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Holocene geologic history of the Clatsop Plains foredune ridge complex

David Karl Rankin
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AN ABSTRACT OF THE THESIS OF David Karl Rankin for the
Master of Science in Geology presented February 25, 1983.

Title: Holocene Geologic History of the Clatsop Plains
Foredune Ridge Complex

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Leonard A. Palmer, Chairman

Robert O. VanAtta

Richard E. Thoms

This research formulated a recent geologic history of
the Clatsop Plains dating from 3500 years BP to present.
Research consisted of geomorphic mapping, near-surface
stratigraphic evaluation, carbon dating and subsurface
interpretation of available data.

The Plains were formed from a series of arcuate shaped foredune ridges and interdunal flats oriented sub-parallel to the coastline. Groups of dune ridges and associated interdunes are differentiated by similar morphology separated by wave cut discontinuities which truncate dune forms. Ages of these prehistoric shorelines range between 3500 years BP, at the mountain front, to 110 years BP, some 1 to over 5 km west. Dune ridges within a group diverge from one another in two distinct patterns: Type A - where the ridge crests are sinuous and hummocky and the westernmost or youngest ridge acts as a main stem from which older truncated ridges branch and Type B - where the ridge crests are subparallel, continuous, and curvilinear and most ridges extend along much of the Plains length.

Sea level oscillations during progradation appear to show a sharp rise at 3500 years BP (initial growth) from -7 meters elevation, peak at 2200 years BP (-1 meters), drop to -3 meters and reversal at 1400 years BP and a rise to present.

Progradation rates apparently are maximum during level peaks and falling sea level. Major accretion occurred from 3500 to 1400 years BP. Between 1400 years (reversal) to 400 years BP, maximum growth occurred in the central Plains. Before and after this period, maximum

growth was in the north. Highest rates have occurred since jetty construction. The discontinuous and longitudinally non-uniform growth is likely due to fluctuating sea level and littoral sediment supply. The shifting zone of maximum accretion apparently is the result of a proportional shift in sediment supplied from the Columbia River or sediment dispersal patterns.

The dune mass rapidly accumulated under likely wet and low velocity conditions with variable influence of binding vegetation. Renewed sand activity appears to have been restricted to localized areas.

HOLOCENE GEOLOGIC HISTORY
OF THE
CLATSOP PLAINS FOREDUNE RIDGE COMPLEX

by

DAVID KARL RANKIN

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
GEOLOGY

Portland State University

1983

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the Committee approve the thesis of
David Karl Rankin presented February 25, 1983.

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CHAPTER I

INTRODUCTION

Purpose

The primary purpose of this research is to investigate the origin and development of the Clatsop Plains by examining the physical and historical record. The approach to this problem includes the following: (1) to describe the landforms and deposits of the area using geomorphic and stratigraphic techniques, (2) to investigate the field indicators of past processes affecting coastal progradation and other geomorphic modifications, and (3) to sample organic material for C^{14} dating to evaluate the rates of coastal progradation and history of relative sea level change.

The work centered on geomorphology, stratigraphy, and lithology. Other data evaluated included archeological dates, distribution of soils and vegetation, peat pollen analysis, and minor paleontological evidence.

Previous Work

Over twenty-five scientists have studied some aspect of the depositional environment of the Clatsop Plains. Beginning with the 1804 Lewis and Clark expedition, there

have been articles, maps/charts and books dealing with the area. After the exploratory period (1804 to 1930) there were three major periods of investigation: 1. circa 1930 -- the Soil Conservation Service sand dune stabilization project concentrated in the Warrenton area, 2. circa 1960 -- (apparently stimulated by Cooper's 1959 book) west coast universities looked into the oceanographic environment of coastal dunes, and 3. early 1970's to present -- environmental studies for coastal land-use planning were done including topographic and photo coverage with inventories of the geology, biota, lakes, soils and hydrology. Research on other barrier systems throughout the world have been performed predominantly after 1960. However, disputes over the theories of barrier development have been ongoing for the last 100 years.

- The Exploratory Period. Lewis and Clark were the first Caucasians to note the unusual nature of the Clatsop Plains. Their journals record the "hummocky nature of the dunes and the extensive undulating grass prairie," (Thwaites, 1905). Later during the Wilkes Expedition in 1839 to 1842, Dana (1849) described the dune ridges from the coast to the east, as a one mile wide "peneplain" with densely wooded ridges to the east. In 1896, Diller (for the USGS) suggested that a possible mode of origin was wind-blown sand.

The 1930's. Of those authors documenting the SCS vegetation stabilization of the dunes in the 1930's, Rowalt's (1936) work is the most comprehensive. Hansen (1941) later analyzed peat pollen from a peat profile sampled east of Gearhart on the Clatsop Plains. Hansen developed a progression of plant succession following the occurrence of blowing sand and forest fires on the Clatsop Plains.

The 1960's. Cooper's (1958) regional reconnaissance of the Clatsop Plains started the renewed interest around 1960. Included in Cooper's work are discussions of the Tertiary and Pleistocene/Holocene geologic history of the Oregon and Washington coast. Based primarily on air-photo mapping of the ridge crests, Cooper presented his theories on the (1) cause of initial progradation, (2) the contribution of wind and sand to dune size, and (3) the causes of anomalous geomorphology which he proposed were due, respectively, to (1) emergence of an offshore topographic high with a fall in sea level from a positive high, (2) fluctuating sediment supply, and (3) selective wind erosion of the foredune immediately landward of the beach front. At about the same time, Dicken (1961) presented a general history of changes since the construction of the Columbia River jetty.

Offshore studies include Byrne's (1963) presentation of submarine data from sonic mapping of the continental shelf. Ballard (1964) detailed the bathymetric changes proximal to the mouth of Columbia since 1792, identified the location of the 1870 shoreline and discussed the general oceanographic conditions and climate near the Clatsop Plains. Kidby and Oliver (1966) presented the original nautical charts of the mouth of the Columbia from 1792 and 1902 that Ballard used and they also mapped the changes in the high water line along Clatsop beach between 1934, 1963 and 1964.

The 1970's. For land-use planning, Clatsop county obtained low altitude color air-photo coverage in 1970 at 1:12000 scale. The U.S. Army Corps of Engineers (USACE) (1971) documented changes in high water mark from 1939 to 1968, Frank (1970) of the USGS defined the eastern limit of dune sand and the groundwater aquifer, performed mechanical analyses of sand samples taken in bore holes, and collected logs of most drilling performed on the Clatsop Plains. Geologic studies concurring with the theories by Cooper (1958), were performed by Lund (1972) who theorized on the development of the area, and Schlicker, et al. (1972), who contributed a surface geologic map. Detailed topographic coverage at 1:1200 and 1:4800 scale was provided by Clatsop County's ortho-photo topographic maps (1973).

Other works during the 1970's include (in chronological order) Sanderson et al., (1973) who performed an inventory of the lakes in the area detailing the lake elevations, depth soundings, bottom sediments, and surface drainage. For the Oregon State University Extension Service, Hansen and Harris (1974), Stockham and Pease (1974), Harris and Harris (1974) and Tolle (1974) performed inventories of the environmental geology, biology, soils, and hydrography, respectively, of the Clatsop Plains. Hasle (1974) performed radiocarbon dating on two shell middens. Phebus and Drucker (1979) presented three carbon dates in the Seaside area at shell midden sites and discussed the history of Indian habitation. Lizaranga-Araniega and Komar (1975) and Stenbridge (1975) discussed the shoreline changes due to jetty construction. Sweet (1977) and Sweet/Edwards (1981) performed extensive near surface drilling and testing of the groundwater aquifer. Palmer (1978), Lund (1979) and Curray (1980) offered their theories of development history. Rankin (1979 and 1980) summarized the scope of research for this work and the correlation between geomorphology and radiocarbon dates of organic peat soils on the Clatsop Plains.

Oregon-Washington Coast. Research on the adjacent Oregon and Washington coasts that pertain to the project area area as follows. Hansen, (1941 and 1942) developed a

summary of forest succession and climatic changes on the coast based on peat pollen analysis from profiles sampled outside the Clatsop Plains. Later, Detling (1968) also presented his interpretation of peat/pollen profiles and correlated them to climatic changes during the Pleistocene.

Sediment sources and dispersal patterns were investigated by many including Gross and Nelson (1966), Scheidegger et al., (1971) and Fox and Davis (1974). Three authors have contributed to the little research that has been done on Holocene sedimentation on the Oregon-Washington Coast. Twenhofel (1946), by mineralogical analyses, developed a theory on nearshore sand dispersal patterns during the Pleistocene and Holocene. Glenn (1978), through sediment analysis and radiocarbon dating, developed a Holocene geologic history of infilling of Tillamook Bay (located 20 miles south of the Clatsop Plains). And Avolio (1973) described the Tillamook Bay sediment distribution.

World Research of Coastal Barrier Systems. Numerous coastal barriers have been studied. Barriers similar to the Clatsop Plains are located in the Netherlands, Eastern Nigeria, Nayarit (Mexico), Australia, South Brazil, and the Gulf and Atlantic seaboard of the United States. Figure 1 includes a partial listing of contributing authors (see King [1972], for references).

World research of coastal barriers (partial listing): 1 - (Jelgersma, 1961; Pons 1963 et al; Van Straaten, 1965; de Jong, 1967; Hageman, 1969; Oele, 1971.), 2 - (Pugh, 1953; Allen, 1965; Godfrey, 1979), 3/4 - (Shephard, 1960; Otvos, 1970; Pierce & Colquhoun, 1971; Swift, 1975; and many others), 5 - (Bird, 1971; Thom, 1981), 6 - (Curry, 1969), 7 - (Bigarella, 1972), 8 - (Rosen, 1979).

Figure 1. World-wide distribution of coastal barrier deposits, (King, 1972).

Schwartz (1973) published a compendium of research on coastal barriers with emphasis on theories of the origin and progradation of barriers. Barrier research of note includes detailed stratigraphic work on the geologic history of the Netherlands (Van Straaten, 1965, and Hageman, 1969), and the coastal dunes of Brazil (Bigarella, 1972). Also, Thom, Bowman & Roy (1981) developed summary cross sections of selected barriers, Curray (1969) presented stratigraphy and theories on the depositional/erosional environment of selected barriers, and Hayes (1979) developed a morphological classification of barriers based on tidal range.

Procedure

The four main approaches of the investigation are summarized below: (1) Bibliographic Review, (2) Geomorphic Mapping, (3) Stratigraphic Investigation, and Carbon 14 Dating.

Bibliographic Review. A bibliographic search was performed at the start and was expanded during and after the field work. The references were read and evaluated for data and ideas on the developmental history of the Plains. Ideas and data were compared to the findings of this investigation as noted in this report.

Geomorphic Mapping. The purpose of geomorphic mapping was to evaluate continuity and trends of dune landforms. Surface traces of unconformities could then be identified for insight into the history of progradation, deposition and erosion of the barrier dunes.

Topographic control was facilitated by 1:4,800 and 1:1,200 orthophoto contour maps (Clatsop County, 1973). Field-controlled and computer plotted map contours were at 2-foot intervals (Refer to Figure 2 for example of an ortho-photo contour map). In conjunction with topographic mapping, 1:12,000 color air-photos (Clatsop County, 1970) were interpreted to evaluate regional trends and verify features shown on the topography plotted in the orthophotos. Topography shown on the ortho-photo map that did not appear on USGS quadrangle maps or in air-photos was field checked and adjusted on the project field map.

Geomorphic analysis was performed on the topographic/photo data base listed above. Trends were delineated and all anomalous relationships (e.g., ridge truncation, ridge divergence, etc.) were noted for later investigation in the field. The locations for east-west field traverses (refer to oversized Figure 9, Sections A-A' and B-B') were chosen because they were (1) representative of the ridges in the vicinity, (2) were considered least altered by

Figure 2. Example of photo-contour map, 1:4800 scale, (Clatsop County, 1973) reproduced here at 64% of original scale.

development and, (3) were determined to be most accessible.*

A summary map (1:24,000 scale) is presented on Figure 9 in back pocket. The base map provided from USGS (1949, 1949, 1949, 1951, 1953). The map includes details on ridge crest definition, break-in slope, spot elevations and other landform data.

Stratigraphy and Carbon 14 Dating. During the initial phases of stratigraphic evaluation, dune exposures were randomly sampled and the sedimentary structures were sketched. Interdune sand and peat deposits were also randomly sampled and classified. Later phases of field work then centered on examination of sites with anomalous stratigraphy, determining the eastern limiting extent of the Clatsop Plains sand, and determining the probable depositional environment of the dune and interdune deposits. Deeper subsurface data was utilized in conjunction with the above to evaluate the progradation of the coastline.

For this work carbon 14 dating was performed to define probable rates of and variations in progradation. The carbon dates were provided and also utilized by the USDA Soil Conservation Service for correlation with dated

*Access was not inhibited by density of vegetation because low density brush typically occurs in least altered areas.

soils and geomorphic surfaces in the lower Columbia River drainage (Parsons, Balister, and Ness, 1970).

Presented on Figure 9 (in pocket of back cover) and discussed lower in the text are the locations of radiocarbon dated samples, representative near surface samples, and peat depths or sample locations. Also presented in Figure 9 are the locations of all known published and unpublished borings logs. Four summary subsurface sections (A-A' through D-D') are located in Figure 9 and presented in Figure 17.

Dune ridge exposures were located using air-photos and topographic maps. Good exposures were found in road cuts and sand mining excavations which are scattered throughout the project area, especially in the northern portions. Trenches were dug by hand at selected locations. Refer to oversize map, Figure 9 for locations of dune exposures.

Sampling of unexposed near surface sediments was done with 3-inch bucket auger and a peat sampler. Bucket auger sampling of the interdune and dune sands was limited by (1) the groundwater table due to extensive caving below or by (2) refusal of the auger to penetrate underlying gravel deposits or very dense sands.

Sieve analysis followed accepted standards of laboratory procedure.

1. Each sample was placed in air-tight plastic bags in the field.
2. A representative portion of the sample was split in the laboratory, weighed, and dried in a 95° C. oven.
3. Since the silt or clay fraction comprised less than 5% of total, each sample was dry sieved over sieve mesh openings between 0.75 and 4.75 phi (phi = $-\log_2$ size in mm) at intervals of 0.25 phi.

In the interdune areas, peat samples were taken between 0 and 4.5 meters below ground surface. The peat was sampled by a special device imported from Europe some 40 years ago by H. P. Hansen, Oregon State University. Figure 3 is a photograph of the peat sampler. Sampler tip diameter is 3 cm and the length is 115 cm. Maximum sampling depth was 14 m using 1.5 meter sections.

The sampler tip provided relatively undisturbed and uncontaminated samples of peat though it could not penetrate sand or other dense material. A metal sheath with a lip on it surrounds the hollow sampler. The tip is augered into the peat clockwise with the sheath closed around the sampler. At the sampling interval, the sheath is opened by counterclockwise rotation, the lip then scrapes peat from the sidewalls of the borehole into the sample tube. Clockwise rotation then closes the sheath around the sample and the peat is retrieved.

Later all peat samples were classified in the

Figure 3. Photograph of peat sampler tip and section end.

laboratory and analyzed for the percent of sand per unit volume and relative pollen count.

Carbon 14 dating peat samples and one log were selected for carbon dating. The sampling procedure is as follows: Five to six sample increments (each 0.1 to 0.15 m vertical thickness) were collected from each dating depth and location. Also, the sampler tip was thoroughly washed with clean water between sample locations. A minimum of 50 grams of peat is needed for accurate carbon dating. The total weight of each sample collected exceeded 200 grams. Each sample was triple-wrapped in thick plastic bags and shipped in hard plastic containers. The University of Washington Carbon Dating Center confirmed that the above method of sample containment avoids contamination by fresh carbon. To insure minimum contamination, a laboratory 50 gram sample was taken from the center of the peat specimen.

Location of radiocarbon dated sample sites plus 3 supplementary archeological dates are presented oversized Figure 9. Locations of the peat samples were selected to be representative of the historic development of peat deposits throughout the project area. Most samples were taken at the bottom* of the peat interval for correlations

*Effects of compaction are eliminated as the underlying sands are not subject to significant settlement especially at depths less than 4 meters typically found in the project area.

with sea level curves. One sample was taken at an intermediate level to evaluate the rate of peat accumulation.

Results of the carbon dating are presented in Table III and discussed in the section on dating. Results of the percent sand per unit peat volume are presented in Figure 14 and pollen analyses performed by Hansen (1941) and Maine (1979) is summarized in Figure 15; the above is discussed in the sections on interdune stratigraphy and radiocarbon dating.

Project Location and General Description

The Clatsop Plains are part of an estimated 10 to 13 percent of the world's coastline consisting of "barrier coasts." An operational definition of barrier coasts is one which includes "all linear, detrital, topographic features along present coastlines which were less than 10 meters above sea level and which are impounding, or at one time have impounded, bodies of water between themselves and the mainland" (Schwartz, 1971).

Location. The Clatsop Plains is located on the north coast of the State of Oregon, U.S.A. The area is situated immediately south of the mouth of the Columbia River. (Refer to Figure 1 and 4 for site location.) The longitudinal limits of the project area are well defined with the Pacific Ocean to the west and the Coast Range to

Figure 4. Vicinity map of the Clatsop Plains, northwest Oregon coast, U.S.A., (Meyer and Chester, 1977).

the east. The deposit is almost 30 km long, averaging 2.4 kilometers wide. The Plains range in east-west dimension from approximately 4.5 km, proximal to the Columbia River, to less than 1 kilometer wide 30 kilometers to the south. Total area of the deposit is approximately 73.8 square kilometers or 28.5 square miles. The deposit is small compared to other barrier complexes some of which are over 25,000 km².

Topography. The surficial landforms on the Plains consist of a series of multiple ridge foredunes oriented subparallel to the coastline separated by nearly flat interdune plains. Elevations of the ridges range from 5m (15 ft) to approximately 30m (100 ft). Low areas between the ridges range in elevation from less than 3m (10 ft) to over 10m (30 ft). See Figure 5 for representative view of the Clatsop Plains at Sunset and West Lake. There are 21 north-south oriented lakes scattered throughout the interdune areas. Distribution of the ridges and lakes are presented on the oversized Figure 9 and discussed later in this work.

Soils. Slight soil development occurs only in the eastern portions of the project area. The degree of soil development increases with distance from the coastline with Westport fine sand near the existing foredune and

Figure 5. Oblique view of south-central Clatsop Plains
in vicinity of West and Sunset Lakes, (Lund, 1979).

Warrenton loamy fine sand found on ridges near the mountain front. [Refer to Figure 6 for a summary of soil types on the Clatsop Plains.]

Economic Resources. Some important economic resources of the Clatsop Plains include the following: (1) ground water, (2) dune sand, (3) land for development and natural preservation and (4) port facilities.

Ground water is generally potable and near the surface though some wells have excessive iron concentration. The largest suitable groundwater aquifer is approximately 10 miles north of Gearhart and west of Highway 101 (Frank, 1970 and Schlicker, et al., 1972).

Dune sand has been used for miscellaneous landfill and has been studied as a mineral source. In engineered fill, sand bulking (pore pressures inhibiting maximum compaction) problems are overcome if the sand is slightly dampened before compaction. Cranberry farms also use sand to improve peaty soils. The mineralogical value of the sand was studied in the Hammond area in 1944 as part of the war program exploring for new sources of iron and alloy minerals. Some dark mineral layers possessed up to 33% iron and 10% TiO_2 . The project was never seriously considered for a number of reasons including a low placer/overburden thickness ratio (Kelly, 1947). A renewed interest occurred in 1963 when the Bunker Hill Company of

WEST

EAST

Figure 6. Soil types on the Clatsop Plains, (USDA, no date)

Kellogg, Idaho applied for a 3,000 acre mining lease in Warrenton, (Oregon Dept. of Geology and Mineral Industries, 1963). At present, no mining has been attempted.

The beaches and dunes are valuable as an economic resource from the standpoint of development and natural aesthetics. Hotels, motels, beach houses, and permanent residences occupy much of the coast. Many tourist and permanent resident facilities are oriented to provide beach and dune recreational and viewing opportunities. Accretion to the coast in the recent past has provided a wide, high quality, underdeveloped beach and dune zone along the coast.

The Clatsop Coastal Plain also provides a natural harbor for shipping, fishing and sport boating. Warrenton is a community based upon fishing and other sport boating providing a protected harbor on the Columbia River estuary's side of the barrier dunes.

Development. The population is concentrated in the north at Warrenton and in the south at Gearhart and Seaside with scattered housing developments and farmhouses elsewhere. Most roads are built parallel to the coastline on top of the ridge crests. Miscellaneous filling and excavation has been performed over the past few decades of American settlement, much of it in the Warrenton area

proximal to the Skipanon River in the north (refer to Figure 21 for location of large cut and fill). These alterations have caused some major surface drainage changes in the central Plains.

Prior to the 1940's, normal drainage from Cullaby Lake flowed into Neacoxie Creek flowing north 5 km, reversing direction and draining into Sunset Lake and Necanicom River in the south Plains. Also, at this time, overflow from high water levels drained out the south end of Cullaby Lake. Presently, surface water drains north along the Skipanon Canal (excavated and maintained since the 1940's) located against the mountain front.

Because of decreased flow and filling (especially at Camp Clatsop in the central plains) the Neacoxie drainage has a slightly larger marshy area.

Vegetation. A gradual succession of plant species from sand binders to climax forest is presently represented on the Clatsop Plains from the coastline to the eastern limits. Figure 7 is a diagram of the four alternate progressions of vegetative succession. The progressions begin with bare sand and progress through species of grass, shrubs, then pine forest, and eventually spruce or hemlock forest. The route the succession takes is generally a function of the activity of the sand and the surface elevation above groundwater.

Figure 7. Plant succession on the Oregon coastal sand dunes, (Stockham and Pease, 1974, after Wiedemann, 1966).

The shore pine (Pinus contorta) is considered a pioneer conifer (i.e., relatively tolerant to salt spray and sand burial). The shore pine typically replaces the spruce in areas of low groundwater, takes over burned areas (Hansen, 1941) and typically is short lived (less than 100 years) until the sitka spruce succeeds it (Cooper, 1948). For discussion of the succession of plants on Oregon and Washington coastal dunes, refer to Cooper (1958), Hanneson (1962) and Wiedemann (1966) and Wiedemann, et al., (1974).

For discussion of existing coastal conditions at the Clatsop Plains, refer to Appendix A. Topics presented include: climate, wind, waves, currents and sediments transport and supply, as well as discussion of the geologic setting up to the early Holocene just prior to the development of the Clatsop Plains.

CHAPTER II

GEOMORPHOLOGY

Introduction

The descriptive geomorphology presented herein comprises the basis for much of the interpretative effort summarized in later sections of this work. The areas of geomorphic research can be divided into six major groups: (1) general characteristics of the dune ridge and interdune areas, (2) north-south trends observed in plan view of the Plains, (3) east-west landforms viewed in slope profile, (4) subdivision into groups of dune and interdune areas with similar morphology separated by surface discontinuities, (5) focused observations of discontinuities within groups, and (6) documentation of historic changes to the Plains since the early 1800's. Items 1 through 5 are presented in the following pages. Refer to Appendix B for discussion of recent changes to the Clatsop Beach.

General Characteristics

Dune ridge elevations range from 6.1 m (20 ft.) to 30.5 m (100 ft.). Ridge height above the interdunal areas

range from 1.5 m (5 ft.) to over 27.4 m (90 ft.). Typical slopes for the dune ridges range from 3 to 27 degrees from horizontal with the west slopes generally steeper than east slopes. Interdune areas can be subdivided into two types as a function of elevation above to the groundwater table: (1) dry interdune, and (2) wet interdune. Dry interdune elevations range from +1.5 m to +12 m and slopes are relatively flat or dip a few degrees to the west or east. Dry interdune surfaces are hummocky in areas, but typically smooth especially in low and perennially wet interdunes where peat has formed. (Refer to Figure 8 for a photo of a representative dry interdune). Wet interdune areas that are wet year-round range in elevation from +3 m to +5 m which roughly corresponds to local groundwater elevations. Slopes are typically flat and very smooth. Refer to oversized (in back cover pocket) Figure 9 for details.

North-South Plan View

In general, the width of dune ridges and interdunes increases from south to north where the result is a divergence of ridge crests to the north. In the south, dune ridges are 60 to 150 meters wide, averaging 90 meters. Some ridges in the extreme west are 300 meters wide because of SCS vegetation stabilization. Ridges in the north range from 90 to 240 meters wide, averaging 120

Figure 8. Representative interdune area, (this work, 1982)

meters. A corresponding increased interdune width is shown by comparing the south area (30 to 370 meters, averaging 150 m) and the north (60 to 1500 meters, averaging 240 meters). Dune ridge elevations greatly increase and interdune elevations slightly decrease in the vicinity of the Columbia River north of the Clatsop Plains. Individual ridges that span much of the Plains length are up to 50 percent higher in elevation in the north than the south. Also, dune slopes and crests typically are less smooth and continuous in the north versus the south Plains.

The zone of south to north morphological transition is relatively abrupt and appears to be located in the mid-section of the Clatsop Plains just north of Camp Clatsop Military Reservation.

The widening interdune areas and the corresponding divergence of ridges to the north has two distinct forms: Type A with branching, sinuous and hummocky ridge crests and, Type B with subparallel, relatively continuous, straight and smooth crests. Refer to Figure 10 for representation of the two forms. In Type A divergence, it appears that the youngest ridge (westernmost) is relatively intact and older ridges branch away to the east from the younger main stem. In Type B divergence, all of the ridges are relatively intact through the length of the

Figure 10. Schematic of two basic forms of south to north divergence.

group of ridges. (Refer to later section on geomorphological groups and discussion of ridge length comparisons on Table I.)

East-West Profile

In general, interdune surfaces rise to the west from +2 meters to over +10 meters. Also, maximum dune ridge elevation and maximum height above the surrounding interdune occurs in the central portions of the east-west sections. Within the area of SCS vegetative stabilization in the west, dune ridge elevation and height above the interdune decreases. Slope profiles were measured from orthophoto contour data (computer plotted and field controlled 2 foot contour intervals) and confirmed by field measurements and other observations recorded at each dune ridge and interdune along selected sections at A-A' and B-B'. These two sections of the four represented in this work, were chosen to be representative of the project area. Refer to Figures 9 and 11 (both in back pocket behind text) for section locations and graphical display, respectively.

Section A-A' (shown in Figure 11) was chosen to represent morphology in the area of ridge divergence. The following is a brief summary of descriptive field observations along the section line. From the extreme east against the 7 meter (22 ft.) high Pleistocene terrace

and for 1.5 kilometers westward to Long Lake (station 9 referring to Figure 11), the interdune elevation increases from +2.5 to +5.5 meters above mean sea level (MSL). The interdune sand surface is no lower than +2.5 to +3.0 meters with the topographic components of the lakes and peat removed. West of Long Lake, interdune elevations range from +7 to +12 meters with an apparent elevation drop to the west.

In the easternmost 900 meters (station 5 to mountain front) ridges are low and shallow with one to two meter crests above the interdune surface and side slopes range from 1 to 3 degrees from horizontal with side slopes of 1 to 3 degrees from horizontal. In the 650 meters between stations 5 and 9 (Long Lake Smith and area), ridges are higher and steeper ranging in elevation from 12 to 13 meters above interdune surface with side slopes of 20 to 30 degrees east and west of the ridge crests. In the remaining 1.6 kilometers west of station 9, the dune ridges (10 to 30 degree side slopes) rise 1 to 5 meters above a hummocky interdune surface. The surface west of station 10/9 has been altered by SCS vegetative stabilization of blowing sand, according to Rowalt (1936).

Section B-B' (refer to Figure 11) was chosen to represent that portion of the Clatsop Plains (1) with

relatively continuous or uniform ridge and interdune morphology and (2) the area south of the point where ridge divergence occurs. In the extreme east, west of the +10 meter marine terrace, the older Pleistocene upland surface slopes westward 24 degrees down to the Clatsop Plains interdune which overlies the older surface at +3 meters. The easternmost dunes from Skipanon Canal to Sunset Lake 1.3 kilometers from station 2 to 14, wet interdune elevations increase from +3 to +6 meters. Removing the topographic component of peat and lakes, the minimum wet interdune elevation ranges from +2 to +3 meters. Higher dry interdune areas increase from +4 meters in the east to +8 meters in the west.

The dune ridges in this area are varied. In the east 1/4 km, stations 2 to 6, ridge side slopes are moderate ranging from 14 to 25 degrees and the ridges are elevated 4 to 5 meters above the interdune. Side slopes ranged from 3° to 5° at station 7 where undulating and discontinuous 2 to 3 meter high ridges are common. Side slopes of the steep dune ridge between station 8 and 9 were 5-7° and 24 to 26°, respectively. The dune ridge here is 8 to 10 meters above the interdune surface. At station 10, discontinuous and undulating ridges approximately 1 to 2 meters above the interdune with side slopes of 1 to 3 degrees were found.

The group of four ridges at station 12 display uniform characteristics. East slopes of the steep, high ridges were relatively straight-line (angle of repose) at 24 to 29 degrees. West slopes were measured 27 to 38 degrees with a hyperbolic or flattened "S" profile with a straight-line (angle of repose) midsection. The flat ridge crests are about 10 meters wide with unusually uniform continuity along the length of the ridges. Where unaltered slopes are uniform, and continuous laterally over 1 kilometer near section B-B' and southward, the crests converged to less than 50 meters apart with a shallow interdune less than 4 meters deep. The interdune elevation is approximately +12 meters and dune ridges are elevated 6 to 8 meters above the interdune surface.

To the west, the surface at station 14 slopes 5° east. West of this point, the banks of Sunset Lake are oversteepened to over 30° by water sapping at the slope base.

The remaining 1.1 km wide area between Sunset Lake and the coastline has been altered by blowing sand and subsequent stabilization efforts by SCS. Moderately steep dune crests are typically hummocky, discontinuous and wider than the unaltered areas east of Sunset Lake. Interdune elevations in this area climb to a high of +12 meters at station 15 and drop westward to +6 meters behind

the primary dune at Station 20 (west of station 19). Dune ridges are 3 to 9 meters above the interdune surface.

Sections C-C' and D-D' located on Figure 9 (in back cover pocket) were developed from topographic data without much field data because the ground surface has been altered by residential and commercial development to the point of obscuring natural conditions.

Slope sections A-A' and B-B' are presented in Figure 11 at 1 inch=100 meters horizontal scale. All four sections A-A' through D-D' are presented in Figure 33 (stratigraphic sections) at 1-inch=200 meters horizontal scale vertical exaggeration is 10x on both Figures 11 and 33.

Based on the foregoing north-south and east-west observations, the Clatsop Plains can be subdivided into distinct morphological groups.

Geomorphological Groups

The Clatsop Plains foredune ridges can be divided into distinct geomorphological groups separated by surface discontinuities. Dune ridges were grouped together on the basis of similar features including width, height, side slopes, crest form, and longitudinal continuity of dune crests and the total dune ridge. The geomorphological discontinuities between ridge groups took three forms: (1) a dune ridge ends abruptly, (2) one dune ridge line

intersects another dune ridge line at an acute angle across the discontinuity, and (3) due east of the discontinuity, the west face of a dune ridge is oversteepened.

Ridge Truncation. The discontinuities between groups are marked by a sharp disappearance of ridges on the northern limits and occasionally in the southern limits. Also, if a ridge crest line were extrapolated across a discontinuity, the ridge line would typically intersect the ridge lines of the other group at a small acute angle. (Refer to the area south of Sunset Lake for a good example in Figure 9.)

Oversteepened West Face. Where the discontinuity is roughly parallel to and between two ridges of different groups along the interdune surface, the west face of the ridge east of the discontinuity is typically oversteepened. (Refer to foldout sections [Figure 11] A-A' east of Long Lake, B-B' east of Neacoxie Creek and east of Sunset Lake also in section B-B'.)

The best example of an oversteepened west face of a ridge is east of Neacoxie Creek where the creek closely follows the surface discontinuity between ridge group 2 and 3 (refer to oversized Figure 9). The west slope of ridge 2B and its branches, slopes 20 to 35° and is relatively straight line with evidence of near surface

creep (i.e., trees bent down slope, and minor slumps). This condition is apparent yet less well pronounced on the west slope of ridge 2B where removed from the banks of Neacoxie. The west slope shows signs of oversteepening partially due to ground and surface water sapping at the slope base.

Group Subdivisions. In oversized Figure 9 groups are numbered progressively westward from 0 through 8. Each group consists of 1 to 5 major ridges, some groups have minor subordinate ridges, especially in group 2. Groups 1 through 4 are well preserved. Note the shaded area in the west covering the limit of SCS vegetative stabilization. Continuity and trend analysis was difficult in this area for ridge groups 7 and 8 in this area. It is also possible that portions of group 6 are altered ridges of group 5.

Ridge Length Comparisons. Ridge length comparisons derived from Figure 9 are presented in Table I. Statistics defined include: (A) length of the Clatsop Plains, (B) ridge group length, (C) ridge group member total length (equals dune ridge length plus gaps in the ridges at interdune elevation along the ridgeline), (D) defined member dune ridge length (equals C statistic less interdune gap length), and (E) well-defined crest length

TABLE I
LENGTH CHARACTERISTICS OF DUNE RIDGES

Ridge Group	B/A(%)	Ridge	C/B(%)	D/C(%)	E/D(%)
0	6	(1)	100	75	33
1	63	1A	13	75	30
		1B	35	81	32
		1C	72	79	27
2	81	2A	49	97	32
		2B	100	76(3)	39
3	73	3A	7	100	70
		3B	43	97	52
		3C	83	85	55
		3D	71	74	57
4	38	(1)	100	56	63
5(2)	8	5A	50	100	30
		5B	63	100	28
		5C	88	100	11
6(2)	85	6A	100	95	23
		6B	100	95	23
7(2)	46	(3)	100	71	33
8(2)	91	(3)	100	100	12

Notes: (1) only one ridge in group

(2) areas in group have been altered by development and SCS stabilization (refer to sections of the text for details); length data is approximate

(3) length calculations include all minor subordinate small ridges

A - Length of Clatsop Plains

B - Ridge Group Length (dune and interdune)

C - Ridge Group Member Total Length (dune and interdune)

D - Defined Member Dune Ridge Length (less interdune)

E - Well-Defined Crest Length for Ridge Group Member

for ridge group member. On Figure 9, a ridge was mapped at the break in slope between the interdune area and the ridge. Those portions of ridges mapped as "well-defined" (solid line) have ridge crests elevations undulating less than 2 meters below the maximum. Dune ridge crests were not well defined where the ridge crest surface ranged from 3 to 10 meters below crest maximum elevation yet above interdune elevations.

The values presented in Table I compare ratios of certain statistics such as: (1) ridge group length compared to the north-south extent of the Clatsop Plains (B/A), (2) ridge group member length to the group length (C/B), (3) percent "defined" ridge length per total ridge length (D/C), and (4) percent "well-defined" ridge length of total "defined" length (E/D).

In Table I ridge groups and members are listed in order from east to west. Three generalized trends can be derived from the table: (1) in ridge groups 1, 3 and 5 dune/group length (C/B) reveals that dune ridge lengths increase from east to west in each group except 3D, (2) in the same groups noted above, the percent defined ridge length (statistic D/C) decreases east to west, except 1A, and (3) also in these groups, the percent "well-defined" length (statistic E/D) decreases (except 1A and 3A) east to west. From Table I, the author considers statistics

D/C and E/D accurate measures of ridge continuity and this data correlates with observed map and field characteristics. Table I shows that younger group members are generally longer in total length yet less continuous.

Based on field observations, ridge group 2 (and perhaps 1) has Type A branching, sinuous and hummocky divergence (Figure 10) and groups 3 and 4 (and perhaps 5) have Type B sub-parallel and continuous divergence. Due to recent vegetative stabilization, groups 6 through 8 cannot be typed. Table I confirms field observations where "well-defined" ridge continuity is lower for Type A ridge groups than Type B (as shown by E/D statistic).

Discontinuities Within Groups

A break in landform which otherwise demonstrates continuity or constant trend was considered anomalous. Anomalies found include gaps in dune ridges, northward convergence (versus divergence typically found) of ridges, easterly cusps on dune ridges, and isolated stacks of Tertiary bedrock.

Dune Ridge Gaps. Breaks or gaps along ridge lines are the most common anomaly in the Clatsop Plains. More than thirty gaps were evaluated and take a few different forms. The gaps range from 30 meters to 1.8 kilometers

along a ridge line trend. Those gaps larger than 500 meters were found to represent areas where the foredune on the historic shoreline was eroded and followed by coastal progradation to the west and formation of a newer foredune which effectively protected the older foredune.

Typically the ground surface elevation in the ridge gap is at or below the interdune level. Where the floor of the gap is below the regional groundwater table, the area is occupied by an interdune west lake. Side slopes of the cut face are usually steeper in the north versus the south side of the ridge gap. Also, gap floor elevations are typically lower in the north. Interdune surfaces due east of the gap are usually unaltered and similar in form to the same interdune surface due east of the intact ridge north and south of the ridge gap.

Below is a summary of those ridge gaps considered representative of the Clatsop Plains. Refer to Figure 9 for ridge reference number and details of the area geomorphology.

Located approximately 4 km north of Gearhart is West Lake, the main body and the northern tip of the lake occupy two different interdune areas. At the main body of the lake (SE1/4 of section 22), slopes of the cut face of ridge 2B average 17° on the north and 2 degrees on the south. Gap floor gradients slope to the north where the

lake is deepest against the ridge cut. The wet interdune surface to the south between ridge 2B and 1C, slopes a fraction of a degree north. Conversely, the sand surface underlying the peat slopes to the south.

At the extreme northern tip of the lake (SW 1/4 of section 15) cut slopes of the ridge cut are 1-2° north and 3-4° south of the gap on ridge 3B. The northern 300 meters of the lake's west shore is 0.3 to 0.5 meters high with steep slopes from 30 to 34° while the east shoreline slopes gently up to the dry interdune. The lake bottom gradient in this area slopes a fraction of a degree south to the lake's main body.

The east segment of the Neacoxie Creek follows the discontinuity between ridge groups 2 and 3. There are two gaps along this segment of the creek (Gap 2A & 2B, refer to Figure 9). Much like West Lake, the gaps have steeper cut slopes on the north side of the gaps than the south side. West of Smith Lake, Neacoxie Creek reverses direction, cuts across ridge 3D and flows south into Sunset Lake. On this segment, the creek occupies the interdune area west of ridge 3D and cuts ridge 4 further south.

Along Sunset Lake, there are 3 gaps in ridge 4 designated 3A through 3C. Each gap possesses the characteristic gap morphology and it is most apparent at

gap 3C. At this gap, the interdune due east is a low, undulating grassy plain with a series of 0.5 to 1.5 m high dune ridges running north-south. Where ridge 4 is intact to the north and south of the gap, the surface characteristics of the interdune to the east are very similar.

The gap occupied by Slusher Lake has some of the characteristic morphologies of dune ridge gaps. The cut ridge slope is steeper on the north side of the gap and the north side of the lake is deepest.

Unlike interdune morphologies east of other gaps in the Plains, the interdune surface to the east is irregular and hummocky compared to this interdune to the north where removed from the gap area.

A small group of three ridges, 5A, 5B, 5C (in the Gearhart area) is only 2 kilometers long with the Necanicum River at the southern terminus. There appears to be no trace of this group to the north though it is possible that group 6 is an altered form of group 5. The ridge group 5 is the shortest (about 2 km) relatively intact ridge set in the Clatsop Plains.

Ridge Convergence to the North. Typically, all ridges within a group diverge toward the Columbia River in the north. Some areas of anomalous convergence from south to north include: (1) T7N/R10E-NW 1/4, (2) 7/10-3-E of

central and 8/10-17-SE 1/4. There are no unusual geomorphic surfaces proximal to the zone of convergence.

Cusps in East Dune Face. Anomalies noted by Cooper (1948) and investigated in the field are short (tens of meters) protrusions off some eastern slopes of dune crests resembling buds of a tree branch. Figure 5 (page 19) shows some of these forms. Two are located in the center of the map approximately three and six centimeters down from the top. These cusped features are best demonstrated on the east flank of ridges in group 3 (which Cooper (1958) noticed with some also attached to group 1 ridges. Oblique air-photos (Clatsop County, 1973) taken of Surf Pines area after blowing sand activity show similar orientations or protrusions off dune ridges and hummocks in the area. Orientations along the cusp axes range from 8 to 22 and 18 to 28 degrees from north for ridge groups 3 and 1, respectively.

Inland Sea Stacks. At Cullaby Lake there are four stacks of Tertiary bedrock designated stacks A through D, on oversized Figure 9. These features range from 9 to 24 meters high and are surrounded by interdune peat except for the stack A. At the southeast edge of stack A there is a 10 meter high and 150 meter long dune ridge extending south of the stack. Stack A shows signs of oversteepening

on the west face. Several 100+ cubic meter slumps are present. Some slumps are overgrown with mature forest vegetation and other slumps have a younger appearance. The slopes have relatively straight-line profiles, where not disturbed by slumping, and tree trunks are bent showing rapid soil creep.

Surrounding stack B, the interdune surface is relatively flat. Within 150 meters of the west slope the surface lowers about 0.5 m and becomes irregular. Slopes on the east and north side of stack B gentle while the south and west slopes range from 20-30°. The steep slopes are nearly straight-line profile and the break-in-slope at the interdune surface is sharp on the west and south. Large Douglas fir trees show signs of pronounced soil creep even where the trees are 0.3 m above the interdune surface.

Recent changes to the Clatsop Plains have been documented since 1806, much of it in this century. For a detailed discussion of recent geomorphic and bathymetric changes to the Plains and Columbia River, refer to Appendix B.

CHAPTER III

RADIOCARBON DATING

The Clatsop Plains can be subdivided into groups of associated ridges and interdunes separated by surface discontinuities. Carbon dating of the interdunal peat assisted in identifying the age of these discontinuities.

Carbon Dates

Radiocarbon dates are presented in Table II. Of thirteen dates, ten were performed for this project and the remainder are archeological dates from other sources. Of the dates done for this project, seven were taken at the peat base / sand contact, one at an intermediate peat depth, one 3.6 m below the peat base / silt contact, and one of a weathered log submerged in a wet interdune. A difference in elevation during formation and final elevation has been described by Hansen (1942,44) who noted that after burial peat can be compacted up to 1/8 of its original volume. Most peat samples were taken at the peat base to best represent the elevation at which the peat was first formed, and to avoid compaction errors. The dated

TABLE II
Radiocarbon Dating, Clatsop Plains

PROJECT CARBON DATES						
C14 DATE (yrs.BP)	Sample Number	Long./Lat.	Grid Coord. (N/W-Sec.)	Depth, m.	Above peat base,m.	Elevation AMSL,m.
2710±85	1 UW-599	123°54'14"/ 46°04'46"	7/10-22 NE½SW¼NE½	3.4	0	+1.8
2000±90	2 UW-600	123°54'14"/ 46°04'46"	7/10-22 NE½SW¼NE½	2.0	1.4	+3.2
2910±115	3 UW-601	123°55'17"/ 46°07'45"	8/10-33 SE½SE¼NE½	2.4	0	-0.4
4050±70 (1)	4 UW-602	123°53'44"/ 46°03'48"	7/10-26 NW½SW¼NE½	8.2	-3.6 (1)	-5.6
1780±50	5 UW-603	123°54'42"/ 46°02'05"	6/10-03 NE½SW¼NW½	0.9	0	+2.6
1305±70	6 UW-604	123°56'13"/ 46°08'00"	8/10-28 NW½SW¼SW½	2.8	0	+1.9
3070±65	7 UW-605	123°53'50"/ 46°03'41"	7/10-26 NW½SW¼SW½	4.5	0	-1.9
415±55	8 UW-606	123°57'31"/ 46°10'59"	8/10-17 NW½NW¼NW½	0.7	0	+3.9
275±50	9 UW-607	123°56'40"/ 46°09'01"	8/10-29 NE½SE¼NW½	1.4	0	+4.2
60±85 (2)	10 UW-608	123°55'16"/ 46°03'25"	7/10-28 SE½SE¼NE½	-	-	+2.6
ARCHEOLOGICAL CARBON DATES						
730±110 (3)	11 WSU-1455 (35CT-(ss))	123°54'53"/ 46°03'16"	7/10-34 NW½NW¼NE½	-	-	+10.8±
1075-1360±70 (4)	12 35CT-20	123°55'51"/ 45°58'32"	6/10-28 SW¼NE¼NE½	-	-	+2.5±
2592-2165±70 (5) 1850-1780 (6)	13 35CT-47	123°55'30"/ 48°58'31"	6/10-28 SE¼NW¼NW½			+2.5±
General Notes:-All peat samples taken for carbon dating consist of 5 to 6 samples (0.1-0.15m thick) per site -Samples collected by author except where noted.						
Notes: (1) Peat base at 4.6 meters. Sample UW-602 from interbedded gray, peaty clayey SILT to silty CLAY						
(2) Wood sample from weathered log with cobbles derived from Necanicum River imbedded in roots.						
(3) Sample collected by Shrakey et al under direction of F. Hasle, Clatsop Community College Disposition: indian midden site covered by 1.95m dune sand.						
(4) Date represents major period of occupation.						
(5) Date represents first period of occupation.						
(6) Date represents approximate period of second major occupation.						

(sources: 1-10, this work; 11, Hasle, 1974; 12-13, Phebus & Drucker, 1979)

samples were collected across the Clatsop Plains to document accretion rates.

Dated peat depths range from 0.7 to 8.2 meters below ground surface. Corresponding elevations of the dated samples range from +3.9 to -5.6 MSL. Locations of all radiocarbon sites are presented on oversized Figure 9. Stratigraphic positions of the dates near the subsurface sections are plotted on oversized Figure 33, on sections A-A' through D-D'. All of the archeological dates presented in Table III were on historic Indian midden sites.

Peat Deposition Rates

As noted above, two segments of one peat section were dated. These dates (UW-599 & 600) were taken from a 3.4 meter peat section at 3.4 and 2.0 meters, respectively. The purpose of this dating was to determine a rough estimate of the rate of peat deposition in the Clatsop Plains. The factors that control deposition can vary over time and include: vegetation type and order of plant succession (refer to Figure 7, page 24), substratum pH, salt water or spray, groundwater fluctuations, nutrient level of hydrosphere, wet interdune morphology, surface humidity, and movement of wind-blown sand. High pH, salt encroachment, extreme groundwater fluctuations, deep and steep interdune surfaces, and sand burial; all greatly

inhibit peat development. On the Pacific Coast, conditions are typically optimum for immediate encroachment of peat into the shallow and nutrient poor lakes, (Hansen, 1941). Based on pollen chronology and relative abundance, marker beds (identifiable volcanic ash layers), and general peat composition of peat profiles over 10 meters thick, Hansen (1941) suggests deposition rates of fibrous peat in the Oregon and Washington coasts of 1 meter per 1700 to 2000 years. Disallowing for minor compaction expected at a shallow depth of 2.0 meters, the carbon dates from UW-599 and UW-600 suggest a rate of 1 meter per 500 years. The discrepancy of peat growth rates could be the result of (among others) (1) inaccurate identification of pollen chronology and type (Peterson, 1979), or (2) unsupported estimates of peat compaction during burial especially at depths over 5 meters.

Clatsop Carbon Dates and Estimated Sea Level

Radiocarbon dates from this research are presented with Pacific Northwest dates and world sea level curves in Figure 12. The error margin for the Clatsop Plains peat dates ranges from ± 50 years to ± 115 years. The margin of error for elevations is approximately ± 1.0 meters. Six of the Clatsop dates were collected 1.8 to 4.2 meters above present MSL. Three of the dates were collected -0.4 to -1.9 m MSL. The date from the weathered log is not

Figure 12. Sea level plot of carbon dates compared to sea level curves from various sources, (modified from Curray, Shephard and Veech, 1970, and Bloom, 1977)

applicable to the sea-level plot because of its recent age.

Justification. Note the arrow symbols pointing down from each project radiocarbon date in Figure 12. This signifies that sea level is estimated at some point below the arrow tip based on the following logic: Ground water controls interdune and peat surface elevations in relation to sea level. Modern peat surface elevations are used to estimate past peat surface elevations in relation to contemporaneous mean sea level (MSL).

Presently, the westernmost peat deposits on the Clatsop Plains are in Long Lake. At this location, as well as throughout the Clatsop Plains, lake and peat surface levels closely approximate the groundwater table elevation. At Cullaby and Long Lakes, the lake surface elevation seasonally ranges between 5 and 7 meters above MSL. Across the Clatsop Plains, lake elevations range between 2.5 and 7 meters above MSL, averaging +4.5 meters. By use of modern levels as a guide, the mean sea level during formation of each dated peat sample has been estimated 4.5 meters below the dated peat sample elevation and is shown by a vertical arrow below each carbon date in Figure 12. Similar extrapolations were assumed by Van Straaten (1965) for the Netherlands that, based on subsurface borings and present conditions, "peat started to grow at or slightly below the local high water level in

adjoining estuaries (and) on the average this may have been 1.5 meters above mean sea level". Thus, Van Straaten plotted inferred sea levels 1.5 meters below the dated peat elevation for the Netherlands barrier deposit.

Analysis. The sea level curve plotted from regional and project carbon dates suggest a later rise of sea level than that shown by other world curves, in the early Holocene from 10,000 to 3500+ years BP. Project carbon dates also suggest a possible ± 3 meter sea level oscillation from 4000 to 1400 years BP followed by a gradual rise to present levels. The oscillation suggests lows at 1300 & 3000 years BP and a high at 2300 years BP.

The subject of Holocene sea level change is controversial. For discussion, refer to the section in Appendix A on Holocene sea level data scatter.

CHAPTER IV

STRATIGRAPHY

Introduction

Scope. The stratigraphy of the Clatsop Plains was evaluated from two standpoints: (1) near surface exposures of sand, peat, and gravel, and (2) published and unpublished logs of borings of the deeper subsurface.

Dune and Interdune Sediments. Near surface data was collected on both the dune and interdune areas. The dune sands internal structure is typically thin-bedded with alternating light and dark layers which exhibit sharp to irregular bed contacts and occasional secondary structures. The average diameter of the sands is 2.5ϕ (0.18 mm) with 0.37 standard deviation and an average skewness of +1.5.

The interdune sands internal structure is typically irregularly bedded with light and dark mineral zones much like the dunes. In the southerly 5 km of the 30 km long deposit, interdunal gravels can be found at or near the surface. In eastern areas of the interdunes, near surface peat deposits overlie sands or silts. The distribution of

these low interdune near surface gravel and peat is presented in Figure 9. Surficial peat covers approximately 28 percent of the total project area. The peat ranges in thickness from 0.1 to 4.6 meters and is typically a fibrous type with varied amounts of spores, pollen and fine sand. The peat overlies wet sand, except in the extreme northeast section and against the mountain front in the drainage areas where peat overlies soft silts. Interdune gravels are only found in the south next to the Necanicum River. Surficial gravels cover only about 12 percent of the total project area, much of which is overlain by a meter or two of sand.

The depth of near surface explorations for sands for this study was limited to areas above the groundwater table or practical refusal of the hand auger in dense sand. Near surface sampling of the peat was limited to sampler refusal on the underlying silt or sand. Deeper subsurface borings by others range from 4.6 to 469 meters in depth. Most of the deep drilling over the years has been performed in the central and western portions of the project areas. Some borings encountered bedrock at elevations ranging from -17 to -28 meters below MSL. Other slightly deeper borings did not penetrate to bedrock probably due to the irregularity of the Holocene/Pleistocene-Tertiary contact.

Dune Ridge - Sedimentary Structure

Exposures. Most large sections of dune sands were exposed in six road cuts and two sand pits. These areas are located scattered about the Plains in oversized Figure 9. Shorter sections of the dune ridge structure was observed in hand dug trenches at 12 locations near sections A-A', B-B' and D-D'. Three other trenches were dug at scattered sample locations throughout the Plains, most of which were at dune ridge gaps. The 23 examined sections represent exposures of all ridge groups 0 through 8 except group 5.

Representative Dune. Of the exposures examined, there was little variation in structure and lithology. One in particular was well exposed and is representative of dune structures and stratigraphy. It is a road cut in ridge 2A about 1.6 km southwest of Warrenton. Presented in Figure 13 is a picture mosaic of the road cut. From the center or highest elevation of the dune, four locations were sampled and evaluated: from the ridge crest (Site A) 40 m west, (Site B) 65 m west, (Site C) 90 m west, and (Site D) 50 m east. All sites except Site D are located near the same stratigraphic position using marker horizons as a guide.

On the west side of the ridge crest bedding structure was uniform with light and dark mineral layers 1 to 30 mm

Figure 13. Photomosaic of representative Clatsop dune (located 8/10-21-SW $\frac{1}{4}$ -SW $\frac{1}{4}$ -site #1).

thick. Sand layers were continuous horizontally from a few centimeters to tens of meters. The sand layers dip from 1° to 4° west and appear to be truncated on the lower west slopes. Multiple layers from 1 mm to over 1 meter thick were separated by irregular iron-stained layers from 1 to 15 mm thick. Typically, the staining occurred overlying a dark mineral layer. (At other dune ridge cuts to the south, wood fragments and possible rain drop impressions were found in the top surface of darker mineral layers). Some beds exhibited low amplitude ripples especially at sites B and C. Ripple crests were rounded or pointed with amplitudes from 0.2-0.5 m and wavelengths 0.003-0.05 m. Secondary structures consisted of animal burrows (top center of Site C photo, Figure 13), and possible root or twig casts.

Beneath the east slope (e.g., Site D), bedding was thinner (0.02-0.14 m) and smoother than the bedding west of the ridge crest. Bedding was cross-bedded with truncated topsets and intact foresets that dipped $15-25^{\circ}$ east. (See Figure 13, Site D.)

Also note the major discontinuity in the top center in the panoramic view of the north side of the ridge. The surficial sand layer is a lighter brown, slightly stained and a trace more silty than the sand below. The unconformity contact is a smooth concave-up curve.

Layering within the upper unit is uniform, more continuous, and has fewer dark mineral layers than the sand unit below. This type of discontinuity was encountered only in this dune exposure.

In summary, dune sedimentary structures show common and repetitive features. Progressively west of the dune crest, bedding contacts became more undulatory and distinct with stronger light/dark mineral zonation. Thickness and abundance of dark mineral layers also increase westward. In addition, the distance between staining increased and the stained zones became more wavy and less continuous progressively west of the crest.

Near the dune crest, the contacts were smoother and less distinct than to the west. Here, light/dark mineral layers were thinner and less abundant. Below the dune crest cross bedding appeared and became more abundant eastward. Topsets were typically truncated by an overlying tabular bed.

Interdunes

Near surface examination of the interdune areas revealed five stratigraphic units: dry sand, wet sand, peat overlying sand, and peat overlying slightly sandy to trace sandy, peaty silt over hard silt (likely weathered bedrock of the Astoria Formation). Dry sand is typically found in the west half of the Clatsop Plains where the

interdune elevation is slightly higher above groundwater. Where the interdunes of ridge groups 4 through 8 are low (below about 20 feet MSL groundwater table), lakes have formed with only slight amounts of peat development around their perimeters.

Peat - Lateral Extent and Thickness. In the interdune areas to the east, much of the sand surface that is below the groundwater table is covered by a mat of peat. The areal extent of peat is shown in oversized Figure 21. Spot probings of peat show a range in thickness of 0.1 to 4.6 meters in the interdunes of ridge groups 0 through 3. Peat surfaces range in elevation from -2.0 to +6.0 m from MSL. Typically, the peat is less than 0.5 m thick north of Clear Lake and in the vicinity of Warrenton. To the south, peat thickness typically range from 1.0 m to a maximum of 2.8 m at isolated point near Smith Lake. Peat is found on the flanks of the narrow channel of Neacoxie Creek throughout most of its length. South of Clatsop Station there is no peat for over 2 km and again appears to the south at Glenwood (3 km to the SSE). From this point south, the peat thickens to a maximum of 4.0 at a point west of Cullaby Lake and to 4.6 m in the protected area around Triangle Lake to the south. Further south 3 km to Lake Karen the peat ranges in thickness from 2.5 to less than 0.5 m.

Peat - Constituents and Contact Relationships. Of

twenty samples tested for this project, the peat is typically fibrous with decayed reeds that decrease in abundance with depth in the peat section. In most locations the organic fraction also becomes more finely divided with depth. Natural water contents range from 50 to 570 percent of dry weight, averaging approximately 100%. Fine sand is found in all peat samples ranging from less than 1 to approximately 5 percent of dry volume. The peat typically becomes more sandy with depth. Where peat overlies sand the contact was found to be sharp except at location 9 (See Figure 21, Section A-A') where the lower 5 cm is about half sand. In the eastern portions of the project area near the upland, the peat overlies soft, gray, slightly fine sandy, micaceous silts. On Figure 9, there is a line marking the boundary between peat over sand and peat over silt. Where overlying silt, the contact is irregular (e.g., within 1 meter lateral distance between borings, the contact varied 1.5 meter). The contact between peat and silt is also gradational. The upper 1 to 2 meters of the silt is peaty silt with numerous to scattered organic fragments to 1 centimeter diameter.

In some locations, the peat was not uniform in composition. Some peat sections consisted of 2 to 5

distinct layers in which percentage of fine sand decreased up section to a sharp contact where sand again became more abundant. Within each layer or cycle, the sand content ranges from 3 to 5 percent (by dry volume), at the bottom of each layer, decreasing to less than 1 percent at the top of each layer.

Five layers, each approximately 0.4 m thick, were found in the 1.7 m thick peat section 500 m south of Shag Lake (8/10-20-SE). Two layers were found along section A-A', at Smith Lake (sample #7). Here, beneath 1.5 meters of fresh green vegetation, is a 0.6 m thick layer overlying a 0.35 m layer. The lower 0.05 meters is a 1:1 mix of peat:sand. Figure 14 presents the sand content of three typical sections (out of over 20 borings) including Smith Lake. On the Clatsop Plains, peat is typically fibrous, whereas at Smith Lake the peat possessed numerous fine (5 to 10 mm) wood fragments.

The pollen content of peat profiles on the Clatsop Plains has been studied by others, (see Hansen, 1941, and Maine, 1979). The peat analyzed by Hansen in Figure 15 was sampled proximal to Triangle Lake (7/10-26-W). Hansen noted the increase in lodgepole pine (pioneer species) and decrease in sitka spruce up section.* Hansen also

*Note that pollen taxonomy has been refined since Hansen's work and so distinction between some species of pine may not have been recognized (personal communication with Rock Raymond, PSU Biology graduate student).

NOTES

50% GRADING TO 20% FINELY
DIVIDED ORGANIC FRAGMENTS
MIXED WITH COARSER GRASSES, &
WOOD (TYPICAL).

SMITH LAKE SECTION

Figure 14. Percent sand of peat volume - selected sites.

Figure 15. Summary of pollen analysis; A. pollen diagram of peat northeast of Gearhart at 7/10-26 location #5, (Hansen, 1941), B. peat profiles at selected sites, (Maine, 1979).

describes the peat found inland of Gearhart rich in humic material consisting of 2.7 m limnetic (freshwater) peat (deposited in relatively open water as well as being rich in colloidal humus and organic detritus) overlain by 4.0 m pollens in profile #2. of peat rich in decomposed fibrous material mostly of grasses.

Three profiles sampled and dated for this work were analyzed for relative proportions of some pollen types, (Maine, 1979). Referring to Figure 15B, note the increase in western hemlock on peat profile #1 and the lack of pollens in profile #2.

Near Surface Gravels - South Clatsop Plains

In the south portions of the Clatsop Plains, north of the Necanicum River, gravel occurs in various linear deposits. Figure 9 portrays the areal extent of the gravel deposits. The linear gravel body just west of highway 101 is overlain by a sand dune ridge. It is within 0.3 to 1.5 meters of the surface along the cut banks of the Necanicum River. Exposed in road cuts and assorted shallow excavations, the linear gravel deposits typically have clasts ranging in size from 50-120 mm, averaging ± 70 mm. The gravels are also very poorly sorted with no silt or sand matrix.

A gravel body immediately east of highway 101 is located in an interdune area in the vicinity of Lake Karen). The gravel pit operation creating Lake Karen has been abandoned. Discussions with the pit operator and others determined that a maximum of 4 feet (1.3 m) of sand overburden was excavated to gain access to the gravel and the gravel body was a maximum 18 ft. (5.5 m) thick (excavation to -1 m MSL). The western limit of the gravel, within the depth of excavation, was the west face of the gravel pit. A subsurface section schematic of the contact relationships is presented in Figure 16A. The east and north limits of the gravel body were investigated with a hand bucket auger at sample locations 6/10-3-#1 & #4 and 6/10-10-#1, #6, & 7. Figure 16B shows two possible eastern contact relationships. Note that due to depth limitations of field equipment and limited deeper subsurface explorations in the vicinity, it could not be determined whether the gravel body may extend east and west (less likely) of the contacts shown in Figure 16.

To the south of the Necanicum mouth, the Seaside area is covered with a large deposit of stream washed gravels, sand terraces and levees. Both the Necanicum and Neawanna Rivers are aligned with the general trends of the interdune areas to the north. The areas between the gravel uplands have been filled with fine sands with some

Fig. A

Fig. B

Figure 16. Schematics of gravel/dune sand contact; A. at 6/10-3 next to sample locations 3 to 5, B. at 6/10-10 at sample location 1, (refer to Figure 22 for site locations).

silts. Field indicators of possible terracing and levee development are common in sections 15, 22, and 28. Figure 9 presents the lateral extent of the gravel bodies.

Subsurface Sections

Data Sources and Comments. Ortho-photo map elevations, deep subsurface borings (published and unpublished), and supplementary field data collected for this work were used to develop subsurface sections. All exploration points are located on oversized Figure 9. Refer to Table III (Appendix C) for a listing of all known subsurface data accessible to date of this work. The boring logs are derived from four different sources. Therefore, the material descriptions cannot be laterally correlated.

General Layering of Units. In general, the boring logs report fine sand with plant remains or logs overlying fine to medium sand with plant remains, silty/clay layers and/or shells. The contact between the two units ranges between 0 and -9 m elevation measured from MSL. The base of these units consists of shells, gravels and/or wood overlying 0 to 6 m clay over hard shale bedrock. This contact appears to be irregular, ranging from -17 to -28 m below MSL and deeper. Refer to logs of borings for details. (Appendix C.)

Oversized Figure 17 at the back of the text presents four east-west summary subsurface sections designated A-A' through D-D'. Sections are located on Figure 9. The graphic logs of all borings near the cross sections are graphically summarized on the section.

Dune, Interdune and Beach Sand - A Comment on Sieve Results and Model Analysis. Sieve analysis was performed on known samples--dune, interdune and beach sand. Much literature is devoted to interpreting depositional environment from size gradation plots. According to various sources, the data is typically more useful for beach sand sources with a higher median and mean grain sizes than that found on the Clatsop Beach.* Size gradation plots and cross-correlation between mean, skewness, sorting and kurtosis of Clatsop data confirms modal analysis is inconclusive. Therefore, test results are not presented in this report.

For a comparison of the stratigraphy of the Clatsop Plains to other world barrier systems, refer to Appendix F.

*For discussion of sieving results and modal analysis refer to Baker (1968), Doeglas (1946), Duane (1964), Folk (1962), Folk and Ward (1957), Friedman (1961), Genhetal (1971), Ineman (1952), Martins (1965), Shephard (1954) Shepart and Yang (1961).

Anthropological Record

During Indian occupation of the Clatsop Plains, harvesting of near shore and estuarine invertebrates was the major source of food. Phebus and Drucker (1979) identified some of the species abundant in the two shell middens (i.e., dump sites) located in Figure 9 in the extreme south Clatsop Plains at Seaside (35CT-20 and 35CT-47). Presented in Figure 18 is a listing of those bivalve species found in abundance at the midden sites: included also are comments from Phebus on the present day occurrence of these species.

Note the comparison between invertebrate habitat and the relative occurrence in the middens versus present day. The Pterus nuttalli and Saxidomus giganteus (both needing protection from surf) are no longer native to the area possibly due to overuse. Also, the Siliqua patula (common in open coasts on sandy to gravelly beaches) has apparently increased abundance since the Indian occupation. The above is likely if (1) the Indians utilized all invertebrates in the area and (2) the middens are representative of the Indians' diet.

<u>Order</u>	<u>Species</u>	<u>Common Name</u>	<u>Habitat (less common in parentheses)</u>	<u>Occurrence</u>
Eulamellibranchia	<i>Pterus nuttalli</i>	blue or gaper	bays/mudflats (outside coasts/low intertidal)	no longer native (possibly by overuse)
	<i>Protothaca staminea</i>	little neck	clayey gravel less than 8" below surface (packed mud or grav./sand mix) rocky shores of bays and estuaries	
	<i>Clinocardium nuttalli</i>	basket cockle	quiet open coast/sandy beach or tidal flats	no longer native (possibly by overuse) rare in midden site common presently
	<i>Saxidomus giganteus</i>	butter	relative protection from surf	
	<i>Siliqua patula</i>	razor	open coast sandy to gravel beaches	
Filibranchia	<i>Mytilus californicus</i>	california mussel	open coast and rocky shores of bays/estuaries. intertidal, hard rock, (gravel beaches).	

Figure 18. Bivalve species abundant at indian midden sites, (Phebus and Drucker, 1979)

SUMMARY AND CONCLUSIONS

This work developed a progradational history of the Clatsop Plains foredune ridge deposit by analysis in eight areas: geomorphology, stratigraphy, radiocarbon dating, and coastal processes with minor supportive data from soil development, vegetative succession, and anthropological interpretation.

Four main approaches of the research centered on bibliographic review, geomorphic mapping, stratigraphic analysis, and radiocarbon dating.

Over 25 authors have published research on the project area. Most work consists of documentation and interpretation of depositional events in the last 180 years. Some other work has inventoried the soils, vegetation and basic landforms in the Clatsop Plains. Cooper (1958) and Hansen (1941, 1942) have completed air-photo and peat column analysis in the area, respectively. Foredune ridge deposits similar to the Clatsop Plains are located throughout the world and the results of this research on these deposits are compared to the Clatsop Plains.

Project area conditions at present consist of wet winters with drier and humid/foggy summers. The coast is dominated by storm waves, moderate tidal range, and both

onshore and along-shore currents. Wave approach is from the southwest and the northwest in the winter and summer, respectively. Sediment supplying the Clatsop Beach is primarily derived from the Columbia River as shown (by others) by sand, size, shape and composition.

The Holocene deposit of the Clatsop Plains rests on Oligocene and Eocene bedrock that has subsequently been terraced during the Pleistocene fluctuations in sea level. The world climate reached a thermal maximum between 8000 and 4000 years BP, since this time the climate has been cooler and moister. The rise in sea level has slowed since 6000 years BP. Clatsop C¹⁴ data suggests a slower relative sea level rise than other parts of the world.

Geomorphology

Summary. Trending from north to south along the Clatsop Plains, the bulk size decreases, the ridge crests are smoother and more continuous, and the interdune areas narrow and increase in surface elevation. Trending in an east-west direction, analysis of slope sections reveal the east slopes of ridge crests are typically steeper than the west slopes, ridge slopes across the project area are more irregular from east to west, and the dune/interdune surface elevations appear (removing peat thicknesses) to increase from east to west to ridge group 6 and fall slightly to the west.

There are nine distinguishable groups of ridges separated by surface traces of landform discontinuities. Within a group, the group members typically become longer yet less continuous.

The discontinuities between groups are marked by a sharp disappearance of the ridge on its north and (occasionally) south limits. The discontinuity typically truncates groups of ridges at a low acute angle. Where the discontinuity roughly parallels two ridges of different groups along the interdune surface, the west face of the ridge east the discontinuity is oversteepened.

Figure 9 presents dune ridge groups subdivided in the Clatsop Plains. Dune ridge correlation by Cooper (1958) is similar to that of this work. Ridge correlation (this work, Figure 9) and Cooper's work (oversized Figure 18 back cover pocket) differ as follows: (1) Cooper attaches ridge 1C to ridge 2A, (2) he terminates ridge 2B at Glenwood in the central Plains whereas it appears to be a main stem of Type A ridge group branching north to the Columbia River, (3) Cooper also shows some pairs of closely spaced ridges as one ridge (e.g., ridges 3A through 3D equal his ridges 5 and 6), (4) Cooper did not map ridge group 5 in the Gearhart area just north of the Necanicum River in the South Clatsop Plains, (5) in the north Plains, 2 km west of Warrenton, Cooper has mapped

ridges 3C and 3D as 7 and 8, and finally, (6) Cooper considered ridge group 6 and 7 both part of a single ridge group. Obviously, many of these differences are the result of better topographic maps and remote imagery now available as well as the ability to perform field investigations.

Cooper's work was limited in scope where he analyzed low altitude black and white airphotos and performed some spot field checks in the area. Also, Cooper's work was also much more regional in scope as it included the Oregon and Washington coast.

Ridge groups exhibit two basic types of divergence from south to north: Type A where the ridges in the group branch out from a main stem ridge and the ridge crests are sinuous and hummocky, and Type B where the ridges are subparallel to each other, extend along most of the group length, and the ridge crests are relatively smooth and continuous. (Refer to Figure 10 for a representation of both types.) Some portions of a few ridge groups possess interdune elevations that are much higher than average in the vicinity. This is especially true in the north portions of the project area that have undergone rapid accretion and vegetative stabilization in this century. High interdune elevations are also found in unaltered areas where the ridge crests are relatively close together.

Landform discontinuities within a ridge group take several forms: isolated stacks of Tertiary bedrock found in the east-central area, isolated gaps in individual ridges, convergence of adjacent ridges from south to north (opposite of that which is typical), and local/small scale protrusions off the eastern slopes of some ridge crests. Coastline changes in the last 180 years have been historically documented and consist of: (1) shoaling at the mouth of the Columbia River that caused separation and divergence the river outflow to the north and south, (2) jetty construction causing scouring proximal to the north edge of the Clatsop Plains with realignment of the river outflow to an east-west orientation, and (3) accretion (combined with man-made vegetative stabilization) of the Clatsop coastline early in this century.

Progradational Development - Geomorphology and Carbon Dating. Progradational time lines have been estimated for the Clatsop Plains on the basis of geomorphic grouping between discontinuities, carbon dates on peat, and archeological dates of Indian occupation. The assignment of rough dates to discontinuities is based on an estimated 300 to 500+ years necessary for peat to initiate growth after formation of a protective foredune barrier immediately coastwise of the interdune. Van Straaten (1965) estimated that peat in the Netherlands barriers

began to grow some 50 to 250 years after formation of the barrier seaward of the innermost (i.e., oldest) and outermost barriers, respectively. Van Straaten concluded that the 200 year difference may be the result of slowed sea level rise before formation of the outermost peat. The lag time for peat development on the Clatsop Plains is estimated 300 to 500 years because of the necessary correlation of carbon date 275 ± 50 years BP (UW-607, located south of Long Lake) and the archeological date of 730 ± 110 years BP (WSU-1455) located north of Gearheart and immediately east of the same discontinuity.

A summary progradational history of the Clatsop Plains with assigned dates to every major discontinuity between ridge groups is presented in oversized Figure 19 (located in back cover pocket). The dated time lines represent the most recent age or time period in which the beach zone was located at the discontinuity.

In general, it appears that the discontinuities can be formed in three ways: 1) a lull in progradation, 2) coastline erosion, and/or 3) selective accretion.

Some detailed conclusions are derived from examination of oversized Figure 19. It is likely, based on carbon dating of inland peat and underlying organic silts, that the prehistoric shoreline was up against the mountain front some 3500 years BP prior to the development

of the short spit (ridge 0) that extend from the mountain front just west of Cullaby Lake in the central Clatsop Plains. Palmer (1979), without benefit of local carbon dating, estimated this time line at 2000 to 3000 years BP. At this time the stacks of Tertiary bedrock were situated just offshore and likely exposed to the base at low low tide. These range in ages corresponding to an elevated flood plain mapped in the Willamette Valley (Parsons, et al., 1970) and down the Columbia River to, and including the Clatsop County Coast.

Groups 1 and 2 were likely generated from 3200 to 2500 years BP. From the time period 3200 to 2500 years BP, ridge group 1 (Type A divergence) had developed. Peat behind the barrier had likely started to accumulate as ridge 1C was stabilized. From 2500 to 2000 years BP, accretion of ridges $2A_1$ and $2A_2$ had taken place in the north. The final form of these and other ridges could have been the result of one or more of the sequences described on the preceding page. The southern limit of this accretionary unit is in the vicinity of Glenwood Station and the south shoreline had stabilized against ridge 1C. From 2000 to 1500 years BP ridges $2B_1$ through $2B_4$ had probably formed and the main stem (ridge 2B) of this divergence pattern had stabilized south to the Necanicum River. Apparently accretion occurred in the

north from 1500 to 1000 years BP (the final ridges for group 2). It is quite possible that the continuity of form of the western most ridge in group 2 is the result not of final formation of ridge 2B₅ but of erosion in the south back to ridge 2A followed by wind and/or wave reformation to the appearance of ridge 2B₅. The last ridge in group two does appear to have been subjected to light wave attack as shown by the common occurrence of oversteepened west slopes especially of the northern tip of Neacoxie Creek and south along the ridge line.

The fan shaped accretion (Type A divergence) of ridge group 2 (Type A divergence) extends south to a common area at Glenwood Station. A likely explanation for this is extensive shoaling at the mouth of the Columbia River fed outward growth of the beach yet the south portion of the Clatsop Plains was deficient in sediment so little accretion occurred and subsequently eroded. The discontinuous and hummocky nature of dune ridges, coupled with the higher dune mass in the north, suggests that there was an excess of sediment in the littoral zone especially in the north and that the coastline was subjected to recurrent periods of massive sand buildup and local as well as coastwide wave attack.

Following stabilization of the shoreline between ridge groups 2 and 3, coastwide accretion of group 3 (Type

B divergence) likely occurred from 1000 to 800* years BP. Contrary to apparent events of past accretionary stages, the growth occurred first in the central and south area of the Clatsop Plains while the beach north of Glenwood station appears to have stabilized against ridge group 2 until later accretion of ridges 3C and 3D. Coastwide accretion of ridges 3A and 3B does not seem likely due to the sharp north termination of these ridges at Glenwood station. During formation of ridges 3C and 3D it is apparent that the north was modified by excessive sand accretion and some localized wave attack. The south portions of these ridges are relatively continuous and uniform suggesting a more optimum condition of sediment input balanced with other destructive and excessively accretionary factors (i.e., approaching equilibrium condition). Those uniform protrusions off the coast slopes of groups 3 and 1 ridges (see Figure 5, page 19, oblique air-photo) in the Central Plains likely indicate nearer equilibrium conditions.

The ridge group 4 developed from 800 to 400 years BP. Much like group 3, the ridge group accreted mostly

*Note that the accuracy of the 800 estimate is considered better than others because it dates the time some 70 years before occupation dune ridge 3D by the coastal Indians. (See (1979) considers 70 years after dune formation a conservative estimate for occupation).

south of Glenwood station. Also, note that the width and mass of the group is larger in the south portions versus that in the north. After development, the ridge had been subjected to considerable localized wave attack as evidenced by the numerous ridge gaps all along the length.

Apparently maximum accretion occurred in the north of ridge groups 1 and 2 yet much of the growth was in the south Clatsop Plains for ridge groups 3 and 4. A possible explanation of this might be (1) the proportional shift after 1000 years BP from the dominance of the Columbia River as sediment source to increase in offshore and/or Necanicum River sources, or (2) a change in sediment dispersal patterns.

Ridge groups 5 and 6 likely accreted between 800 and 400 years BP. The units are considerably thicker in the central Clatsop Plains than the north or south much like the ridge groups 3 and 4. Group 7 also is thicker in the central and the south portions. Ridge group 7 likely accreted from 180 to 110 years BP according to comparisons with the Lewis and Clark map of 1806. Ridge group 8 represents the accretion that is well documented from 110 years ago to present. Massive accretion of group 8, overgrazing and forest fires in the Clatsop Plains early in this time period created serious problems with wind blown sand and, to a lesser extent, storm wave washovers. Because of this recent activity, and man-made development

of the Clatsop Plains near the coastline, much of the ridge groups 6 through 8 have been altered to the point where historical interpretation is difficult.

The Clatsop beach has undergone reformation after jetty construction. The northwest tip of the Clatsop Plains has changed from a blunted drumstick shape to a smooth westward facing concave shoreline extending from the south jetty to Tillamook Head. After stabilization of this form, coastal conditions have been upset resulting in a depletion of sediment supply to the beach immediately south of the jetty. A few causes of this have been formulated by other authors (see earlier text for discussion): 1) the north Clatsop Beach is in the shadow of the south jetty as summer sand building waves approach from the northwest, 2) sand shoaling at the mouth has been pushed further west possibly decreasing the amount of sediment available to the littoral zone, and 3) after the mid 1960's, tributary and main stem dams on the Columbia have trapped sediment in the reservoirs and virtually controlled the likelihood of major flood discharges in the spring. Since maximum accretion early this century, the shoreline appears to be eroding and accreting north and south of a pivot point in an attempt to establish a shoreline curvature and orientation near equilibrium, and 6) European beach grass (Ammophila arenaria), among other non-native species, have dominated the active coastal zone

since their introduction to the Clatsop Plains.

Note that time line plots in the Clatsop Plains south the Necanicum River mouth are approximate and are based on surface trends of exposed fluvial sands and gravels. Refer to later section on stratigraphic interpretation for an explanation.

Progradation and Estimated Sea Level Changes. An estimated sea level curve for the Clatsop Plains was presented earlier in the text on Figure 12. Note the oscillation from 3000 to 1400 years consisting of a sharp rise from 3000 to 2300 years BP followed by a leveling and more gradual drop from 2300 to 1400 years BP and a subsequent gradual rise from 1400 years to present. If these sea level trends are considered close to actual, then some details of the progradational history of the area can be examined.

Comparing the sea level curve Figure 12 to the plotted time lines on oversized Figure 19, it appears that massive progradation of ridge group 1 (Type A divergence) was occurring while sea level was rising at a rate of 5 to 8 meters per thousand years. During the leveling out and subsequent fall of sea level, ridges $2A_1$ through $2B_4$ had accreted. Continuing the trend of fan shaped accretion (Type A divergence), ridges $2B_5$ and $2B_6$ likely accreted during that early portion of the

designated time period from 1500 to 1000 years. Ridge group 1 had likely been subjected to significant wave attack yet because the ridge line of 1C is found along most of the coast, yet the group does not show apparent evidence of major reorientation of the strand line. This major change in the strand is more likely for ridge group 2 because of the fan shape accretion described earlier. In agreement, Cooper considers a constant or slightly dropping sea level as likely condition during formation of ridge groups 1 through 2 where massive progradation was the norm in the north with a relatively stable shore in the south.

The change in accretionary form from a thick fan shape in the north (ridge groups 1 and 2) to a thicker progradational wedge at the initiation of ridge group 3 in the south and central Clatsop Plains appears to coincide with the reversal of sea level at 1400 years BP followed by a gradual rise to present levels. After the reversal, the ridge divergence pattern also shifts to Type B and ridge continuity improved during formation of ridge groups 3 and 4. It is apparent, as Cooper (1958) has stated, that this formational period was not one of rapid progradation or serious coastwide wave attack (unless the record has been eroded). In areas that appear unaltered by stabilization during this century, groups 5 through 8

appear to be more of the Type A divergence (i.e., more massive, hummocky and discontinuous). This marks another likely change in process at 400 years BP at the initiation of ridge group 5 to more massive progradation and wave attack.

Estimated Accretion Rates. A summary of accretion rates for each progradation period is presented in Table IV. The time period, the range of accretion, the average growth, and the estimated rate of growth are presented. General sea level trends are also indicated. Note that accretion rates are approximate for all growth phases and are likely unreliable for ridge group 2 accretion because of possible massive reorientation of the strand line.

From Table IV, accretionary stages lasted from 110 to 700 years. Estimated accretion rates range from .48 to 4.1 kilometers per 1000 years. Maximum accretion rates had occurred during the minor drop in sea level while ridge group 2 (Type A divergence) was forming. Minimum rates occur after sea level reversal after 1400 years BP while ridge groups 3 and 4 (Type B divergence) were forming. Because groups 3 and 4 were forming during the postreversal rise in sea level, much of the accretionary wedge of coastline may have been eroded during reorientation of the strand.

TABLE IV

ACCRETION AND SEA LEVEL

Ridge Group or Sub-Group	Time of Accretion (years, BP)	Accretion Range, (km)	Average Accretion (km)	Sea Level Trends	Accretion Rate (km/1K yrs)
0	3500-3200	na	0.16	sharp rise	0.55
1	3200-2500	1.4-2.6	0.74	/	1.1
2A ₁ -2A ₂	2500-2000	0.0-1.1 ⁽¹⁾	0.74	peak @ 2200 fall	1.5
2B ₁ -2B ₄	2000-1500	0.0-2.1 ⁽¹⁾	1.0	/	2.0
2B ₅ -2B ₆	1500-1000	0.0-0.6 ⁽¹⁾	0.4	reversal @ 1400	0.8
3	1000-800	0.2-0.6	0.4	/	0.54
4	800-400	0.1-0.2	0.2	gradual rise	0.48
5/6	400-180	0.1-0.6	0.4	/	1.7
7	180-110	0.1-0.6	0.3	/	2.3
8	110-P	0.2-1.1	0.5	/	4.1

NOTES:

- (1) Accretion range noted from 0.0 km due to disappearance of group to south of area proximal to Glenwood Station.

Conclusions. The above data and analysis suggests a cyclic succession of accretion, erosion, and/or stabilization followed by renewed progradation. Following initial stabilization of the ridge group 0 at Cullaby Lake, there was a period of massive accretion with significant modification by waves during the sea level rise from 3000 to 2200 years BP. During the peak and subsequent sea level drop from 2200 to 1400 years BP, group 2 developed large massive dunes during a period with less significant wave attack with some wind alteration of the ridges.

After the sea level reversal at 1400 years BP, it is apparent that a major reorientation of the strand line occurred with accretion of groups 3 and 4. Remnants of this accretionary period to 400 years BP appears to have been less altered by wind and waves, excluding localized wave attack, as evidenced by improved ridge continuity and the appearance of local ridge gaps. Also, sediment flux into the beach zone during this time appears to have been more gradual. Though it is difficult to tell because of recent alterations of natural slopes, accretion rates and irregular dune forms developed in the last 400 years point out a likely proportional sediment flux and subsequent modification of the dune ridges.

Stratigraphy

Summary. Dune exposures revealed irregular light and heavy mineral accumulations. Contacts between the layers were irregular or incipiently rippled and typically sharp in color contrast. Contact smoothness improved from west to east. Layering thinned from the base to the top of the dune ridge. Each layer was laterally broken with a west to east onlap over the underlying unit. Typically each successive accumulation did not disturb the underlying primary structures except on the east where the crossbedding topsets were located. Iron staining was observed on top of many dark mineral layers. In one dune exposure, a hollow in the top of the ridge crest had been subsequently filled in by a later accumulation of sand. Secondary structures, such as animal burrows and twig imprints, were rarely found. Foreset angles were typically much lower than the angle of repose. In scattered locations, secondary structures such as contorted bedding were found.

A discontinuity was noted during descriptions of one typical dune ridge exposure. Bedding above the discontinuity was more continuous, thinner and more distinct. Darker mineral zonation was less common and fine sand had a trace more silt than the sand below. This type of discontinuity was encountered only in this section out of 23 examined.

Interdune peat profiles typically increased in sand content and decreased coarse humic matter with depth. The pollen count of Hansen's (1941) peat column shows a fluctuating increase in the pioneer species (pine). Some of the peat columns had multiple layers of increasing sand with depth. The surface trace of the sand overlying peat versus sand overlying silt contact has its western most limits proximal to Cullaby Lake behind the knobs of Tertiary bedrock.

Gravels were found in interdune areas and underlying dune ridges north of the Necanicum River. Gravels covered most of the area to the south of the Necanicum mouth. A representation of possible contact relationships is presented in Figures 16 and supplementary text.

Conclusions. Stratigraphic data and analysis of the dune ridges and sandy interdune surfaces suggest that sand accumulated seasonally, rapidly, and under conditions of light winds and, at times, relatively wet conditions. Peat profiles appear to show accumulations under near optimum growth conditions with the localized but rare occurrence of renewed wind erosion of dune or interdune sand.

It appears that the layering of light and dark sand grains in dune and interdune sand suggests seasonal accumulations. Also, deposition is inferred rapid and

nonerosive because of the minor occurrence of erosive, vegetative or animal disturbance to sedimentary structure. Bigarella (1972, 1977) concludes that contorted bedding and low angle cross-stratification or tabular to wavy bed forms are indicative of rapid and non-erosive conditions, respectively. Bigarella also offered rippling and low angle crossbedding as indicators of light wind and wet conditions, respectively.

Peat growth occurred at near optimum conditions as shown by the highly humic nature of the peat as well as the relatively continuous pollen chronology (Hansen, 1941). The lack of sand in the peat also is an indicator of relative isolation of the peat from disruptive coastal influences such as ocean flooding or burial by wind blown sand. The rare occurrence of multiple layers of peat with varied percentages of sand indicates there were some localized areas of wind erosion.

In the south, occurrence of invertebrates in middens compared to present conditions appear to indicate a change in coastal conditions around the Necanicum River (south Plains) from a bay or estuarine condition to open sandy or gravelly beach. Although anthropological explanations are also a reasonable explanation for the occurrence of certain invertebrates in midden states.

The near surface gravels found in interdune areas northeast of the Necanicum River mouth likely represent foreshore gravels deposited during storm wave conditions. The source of the gravels is apparently the Necanicum River and Tillamook Head. The dune ridge to the east of this gravel body was likely formed after deposition of the gravels and subsequently followed by progradation and formation of ridge 2B. There may be other scenarios but even the one given is just speculation.

Both the Necanicum and Neawannan Rivers trend northsouth and occupy low areas between higher gravelly surfaces. Figure 9 presents details on the lateral relationships of units: sand overlying gravel and gravel. Superimposition of time lines from Figure 19 put the 2500 year line at Bear Valley ridge (just west of Stanley Lake), the 1500 year line on the east bank of the Neawanna, the 800 year line on the east bank of the Necanicum and the 400 year line just east of the primary dune in Seaside. Because of the lack of deep drilling in the area, the possible subsurface conditions and modes of development can only be estimated. Presented in Figure 20 are two alternative depositional sequences that could produce the gravel ridges on either side of the river beds of sand overlying gravels. In Figure 20(A) a beach ridge of gravels is formed followed by west development of a

Fig. A.

Fig. B.

DIAGRAMMATIC

Figure 20. Possible contact relationships and modes of development for gravel and sand/gravel units (Necanicum and Neawanna River area, south Plains).

sand ridge with associated near shore sands and subsequent initiation of a gravel ridge. Figure 20(B) shows the development of two gravel ridges where the interridge area was subsequently filled in by wind laid sand and/or river deposits that have been reworked over time.

Progradational Development - Subsurface Section.

Based on evaluation borings and near surface sampling of near surface and deep subsurface borings made in the Clatsop Plains (see Appendix C) and a comparison to barrier systems throughout the world (see Appendix F), the discontinuities dated in oversized Figure 19 are extrapolated onto the surface sections (Figure 17) and are presented in oversized Figure 21. The time lines are roughly correlated with the contact points between indicator beds. Also, included is a best estimate of the beach sand/dune sand contact extrapolated from the plot of sea level rise between accretionary periods (note that the contact slope plotted assumes no erosion of the strand line after progradation).

Note in the sections that the vertical difference between estimated beach/dune contact and interdune surface (disregarding peat accumulations) has fluctuated in the range of 5 to 9 meters except in areas with high interdune platforms (e.g., ridge group 6) or closely spaced group members (eg., group 3). Perhaps this shows that the

groundwater table elevation above contemporaneous sea level has remained relatively uniform throughout the growth of the Clatsop Plains.

Further Study.

Certainly more work on the Clatsop Plains would be helpful in fine tuning understanding of the developmental history. Deep vibracoring in the area, especially in the inland dune/interdune areas, could (1) identify the beach/dune sand contact by evaluating sedimentary structure, fossil type and zonation, and other sedimentary analysis, (3) accurately determine the depth to bedrock especially in the east area, (4) to find and date organic horizons to locate the subsurface contact between accretionary wedges, and (5) to identify the beach/nearshore and transgressive/basal layer contacts.

Interdune peats could be studied further to develop better peat chronology, determine if the vegetative succession was local or regional in extent and if there were any episodic or periodic upsets in the vegetative cycle. Growth rates could be more accurately determined with further dating of intermediate layers coupled with consolidation testing of peat to determine the extent of compaction under overburden weight. Peat could also be evaluated to determine the growth environment and how this may correlate to sea level changes.

Other work that is needed includes further evaluation of the dune ridge sedimentary structure to more accurately define the depositional environment of each dune and dune ridge group. The elevated and buried river terraces and recent flood plain sediments of the Necanicum could reveal some information on the conditions during Clatsop Plains development. The inland silts and clays that underlie the peat in the Clatsop Plains could likely yield abundant information on sea level trend just prior to initiation of progradation.

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APPENDIX A

APPENDIX A

PROJECT COASTAL CONDITIONS AND GEOLOGIC SETTING

Project Coastal Conditions

Conditions discussed in summary below include the following: (1) climate, (2) eolian transport, (3) waves, (4) tides, (5) currents--offshore and nearshore, (6) nearshore sediment transport--alongshore and onshore.

Climate. The climate in this area is typically wet with winter winds from the south and much drier in the summer with dominant winds from the northwest. Mean monthly precipitation and air temperatures range from 2.5 cm (1 in.) to 30 cm (12 in.) and 2°C. (35°F) to 21°C. (69°F), respectively. Refer to Figures A-1 and A-2 for a summary of the area climate. Seasonally, the climate is relatively varied. Note on Figure A-1 that the temperature maximum-minimums encompass a broad range between -6°C (14°F) and 38°C (100°F) and rainfall is heavy in winter (from November through March) and is at a minimum in summer (June, July and August). The average annual precipitation is 196 cm (77 in.) and ranges from 216 to 172 cm (84 to 68 in.) but only 4 percent of the annual rainfall occurs between June and September (Hansen 1974). Locally, rainfall has been observed to be slightly less to

Figure A-1. Wind roses for January and July, (Stenbridge, 1975).

Fig. A

MEAN MONTHLY PRECIPITATION
AT ASTORIA, OREGON
(1954-1975 inclusive)

Month	Precipitation (Inches)
January	11.61
February	7.76
March	7.43
April	4.97
May	2.64
June	2.65
July	1.11
August	1.38
September	2.91
October	6.82
November	10.40
December	11.96

Fig. B

AIR TEMPERATURES (°Fahrenheit)
AT ASTORIA, OREGON*

Month	Minimum Maximum	Normal Maximum	Normal Average	Normal Minimum
Jan	14-65	47	41	35
Feb	19-68	50	43	36
Mar	24-69	52	45	37
Apr	29-83	57	49	41
May	30-86	62	53	45
Jun	38-93	65	57	50
Jul	42-100	69	61	53
Aug	43-82	69	61	53
Sep	37-92	67	58	49
Oct	30-78	61	53	45
Nov	15-69	54	46	39
Dec	22-63	49	43	37

Fig. C

SEASIDE STATION, CLATSOP CO.

Figure A-2. Precipitation and evapotranspiration; Astoria, Oregon, (figures A and B, Meyer and Chester, 1977, and figure C, Harris and Harris, 1974).

the north, (Hansen and Harris, 1974) probably due to the orographic effect of the Coast Range which is higher to the south. Fog is common, especially from June through September (months of low rainfall); the frequency of days of rainfall is generally inversely proportional to the number of fog days, (this implies high humidity during dry as well as wet periods). There are an average of over 40 days of dense fog per year, (Cooper, 1948).

The distribution of meteoric water in the local hydrologic cycle has been estimated at 25% evapotranspiration, 20-25% surface runoff, and 50-55% subsurface groundwater recharge (Refer to Figure A-2(c) for a summary of precipitation and evapotranspiration). Based on an average annual precipitation of 202 cm (79.7 inches), evaporation is 51-53 cm/yr. (20-21 in./yr.) or 26 percent. Out of a maximum summer evaporation potential of 64 cm (25 in.), or 32 percent, an estimated 53 cm (21 in.) or 83 percent of evaporation is due to vegetation transpiration. Estimates of the annual recharge of the sand aquifer are less than 38 cm/yr. (15 in./yr.) or 19 percent; much of it lost through leaks and seeps, (Tolle, 1974).

Due to the shifting patterns of the North Pacific High and the Aleutian Low pressure cells, winds shift from the south/southwest octant in the winter to the

north/northwest octant in the summer months, refer to Figure A-1. Because summer winds have the greatest average velocity (Cooper, 1948) the greatest frequency of velocities over 4 mph (6.4 kph), (Lizzaraga-Araniega and Komar, 1974) and the summer is drier, this time considered the season of greatest blowing sand. In the wet winter, higher winds are more frequent but the average velocity is lower.

Eolian Sand Transport. Sand is transported away from the beach zone by suspension, saltation and creep. Creep has been noted to account for approximately 20% of total movement at all wind speeds (King, 1972). Studies show that just 2 to 3% moisture significantly affects the threshold shear velocity needed to pick up a sand grain. As an example; with 0.1% versus 3% moisture, the threshold velocities are 35 cm/sec. versus 58 cm/sec., respectively (King, 1972).

The net wind transport along Clatsop Beach was estimated in 1936 to range between 180 and 410 kilograms per meter per day (120 and 270 pounds per foot per day) to the NNE (O'Brien, 1936). This was during a time when much of the Clatsop Beach consisted of exposed sand. Refer to later sections of this work for a summary of changes to the coastline due to the jetty construction early this century.

Waves. Waves along the Oregon Coast are more energetic than most coasts of the world. King (1972) classifies the Oregon Coast as dominated by storm waves (Figure A-3). Referring to Figure A-4, in at least two quarters of the year, the frequency of occurrence of waves over 8 feet (2.4m) is greater than 40%. Waves greater than 20 feet high (6.1m) occur on the coast with a frequency of 3% or greater in at least two quarters of the year.

The magnitude of wave heights have been recorded in a study at Tillamook Bay, (south of Clatsop Plains) winter storms generated 20 to 30-foot (6.1-9.1m) waves (deep water height) that approach the coast from the southwest. Summer swell waves were lower with a longer period. Also noted were higher local seas in the autumn and winter than in the spring and summer (Terich and Komar, 1974).

Direction of wave approach varies with the season and coincides with the annual directional shifting of winds. As shown in Figure A-5, observations of dominant wave directions coincide with the direction of winter wind approach, especially when observations are weighted in proportion to the square of wave height. Breaker heights at Clatsop Plains have a winter maximum of 4.5m and summer average of approximately 1m (Lizarraga-Araniega & Komar, 1975). In the historic record, the largest tsunami

Figure A-3. World distribution of wave types, (King, 1972).

Fig. A. Percentage frequency of occurrence in at least two quarters of the year of waves 8 ft high or higher. Data compiled by Meisburger (1962.)

Fig. B. Greatest height in feet reached by waves occurring with a frequency of 3% or greater in at least two quarters of the year. From data compiled by Meisburger, (1962.)

Figure A-4. World distribution of storm waves, (Davies and Clayton, 1977).

WAVE DIRECTIONS OBSERVED FROM COLUMBIA
RIVER LIGHT VESSEL (O'Brien, 1951).

Direction	Percentage of total observations	Percentage weighted in proportion to H^2 *
N	0.73	0.57
NE	1.80	1.44
E	3.18	1.26
SE	2.38	3.30
S	15.02	25.14
SW	18.74	36.36
W	30.03	23.70
NW	16.57	8.24
Calm	11.54	---
*H = WAVE HEIGHT		

Figure A-5. Wave directions observed from the Columbia River
Tight vessel, (Lizarraga-Araniega and Komar, 1975).

observed on the Clatsop Beach was 2.1 to 4.2m (7 to 14 feet) in 1964 (Reckendorf, 1975).

Tides. Tidal fluctuations are governed by the ten day cycle of lunar phases. Every tidal (i.e., lunar) day consists of two high and two low water levels. The curve cycle for Seattle, shown in Figure A-6(A), is similar in shape to the Astoria curve. According to 1982 tide tables, the Astoria annual tidal range is +3.0 to -9.6 meters measured from mean low low water level, (U.S. Dept. of Commerce, 1981). In comparison with the rest of the world, the northwest coast is classified as a meso-tidal coast (Refer to Figure A-6(B)).

Beach erosion during high tides can be amplified by storm seas generated by onshore winds, erosive swell, and local beach morphology. Discussion of the significance of tides on morphology will follow in later sections of this work.

Currents. Currents consist of two types: (1) offshore and (2) nearshore (littoral). Both currents can possess vector components normal to the coastline.

Referring to Figure A-7 for schematic of offshore currents, the Subarctic Current approaches the West Coast of the U.S. and some distance offshore, diverges into a northerly Alaskan Current and a southerly California Current. Somewhat nearer the shore, the northerly

Fig A.

Fig. B.

Figure A-6. Typical west coast U.S.A. tidal curves and world tidal range versus barrier occurrence, (figure A, U.S. Dept. of Commerce, 1981, and figure B, Hayes, 1979).

Figure A-7. Schematic of offshore currents, west coast, U.S.A., (derived from Ballard, 1964).

Davidson Current develops at about 48°N . latitude. In the winter, this current is at the surface and thought to exist below the surface in the summer months as it is obscured by the effects of the California Current and surface upwelling (Ballard, 1964).

The effect of currents on sea level is considered minimal. Komar (1976) points out that maximum Davidson current upwelling occurs in the spring during the lowest monthly mean sea level. The summer surface California Current in combination with surface upwelling has even less influence on the coast due to low velocities (approx. 0.75 knots) and is susceptible to reversal by surface winds, (Dicken, 1961).

Ocean measuring stations typically show seasonal variations in sea level less than 15 centimeters, (U.S. Dept. of Commerce). The monthly maximum sea level occurs in late autumn to early fall during maximum solar heating in September, (Komar, 1976). Komar also notes that warming of surface waters affects the entire water column and can result in a maximum level increase of 3.7 centimeters.

A seasonal reversal of offshore currents has been shown by observations of Columbia River effluent dispersal patterns. Observations of the Columbia River plume (esp. silt and clay fractions), (O'Brien, 1936) and radioc~~h~~ide sampling in the Astoria Fan (Gross and Nelson), 1966) show

distinct north (winter) and south (summer) dispersal of sediment with northerly dispersal apparently more pronounced.

Coinciding with the wind and wave patterns, nearshore currents on the coastline move north and south in the winter and summer, respectively. Sand is transported along with this current. Controversy exists over whether the net transport is to the south, north or essentially zero over several years time span.

Nearshore Sediment Transport--Alongshore. Based on seasonal wind patterns, a typical model for littoral transport can be summarized. Summer winds have higher average velocities and frequencies than winter winds. The summer winds approach the coast in a narrow sector parallel to the shore or one octant offshore. These winds generate lower and longer waves (with a corresponding lower steepness ratio) with a lower breaker height. These waves transport sediment onto and along the shoreline. Winter winds approaching from the south and southwest produce steeper and more erosive waves that transport sediment along and away from the shoreline. In combination with storm generated seas, beach erosion is dominant in the winter.

The dominant mode of sediment movement in the winter on the beach zone is generally by oscillatory motion of

the bed load in the breaker zone and foreshore. In the summer, sediment is longitudinally transported in the same area as suspended load, (Sauille), 1950). The volume of transport is dependent on longshore energy flux (function of wave height and period among other factors). Comparing longshore energy to longshore transport in California and Florida, there was a linear log-log relationship.

Both offshore and nearshore currents approach the coast at oblique angles. The components of these currents normal to the coast have been discussed by O'Brien (1936), Lockett (1959), Dicken (1961), Ballard (1964), Nelson (1968), McManus (1972), Reckendorf (1975), and others.

Research of bottom current velocities at the Astoria Fan suggests the occasional transport of sand offshore from the nearshore zone, (Nelson, 1968). Reckendorf (1975) believes that the Davidson Current, when below the surface in the summer, scours the sea floor. This scouring in combination with onshore summer beach building waves is said to contribute to the build-up of the beach zone. Dicken (1961) recognized that since the Davidson Current is nearer shore than the California, the possibility exists for a current component (not necessarily sediment transport) transverse to the coast.

On the Oregon coast, there appears to be only a slight exchange of sediment onshore from offshore zones.

Glaucophane sands derived from the Klamath Mountains (south Oregon coast) are present on the outer shelf but not on the inner shelf area to a great degree, (Twenhofel, 1946 and Schiedegger, 1971). Komar (1975)) concludes from this that the importance of the shelf as a contributor to the littoral supply has diminished with the Holocene rise in sea-level. Discussion of the significance of sea-level rise will follow in later sections of this work.

Sediment Supply in the Littoral Zone. The cycle of sediments in the littoral zone is represented in Figures A-8(A) and A-8(B). In Figure A-8(A), stream discharge is likely the significant distributive source of sediment near the Plains. Erosion of the barrier appears to be the major cyclic source of sediment. Also note the interaction of sediment sources and temporary storage. The information in Figure A-8(B) focuses on the credits and debits in the littoral zone. The credits not significantly affecting the sediment budget on the Plains are sea cliff erosion, biogenous deposition, hydrogenous deposition, and wind transport onto the beach. Figure A-8(C) presents factors affecting wind transport of sand inland to the dunes (acting as a sediment "sink"). All factors are considered important to the formation of the Clatsop Plains dunes. Obviously, there are multiple

Fig. B

The Budget of Littoral Sediments (After Bowen and Inman, 1966)

CREDIT	DEBIT	BALANCE
Longshore transport into area	Longshore transport out of area	Beach deposition or erosion
River transport	Wind transport out	
Sea cliff erosion	Offshore transport	
Onshore transport	Deposition in submarine canyons	
Biogenous deposition	Solution and abrasion	
Hydrogenous deposition	Mining	
Wind transport onto beach	Rising sea level	
Falling sea level		

Fig. C

FACTORS AFFECTING WIND TRANSPORT FROM BEACH ZONE

- SAND SUPPLY
- WIND VELOCITY, FREQUENCY, TURBULENCE
- HUMIDITY
- SURFACE WETNESS
- GRAIN CHARACTERISTICS (esp. sphericity)
- TIDAL REGIME (esp. range, cycle duration)

Figure A-8. Review of littoral and beach sediment budget:
 A. cycle of sediments in the coastal zone, (Field and Duane, 1976), B. budget of littoral sediments, (King, 1972, modified),
 C. factors affecting wind transport from the beach zone, (Davies, 1977, modified).

factors controlling the dynamics of littoral deposition and erosion.

Of those possible sources of sediment to the Clatsop Beach, the fluvial discharge of the Columbia River is likely the major contributor of sands. Hodge (1934) noted the "freshness" and high angularity of the beach sands and concluded that the sediments transported downstream during spring freshet flows was the major source of sand. Other direct evidence cited by many authors is (1) the general narrowing of the Clatsop Plains with distance from the mouth of the river and, until recently, (2) the lack of beach sand on the extreme south at Seaside. Ballard (1964) cited heavy mineral analyses. Mineralogical suites with the particular occurrence of hypersthene pointed to inland andesitic terrain in the Columbia drainage as major provenance source for sands.

Ballard (1964) best evaluated the conclusion that net transport is northward based on the following sequence of events. Most of the sand is transported northward in winter months: (1) maximum upland runoff occurs in May and June, (2) river discharge velocities in spring become high enough to deposit sand outside the estuary, (3) in winter, littoral currents are more effective causing bottom scour and (4) sand is transported to the north as the winter waves approach from the south. His evidence for

this includes: (1) higher longshore energy flux of the more erosive winter waves, (2) sediment size ranges and mean diameters in the beaches north of the river mouth are similar to the Columbia River bed load, (3) higher concentration of heavy minerals occur to the north (esp. hypersthene), and (5) historic bathymetric changes near the mouth of the Columbia River that show early erosion in the south and progressive buildup to the north. Refer to Pacific Northwest River Basins Commission (1980) for an annotated bibliography of most work on sedimentation in the Columbia River estuary.

Geologic Setting

Figure A-9 summarizes the stratigraphic units and their distribution surrounding the Clatsop Plains.

Tertiary. A Tertiary geologic history of the northwest corner of Oregon has been presented by Dana (1849), Warren (1945), Baldwin (1950), Snavely, et al, (1971), Wells (1961), Niem and VanAtta (1973), Hansen and Hansen (1974) and Wiedemann (1974). Beginning with those units found in the vicinity of the Clatsop Plains (Figure 9.) Oligocene and Eocene marine sedimentary rocks were deposited in a marine environment. These sediments were subjected to uplift and erosion in early Miocene times. Renewed deposition of sandstone and shale of the Astoria Formation took place during the Miocene. Mafic intrusive

GENERALIZED GEOLOGIC UNITS

QUAT.	CLATSOP DUNE/BEACH SAND
	ALLUVIUM: silt and clay with minor sand
Pliocene	MARINE SEDIMENTARY ROCKS: sandstone, shaly sandstone
mid Miocene	COLUMBIA RIVER BASALT
	MAFIC INTRUSIVE ROCKS
	ASTORIA FORMATION: fine sandstone grading upwards to shale with overlying sandstone
u. Eocene to lower Oligocene	MARINE SEDIMENTARY ROCKS: tuffaceous sandstone-siltstone, shale, and mudstone

Figure A-9. Generalized geologic units and history.
(modified from Wells, 1961).

activity and outpourings of Columbia River Basalt occurred in the mid-Miocene. Originating in Eastern Oregon area through fissures, the basalt flowed westward through ancestral valleys of the Columbia River. Before the basalt cooled, the hot mass boiled downward into the soft and wet sediments of the Astoria Formation. (Beeson, et al, 1979).

Uplift of the Coast Range also began during Miocene time, progressing to its maximum height approximately 12 million years BP. After an erosional interval, younger Pliocene non-marine or nearshore sediments were deposited (predominantly sandstone likely related to the Troutdale formation to the west). These sediments likely were eroded to be unconformably overlain by Quaternary deposits formed during an episode of extreme sea-level fluctuations starting approximately one million years BP.

Pleistocene to early Holocene - Sea Level. The estimated sea level curves for the Quaternary approximate a crude periodic curve oscillating approximately 100 meters about a trend line beginning at approximately +175 m in Pleistocene and sloping down in elevation to -50 meters approximately the middle of the late Pleistocene transgression. The last low sea level, occurring some 21 thousand years BP, has been estimated at -125 meters (Komar, 1976).

The combined oscillation and downward trend of sea level created a series of coastal terraces. In general, the older terraces are at higher elevations than younger terraces. Only remnants of the younger terraces are present in the Coast Range proximal to the Clatsop Plains. According to Baldwin (1950) remnants of a "30 meter terrace" can be found on the Oregon Coast although it has been tectonically deformed to +60 to -60 from MSL. Cooper (1958) speculates that the Clatsop Plains is partially if not wholly founded on a terrace remnant much like other dune sheets found on the Oregon and Washington coastline. According to bathymetric mapping on the Oregon and south Washington continental terrace there are no apparent submerged topographic terrace forms within the limit of the lowest sea level (Byrne, 1963). Apparently, topographic benches exist beneath this depth, but are considered structural in origin and related to regional plate boundary conditions.

During the low stand of sea level, the coastal rivers downcut the exposed continental terrace. These ancient river valleys of the Columbia, Willapa, and Chehalis rivers coalesced in a broad submarine valley between elevations -600 and -3000 meters (Twenhofel, 1946). Figure A-10 presents a schematic of the tri-valley system.

After the minimum sea level 21 thousand years BP, the sea rose rapidly beginning about 10 to 12 thousand years

Figure A-10. Schematic of tri-valley system during low sea level, (this work, after Twenhofel, 1946).

BP until about six to seven thousand years BP. The controversy and conflicting evidence for the shape of this curve is shown by the family of curves presented on Figure A-11. For the Pacific Northwest, Cooper (1958) speculates the latest (Flandrian) rise sea-level curve was fairly gentle. Plotted in Figure A-12 are a few radiocarbon dates from the Pacific Northwest. These correlations to sea level seem to follow a gentle upcurve.

Holocene Sea Level Data Scatter - Comment. Note the widely varied interpretations of sea level from different sources shown in Figure A-11. Some curves are a collection of dates from coastal areas considered tectonically active, other curves are derived from regions considered stable. Strong controversy centers around positive sea levels during the mid to late Holocene. Many authors, of which Morner (1971) is one, conclude that a sea level curve is likely applicable to a region with similar tectonic, structural, and/or depositional history. Based on sea level curves (1) derived from tectonically "stable" areas where isostatic and eustatic factors can be distinguished and (2) compared to vegetative and glacial changes during the Holocene, Morner (1971) concludes Holocene sea level consists of a low amplitude oscillating curve where the age of the lows and highs are dependent on regional controls mentioned above.

Figure A-11. Sea level curves from various sources, (Curry et al, 1970). Pacific Northwest (Bloom, 1977).

Morner also comments on the possibility of concurrent highs and lows occurring in the same region where a coastline that is hydrostatically deformed by submergence also exhibits a compensational upwarping inside the axis of subsidence. This effect may be more applicable to an area with broader coastal plains capable of massive submergence than for the Clatsop Plains.

Sea Level - Recent Historic Changes. Komar (1976) concludes from the historic record that sea level changes in the last 250 years have correlated well with climatic change so that the rate of sea level rise has slowed during cooler periods. Komar determined rising rates of 1.2mm/year from 1725-1770, slowing rise rate from 1800-1850, and 1.25mm/year rise since 1850.

Pleistocene to Early Holocene - Sediment Distribution. Theories on the Pleistocene and early Holocene sediment supply during this period have centered on around the idea of net movement of littoral sediments to the north by longshore transport. Mineralogical suites derived from the Klamath and Siskiyou mountains in southern Oregon have been found in continental terrace sediments as much as 170 miles north of the source, (Schiedegger et al., 1971). It is thought this north littoral transport continued until over 3000 years BP. At this time the coastal headlands

became a barrier to coastwise transport. The evidence supporting this is the lack of Klamath/Siskiyou mineral suites in inner shelf versus outer shelf sediments.

Information on late Pleistocene and early Holocene sediment supply and dispersal has been gleaned from study of the Astoria Fan. Nelson (1968) noted stratigraphic evidence from a number of density currents having developed in the Astoria canyon and fan areas. It is inferred that most of the deposits occurred prior to the circa 6000 years BP eruption of Mt. Mazama (presently Crater lake in south Oregon Cascades) because no coarse ash was found in the fan deposits. Two explanations were offered: (1) During the lower sea level, sand traveling north in the littoral zone of the prehistoric coast parallel to the present coast, was intercepted by the submarine canyons of the tri-valley system and transported down the continental slope, and (2) the sedimentation rate in the fan during the glacial periods is estimated to be 10 times that of post-glacial interval. Nelson (1968) considered that during this interval subareal and channel erosion of the excess glacial sediments in the Columbia drainage occurred. In addition, there were periodic contributions of the Missoula Flood in-flux of sediment

during the late Pleistocene (approx. 13,500 yr. BP)*. The above mentioned influx of sediment occurred during the Pleistocene epoch at extreme low sea level. The impact of this sediment on late Holocene deposition has not been studied in the literature, and is considered somewhat removed from the scope of this work and therefore is not considered.

Pleistocene to Early Holocene - Climate. Climate in the Pacific Northwest during the Flandrian sea-level rise generally consisted of cool and moist conditions from 18 to 15 thousand years BP changing to an increasing warm and dry climate to 8 thousand years BP. A thermal maximum was reached between 8 and 4 thousand years BP. Since this time, the climate has generally become cooler and moister, (Hansen, 1946, and Detling, 1968). This general view of regional climate should be modified for the coastal zone to account for the moderating influence of marine climates on moisture and temperature, (Hansen, 1941).

From a peat core extending back to 15,000 years BP, increases in pollen content from lodgepole pine indicate

*For details on the Missoula Flood, refer to: Allison, I.S. (1978), Late Pleistocene Sediments and Floods in the Willamette Valley; Oregon Dept. of Geology and Mineral Industries, the Ore Bin, v. 40, no. 11, p. 177-191 and v. 40, no. 12, p. 132-202. Also see Baker & Nummedal (1978), The Channeled Scabland, NASA (National Aeronautics & Space Administration) Office of Space Science, Washington, D.C. 20546, 186p.

cooler and moister climate from 15,000 to 12,500 BP, and 11,000 to 9,500 with warmer and drier climate indicated by increases in Douglas-fir pollen at other times (Hansen, 1944). (Refer to later sections in the main body of this work for discussion of climatic change just prior to and during development of the Clatsop Plains.)

APPENDIX B

APPENDIX B

RECENT CHANGES TO THE CLATSOP PLAINS

Recent coastal changes have been documented by historical records beginning in 1806 with the Lewis and Clark Expedition, which camped the Clatsop Plains (Thwaites, 1905). From this time, topographic and bathymetric changes at the Columbia River mouth have been documented. Refer to section on Previous Work for discussion of sources.

Lewis and Clark Expedition - 1806. Figure B-1 is a copy of Lewis & Clark's original sketch map dated 1806. The map can be compared with present conditions. The most striking change is the progradation to the north and west after that time. Also, note the connecting stem of water between the Neacoxie Creek and the coastline. There is a low and seasonally wet area (elevations +3 to +6 M) existing in the vicinity of this area with a similar trend, but at present there is no surface drainage path to Sunset Lake. Note also on the 1806 map the attachment of Neacoxie Creek to Stanley Lake and that the Neawanna River had not been mapped.

Bathymetric Changes Near the Columbia River Mouth. Much information exists (USACE and other charts) on the bathymetric changes at and proximal to the mouth of the

Columbia River. With this information, many authors have evaluated the net effect of jetty construction on the coastline and nearshore areas. The subject is controversial and below is a summary of some views on the subject.

Phipps and Smith (1978) note that even the maps and charts may not be reliable because (1) the shoreline in older US Coast and Geodetic Survey Maps is questionable and some of the annual charts may have used shoreline data from previous maps, (2) some of the shorelines were mapped using mean high water (i.e., +8.0 tide) and other maps used mean higher high water line (i.e., +9.3 tide), (3) some of the shorelines were mapped using aerial photos without conversion to mean high water, and (4) even with air-photos it is questionable if the dry/wet boundary can be accurately located. The net effect is a possible horizontal error ranging from 100 meters on older maps to 10 meters for the interpretations using air-photos.

Shoaling patterns of the Columbia River have been reconstructed from the above mentioned data since 1762 (refer to Kidby, 1966). Upstream of Point Adams (ancient north tip of Clatsop Plains, refer to Figure 4, page 17) shoaling had caused separation of the Columbia River into two channels by 1792. Afterwards, the shoaled sand areas gradually shifted downstream.

By 1839 there were two shoaled areas NNW of Point Adams around which two channels of the Columbia separated. By 1879, shoaling of the south channel had created a sand shoal partially attached to the Clatsop Plains mainland.

Continued shifting of channels and shoaling caused navigation problems and instigated construction of a jetty at the north end of the Clatsop Plains in an attempt to improve the river entrance. Prior to jetty construction, the shoaling was extensive but did not elevate above mean low water (MLW).

Between 1884 and 1887, immediately after the commencement of jetty construction, rapid progradation of the north Clatsop Spit occurred. Most of the accretion from 1877-1926 (presented in Figure B-2(A)) had occurred during construction from 1885 to 1887. Both rapid erosion and shoaling occurred south of the south jetty. From 1877-1926 up to 12 meters of scouring occurred near the river mouth and offshore. The shoaled area in the bay to the east had elevated and finally raised above mean-low-water level by 1889. Further shoaling at the mouth of the Columbia pushed the river outlet westward. By 1902 the north tip of the Clatsop Spit had nearly obtained its present form.

During the second phase of jetty construction (1903-

Fig. A
1877-1926

Fig. B
1926-1958

Notes:

- depths in fathoms (6 ft. = 1.8 m.)
- two fathom contour interval
- modified from chart, USACE,
River and Harbor Section.

Figure B-2. Depth changes near the mouth of the Columbia River for periods 1877-1926 and 1927-1958, (Ballard, 1964).

1913) offshore scour was at a maximum next to the south jetty. Following construction, the Columbia Channel at the river mouth rapidly reoriented from north-south (deflected at Middle Sands) to an east-west orientation where jetty construction concentrated channel flow.

Referring to Figure B-2(B) note that scouring south of the mouth had diminished and shoaling increased to the northwest.

Accretion and Blowing Sand Stabilization. From just before the turn of the century until approximately 1935 the Clatsop Spit had prograded up to 700 meters. The rate of growth was most rapid from 1885-1887 (Meyer and Chester, 1977). Much of the growth was too rapid for natural vegetation to stabilize the exposed sand and initiate foredunes or other accretionary dune forms. Blowing sand was considered a major hazard in the north Clatsop Plains. Without dune sand stabilization, storm generated wave surges in the north had penetrated up to 0.5 kilometer inland (Dicken, 1961).

By 1935, 3000 acres of the northern Clatsop Plains were exposed, mobile sand (Dicken, 1961). The portions of the Clatsop Plains affected by the sand activity were divided into two areas: the north half consisted of an unvegetated sand flat which supplied sand to scattered hummocky vegetated dunes, and the south portion, large

sections of established dune ridges had been exposed to wind erosion after grazing had removed the vegetation. Refer to Figure B-3 for an example of the ridge exposures in the south portion of Clatsop Plains comparing the same area in the 1930's and the 1960's.

At this time, the USDA Soil Conservation Service (SCS) began a massive dune stabilization project consisting of planting of sand binding grasses (esp. Ammophila with the common name "European beach grass", scotch broom and coast pine which followed ineffective effort at sand fencing. (Refer to Warrenton Dune and Water Conservation District, 1966.) Prior to the importation of sand binding plants, foredunes and deflations plains near the beach did not exist during recorded time. Some native plants are sand binders but are less tolerant of salt spray and burial (refer to Figure 7, page 24 for varied representation of species succession from bare sand to climax forest).

After Vegetative Stabilization. Since the SCS stabilization by vegetation, the changes in the coastline have become less pronounced. Based on post-jetty plotting of high water line for selected dates (Kidby, 1966) the coast has progressively eroded south of a pivot point on the Clatsop Beach. The time lines of 1939, 1948, 1964, 1967, and 1968 pivot at a point approximately 490 meters

Fig. A.

Fig. B.

Figure B-3. Oblique view of Gearhart: circa 1930 and circa 1960, (figure A - circa 1930 and figure B - circa 1960, photos from SCS, Astoria Field Office).

NNW of the Peter Iredale shipwreck (see oversized Figure 9, 8/10- 18-NW 1/4). In the time span (1939 to 1968) maximum beach erosion had occurred immediately south of the south jetty and maximum accretion north of the Necanicum River mouth (Gearhart area). Accretion diminished south of the Necanicum. Maximum erosion of 490 meters and an accretion of 110 meters were noted in the time span between 1939 and 1968. A specific example of beach accretion near Gearhart was noted by Dicken (1960): the high tide line at mile 14 in 1960 was about 335 meters west of the estimated 1850 shoreline (6/10-4, Figure 9). Dicken noted that about 46% of this shift had occurred from 1944 to 1960.

As an explanation for coastline erosion and accretion pivoting on the Peter Iredale nodal point, Kidby offers two possibilities: (1) winter littoral currents traveling north are deflected offshore upon impact with the south face of the jetty and cause severe erosion there and/or the beach north of the nodal point is in the shadow of the jetty during the approach of summer beach building waves from the northwest. With the lack of sand nourishment to this portion of the beach zone, the nearshore bottom gradient can be steeper which allows more storm wave energy from the southwest to be dissipated on the foreshore, by erosion, rather than on bottom drag.

Controversy. The above points are one facet of the controversy over sediment budget. Columbia River spring freshet flows produced channel bottom scouring until 1969. Since this time, dams have controlled peak flows (Dicken, 1961 and Kidby, 1966). Both authors agree that this loss of sediment input in the coastal zone has caused a slight reversal of the quasi-equilibrium and Kidby assumes that this means the nodal point may shift south and erosion will increase in the north. It is possible that recent undercutting observed in localized areas north of Slusher Lake and continuous undercutting 1 mile south of Peter Iredale (Reckendorf, 1975) may also signify a shifting equilibrium.

As in the preceding two paragraphs, the net direction of littoral transport is also controversial. Lizarraga and Komar, (1975) proposed that net transport on the Oregon coast is zero, except near the Columbia River. Ballard (1964) and Gross and Nelson (196) site the north movement of the mouths of the Columbia, Willapa and Chehalis rivers and the slightly dominant north transport of Columbia plume effluent as evidence of a slight net north transport. Kidby (1966) agrees that the net transport was northerly prior to jetty construction. After jetty construction, Kidby interprets the net transport to the south based on the recent high water

lines (described above), the accretion of the north side of the north jetty, and the orientation (NE-SW) of the Columbia River channel west of the jetty. Kidby disagrees with Ballard that a decrease in beach sand median diameter with distance north of the Columbia is indicative of net north transport. Kidby did agree with Ballard that the net longshore energy flux is higher in the winter but he concluded that much of the sediment is taken offshore in winter and subsequently transported onshore to the south in the summer.

For further reading refer to Cooper (1958), Kidby (1966), Meyer and Chester (1977), Dicken (1961), Tolle (1974), Ballard (1964), Reckendorf (1975), O'Brien (1936), and Hodge (1934) for discussion of the changes in the coastal conditions at the mouth of the Columbia River and on Clatsop Beach.

APPENDIX C

APPENDIX C

TABLE III

Logs of Borings, Clatsop Plains

	THICKNESS, ft.(m.)	DEPTH, ft.(m.)
<u>6/10 3abd</u> ⁴ el. +13.1' (4.0m) (logged from auger returns)		
Fill	1½(0.5)	1½(0.5)
Brown, fine to medium SAND; poorly sorted	12½(3.8)	14(4.3)
<u>6/10 3aca</u> ⁴ el. +20'±(6m±)		
PEAT	1½(0.5)	6-7½(1.8-2.3)
<u>6/10-3cbd</u> ⁴ el. +23.5' (7.2m) (logged from auger returns 6-14½')		
Fill	1(0.3)	1(0.3)
Redish-brown, SAND; soil development	1(0.3)	2(0.6)
Medium gray-brown, medium grained, well-sorted angular SAND	12½(3.8)	14½(4.4)
<u>6/10 3ccc(2)</u> ⁴ el. +23.5' (7.2m) (logged from auger returns)		
Fill	4(1.2)	4(1.2)
Medium gray-brown, medium SAND; well-sorted, angular...	41(12.5)	45(13.7)
Medium gray-brown, medium SAND; well sorted, subrounded, less than 2% SHELL fragments and minor diabase gravels from ½" to 2½" dia.	5(1.5)	50(15.2)
Medium gray-brown, medium SAND; well-sorted, angular	13(4.0)	63(19.2)
<u>6/10 3cdc</u> ⁴ el. +11.6' (3.5m) (logged from auger returns 6-13½')		
Medium SAND; well-sorted clean, some roots	4½(1.4)	4½(1.4)
Same as above with organic material	1½(0.5)	6(1.8)
Medium SAND: Well-sorted, clean (auger refusal on GRAVELS or LOG).	7½(2.3)	13½(4.1)
<u>6/10-4ddc</u> ⁴ el. 36.0' (11.0m)		
Fine-medium SAND; well-sorted, clean, with trace silt & roots.	1(0.3)	1(0.3)
Medium SAND; well sorted, clean heavy minerals 5-5½, some iron staining at 8; 10½; 13½; moderate iron cementation ½"- ¾" thick at 16½ & 17' (roots at 17'), occasional 4"-6" iron staining 17'-26'	33½(10.2)	34½(10.5)
<u>6/10-9aac</u> ⁴ el. +36.0' (11.0m) (logged from auger returns 23-34½')		
Medium brown medium SAND; well sorted, heavy min- eral concentration at 9-9½'	34½(10.5)	34½(10.5)

TABLE III
(continued)

	THICKNESS, ft.(m.)	DEPTH, ft.(m.)
<u>6/10 10aca⁴</u> el. +9.3' (2.8m) (logged from auger returns 4-15') Sandy loam topsoil, sod Organic rich, black "A" horizon grading dark brown, oxidized SAND.....	1½ (0.5)	2 (0.6)
Medium brown, medium SAND; angular, well sorted.....	8 (2.4)	10 (3.0)
Gray unoxidized, medium SAND; well-sorted, angular.....	5 (1.5)	15 (4.6)
<u>6/10 10bbd⁴</u> el. +13.1' (4.0m) (logged from auger returns 9-15½') Medium SAND; well sorted, clear faint iron stains.....	19½ (5.9)	19½ (5.9)
note: 2' Root 5' Dark heavy mineral layer 10' Dark gray SAND with organics, decayed smell		
<u>6/10-22 Ax¹</u> Topsoil	3 (0.9)	3 (0.9)
Brown CLAY	12 (3.7)	15 (4.6)
Blue CLAY	5 (1.5)	20 (6.1)
Soft blue CLAYSTONE	150 (45.7)	170 (51.8)
<u>5/10-22Rx¹</u> Coarse GRAVEL	20 (6.1)	20 (6.1)
Sea-SAND	18 (5.5)	38 (11.6)
Coarse GRAVEL	12 (3.7)	50 (15.2)
<u>5/10-29Ax¹</u> Soil	3 (0.9)	3 (0.9)
Brown CLAY.....	22 (6.7)	25 (7.6)
Blue CLAYSTONE	115 (35.1)	140 (42.7)
Water bearing SAND	2 (0.6)	142 (43.3)
Blue CLAYSTONE	8 (2.4)	150 (45.7)
<u>7/10-4dca⁴</u> el. +47.4' (14.5m) (logged from auger returns) Gray-brown, medium, SAND; poorly graded.....	5 (1.5)	5 (1.5)
Dark-brown, ORGANIC RICH medium SAND.....	2 (0.6)	7 (2.1)
Same as 0-5'.....	31 (9.5)	38 (11.5)
<u>7/10-9dc²</u> el. +25'±(7.6m±) Fill (boulders & beach sand)	8 (2.4)	8 (2.4)
Muddy gray-brown SAND-LOGS.....	30 (9.1)	38 (11.5)
Gray-brown SAND & occasional CLAY seams.....	7 (2.1)	45 (13.7)
(abandoned moved south) Fine gray SAND.....	3 (0.9)	3 (0.9)
Fine brown SAND with WOOD and CLAY streaks.....	35 (10.7)	38 (11.6)
Fine Brown SAND with occasional brown CLAY seams	15 (4.6)	53 (16.2)
Soft, dark gray, sandy CLAY	12 (3.6)	65 (19.8)
Fine-medium gray SAND with WOOD & SHELLS	17 (3.7)	82 (25.0)
Fine gray sandy SHALE	3 (0.9)	85 (25.9)

TABLE III
(continued)

	THICKNESS, ft.(m.)	DEPTH, ft.(m.)
<u>7/10-22N1</u> ³ el. 25' (7.6m)		
SAND	8 (2.5)	8 (2.5)
SAND water-bearing	17 (5.2)	25 (7.6)
SAND, heaving	37 (11.3)	62 (18.9)
<u>7/10-26Ax</u> ¹ el. +25'± (7.6m±)		
Brown CLAY, large GRAVEL	10 (3.1)	12 (3.7)
Yellow CLAY	25 (7.6)	37 (11.3)
Brown SAND & GRAVEL, water-bearing.....	2 (0.6)	39 (11.9)
Brown CLAYSTONE	17 (5.2)	56 (17.1)
<u>7/10-33H2</u> ³ el. +46.3' (14.1)		
Light-brown, very fine, silty SAND; perched water 5-20'.....	45 (13.7)	45 (13.7)
Light-brown, very fine-medium, SAND; plant remains and woodchips at 64 ft.....	19 (5.8)	64 (19.5)
Gray, very fine-medium SAND with plant remains; fossiliferous	18 (5.5)	82 (25.0)
Grayish-black, very fine-fine SAND with large amounts of grayish-green SILT; fossiliferous.....	38 (11.6)	120 (36.6)
Very fine-medium SAND; some basalt GRANULES, with some grayish-green SILT	7 (2.1)	127 (38.7)
Black SILT and CLAY	13 (4.0)	140 (42.7)
<u>7/10-34ccc</u> ⁴ el. +19.3' (5.9m) (logged from auger returns 7-18½')		
Black, highly organic silty SAND grading to dark-brown oxidized SAND.....	½ (0.2)	½ (0.2)
Medium gray-brown, medium SAND; angular, well sorted...	7 (2.1)	18½ (5.6)
<u>8/10-7A1</u> ³ el. +23'± (7.0m±)		
Yellow SAND	40 (12.2)	40 (12.2)
Blue and gray SAND with some WOOD from 98-125 feet. log at 118 feet.....	130 (39.6)	170 (51.8)
Blue, very fine SAND; micaceous .	93 (28.4)	263 (80.2)
Blue coarse SAND	9 (2.7)	272 (82.9)
Brown SANDSTONE	8 (2.4)	281 (85.6)
Gray SANDSTONE	13 (4.0)	294 (89.6)
Blue SAND.....	3 (0.9)	297 (90.5)
Gray SAND	2 (0.6)	299 (91.1)
Blue SAND	4 (1.2)	303 (92.4)
Gray SANDSTONE.....	2½ (0.8)	305½ (93.1)
Blue SAND.....	3 (0.9)	308½ (94.0)
Gray SANDSTONE	1½ (0.5)	310 (94.5)
SAND.....	90 (27.4)	400 (121.9)
Blue CLAY, and SAND	34 (10.4)	434 (132.3)
Light colored SANDSTONE	29 (8.8)	463 (141.1)
SHALE	34 (10.4)	497 (151.5)
Gray SANDSTONE	135 (41.1)	632 (192.6)
Gray SHALE with streaks of talc..	168 (51.2)	800 (243.8)
<u>8/10-9Ax</u> ¹		
Soil	3 (0.9)	3 (0.9)
Brown CLAY.....	17 (5.2)	20 (6.0)
Blue CLAY.....	15 (4.6)	35 (10.7)
Fine SAND, water.....	35 (10.7)	70 (21.3)
Compressed CLAY & GRAVEL.....	6 (1.8)	76 (23.2)
SAND, water bearing	1 (0.3)	77 (23.5)

TABLE III
(continued)

	THICKNESS, ft.(m.)	DEPTH, ft.(m.)
<u>8/10-9D1³</u> el. +10' (3.1m)		
SAND and SILT.....	12 (3.7)	12 (3.7)
SAND, heaving, some WOOD at 138-142 feet.....	131 (39.9)	143 (43.6)
Coarse SAND, and SHELLS	2 (0.6)	145 (44.2)
SAND, heaving	50 (15.2)	195 (50.4)
Gray SAND and WOOD & GRAVEL..	45 (13.7)	240 (73.1)
SAND and LOGS.....	22 (6.7)	262 (79.9)
SAND	23 (7.0)	285 (86.9)
Silty CLAY.....	3 (0.9)	288 (87.8)
Silty SAND.....	17 (5.2)	305 (93.0)
Sandy CLAY	14 (4.3)	319 (97.2)
SANDSTONE, soft.....	1 (0.3)	320 (97.5)
SANDSTONE, hard	19 (5.8)	339 (103.3)
SAND, coarse, sharp	23 (7.0)	362 (110.2)
SAND, coarse, sharp, micaceous; salt water.....	7 (2.1)	369 (112.5)
<u>8/10-9K1²</u> el. +10' (3.1m)		
SAND.....	240 (73.1)	240 (73.1)
Blue CLAY, soft; small LOG at 262 feet	22 (6.7)	262 (79.9)
SHAPE, moderately hard.....	7 (2.1)	269 (82.0)
CLAY, soft.....	9 (2.7)	278 (84.7)
SAND, fine	38 (11.6)	316 (96.3)
SHAPE.....	11 (3.4)	327 (99.7)
SAND.....	62 (18.9)	389 (118.6)
SHAPE, very sticky	37 (11.3)	426 (129.8)
SAND, coarse	25 (7.6)	451 (137.5)
SHAPE, brown.....	43 (13.1)	494 (150.6)
SAND, coarse; salt water	2 (0.6)	496 (151.2)
SHAPE, blue	734 (223.7)	1,230 (374.9)
SHAPE, very hard.....	50 (15.2)	1,280 (390.1)
SHAPE	230 (70.0)	1,510 (460.3)
SHAPE, very hard	28 (8.5)	1,538 (468.8)
<u>3/10 16 cbb⁴</u> el. +4.0 (1.2m) (logged from auger returns 5-17')		
Topsoil; organic loam, clay loam.....	1 (0.3)	1 (0.3)
Gray-brown, organic rich, clayey SILT; saturated medium plasticity, low dry strength	3 (0.9)	4 (1.2)
2" WOOD	4 (1.2)	4 (1.2)
Same as from 1-4'.....	1 (0.3)	5 (1.5)
Gray, Medium SAND; medium sorted, subangular.....	12 (3.7)	17 (5.2)
<u>3/10-18acb⁴</u> el. +36.0' (11.0m)		
Peat.....	2 (0.6)	20-22 (6-6.7)
<u>8/10-20aaa⁴</u> el. +21' (6.4m) (logged from auger returns 6-15')		
Medium gray-brown, medium SAND; well-sorted, sub- angular.....	15 1/2 (4.7)	15 1/2 (4.7)
<u>8/10 20dab-1⁴</u> el. +28' (8.5m) (logged from auger returns)		
Dark brown-black "A" soil horizon over oxidized dune sand.....	1 1/2 (0.5)	1 1/2 (0.5)
Brown, medium SAND; shades of brown due to varied degrees of oxidation.....	18 (5.5)	19 1/2 (5.9)

TABLE III
(continued)

	THICKNESS, ft.(m.)	DEPTH, ft.(m.)
<u>8/10-20dab-2</u> ⁴ el. 26' (7.9m) (logged from auger returns) Oxidized brown grading- gray-brown, medium SAND; well-sorted, subangular.....	10 (3.0)	10 (3.0)
Gray, medium SAND; well sorted, subangular.....	8 (2.8)	18 (5.5)
<u>8/10-20dba</u> ⁴ el. +38.7 (11.8m) (logged from auger returns 19-29') Present "A" horizon; dark brown to black, organic rich, SAND grading to oxidized SAND	1 (0.3)	1 (0.3)
Medium gray-brown, medium SAND; well-sorted, subangular.....	1½ (0.5)	2½ (0.8)
Buried Soil horizon, Prominent "A" horizon.....	1½ (0.5)	4 (1.2)
Same as from 1 to 2½.....	2½ (0.8)	6½ (2.0)
Buried Soil horizon.....	1 (0.3)	7½ (2.3)
Medium Gray-brown, medium SAND; well sorted, subangular.....	22 (6.7)	29½ (9.0)
<u>8/10-20M1</u> ³ el. +35' (10.7m) Brown, fine SAND; plant remains at 23 feet.....	23 (7.0)	23 (7.0)
Gray SAND; plant remains and small amount of mica	37 (11.3)	60 (18.2)
Gray SAND; fossiliferous	5 (1.5)	65 (19.8)
Gray, very fine to medium SAND; micaceous	50 (15.2)	115 (35.1)
Gray, fine-medium, SAND; a few scattered GRAVELS and FOSSILS	7 (2.1)	122 (37.2)
Gray, fine-medium, SAND with SILT, WOOD chips, and a few small GRAVELS; fossiliferous.....	10 (3.0)	132 (40.2)
Gray, very fine, SAND with thin lenses of SILT	28 (8.5)	160 (48.8)
<u>8/10-21acd</u> ⁴ el. +5.0 (1.5m) (logged from auger returns, SPT 5-6') Coarse GRAVEL; FILL Material.....	4½ (1.4)	4½ (1.4)
Blue-gray clayey SILT; possible fill material.....	½ (0.2)	5 (1.5)
Gray, medium SAND; subangular, slightly finer than dune sand encountered to south.....	10 (3.0)	15 (4.6)
<u>8/10-21dab</u> el. 5.5' (1.7m) (logged from auger returns 13½- 28') Crushed rock Fill.....	½ (0.2)	½ (0.2)
Medium gray-brown, medium SAND; well-sorted, angular.....	1½ (0.5)	2 (0.6)
Highly organic, clayey SILT; dark gray, saturated, moderate plasticity, low dry strength.	3 (0.9)	5 (1.5)
LOG	1½ (0.5)	6½ (2.0)
Same as 2-5'.....	6½ (2.0)	13 (4.0)
Gray, medium SAND; subangular, gradational contacts with above and below, uncertain thickness.....	½ (0.2)	13½ (4.1)
Same as 2-5'.....	14½ (4.4)	28 (8.5)

TABLE III
(continued)

8/10-33 N1 ³ el. +34.6' (10.6m)	THICKNESS, ft.(m.)	DEPTH, ft.(m.)
Light-brown very fine SAND	40 (12.2)	40 (12.2)
Light-brown, fine-medium SAND; micaceous	10 (3.0)	50 (15.2)
Light-brown, very fine-fine SAND; some silt	5 (1.5)	55 (16.8)
Light-brown, fine-medium SAND	18 (5.5)	73 (22.3)
Gray, fine-medium SAND; some SILT and a few PLANT remains and WOOD chips	2 (0.6)	75 (22.9)
Gray, fine-medium SAND	13 (4.0)	88 (26.8)
Gray, fine SAND	10 (3.0)	98 (29.9)
Gray, fine SAND		
Gray, tight SAND, with some basaltic PEBBLES in a silty CLAY matrix	2 (0.6)	100 (30.5)
Blackish-gray, very fine-medium SAND with some SILT	8 (2.4)	108 (32.9)
Greenish-blue CLAY with streaks SHALES	17 (5.2)	125 (38.1)
Grayish-green, hard SHALES	10 (3.0)	135 (41.1)

Notes:

¹ Author letter designation for map plotting (see note 2)² Unpublished U.S.G.S. logs (U.S.G.S, misc. dates)³ Published U.S.G.S. logs (Frank, 1971)⁴ Unpublished logs (Sweet, Edwards & Assoc., 1980)all elevations relative to mean sea level (MSL)
metric conversion from english

APPENDIX D

APPENDIX D

Barrier Development: Theories and
Contributing Coastal Factors

Introduction

There are many varied theories of barrier or dune ridge development. All have evaluated the relative importance of multiple contributing factors in the coastal environment. Factors considered significant to varying degrees in creation of barrier dune coasts are (1) net sediment input into the littoral zone, (2) low near shore gradient, (3) dominance of low energy swell waves, (4) moderate to low tidal range, (5) gradual rising, gradual falling or "stable" sea level, (6) onshore wind component, (7) precipitation and significant humidity, and (8) embayed shoreline shape.

In addition, it is assumed that barrier dunes depend upon initiation of a topographic high on which to build barrier dunes. On the basis of existing barrier morphology and historical record along with stratigraphic evaluation of barriers and the nearshore three basic theories have developed: (1) bar emergence, (2) submergence of a preexisting high, and (3) progradation by spit development. Recent publications on the subject

support the principle that barriers are initiated by a combination of the above three modes of barrier development.

Conditions for Barrier Development and Origin of Barriers. Of the many factors that contribute in varying degrees to the generation and alteration of coastal barrier complexes there are five most commonly noted by authors: sediment supply, coastal form, waves, tide, and sea level.

Net Sediment Input. A controversy exists over the relative contribution of sediment input alongshore and transverse to the shore. Of the seven following publications which discuss the topic, two considered transverse input more important than longshore (Zenkovich, 1962, and Leontyev, 1969), while Van Straaten (1965) and Pierce & Colquhoun (1971) determined the longshore component of sediment input more important. Field & Duane (1976) concluded from U.S. Atlantic coast mineralogical studies, that both sources have an effect. Longshore input had a local influence on shorelines near cliff or river sources, however, on a regional scale, the mineralogy indicated that most of the barrier sands were derived from offshore Pleistocene sands and older bedrock formations.

The amount of sediment added to the littoral zone is considered to have an effect on the appearance of coastal barriers by Allen (1965). He noted broad and narrow ridges near the Niger Delta and attributed the wider ridges to an increase in sediment supply and/or a change in climate affecting the vegetative and/or sediment accumulation on the coast.

Not just the amount of sediment but also the size of sediment contributes to the generation and appearance of coastal barriers. Hoyt (1967) notes that a sandy beach ridge can be elevated some 30+ meters above MSL by wind transport while a beach composed of coarse sand, gravel or shells can produce beach ridges up to 7 meters above high water level by wave action.

Low Near Shore Gradient. Considered significant as a barrier foundation and sediment source by onshore transport some barriers have also been developed on steeper near shore gradients. This factor was considered important to varying degrees depending on the depositional environment of the barrier studied by each author.

Dominant Low Energy Swell Waves. Waves have two significant effects on the beach morphology: (1) sand eroding or building potential, and (2) shore gradient. The wave steepness ratio (wave height/wave length) is a

reliable indicator of wave effect. Steep waves (steepness ratio more than 0.025) are erosive although both flat and steep waves can be destructive with local seas generated by onshore winds, (King, 1972). Maximum sediment transport (and resulting beach building) in the littoral zone typically occurs when steepness ranges from 0.015 to 0.25 and maximum beach building typically occurs with steepness ratios less than 0.012, (King, 1972).

The volume of sediment transported is also proportional to wave period (P) and long shore energy flux (E) (related to wave length and height) and inversely proportional to water depth (d), (i.e., $Q \propto PE/d$). In terms of longshore energy flux, winter seas not winter swell on Clatsop coastline are more frequently in the range of values for sediment transport, not deposition. Conversely, swell in the summer is more concusive to sediment transport and buildup of beach. Uncertainty exists in determining the net total annual longshore energy flux but Ballard (1964) believes in a net value to the north due to winter seas approaching from the south. Refer to Ballard (1964), Fox & Davis (1974), Sauille (1950), and Terich and Komar (1974) for discussion of longshore energy flux and wave steepness.

Storm waves also thus play a major role in beach sand transport. Severity of storm wave erosion is proportional

to size and intensity and inversely proportional to the velocity of storm movements and the time lag between storms, (Stembridge, 1975). Morphology of the beach plays a role in localized erosion where rip currents cause embayments allowing waves to focus more energy on the beach foreshore than would otherwise be depleted in bottom drag and breaker development, (Terich and Komar, 1974). Tide is also a factor, as noted below.

Moderate to Low Tidal Range. Hayes (1979) concluded that barriers are most common and best developed on a low wave energy coast with a moderate to low tidal range from 4 to less than 2 meters. Barriers are typically reworked or destroyed on coasts with higher tidal ranges and wave energies. However, if excess sediment is coupled with low tidal range and moderate to high wave energy, barriers will become well developed.

According to Hayes, tidal ranges over 4 meters typically produce offshore linear bars, tidal flats and salt marshes. Tidal ranges from 4 to 2 meters (Clatsop Plains Coast) produce short, stunted and drumstick shaped barriers. In this tidal range, Hayes notes in general the importance of ebb deltas that act as sediment storage and a contributor to inducing wave refraction. On coasts with tidal ranges less than 2 meters, barriers are typically long and linear with a predominance of storm washovers.

The main reason for optimum barrier development on low tidal range is that waves can break over a more concentrated area for a longer time period.

Sea Level Fluctuations. There are mixed attitudes about the significance of sea level changes. Hoyt's (1967) theory incorporates rising sea level during the essential net sediment influx. Whether sea level is rising, falling or relatively stable, King (1972) considers the first three above-mentioned factors essential. Swift (1975) considers a net sediment influx necessary regardless of the state of sea level.

Sea level can have an effect on the lateral character of the barrier. Given sufficient sediment supply for barrier progradation, an emergent coastline will show multiple foredune ridges where the older ridges are at higher elevations (Zenkovich, 1962). On a submergent coast, the older ridges are lower (Hoyt, 1967). Fisher (1968) sites rapid multiple ridge growth or ridge widening as sea level stabilizes, given sufficient sediment supply. King (1972) and Curray (1969) tend to feel that sea level fluctuations do not have as direct a control over the morphology of barriers; they conclude there are the other factors to consider.

Some authors have noted that a major buildup of barriers has occurred in the last few thousand years

during the late Holocene stabilization of changing sea level (see Jelgersma, 1961, Van Straaten, 1965, and King, 1972) Field & Duane (1976), in agreement, cited nearshore stratigraphy (U.S. Atlantic Coast) to prove landward barrier migration during more rapid sea level rise (early Holocene). Vibracorings show sediments interpreted as inner shelf sands overlying (in order of depth) back barrier fine sands, marsh organic silts, lagoonal/estuarine clayey-sandy silts and Pleistocene dewatered sediments and bedrock.

There are other factors that control the development of barrier complexes. Those listed below were not cited or not considered significant in the publications reviewed for this project.

Wind Conditions. Those aspects that are important to beach and foredune development include wind approach, directional frequency, and speed frequency. These factors affect, among others, sand transport, vegetation establishment and vegetative succession to the landward of the beach swash zone.

Hansen (1944) and Cooper (1958) have noted the occurrence of sand grains throughout most of the peat bogs in the Pacific Northwest coast and conclude that there has been relatively continual wind blown sand activity in the

past 7000 to 4000 years. Hansen supports this conclusion by the increased abundance of coast pine pollen in the upper sections of peat columns that have been sampled. In a peat column taken inland of Gearhart (Clatsop Plains) Hansen noted an increase in pine in the upper 2 meters. Using the assumed rate of peat growth discussed in earlier sections of this work, this indicates that sand activity within the vicinity of Gearhart has increased in the last 1000 years.

Precipitation and Humidity. In concert with wind patterns, factors such as the following should be considered: seasonal distribution of precipitation, air temperature, evapotranspiration potential, and humidity. The above affects blowing sand, vegetative patterns, etc.

Hansen (1941), verified by Detling (1968), concluded from peat pollen analysis, that the coast in the Pacific Northwest region has experienced cooler and moister weather in the last 4000 years as evident by the increase in *Tsuga* (i.e., western hemlock) pollen and the lack of pollen derived from species tolerant of drier climates.

Increased moisture and decreased temperature could enhance the growth climate for fast growing dune sand binding species or moisture conditions could increase the minimum wind velocity necessary for transport of sand by siltation.

Vegetative Establishment & Succession. Once vegetation is established the rate of succession is important to the rate and degree of dune stabilization. Most important is the establishment species that are sand binders and tolerant of sand burial (see Figure 7, page 24, and explanatory text).

Shoreline Shape. Irregularities cause irregular wave energy distribution against the foreshore. More regular shoreline shape results in more uniform barrier development (all other factors equal).

Comment. Given all factors that contribute to the development of coastal deposits, it is apparent the sediment supply is one of the primary controls. It is clear that other controlling factors affect sediment flux excluding the importation of sediment into the littoral zone by rivers, eroding coastlines, and offshore deposits. Changes in sea level, vegetation, climate, waves, currents, and/or tides can also affect change in available sediment to the littoral zone. Figure 16 (page 66) presented in this work summarizes the possible sources, storage areas, and sinks of sediment.

Expansion on the conditions for barrier development will follow in later sections with discussion of the Clatsop Plains. Refer to the following publications for

more details: Zenkovich (1962), Van Straaten (1965), Leontyev (1969), Pierce & Colquhoun (1971), King (1972), and Swift (1975). Schartz's (1973) publication is a complete source of reprinted articles representing the evolution of barrier island theory.

Origin of Coastal Barriers

The above-mentioned conditions necessary for barrier development are generally agreed upon. Every author places special emphasis on some factors more than others. The underlying controversy over barrier theory surrounds the origin of coastal ridges. Attempts have been made in the last 150 years to propose a method or methods of generating topographic highs in the beach zone. Stratigraphic, historical and geomorphic evidence have led authors to three distinct theories: (1) emergence of an offshore bar, (2) submergence of pre-existing ridgelike coastal features, and (3) where barriers elongate by spit progradation and become separated from the mainland, by cutting of inlets or breaches by waves.

Emergence. This theory incorporates offshore bar formation as a precursor to barrier development. The modes of offshore bar formation include (1) longshore currents along the shoreface that add sediment which builds the bar (after Gilbert, 1885, from King, 1972), and

(2) waves which excavate the sea floor and transport sand shoreward (after de Beaumont, 1945, from King, 1972). Presented in Figure D-1(A) is a representation of these theories.

Leontyev (1969) is one of the first authors recognized for proposing that submarine bars emerged during late Holocene sea level regressions and subsequently aggraded. From studies of Gulf Coast barriers, Otvos (1970) proposed that shoals emerge while nourished from littoral sediments during a rise in sea level without minor regressions. Based on wave studies noted by Hoyt (1967), emergence by aggradation is not possible. On the contrary, Otvos (Schwartz, 1971) cites charts and observations proving that some of the Gulf barriers emerged from shoaled areas.

The controversy between Otvos and Hoyt continued. The expected sedimentary section according Otvos's emergent theory is presented in Figure D-1(B) compared to Hoyt's submergent theory (discussed below). Note that the barrier ridge can overliesubtidal and open marine deposits. Hoyt (1967) comments if emergence is an acceptable theory, open marine nearshore sediments (below lagoonal/estuarine facies) should be found landward of the barrier. Otvos contends that this argument is not possible because some lagoonal areas are sandy and some

Fig. A

Fig. Ba

Fig. Bb

Fig. C

Fig. D

Figure D-1. Emergence and submergence theory; from A) Shephard, 1970, B) Otvos, 1970, C) Zenkovich, 1962, D) Fisher, 1968.

open coasts are marshy. Hoyt (1968) refutes the claim that significant marsh growth occurs on open coasts, especially under coastal conditions such as the Gulf and U.S. Atlantic coasts.

Otvos maintains that, after formation, the barrier can migrate from its original position; this destroying any sedimentary evidence of origin. In reply Hoyt (1968) notes because the sedimentary column can be destroyed during emergence, "little can be proved by drilling through displaced barriers" as Hoyt implies that Otvos had evaluated.

Some authors are in agreement with the alternative of an emergence theory when sea level drops exposing the offshore bar (Hoyt, 1968) and King, 1972). Hoyt perceives sea level fluctuations as local in scale and as a mode of barrier development cannot be generally applied. King comments that buildup of barriers above high water level is also permissible along slow energy coastlines with a narrow tidal range.

Submergence. Zenkovich (1962) and Hoyt (1967) support submergence of pre-existing mainland coastal barriers. Zenkovich proposed two processes by which offshore barrier islands can form: (1) by submergence of a prograding wave built subaerial terrace, and (2) by submergence of an alluvial plain with a concurrent shift

in coastal foredune and nearshore profile. (Refer to Figure D-1(C) for a representation). In both cases, sediments of fluvial or littoral origin would necessarily underly any brackish or lagoonal sediments landward of the barrier.

Similar to Zenkovich's second alternative, Hoyt developed his theory with the following conditions: (1) dune and/or beach ridges are formed on the mainland shore, (2) partial submergence causes ridge detachment from the mainland and a lagoon forms behind the barrier. (Refer to Figure D-1(Bb) for representative stratigraphic section.) At this point, the ridges may migrate, stabilize, and/or aggrade vertically and horizontally depending on submergence rate, sediment supply and other factors. In some cases, Hoyt admits barriers may also form from submergence of emerged/aggraded offshore bars or submergence of spit barriers (discussed in the previous and following sections, respectively). Hoyt contends that only in these two cases can marine sediments be found landward of the barrier.

King (1972) in an adaptation of Hoyt's views proposed the following conditions that a theory of barrier island formation must incorporate: (paraphrasing) (1) absence of shallow-water neritic and marine sediments landward of the

barrier, (2) capability of the barrier to reform after growth is terminated by removal from the shore zone, (3) absence of worldwide sea levels higher than present, and (4) capability of the barrier to build and maintain itself during slow submergence. Item 1 is a direct adaptation of Hoyt's views (refer to Figure D-1(Bb)). Item 2 pertains to migration and/or progradation of the primary barrier after formation. Also, Holocene sea levels higher than present (Item 3) would destroy barriers or evidence of such. King includes Item 4 based on the recognition that most of the world's barriers have formed during slow submergence in the late Holocene.

Among other authors, Leontyev (1969) supports the emergence theory based on higher than present sea levels yet considers Zenkovich's theory as an alternative mode of barrier development. Pierce and Colquhoun (1971) support the theory of submergence and/or barrier formation by spit progradation with potential reworking and migration of the barrier.

Fisher (1968), in discussion of Hoyt's submergence theory, notes that the subaerial vegetation (grasses, shrubs and forest) immediately landward of the pre-existing barrier are submerged and incorporated into lagoonal sediments. Refer to Figure D-1(D). The sedimentary record of the lagoon should reflect this

occurrence but according to Fisher, in U.S. Gulf coast lagoonal records no evidence of historic tree or shrub growth has been found aside from lagoons with some salt marsh and root fragments. Also, none of the sediments show signs of open marine conditions. Fisher concludes that the base of the lagoon could never have been "significantly" above or below sea level as Hoyt and Otvos respectively theorize.

Spit progradation. The development of spit barriers is represented in Figure D-2(A). In later phases, barriers become detached from the mainland by cutting of inlets. Figure D-2(A) illustrates one of two conditions (according to Hoyt) where open marine sediments may be found landward of the barrier. Hoyt (1967) considers spit progradation having a minor role in barrier island theory and limited to a local scale on small segments of the Coast near a cliff, or river mouth delta where longitudinal sediments transport sand to the spit.

Fisher (1968) has applied Hoyt's theory of submergence and barrier development to dating progradational episodes of a spit with an intermediate rate of submergence. Figure D-2(B) portrays the contacts between prograded units where, in Hoyt's sketch, ridges 1 - 3 progradation is followed by submergence and upbuilding of the barrier (ridge 4) followed by ridge 5. Hoyt

Fig. A

Fig. B

Fig. C

Fig. D

Figure D-2. Spit progradation; from A) Hoyt, 1968, B) through C) Fisher, 1968, and D) Hoyt, 1968.

incorporates upward and seaward accretion, whereas, Fisher indicates predominantly seaward progradation. Fisher concludes, based on radiocarbon dating of U.S. Gulf coast barriers, the time sequence portrayed in Figure D-2(B) "is adequately explained by spit development". Fisher, contrary to Hoyt, considers spit development as the common mode of development for major barrier systems of the Middle Atlantic Bight from Long Island to North Carolina that have developed during the late Holocene submergence.

Hoyt and Fisher also disagree on the type of sediments found landward of the barrier. As mentioned before, Hoyt considers open marine sediments can be found landward of a barrier formed by spit progradation. Fisher (1968) in Figure D-2(C), presents a sketch of the barrier development and the pre-barrier foundation (below ridge 1) with overlying shallow water sediments. Hoyt (1968) has redrawn Fisher's sketch (Figure D-2(D)) with alterations that show stratigraphic relationships for marine sediments landward of the barrier. Here the mainland barriers (ridges 1 & 2) are formed and open marine condition prevail prior to spit progradation blocking off the bay mouth. Comment: The author considers Hoyt and Fisher to be disagreeing over what they agree on. For example, (referring to Figure D-2(D) if the bay was narrower, ridges 1 through 5 could have prograded directly onto the

shoreward face of the mainland foredune. The resulting sedimentary column behind the barrier would conform to Fisher's analysis, given the necessary sediment input and slowly rising sea level with other conditions constant.

Multiple Causality for Barrier Development. A number of authors, cited and not cited to this point, have alluded to or directly commented on the alternatives available to explain barrier development. Of the group that supports the theory of submergence: Hoyt (1967) comments that emergence and spit progradation are possible alternatives but are the exception rather than the rule, Leontyev (1969) comments that emergence is possible, Pierce & Colquhoun (1971) support submergence and/or spit progradation, and King (1972) also supports spit progradation and comments that emergence is possible.

Schwartz (1971) appears to have been the first to support "multiple causality":

Current geology texts and journal papers support: (1) the predominance of barrier islands or one origin, (2) the acceptance of two of three proposed origins, or (3) the recognition of one origin as the cause for barrier islands in a particular region. The broader question is not a matter of degree, combination or locale; but a plea for the acceptance of multiple causality, somewhat akin to Chamberlin's (1890) method of multiple working hypotheses. It is deemed feasible that any of the above causes, proceeding independently or in concert, can form a barrier island.

Swift (1975) concurring with Schwartz, comments that barriers form due to a multiplicity of factors and will form if conditions are optimum especially where there is a net sediment input into the littoral zone.

APPENDIX E

APPENDIX E

GEOMORPHOLOGY: COMPARISON TO WORLD BARRIER SYSTEMS

Similar barrier deposits of the world exhibit widening of ridge groups with proximity to sediment source, close parallelism of selected ridge sets, and the appearance of high interdune platforms. Four barrier deposits located outside the West Coast of the U.S. are presented in Figure E-1 in plan view sketches. Notice the discontinuous nature of the sets of sub-parallel ridge crests and the escarpments. Figure E-(A) a sketch map showing offshore ridges formed during a lower sea level. Note the varied alignments of ridges and that these ridges are much more discontinuous than the Clatsop Plains. The deposits represented in Figures E-1(B) through E-1(D) are more like the appearance of the Clatsop Plains.

Note in Figure E-1(B) the mode of buildup by spit extension and the resultant interdunes that cut across the ridge alignments. Like the Clatsop Plains, there is a widening of ridge systems near the sediment source, major truncation of older ridge systems, and close parallelism of individual ridges within each group. These similarities are apparent even though, unlike the Clatsop Plains, the Niger area tidal range is smaller, wave effect is less significant, and the ridges are only a few meters

Fig. A
U.S. Atlantic Coast
Submarine Plain

Fig. B
Niger

Fig. C
Australia
Burdekin Delta

Fig. D
Australia
Darling River

Figure E-1. Plan view of selected barrier complexes, A. Mid-Atlantic Bight, USA (Swift, 1975), B. Niger River delta and proximity, Nigeria (Allen, 1965), C. n. of Burdekin delta, s. Australia (Bird, 1971), D. s. of Darling River, s. Australia (Bird, 1971).

high (because the humid/warm climate promotes rapid vegetative stabilization of the ridges and backshore areas).

Two Australian barrier deposits are presented in Figure E-1(C) and E-1(D). The ridges shown in an area north of Burdekin delta (Figure E-1(C)) possess close parallelism and slight divergence near the sediment source. Those ridges exhibited in Figure E-1(D) possess close parallelism with some large scale discontinuities in the central areas.

The examples above show similarity in having parallelism of dune ridge sets, major truncation of older ridge sets by younger sets, a general divergence of ridge crests toward the sediment source, and a repetition of the overall form of the dune ridge map patterns and the pattern of the modern beach.

Lateral cross sections of some world barriers are presented in Appendix F. Some of the sections may not be representative of the coastal deposit yet they can be compared to the Clatsop Plains. Note the high and broad interdune/dune platform in F-2 (Appendix F) like that found on the Clatsop Plains. In general, the Seal Rocks section (Figure F-2) is most like the appearance of the Clatsop Plains sections (Figure 17). The Seal Rocks section appears to have high hummocky interdunes and more irregular and gently sloping windward slopes.

APPENDIX F

APPENDIX F

STRATIGRAPHY: COMPARISON TO WORLD BARRIER SYSTEMS

Internal Geometry of Coastal Dunes. Many barriers throughout the world consist of vegetated coastal dunes with intervening interdunes of sand or low wet peat and silt/clay. The internal geometry of coastal dunes show tabular planar bedding, truncated topsets on the leeward side of the dune, minor ripple development, and occasional deformational structures similiar to the Clatsop Plains. Refer to Figure F-1 for a selection of dune ridge cuts sketches from Bigarella (1972). Note the similiar bedding characteristics with orientation to the direction of dominant wind. Deformational structures in the lower right of Figure F-1 were found at some sites in the Clatsop Plains dune cuts. Studies of interdune peats from other barriers could not be located in the literature so comparison could not be made.

Bigarella (1972, 1977) represented some sedimentary structures as indicators of the dune depositional environment. He considers lower angles of repose in dune deposits as indicative of wet conditions during deposition and preservation of underlying structures is likely because of rapid accumulation. Bigarella (1972) concludes that simple accumulations with moderate to low angle cross

Figure F-1. Internal structure of coastal dune ridges: Porto Novo, Togo (Africa), Ipanema, Praia de Leste, Parana (Brazil), Barra do Sul, Santa Catarina (Brazil), and Jardim Sao Pedro (Brazil), (from Bigarella, 1972).

stratification and tabular or wavy bed forms are indicative of non-erosive accumulations. Bigarella also noted that the occurrence of ripples indicate weak winds of less than 30 kilometers per hour and a depositional period of neither marked erosion nor deposition.

Contorted bedding

Bigarella considers an indicator of rapid accumulation.

Subsurface Sections. Summary subsurface sections of deposits similiar to the Clatsop Plains are presented in Figure F-2. Referring to Figure F-2(A), note the occurrence of interbedded clay and sand (unit 2), sand and gravel at the base of the section as well as up section in pockets, and dune ridges of two distinct ages.

Fossiliferous sands are common below sea level in the Newcastle Bight (Figure F-2(A). Note the clay with shells and organic mud at an intermediate depth overlying basal sands and fossiliferous sands in the Salt Ash section. Interlayered fine sediments also appear beneath the barrier proximal to the Niger delta (refer to Figure F-2(F)).

Buried soil horizons were encountered in the Seal Rocks section (Figure F-2(D)) and the Eurunderee section (Figure F-2(E)) showing signs of separate stages of dune buildup. Also in Figure F-2(E) is the thick older sequence of humate impregnated sand (recalling the thick

Fig. A

Geologic cross section through Newcastle Bight embayment showing lithofacies: (1) basal fluvial sands and gravels; (2) interbedded clays and sands (composite estuarine unit); (3) Inner Barrier marine sands; (4) Pleistocene dune sands; (5) fluvial sands and gravels; (6) late Pleistocene marine and estuarine sands; (7) marine transgressive sands; (8) backbarrier sands and muddy sands; (9) Outer Barrier marine sands; (10) Outer Barrier transgressive dune sands; and (11) Holocene estuarine muds.

Hypothetical section through Newcastle Bight showing relationship between onshore marine, estuarine, and fluvial facies and inner-continental shelf deposits (after Roy and Crawford).

Fig. D

Radiocarbon dates are on charcoal pieces sampled from buried soil surfaces in sand-mining excavations: (1) 1265±135 yr. BP, (2) 3025±135 yr. BP, (3) 2485±135 yr. BP, (4) 1975±110 yr. BP, (5) 2600±110 yr. BP.

Fig. F

Generalised horizontal and vertical sequence of sediments in Niger delta area.

Fig. E

Cross section of the Outer Barrier in the Eurunderree embayment. This bay barrier is composed of a nested set of parabolic dunes. Four phases of dune development are inferred: I, pre-6500 yr B.P.; II, mid Holocene (>3500 yr B.P.); III, late Holocene (<2500 yr B.P.); and IV, modern. Radiocarbon dates are on organic carbon (SUA-1056 courtesy of P. Hesp and A. Short).

Fig. B

Radio carbon dates are on shell detritus and are corrected for environmental or ocean reservoir effect. Three phases of transgressive dune formation are: 1. mid-Holocene (>4000 yr. BP), 2. late-Holocene (>2500 yr. BP), 3. modern.

Figure F-2. Generalized transverse stratigraphy of other coastal barrier complexes: A. Newcastle Bight, inner barrier, B. Newcastle Bight, outer barrier, C. Newcastle Bight, facies relationships, D. Seal Rocks, E. Eurunderree, outer barrier, F. Niger delta proximity, (A. through E., Thom, 1981, and F., Allen, 1965).

sequences of sand with plant remains portrayed in Clatsop Plains sections, Figure 17).

Figure F-3 presents all pertinent data from stratigraphic analysis of the Holland barrier deposit. Graphic logs and cross sections present median grain size distribution, indices of grayness, and the distribution of sedimentary units in each boring and laterally across a section.

Note the distribution of shell beds in Figure F-3(A) and F-3(C). Indices of grayness (Figure F-3(E) show an increasing grayness to -12 m MSL with a rapid decreased grayness below. Note also the occurrence of clay beds in Figures F-3(A to C), as they are interbedded with the sand and shell layers and gradationally increase thickness with depth.

Referring to subsurface sections of the Clatsop Plains, oversized Figure 17, silt or clay lenses were found at elevations similiar to the Holland barrier deposit. Fossiliferous zones were encountered near -10 m MSL beneath the Clatsop Plains. In Holland, shells were found at the same level and up to - 1 meter MSL. In most of the Clatsop borings, there was a distinct transition from brown to gray sands down to bedrock or basal layer. In Figure F-3, the Holland deposit has a similiar appearance in the upper 5 to 8 meters where below this

Fig. A
Ijmuiden excavation

Fig. B

Lithology of coastal deposits in borings I—VIII (fig. 5) and of samples from sea floor off Scheveningen (fig. 11).

The curved lines connect the estimated median values of the grain size frequency distributions of sand laminae.

Heavy dots = median diameters according to sieve analyses.

Black = average clay content of successive layers of 10 cm thickness.

Vertical striations = Peat.

S = Highest shell layers.

Horizontal lines = Boundaries of formations and sedimentary units (see fig. 6).

Fig. C

Inferred distribution of median diameters of sand laminae in profile from Scheveningen to Voorburg.

Distribution of indexes of greyness of coastal barrier sand between Scheveningen and Voorburg.

- 6) 2.0–0.0 m above N.A.P. : cross bedded dune sand;
5) 0.0–1.3 m below N.A.P. : sand with approximately horizontal laminations;
4) 1.3–1.8 m below N.A.P. : sand with shells, and with parallel and cross laminations;
3) 1.8–3.2 m below N.A.P. : sand with abundant shells, partly concentrated in separate beds;
2) 3.2–7.2 m below N.A.P. : sand with thin shell beds and with scarce, thin, clayey laminae;
1) 7.2–8.5 m below N.A.P. : alternations of clay and relatively fine-grained sand, with thick shell beds. This deposit was only partly exposed. The data given in fig. 4 are mainly based on a core taken from the floor of the excavation.

Figure F-3. Stratigraphy of Holland coastal sand barrier deposit : A. representative sedimentary column at Ijmuiden excavation, B. sedimentary columns of borings aligned transverse to the coastline, C. generalized cross-section, D. inferred distribution of median diameters of sand, E. distribution of indexes of greyness, (van Straaten, 1965).

point the sands turn brown and less gray.

Interpretation. Those authors who have studies subsurface drilling records in barrier deposits, use the sediment descriptions and minor constituents as indicators to determine the approximate location of sea level and the changes in sea level during deposition of the various facies. Thom (1981) and Van Straaten (1965) consider the top of fossiliferous sands the contact between dune and beach sediments. Some authors (summarized by Thom, 1981) considered the base of humate impregnated or crossbedded sands as the contact between dune and beach sands. According to Van Straaten (1965), the highest shell layers are deposited at or above mean high tide and strongly crossbedded sands are deposited in the zone of heavy waves influence (roughly equal to mean low tide). Finer unoxidized clays and silts with fine sands are considered nearshore facies unless other indicators prove contrary. Basal gravels near the top of bedrock are considered the regression surface by many authors. Pockets of clean gravels up in a section likely represent a former gravel beach slope. Van Straaten (1965) also noted that interpretation of former sea levels based on beach gravels should be avoided because the gravels are storm wave deposited much above sea level at the time of deposition.

Related to the inland silts found underlying peat

in the Clatsop Plains, Zonneveld (1965) noted the appearance of alluvial fines deposited as a function of sea level change: (1) with rising sea level, soft gray "pyritic clays" are deposited with a high amount of organic matter where the fines are found underlying peat deposits, (2) with a relatively constant sea level there is sedimentation mostly at the shoreline and landward of the shore, salt or fresh water sedge and pass marshes without much clays are deposited, and (3) dropping sea level results in desalinized and oxidized brown and rust colored clays.