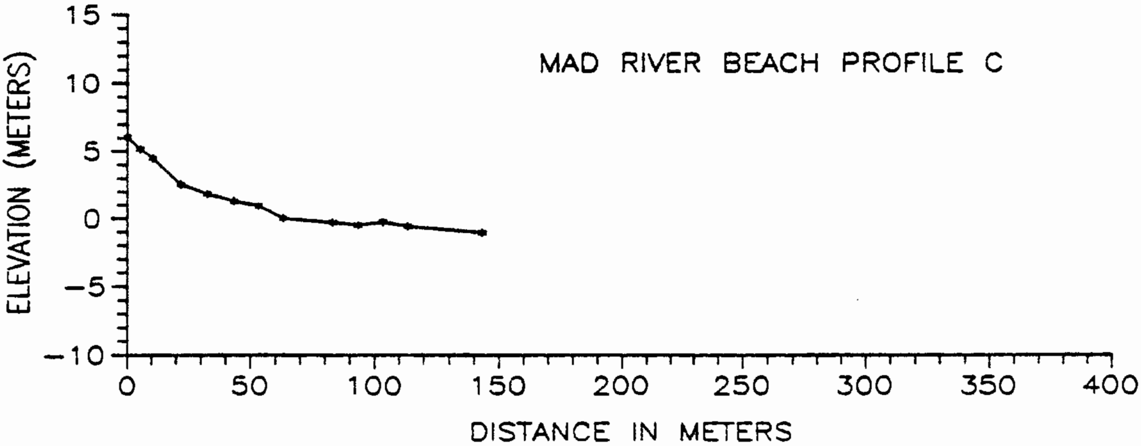
350
400
DISTANCE IN METERS


MAD RIVER BEACH PROFILE C
ELEVATION (METERS)
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−10
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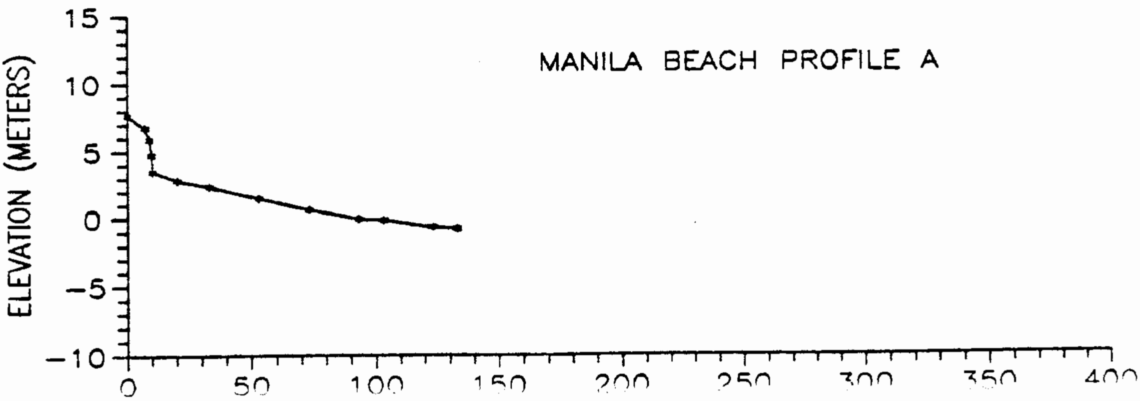
150
200
250
300
350
400
DISTANCE IN METERS


MANILA BEACH PROFILE A
ELEVATION (METERS)
15
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−5
−10
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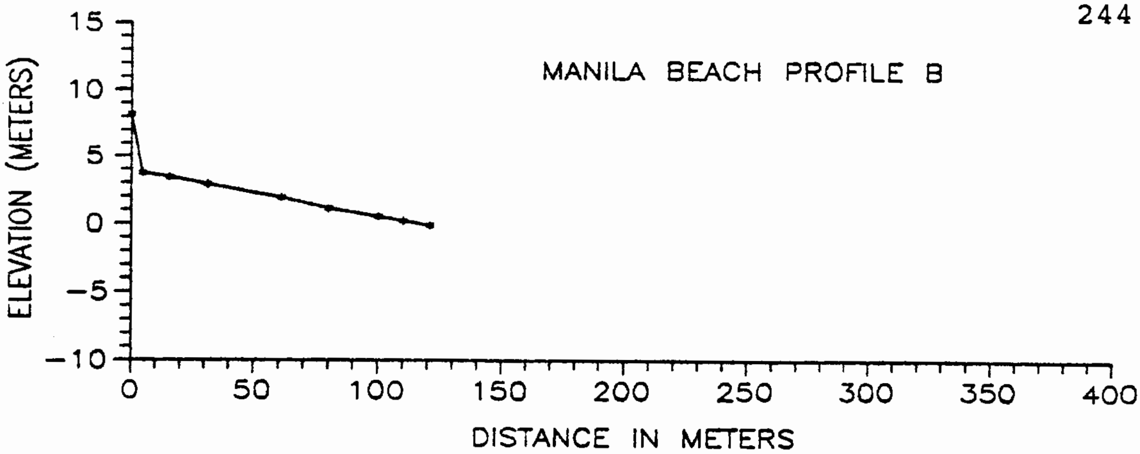
100
150
200


MANILA BEACH PROFILE B
ELEVATION (METERS)
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−5
−10
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150
200
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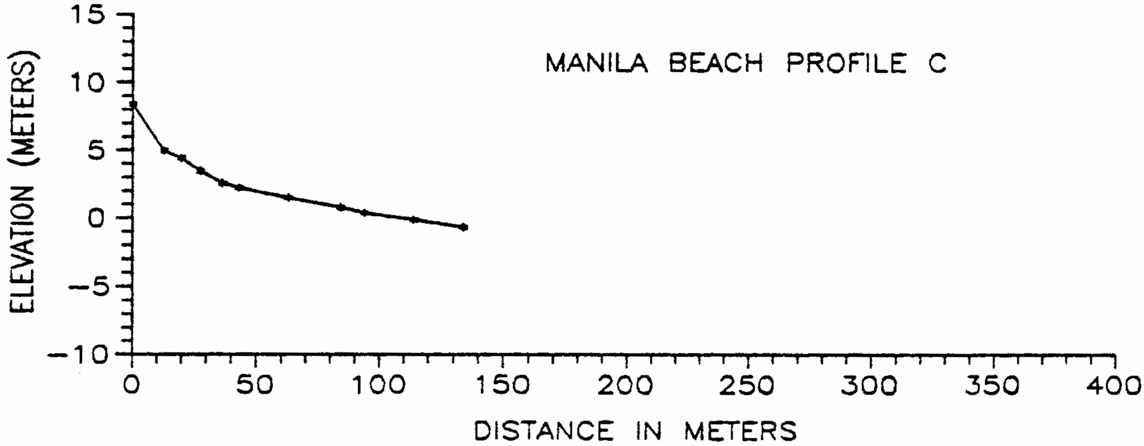
350
400
DISTANCE IN METERS


MANILA BEACH PROFILE C
ELEVATION (METERS)
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−5
−10
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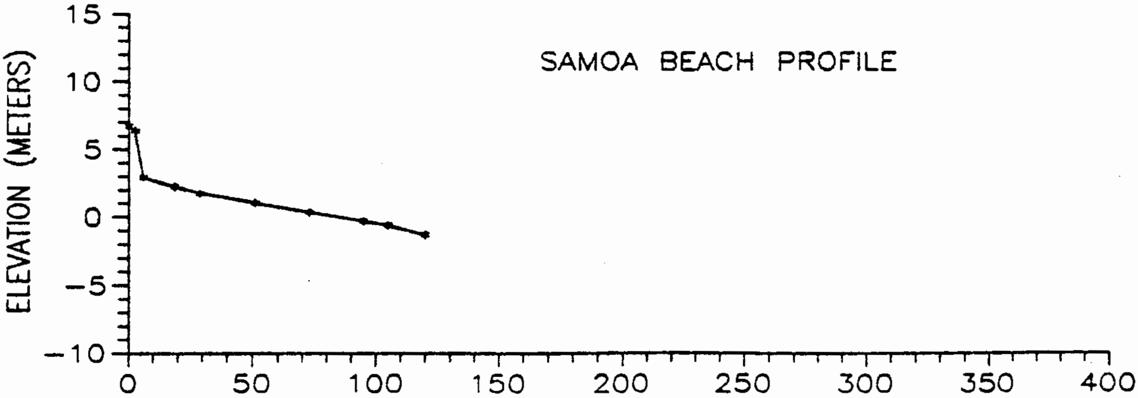
150
200
250
300
350
400
DISTANCE IN METERS


SAMOA BEACH PROFILE
ELEVATION (METERS)
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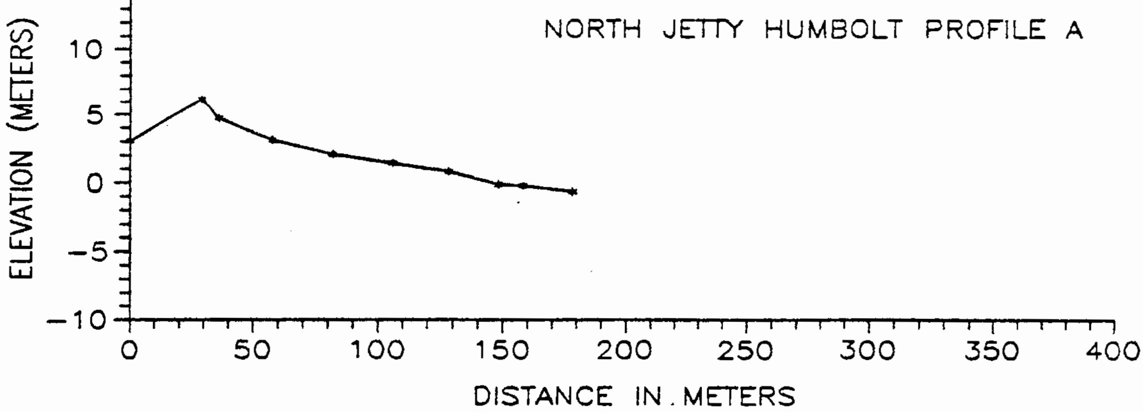
350
400


NORTH JETTY HUMBOLT PROFILE A
ELEVATION (METERS)
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0
−5
−10
0
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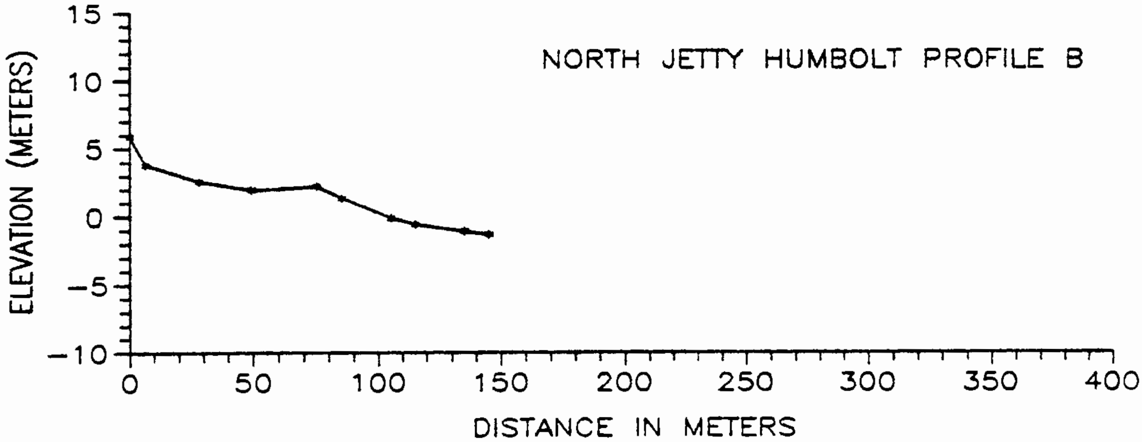
100
150
200
250
300
350
400
DISTANCE IN. METERS


NORTH JETTY HUMBOLT PROFILE B
ELEVATION (METERS)
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0
−5
−10
0
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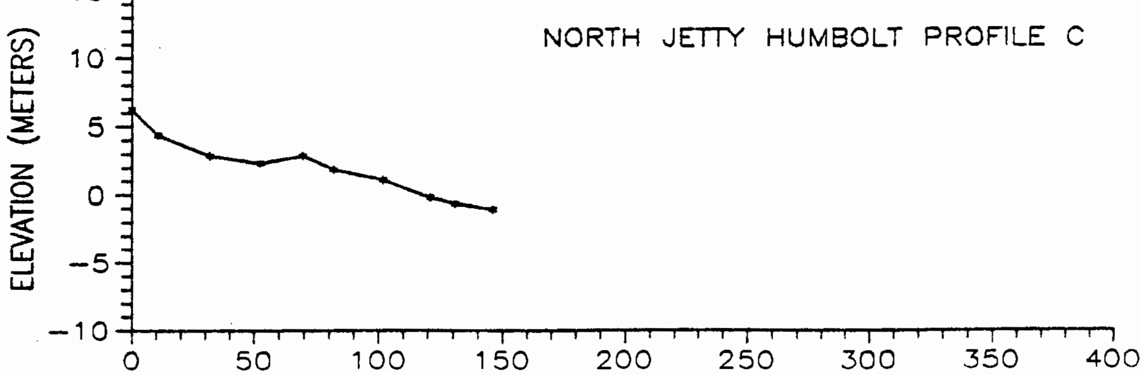
150
200
250
300
350
400
DISTANCE IN METERS


NORTH JETTY HUMBOLT PROFILE C
ELEVATION (METERS)
15
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0
−5
−10
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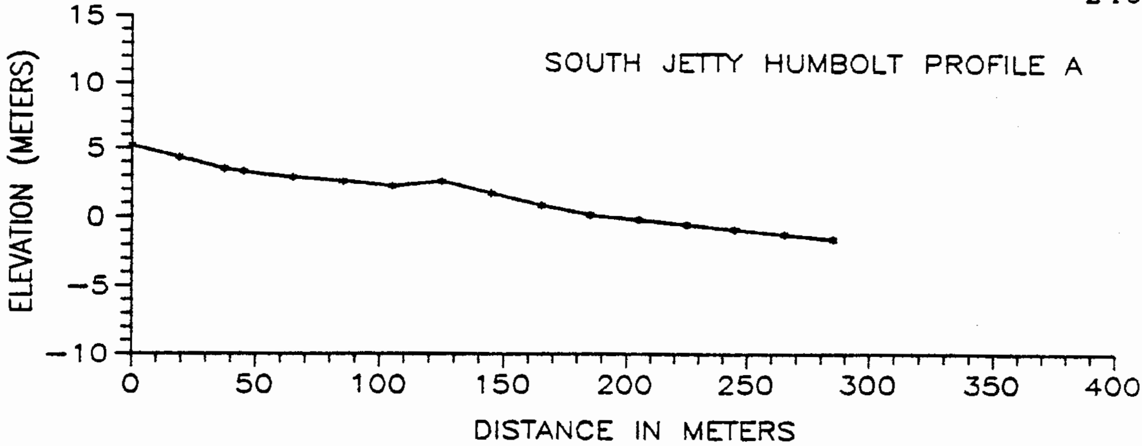
350
400


SOUTH JETTY HUMBOLT PROFILE A
ELEVATION (METERS)
DISTANCE IN METERS
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10
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0
−5
−10
0
50
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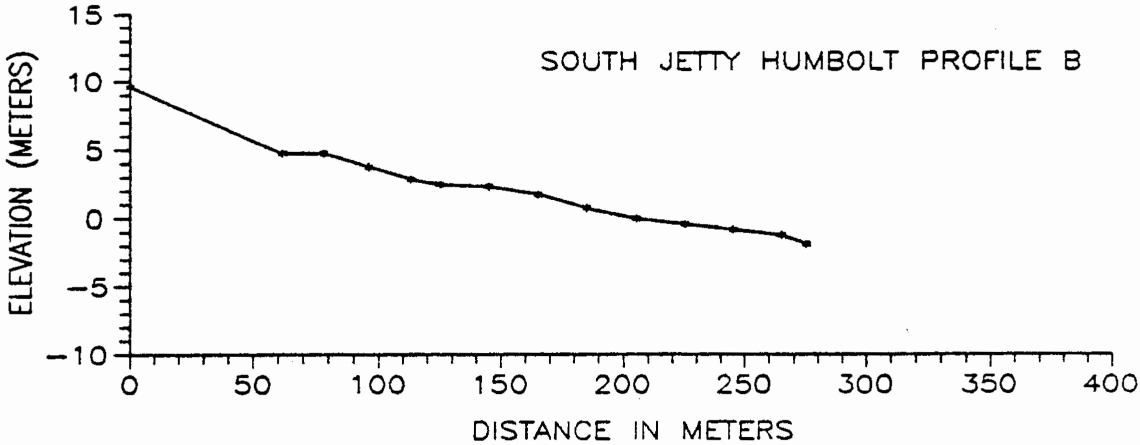
350
400


SOUTH JETTY HUMBOLT PROFILE B
ELEVATION (METERS)
DISTANCE IN METERS
15
10
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0
−5
−10
0
50
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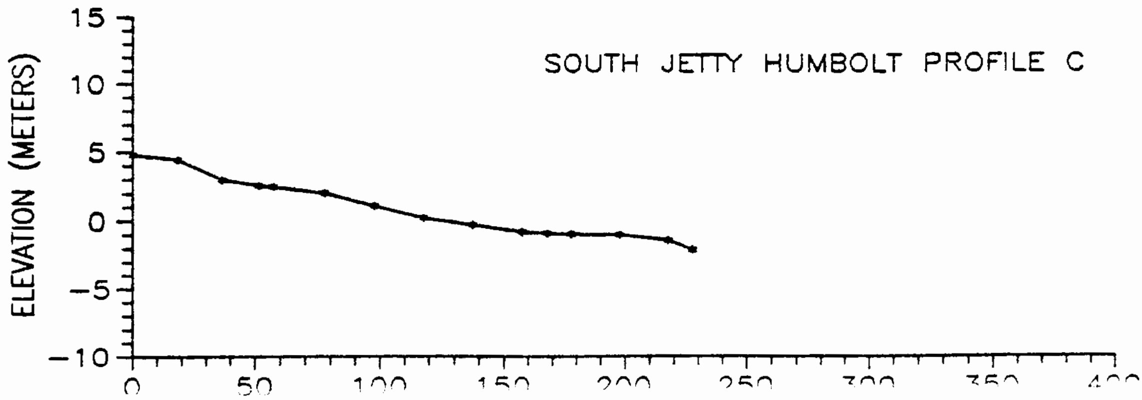
350
400


SOUTH JETTY HUMBOLT PROFILE C
ELEVATION (METERS)
15
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5
0
−5
−10

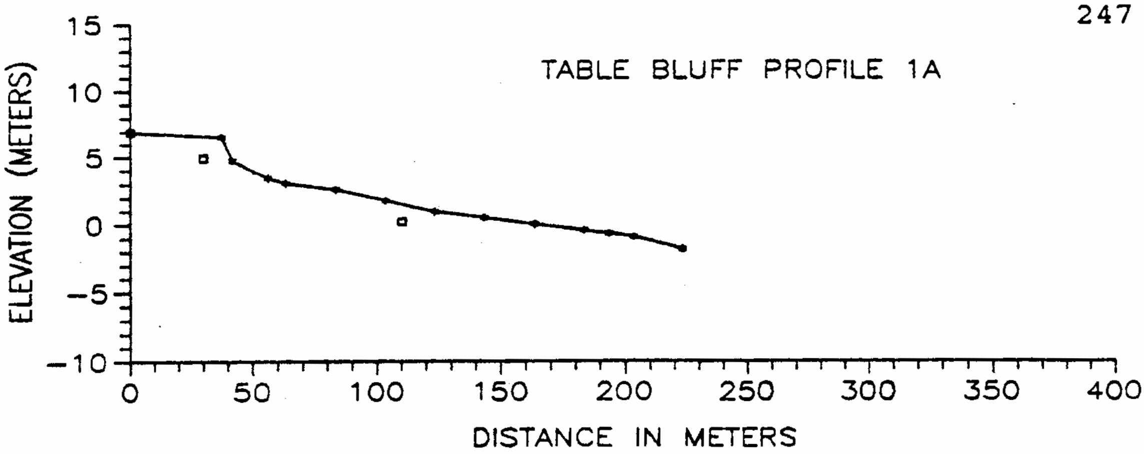
TABLE BLUFF PROFILE 1A
ELEVATION (METERS)
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0
-5
-10
0
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150
200
250
300
350
400
DISTANCE IN METERS

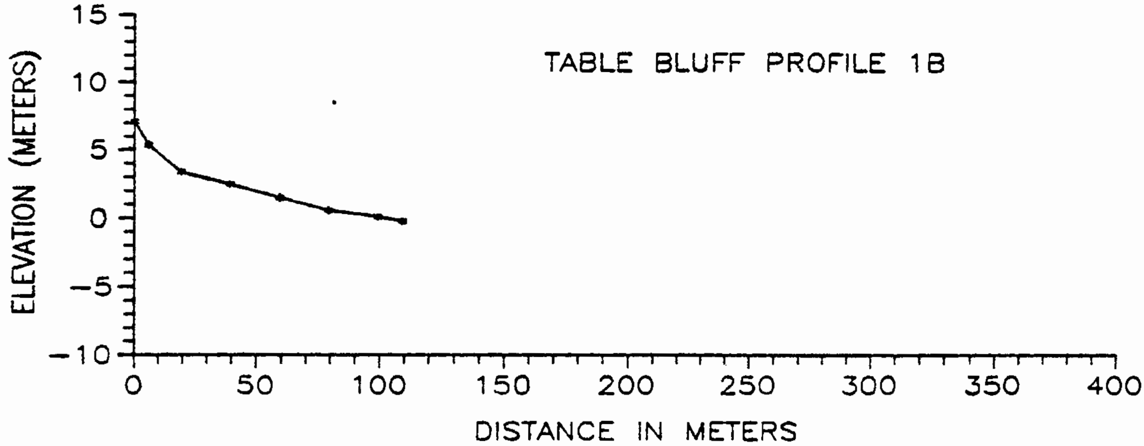
TABLE BLUFF PROFILE 1B
ELEVATION (METERS)
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0
-5
-10
0
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150
200
250
300
350
400
DISTANCE IN METERS

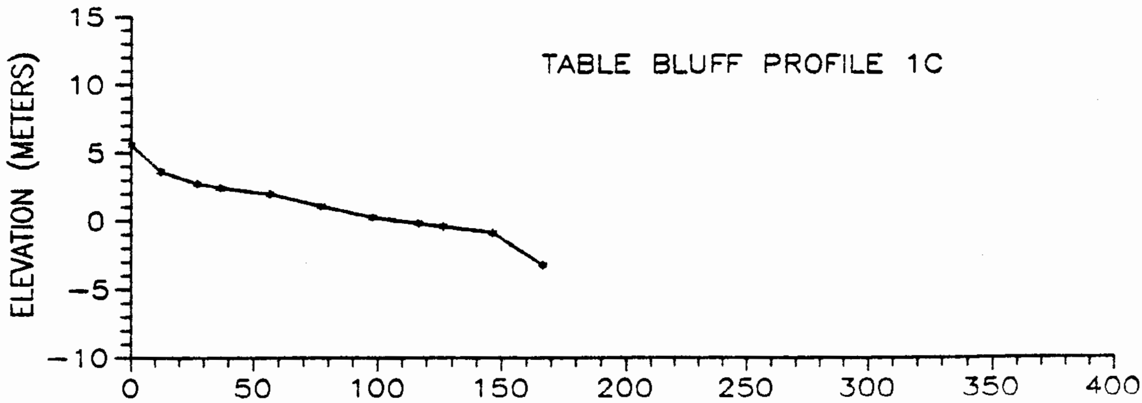
TABLE BLUFF PROFILE 1C
ELEVATION (METERS)
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-5
-10
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100
150
200
250
300
350
400

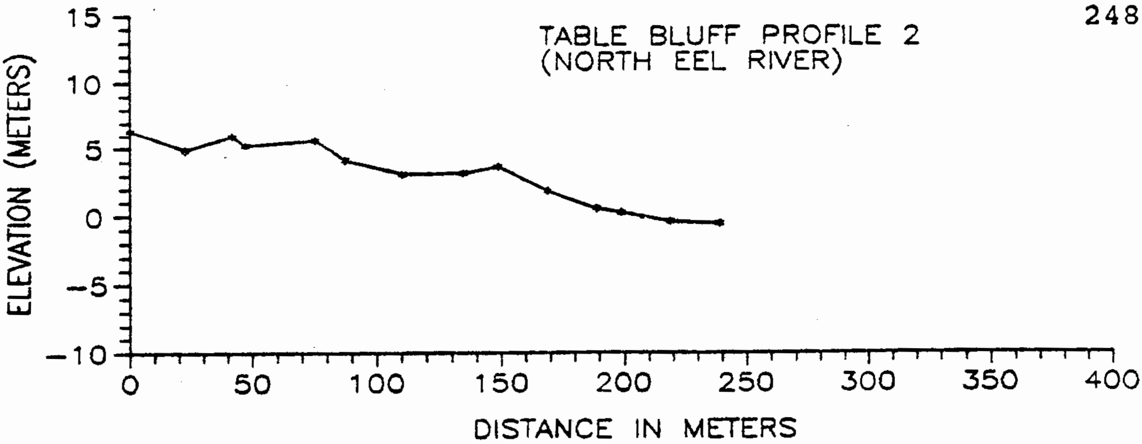
TABLE BLUFF PROFILE 2
(NORTH EEL RIVER)
ELEVATION (METERS)
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0
−5
−10
0
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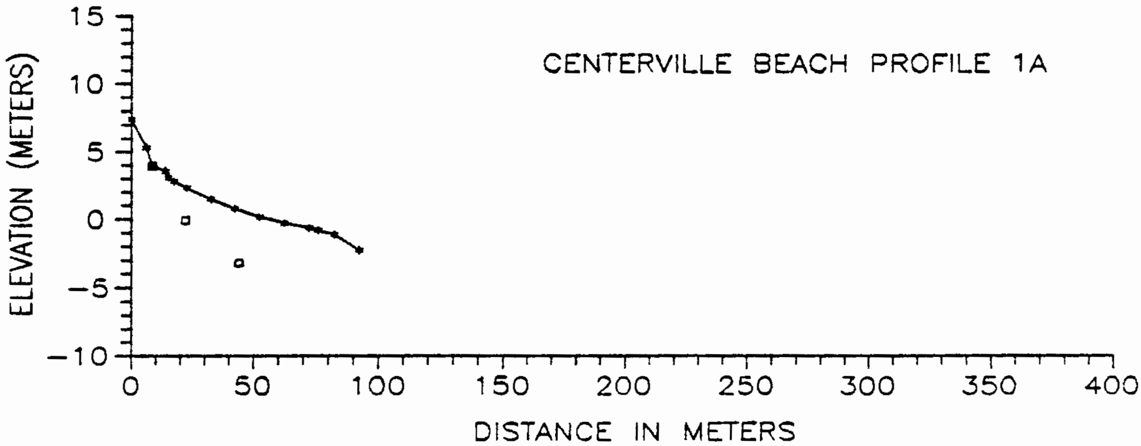
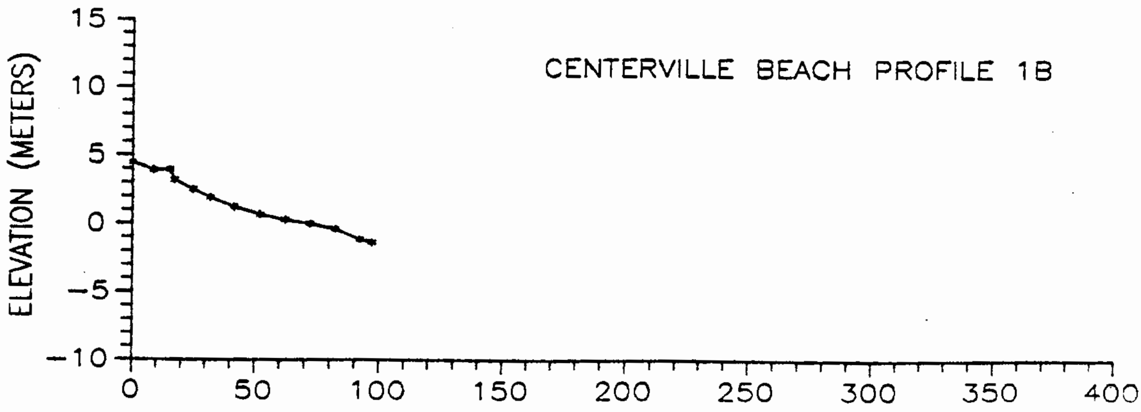
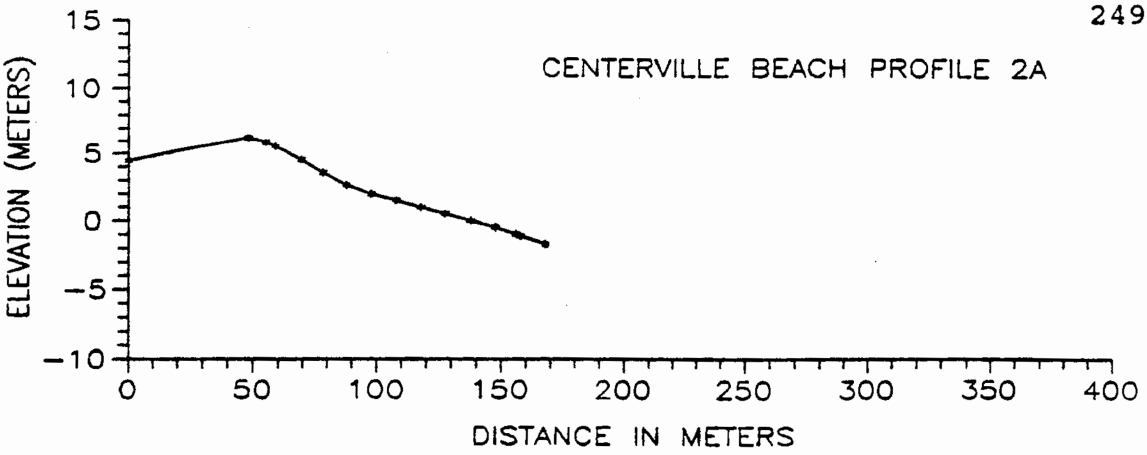
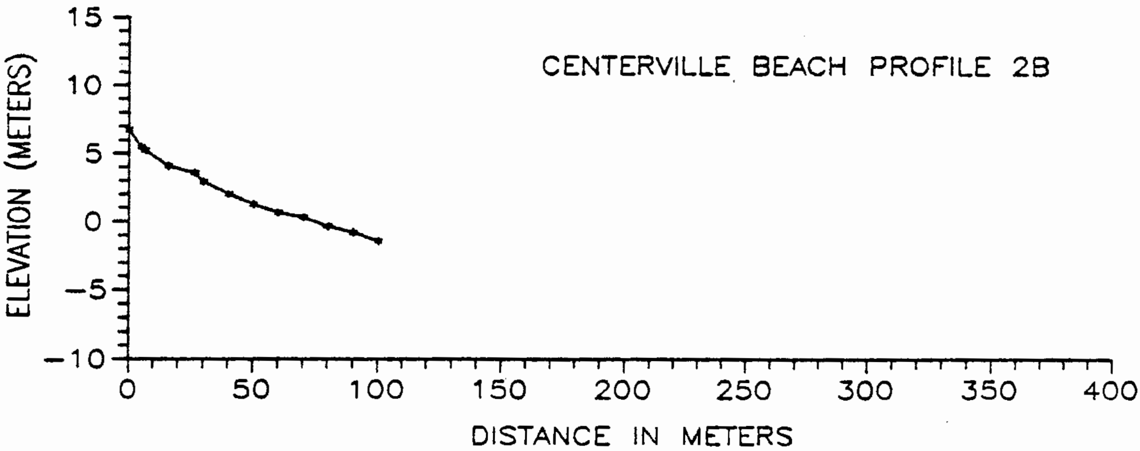
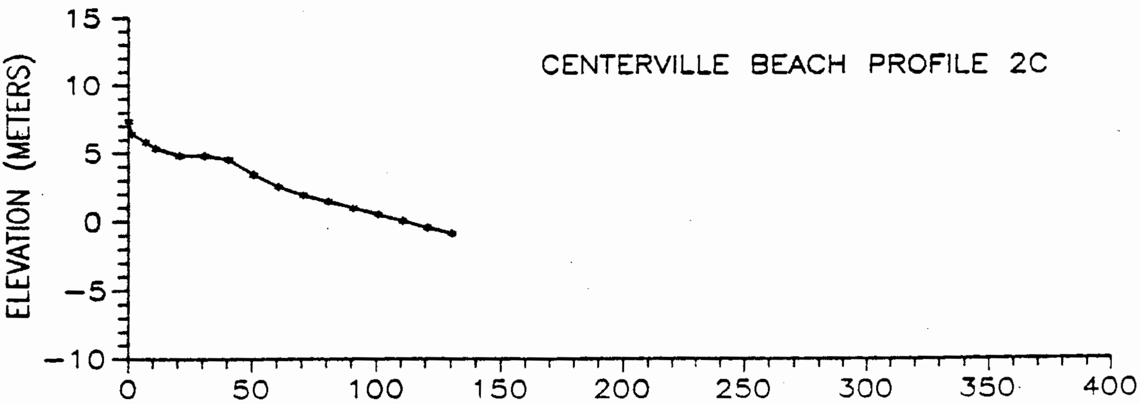
100
150
200
250
300
350
400
DISTANCE IN METERS


CENTERVILLE BEACH PROFILE 1A
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


CENTERVILLE BEACH PROFILE 1B
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400


CENTERVILLE BEACH PROFILE 2A
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


CENTERVILLE BEACH PROFILE 2B
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400
DISTANCE IN METERS


CENTERVILLE BEACH PROFILE 2C
ELEVATION (METERS)
15
10
5
0
−5
−10
0
50
100
150
200
250
300
350
400