AN ABSTRACT OF THE THESIS OF

Campbell Cary Rea for the degree Master of Science
(Name) (Degree)

in Oceanography presented on 13 December 1974
(Major department) (Date)

Title: THE EROSION OF SILETZ SPIT, OREGON

Abstract approved: Redacted for Privacy

Siletz Bay is a drowned river valley filled with Holocene alluvial and estuarine sediments and is separated from the ocean by a sand spit 3.8 km in length. Since the area was settled by white man in the 1890's, the bay has apparently experienced rapid siltation, due to increased farming and logging. This along with the damming of the Siletz River sloughs has altered circulation patterns in the bay. Deflection of the Siletz River flow by the prograding Drift Creek delta has caused 105 m of erosion since 1912 on the east side of Siletz Spit. The ocean side of the spit suffers periodic erosional episodes separated by periods of accretion and dune building. The most recent and publicized erosion occurred during the winter of 1972-73 when it was feared that the spit might be breached; one partially constructed house was lost and three others were saved only by timely riprapping. A sand mining operation may have aggravated the recent erosion by disrupting the sand budget, the balance of sand additions and losses

from the beach. All of the foredune on the spit has been stabilized by dune grass and much of it has been riprapped. The long term effects of stabilization and riprapping are uncertain.

The Erosion of Siletz Spit, Oregon

by

Campbell Cary Rea

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Commencement June 1975

APPROVED:

Redacted for Privacy

Associate Professor of Oceanography
in charge of major

Redacted for Privacy

Dean of School of Oceanography

Redacted for Privacy

Dean of Graduate School

Date thesis is presented 13 December 1974

Typed by Marjorie Wolski for Campbell Cary Rea

ACKNOWLEDGEMENTS

This study was aided by many persons in the Lincoln County Survey and Planning Offices, Lincoln County Historical Society, U. S. Bureau of Land Management, U. S. Army Corps of Engineers, and Oregon State Highway Department who graciously gave of their time to help collect historical and geological information, survey plats, and aerial photographs. I am especially grateful to the Oregon Air National Guard 1042nd M. I. Company (Aerial Surveillance) in Salem for generously providing aerial photographic coverage periodically from February through June, 1974.

Sincere thanks is extended to Marty Miller, Mike Gaughan, and Roman Lizzarraga who assisted with the beach surveys. I am triply indebted to Bill Fox who taught me his surveying technique, helped with the surveys, and adapted his computer mapping program for my use.

Clayton Creech made available the wave data at the OSU Marine Science Center in Newport, Oregon, and Henry Pittock gave me access to his National Ocean Survey tide records for Newport and Depot Bay, Oregon.

This study has been supported in part by the National Oceanographic and Atmospheric Administration, U. S. Department of Commerce, Institutional Sea Grant 2-35187.

TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
II. BACKGROUND INFORMATION	3
Physical Description	3
Geologic Evolution	7
Geology of the Area	11
Development and Alterations of Siletz Bay	15
III. HISTORY OF EROSION AND ACCRETION	18
Erosion on Siletz Spit	18
Sedimentation within Siletz Bay	42
IV. CAUSES OF CHANGES WITHIN THE BAY AND ON THE BAY-SIDE OF THE SPIT	46
V. BUDGET OF SAND ON SILETZ BEACH	52
Onshore-Offshore Exchange	54
Longshore Transport	57
River Source	63
Cliff Erosion Input	70
Total Sediment Budget	72
Sand Mining	75
VI. LONG TERM SEA LEVEL CHANGES	77
VII. WAVE ACTION AND SPIT EROSION	78
VIII. RECOMMENDATIONS FOR CONTROLLING EROSION	87
IX. SUMMARY	93
BIBLIOGRAPHY	96
APPENDIX A	102
APPENDIX B	104

LIST OF TABLES

Table		Page
1	Description of Measurements Used in Long Term Erosion Study.	26
2	Comparative Measurements, 1875-1974.	27
3	Numbers of Days Having Average Wave Energy Fluxes Between Given Limits During Four 92 Day Periods Since 1971.	86

LIST OF FIGURES

Figure		Page
1	1971 Aerial photograph of Siletz Bay and sand spit.	2
2	Map of Oregon coast from Yaquina Bay to Cape Kiwanda.	4
3	Map of Siletz Bay.	6
4	1939 Aerial photography mosaic of Siletz Bay	10
5	Geologic map of Siletz Bay area.	12
6	Marine terrace deposit overlying seaward dipping Tertiary strata in sea cliff at Fogarty Creek Beach Park.	13
7	1875 Survey plats	
	a. Portion of Township 7 South Range 11 West Willamette Meridian.	19
	b. Portion of Township 8 South Range 11 West Willamette Meridian.	20
8	Aerial photograph of Siletz Bay showing location of section lines.	22
9	Map of Siletz Bay showing locations of comparative erosion measurements.	25
10	Graph of comparative erosion measurements.	28
11	Saw-cut logs protruding from erosion scarp in foredune.	31
12	Foredune accretion sequence.	
	a. Logs accumulating at base of erosion scarp.	34
	b. Logs trapping wind-blown sand.	34

List of Figures, continued:

	c. Dune grass becoming established on built-up pile of sand and logs.	35
13	Areas of erosion on Siletz Spit since 1970.	36
14	Remains of house destroyed by waves, January 18, 1973.	38
15	Aerial view of eroded area, February 8, 1973.	39
16	Position of foredune before and after the erosion in 1972-73.	41
17	1934 survey of Siletz Bay and Spit.	44
18	Marsh expansion in the southern portion of Siletz Bay.	45
19	1897 map of Siletz Bay and Spit.	47
20	Comparative beach profiles, February 1 and May 8, 1974.	55
21	Aerial photograph of rhythmic beach topography on Siletz Spit, February, 1973.	58
22	Map of Siletz Bay showing sand sample locations.	60
23	Climatic variation of sediment yield.	67
24	Actively eroding cliff south of Siletz Spit.	71
25	Wave energy flux smoothed by three-day moving average. Peak one-day averages indicated by o.	83
26	Houses riprapped after storm on December 24, 1972.	84

THE EROSION OF SILETZ SPIT, OREGON

CHAPTER I

INTRODUCTION

Siletz Spit (Figure 1), located in Lincoln County on the central Oregon coast, has in recent years been the site of severe beach and property erosion which has caused concern among homeowners in the Salishan Resort development. It was also feared that the spit might breach and thereby cause damage to Siletz Bay, filling the Bay with beach sand.

At the time of beach erosion in 1971-1973 the existing houses on the spit had been present for less than ten years and there had been no prior development so that little was known concerning erosional processes in the area. It was uncertain then whether the recent episode of erosion was the start of a new disaster similar to that which occurred at Bayocean Spit and led to the destruction of the spit (Terich and Komar, 1973), or if the erosion was only some natural cycle of erosion followed by accretion, noted now because of the presence of the houses.

The purposes of this study are: (1) to examine the history of erosion on Siletz Spit; (2) to determine whether the erosion is part of a long term trend or is cyclical; and (3) to suggest probable causes

Figure 1. 1971 Aerial photograph of Siletz Bay and sand spit.

and possible remedies for the erosion.

Information on past erosion was obtained from the original survey plats made in 1875, a 1912 tidelands survey, and series of aerial photographs dating back to 1939. The photographs also supplied information on the erosion of the adjacent coastline which was used in calculating the sand budget for the area. Beach surveys made on Siletz Spit during the spring of 1974 and wave data from the Oregon State University Marine Science Center in Newport were used in determining the relationship between wave energy and erosion or deposition on the spit. Finally, much of our information, surveys, photographs, and so on, comes from on-site visits during times of maximum erosion on the spit.

CHAPTER II. BACKGROUND INFORMATION

Physical Description

Siletz Spit (Figure 1), is a low narrow sandy spit approximately 3.8 km in length separating Siletz Bay from the ocean. It forms part of a nearly continuous sandy beach that stretches for 24 km along the central Oregon coast from Government Point to Cascade Head (Figure 2). The width of the sand spit varies from about 390 m at the base to 60 m at its narrowest point west of Cutler City. The southern third consists of stabilized forested dunes with maximum elevations greater

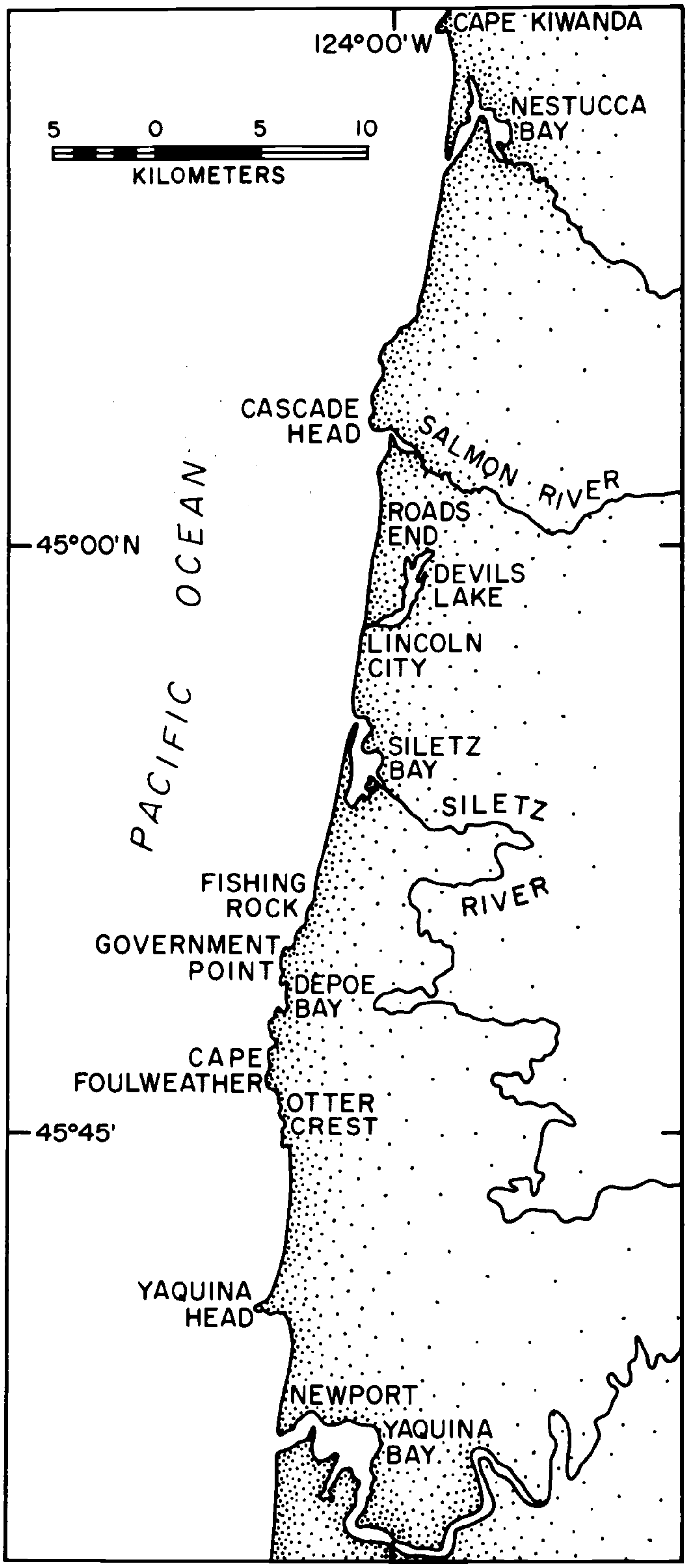


Figure 2. Map of Oregon coast from Yaquina Bay to Cape Kiwanda.

than 15 m, separated by lower grassy areas where wind eroded blow-outs or washovers by high waves occurred prior to stabilization by dune grass. Along the northern two-thirds there is a low grassy foredune with crest heights generally not exceeding 6 m above mean sea level. A steep slope or erosional scarp forms the seaward edge of the dunes (in many cases protected by riprap), while on the bay side the slope is very gradual except where active erosion is occurring west of Cutler City.

Siletz Bay (Figure 3), is a shallow body of water about 4 km long parallel to the coastline trend, varying in width between 0.7 and 1.5 km. The total area of the estuary is approximately 4.7 square kilometers (1160 acres) of which 65% is exposed at low tide (Percy et al., 1973). The three main streams that flow into the estuary are the Siletz River which forms a delta in the southeastern portion of the bay, Drift Creek forming a smaller delta south of Cutler City, and Schooner Creek entering at the northeast corner. A very small stream, Sijota Creek, flows into the bay at the south end. The total freshwater discharge into the estuary is estimated to average 2.06×10^9 cubic meters annually of which 84% is contributed by the Siletz River (Percy et al., 1973). Nearly all of this discharge occurs during the rainy season between November and March.

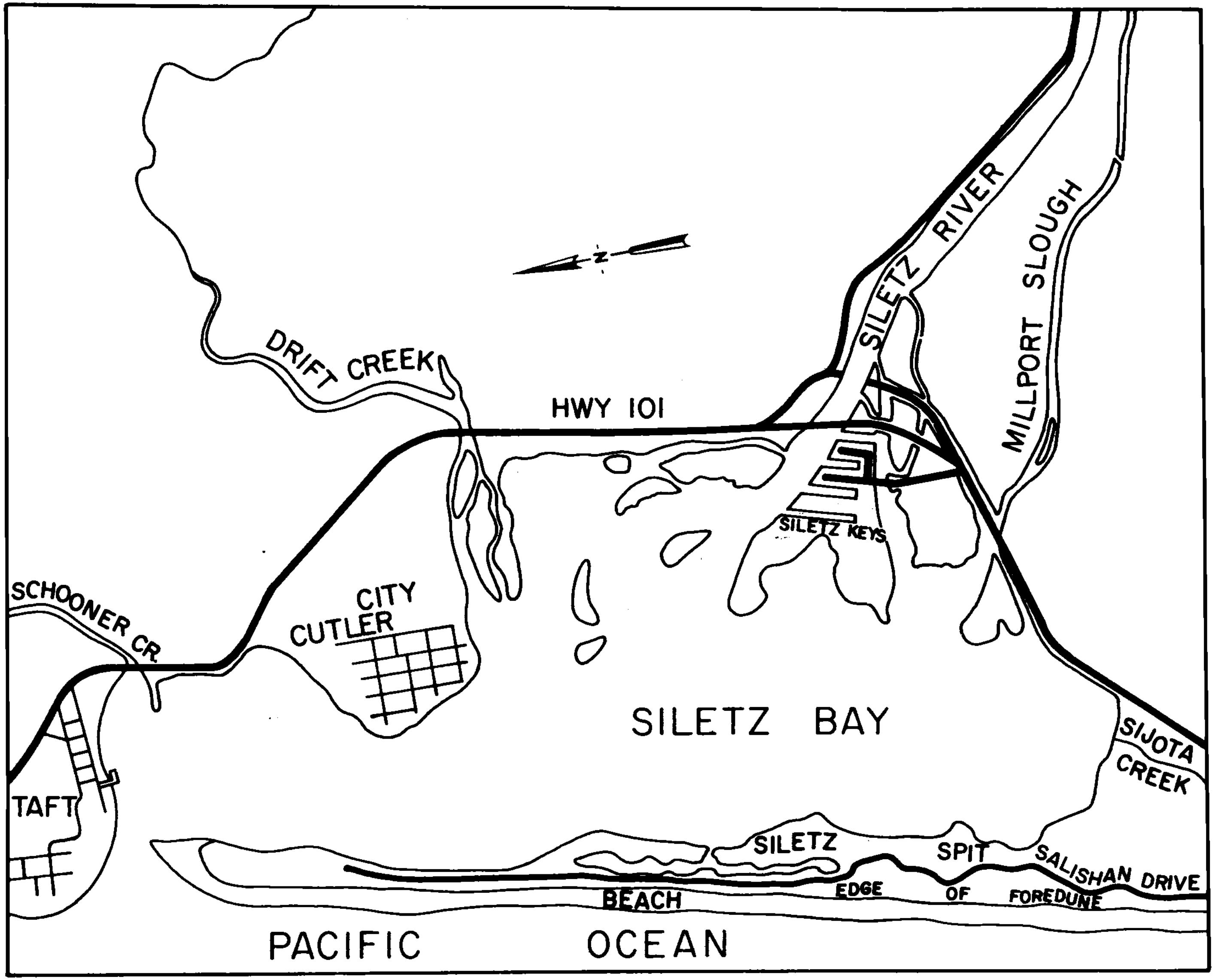


Figure 3. Map of Siletz Bay

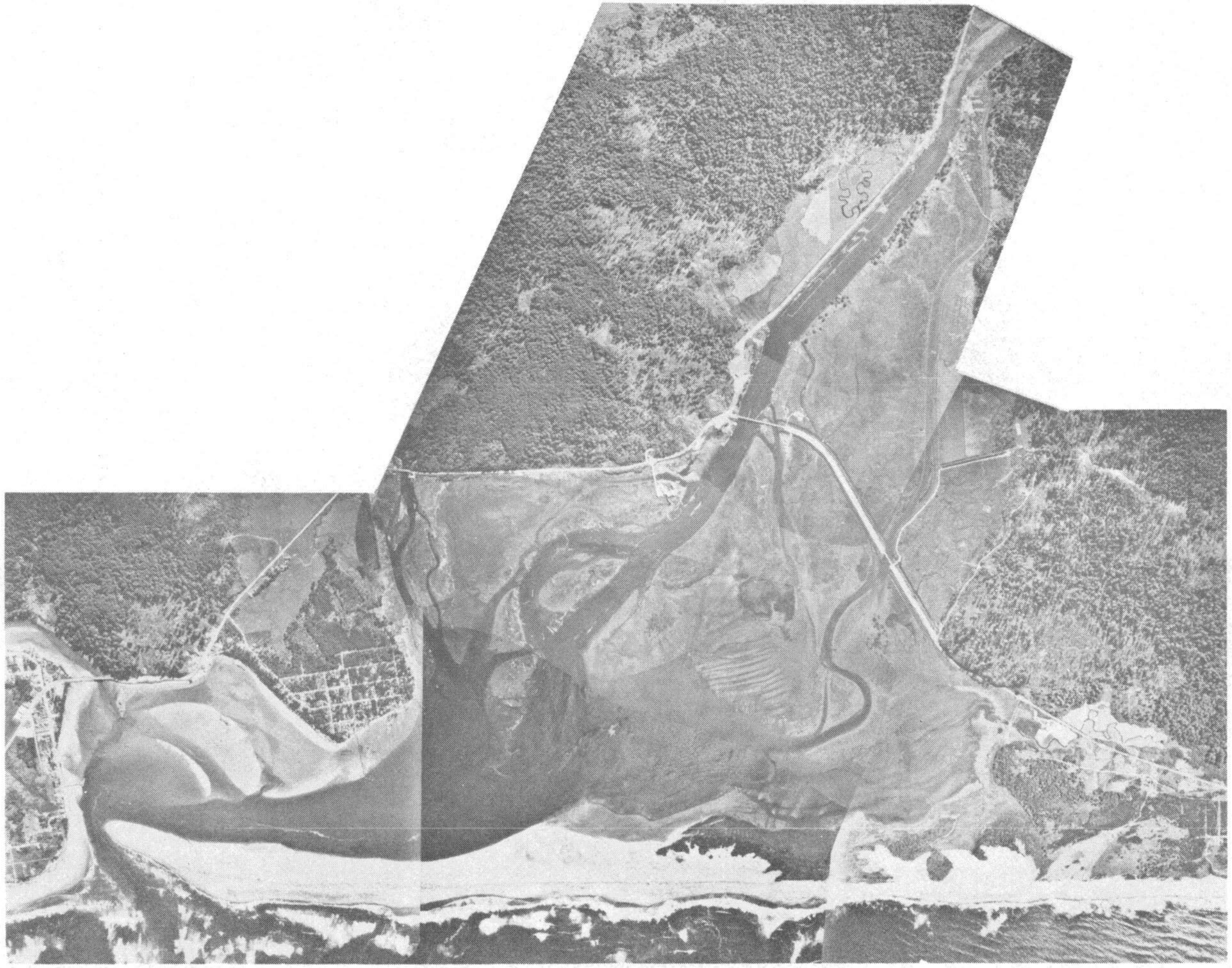
Geologic Evolution

The Siletz estuary was formed when rising sea level drowned the Siletz River valley after the most recent period of glaciation (Wisconsin). Sometime between 20,000 and 15,000 years B.P. (before present) the sea which was about 130 m below its present level began to rise rapidly at rates averaging 15 meters/1000 years (Milliman and Emery, 1968; Curray et al., 1970). The rate began to decrease about 7000 years B.P. and the sea was at or near its present level by about 4000 years B.P. The depth to bedrock beneath the Siletz River where it enters the bay is 36 m (OSHD, 1970) so that the head of tidewater probably reached the location of the present estuary approximately 8,000 to 9,000 years B.P. As sea level continued to rise, the river gradient decreased, allowing sedimentation to occur in the channel. The valley was probably partially filled with alluvial sediment by the time the sea reached its present level. The arms of the bay extending inland along the drowned stream channels filled rapidly and tidal marshes spread seaward. Meanwhile, longshore currents deposited beach sand in the bay mouth and sand spits began to grow, possibly from both sides since sand transport along the Oregon coast is to the south during the summer and to the north during the winter. The growth of spits caused a reduction in wave energy within the bay, allowing sedimentation to accelerate in the protected area.

Eventually the southern sand spit prevailed and the bay mouth was reduced to a narrow opening at the north end of the bay. As continued sedimentation reduced the volume of the tidal prism in the estuary, the mouth narrowed still further until it now varies between 60 and 200 m in width with shifts in the position of the north extent of the spit.

The low, narrow configuration of the northern half of the sand spit and the scarcity of natural vegetation suggest that this portion may have eroded away periodically following shifts in the location of the opening. The apparent stability of the present mouth indicates that any shifts would probably be initiated by a breeching of the spit and would be only temporary. Some "old-timers" on the coast have reported that the base of the spit covers the former channel of the Siletz River (Schlicker et al., 1973). If such a southern opening to the bay did exist, our evidence indicates that it must have been in prehistoric times, well before the births of the coastal "old-timers." In 1849 Lt. Talbot led an army exploration party northward along the spit and reported crossing the mouth at the north end (Lincoln County Historical Society, 1948), and the earliest survey plats made in 1875 by John A. Hurlburt also show the opening at the north end. The 1912 tideland survey (Corvallis and Eastern Railroad Co., 1912) shows the entrance at the north end and gives no indication of any change in the marshland at the south end since 1875. The trees presently growing on the southern end of the spit rule out any breaching there since 1912 so that the available evidence indicates no southern bay mouth since 1849.

However, there is some evidence for a still earlier opening at the south end and it is possible that the "old-timers" obtained their information from the Indians living there prior to settlement by the white man. First, the foredune is lower at the southern end than it is a little further to the north. Second, the smooth concave curve of the hill just south of the spit (Figure 4) could have been formed as the cut-bank on the outside of a river bend. If the mouth of the Siletz was ever at the south end of the spit, the southward flow would have been deflected seaward along the base of the hill and eroded into the hill producing the observed concave cut in the hill. The absence of such a curve cut into the cliff north of the present bay opening argues against this line of evidence, but the cliff north of the present mouth is protected by a rock ledge extending into the entrance (U. S. Army Corps of Engineers, 1973). Although the evidence is uncertain, there is some indication that the mouth of the Siletz River once existed at the southern end of the spit. If it did, then it was sometime before 1849, probably much before 1849. The present pattern of tidal marshland in the estuary could not exist if the circulation were much different than at present and in 1912. If a southern river exit ever existed, it must have been at least several hundred years ago to allow the



SILETZ BAY 1939

73-17

Figure 4. 1939 Aerial photography mosaic of Siletz Bay.
U.S. Army Corps of Engineers mosaic.

marsh to become established.

Geology of the Area

Rates and patterns of erosion on the Oregon coast are largely determined by the local geology. Tertiary marine sediments are exposed to erosion along much of the coast (North and Byrne, 1965). Where these rocks have an appreciable seaward dip landsliding is common, occurring along bedding planes (Byrne, 1963).

Schlicker et al. (1973) give a summary of the geology and erosion in Lincoln County including the Siletz area. Part of their geologic map of the Siletz River section is shown in Figure 5. The coast north and south of Siletz Bay consists of an uplifted marine terrace 0.2 to 1.5 km in width backed by the foothills of the Coast Range. The Pleistocene marine terrace deposits are massive fine- to medium-grained, friable sandstone of beach origin with thin interbedded siltstones. Pebble layers are common low in the section, and old semi-consolidated dune sands overlie the terrace deposits. At Fogarty Creek, 6 km south of the bay, the terrace deposits mantle a wave-cut platform of tilted Tertiary strata which form the bottom half of the sea cliff (Figure 6). Tertiary sediments crop out again in the cliff north of Roads End about 10.5 km north of Siletz Bay. In between, the Tertiary rocks are generally buried but occassionally are exposed in the beach during the winter when the beach sand moves

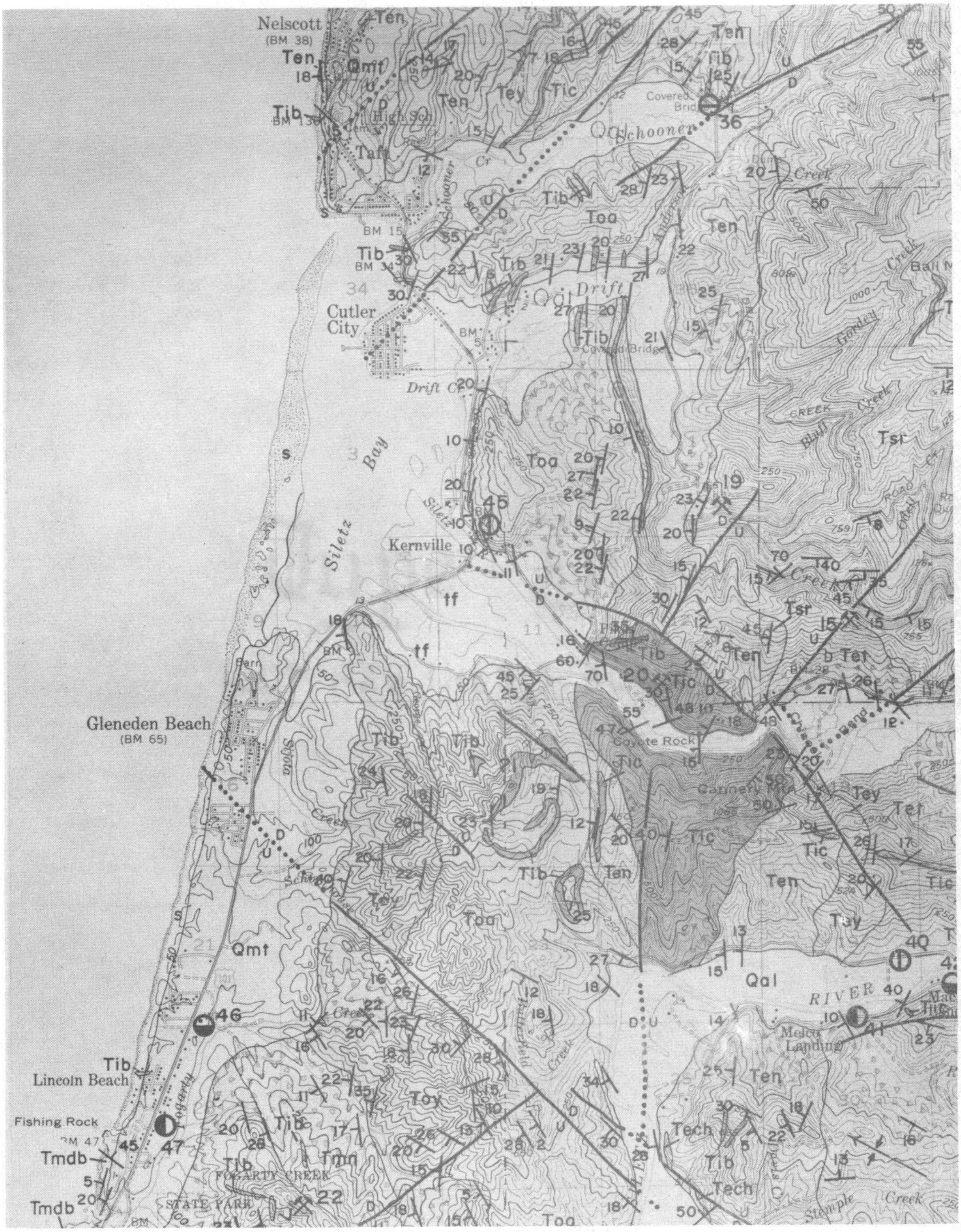


Figure 5. Geologic map of Siletz Bay area. From Schlicker et al. (1973).

Figure 6. Marine terrace deposit overlying seaward dipping Tertiary strata in sea cliff at Fogarty Creek Beach Park.

offshore.

The hills behind the coastal terrace are composed of Tertiary sedimentary formations that outcrop in narrow bands trending NNW-SSE. Dips vary but are generally 15 to 20 degrees to the southwest. The ridge at the southeast corner of the bay is composed of Late Oligocene to Early Miocene sandstone, conglomerate and tuffaceous siltstone known as the Yaquina Formation (Toy). This section conformably overlies the Early Oligocene siltstone of the Alsea Formation (Toa) which forms the east side of the aforementioned ridge as well as the hills on the east side of the bay between the Siletz River and Schooner Creek. The siltstone of Alsea, which probably underlies most of the bay, is composed of fossiliferous tuffaceous siltstone and very fine-grained sandstone, locally concretionary. North of Taft and Schooner Creek, the eastern hills are comprised of the Middle to Upper Eocene Yamhill Formation (Tey) which is unconformably overlain by the Nestucca Formation (Ten) to the west.

The bay and lower river valleys are filled with well over 30 meters of Holocene estuarine and alluvial sediments (tf), mainly fine sand and clayey silt containing organic remains of plants and marine organisms (OSHD, 1970). Modern uncondolidated fine- to medium-grained beach and dune sands (S) form the beaches and sand spit and possibly the Cutler City peninsula which appears to consist of low dunes formed by sand blown off the large sand bars in the northern part of the bay.

Intrusive and extrusive igneous rocks are found at several places in the Siletz Bay area. They are generally more resistant than the local Tertiary sedimentary rocks and terrace deposits and result in much reduced rates of erosion where they occur along the shore. Tertiary basalt flows cap less resistant sedimentary rocks north of Roads End and form most of the shoreline from Fishing Rock to Otter Crest south of Siletz Bay. Within the bay itself, the line of stacks located just south of Schooner Creek is part of a Tertiary basalt dike (Tib). The rock ledge reported on the north side of the Bay inlet (U. S. Army Corps of Engineers, 1973) may be part of the same dike complex as it is nearly in line with the Schooner Creek rocks. Another basalt dike forms the foundation for The Inn at Spanish Head on the beach north of Taft.

Development and Alterations of Siletz Bay

The Siletz Bay region was first surveyed in 1875 and serious settlement began around 1895. Daniel Kern introduced the first industry into the area in 1896 when he constructed a salmon cannery on the north side of the Siletz River a little over a mile above the present site of Kernville (North Lincoln News Guard, August 27, 1970). Logging began around the turn of the century and eventually superseded fish canning as the main industry. During World War I, the

Siletz River watershed provided much of the Sitka Spruce used in aircraft construction (Oregon Journal, November 4, 1945). A number of lumber companies operated in the Siletz area during the first third of this century. A large proportion of the logs harvested were made into ocean-going rafts which were towed north along the coast as far as Portland or Gray's Harbor, Washington. Between 1925 and 1939 the Lincoln County Logging Company, which owned two tugboats, took over 800 million board feet of logs out of Siletz Bay in rafts. In all, over 1.25 billion board feet were taken over the bar (Kerry, 1951). Occasionally rafts were broken up by storms, littering the beach with logs.

Since 1900, human activity has had considerable direct and indirect effect on Siletz Bay. Logging, farming, and man-caused forest fires have all served to increase the sediment load carried into the bay by rivers. This has resulted in an increased rate of siltation in the bay and also smothered salmon spawning grounds upstream. Most of the marsh land on the east side of the bay and along the rivers has been diked for agriculatural use so that the large volume of sediment formerly deposited on the marsh during winter floods is now carried into the bay (Dicken, 1961). The Highway 101 causeway completed in 1926 across the marsh on the southeast side of the bay, a causeway constructed in 1951 across Millport Slough (Rauw, 1954), and the Siletz Keys landfill built around 1963 all serve to nearly eliminate flow from the Siletz River into the southern part of the bay, thereby reducing circulation and allowing sedimentation to increase. The damming of the sloughs confines all of the Siletz River discharge to the main channel which has had erosive effects on the bay-side of the spit. This will be discussed later. In addition to the increase in the siltation rate caused indirectly by human activity, 0.14 to 0.16 square kilometers (35 to 40 acres) of marsh and mudflat have been covered by landfill since 1939. The filled areas include a few acres along the south side of Cutler City, about 0.06 square kilometers (16 acres) in the Siletz Keys development, and approximately 0.08 square kilometers (19 acres) at the south end of the bay which form part of the Salishan golf course. Originally the Salishan development plans called for construction of an airplane runway in the south bay along the east side of the sand spit. Fortunately, this airport was eventually situated on dry land farther south and inland. On the sand spit itself, the impact of development has been considerable in recent years. Prior to 1962 the only alteration was the planting of dune grass to stabilize the foredune. Since the beginning of the Salishan development in 1962, thick grass has been established over the entire unforested portion of the spit, 35 houses have been built on the crest of the low foredune, dangerously close to the ocean, and approximately 55% of the foredune has been riprapped as well as 600 m of the shoreline on the bay side of the spit. These changes have had significant effects on the natural erosional processes operating on the sand spit.

CHAPTER III. HISTORY OF EROSION AND ACCRETION

Erosion on Siletz Spit

The main purpose of this study is a detailed analysis of erosion on Siletz Spit. An important part of the analysis is the determination of trends and patterns of erosion which requires a knowledge of the history of erosion. Such information is usually obtained by comparing old maps and photographs with recent coverage. In the case of Siletz Bay most maps, even modern ones, are of too small scale and lack the necessary detail for a valid estimate of changes. The reason for this is the short history of white settlement in the area and the bay's unimportance as a harbor. The earliest published maps show only the mouth of the Siletz River while later ones produced in the 1890's show the bay with a spit and an opening at the north end. Fortunately, the survey plats (Figure 7) and field notes for the first land survey have been preserved in the Portland office of the Bureau of Land Management and provide the first quantitative information on the dimensions of Siletz Bay and Spit. This survey was conducted by John S. Hurlburt in 1875, only 26 years after Lt. Talbot's initial exploration (Lincoln County Historical Society, 1948). The next detailed measurements come from a 1912 tidelands survey (Corvallis

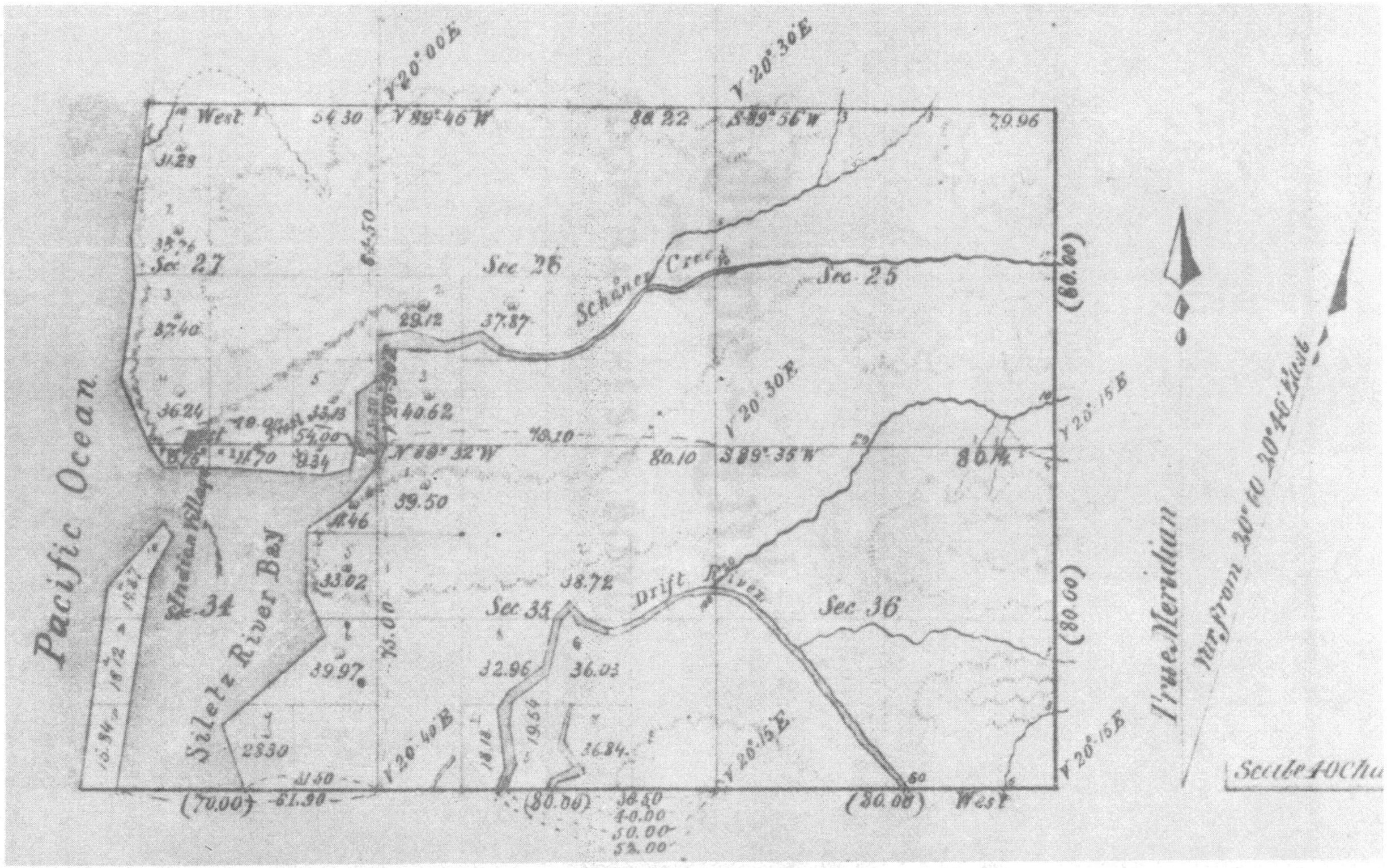


Figure 7a. 1875 Survey plat, portion of Township 7 South Range 11 West Williamette Meridian.

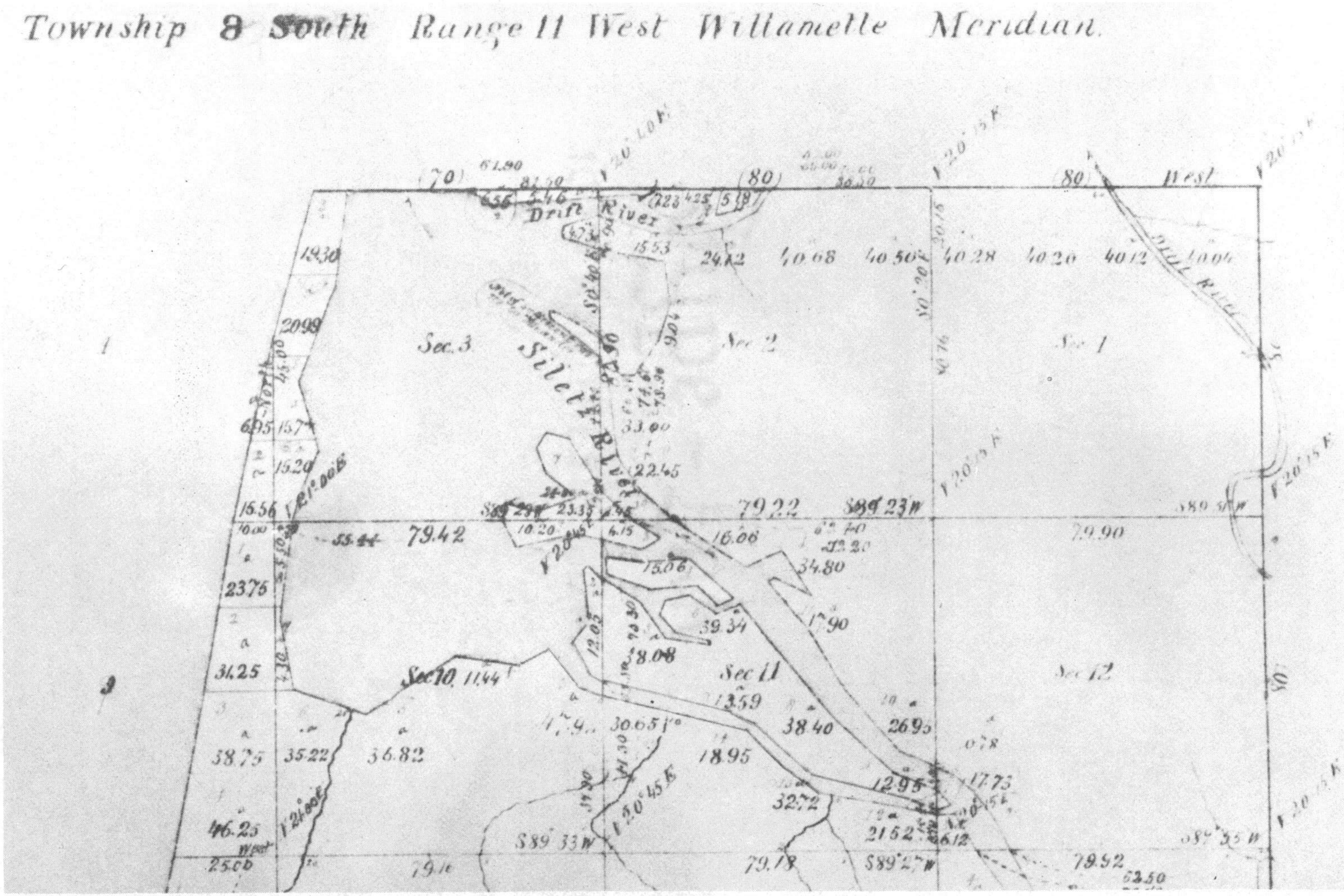


Figure 7b. 1875 Survey plat, portion of Township 8 South Range 11 West Williamette Meridian.

and Eastern Railroad Co., 1912). Aerial photographs taken between 1939 and 1974 were collected for comparison with the two surveys and with each other. They are listed in Appendix A.

In Figure 7 various measurements in chains and links are shown along the southern boundaries of Section 34 in Township 7 South and Section 3 and 4 in Township 8 South, Range 11 West of the Willamette Meridian. One surveyor's or Gunter's chain measures 66 feet (20.1 m) and contains 100 links. For comparison, the same section lines were located on the aerial photographs and measurements were made (Figure 8). Before the resulting data could be analyzed, it was first necessary to determine the accuracy of the 1875 survey and the photomeasurements. On the survey plats (Figure 7) each section is supposed to be one mile (80 chains) square, but some of the sides are off by as much as 90 links (eg., the east side of Section 3, Township 8 South). Hurlburt's field notes indicate that he measured this line twice in opposite directions obtaining a total distance of 80.9 chains each time. This suggests that most of the distance error is caused by an error in angle measurements. If the north and south boundaries of a section are out of parallel by 0°39', the difference in length between the east and west boundaries would be 90 links. This angular error suggests that distances determined by triangulation, such as the width of the bay, are possibly in error because they depend on accurate angle measurements.

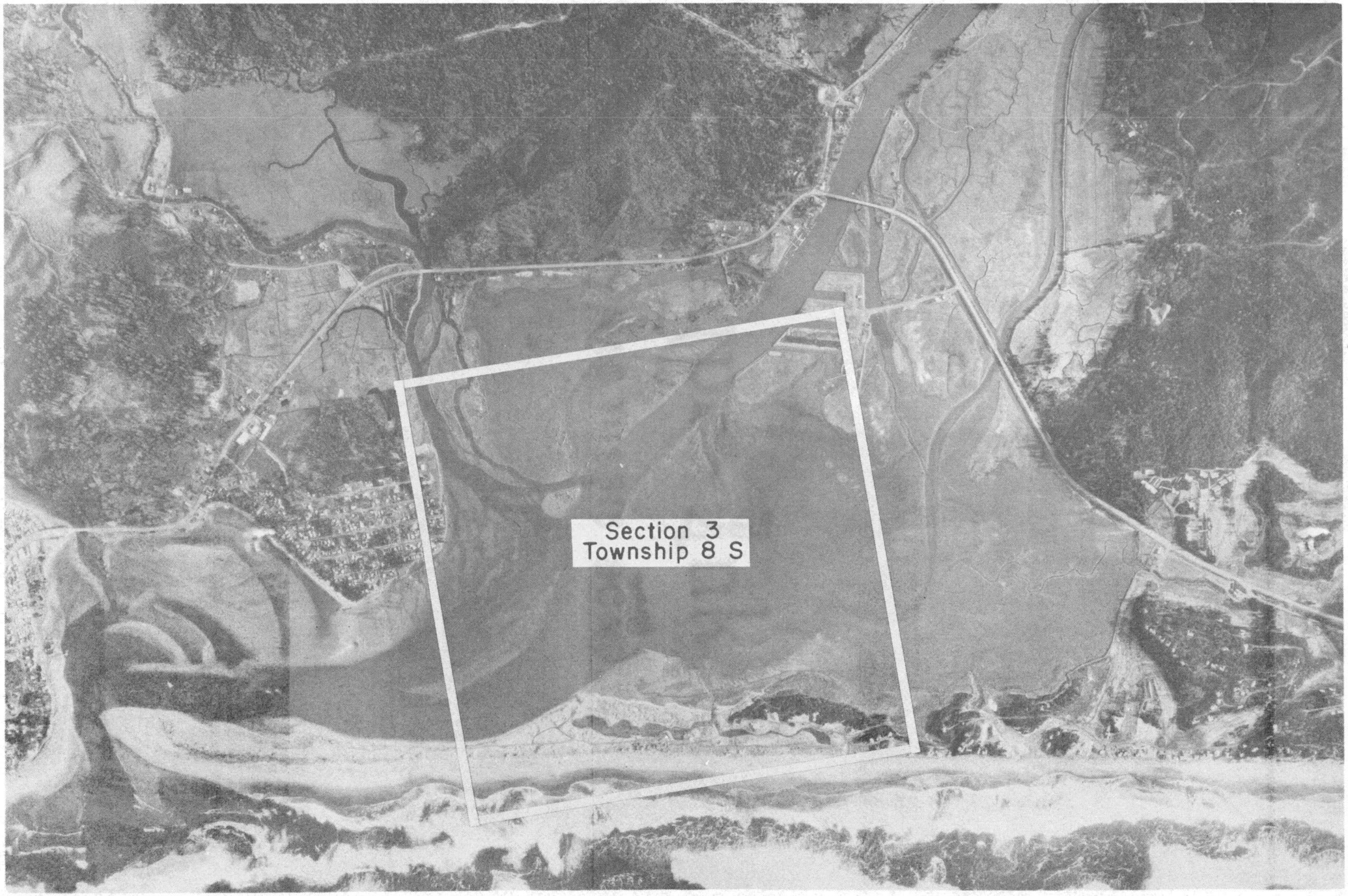


Figure 8. Aerial photograph of Siletz Bay showing location of section lines.

However, it is more likely that Hurlburt's angle measurements were correct but that he had difficulty surveying in a straight line through dense forests and over hills where only a short portion of the line could be seen from any one point. Therefore, we have assumed that distance errors in the 1875 and 1912 surveys are at worst no greater and probably much less than those inherent in photomeasurements.

Measurements on aerial photographs are subject to a number of possible errors. One of the most difficult to deal with without sophisticated photogrammetry equipment is scale error. Unless a vertical aerial photograph is rectified so that the scale is constant, there will usually be a significant difference between the scale at the center and that near the edge. This is caused by the variation in the angle of obliquity (deviation from vertical line of sight) from a maximum at the corners to zero at the center if the aircraft was flying level. This error can be reduced by using a long focal length camera lens. Another source of error is the actual measurement made on the photograph; with standard measuring devices accuracy is limited to approximately 0.01 inch or 0.1 millimeter. By analyzing the scatter of values for photographs made in the same year we found that the combined error produced a total scatter equal to about 1% of the average value for distances on the order of 750 meters between easily identifiable end points. Shorter distances, 50 to 100 meters, gave a scatter equal to 7% of the average because the percentage error is proportionally greater for shorter distances.

Figure 9 illustrates the distances used to compare the survey plats and aerial photographs. They are described in Table 1, and Table 2 lists the results of the measurements in chronological order. Note that the width of the bay along the north side of Section 3 (Figure 7) is 30.40 chains (612 meters), but in Table 2 the 1875 and 1912 values for B have been increased by 10 meters to allow for the setback of the house used as the eastern end of B on the photographs. In order to better illustrate erosional trends, the values in Table 2 are presented graphically in Figure 10.

In analyzing the data in Table 2 and Figure 10, it is clear that A, the distance from the northeast corner of Section 3 to the east side of the bay, has remained constant within the limits of error discussed above. This is understandable since the only source of change would be erosion of the Cutler City peninsula which is in a protected location. There may have been some slight erosion because a seawall was constructed at the western end of A sometime before 1939, apparently to protect a small landfill. The observed variation in A since 1939 is due to scale and measurement errors. Measurement A was included in the study to demonstrate that the east end of B and D has remained fixed. Changes in B and D therefore reflect erosion or deposition to the shorelines of the spit.

The distance across the bay (B) shows an increase of 135 meters

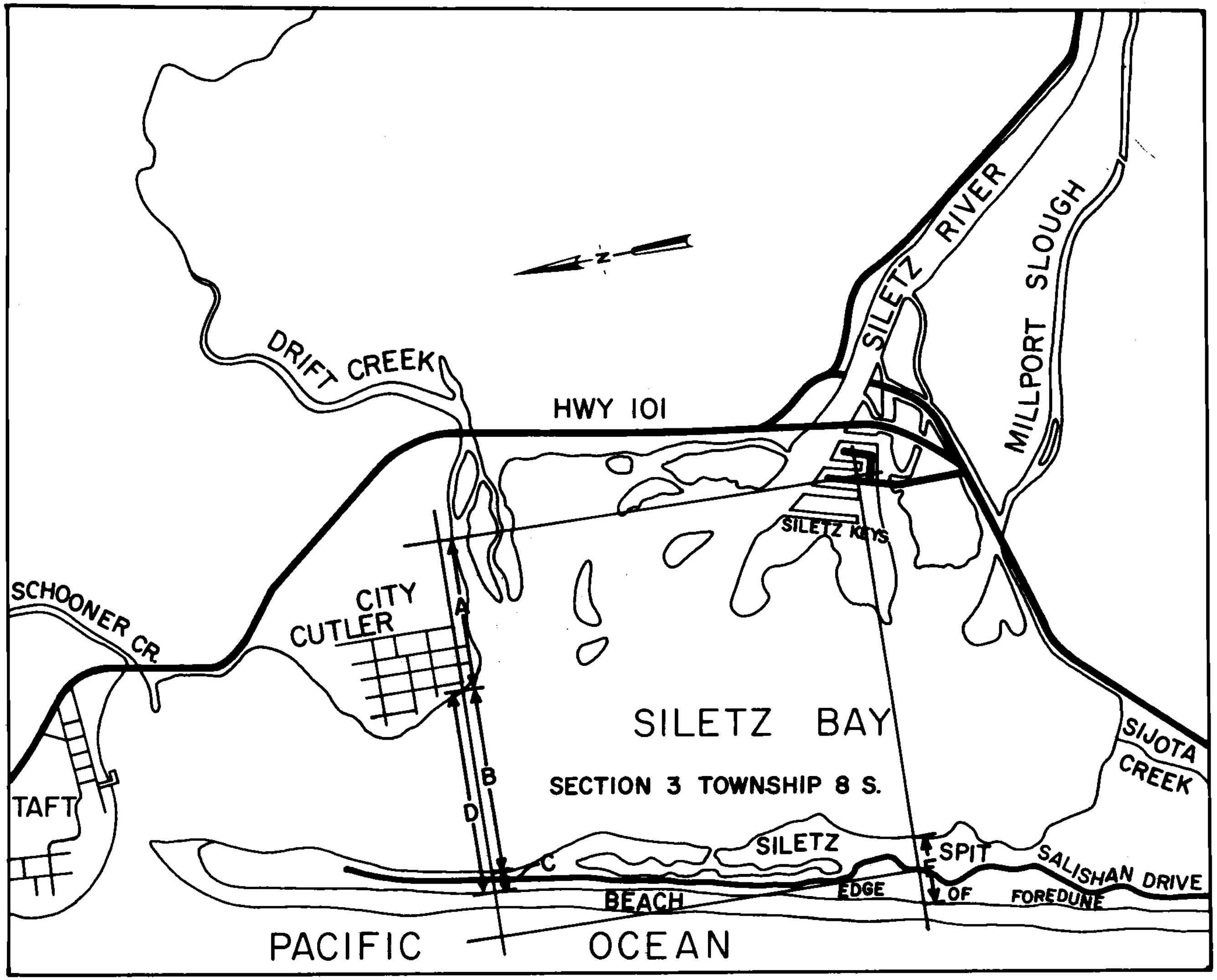


Figure 9. Map of Siletz Bay showing locations of comparative erosion measurements.

TABLE 1. DESCRIPTION OF MEASUREMENTS USED IN LONG TERM EROSION STUDY.

Measurement	Description
A	Along north side of Section 3 Township 8 South from northeast corner of Section 3 to the east side of Siletz Bay.
B	Width of Siletz Bay along the north side of Section 3 from the west end of a house located just south of the section line on the east side of the bay to the intersection of the section line and the erosion scarp on the west side of the bay.
C	Width of Siletz Spit along the north side of Section 3 from the erosion scarp on the east side of the spit to the edge of the dune grass or crest of the foredune on the west side of the spit.
D	B + C.
E	Width of Siletz Spit along the south side of Section 3 from the eastern edge of the marsh on the east side of the spit to the base of the dune on the west side of the spit.

TABLE 2. COMPARATIVE MEASUREMENTS, 1875-1974.

Date mo-da-yr	Distances in Meters A	B	C	D	E
Oct. 1875	634	622	163	785	288
1912	638	654	NA*	NA*	NA*
5- 3-39	631	695	102	797	267
7-17-39	630	692	104	796	268
9-19-45	NA*	702	103	805	271
10- 5-52	637	714	87	801	266
6- 6-62	637	724	66	790	258
7- 2-62	634	725	63	788	255
10- 4-64	634	730	56	786	267
9-23-65	NA*	730	58	788	262
9- 3-67	NA*	NA*	56	NA*	261
1- 5-71	634	750	58	808	261
8- 6-71	634	750	60	810	268
5-24-72	NA*	754	56	813	268
7-17-72	636	753	53	806	268
2- 6-73	637	752	58	810	265
4- 8-73	NA*	748	56	804	267
5-11-73	634	752	56	807	268
9- 5-74	NA*	758	52	810	NA*

*NA = photo coverage not available.

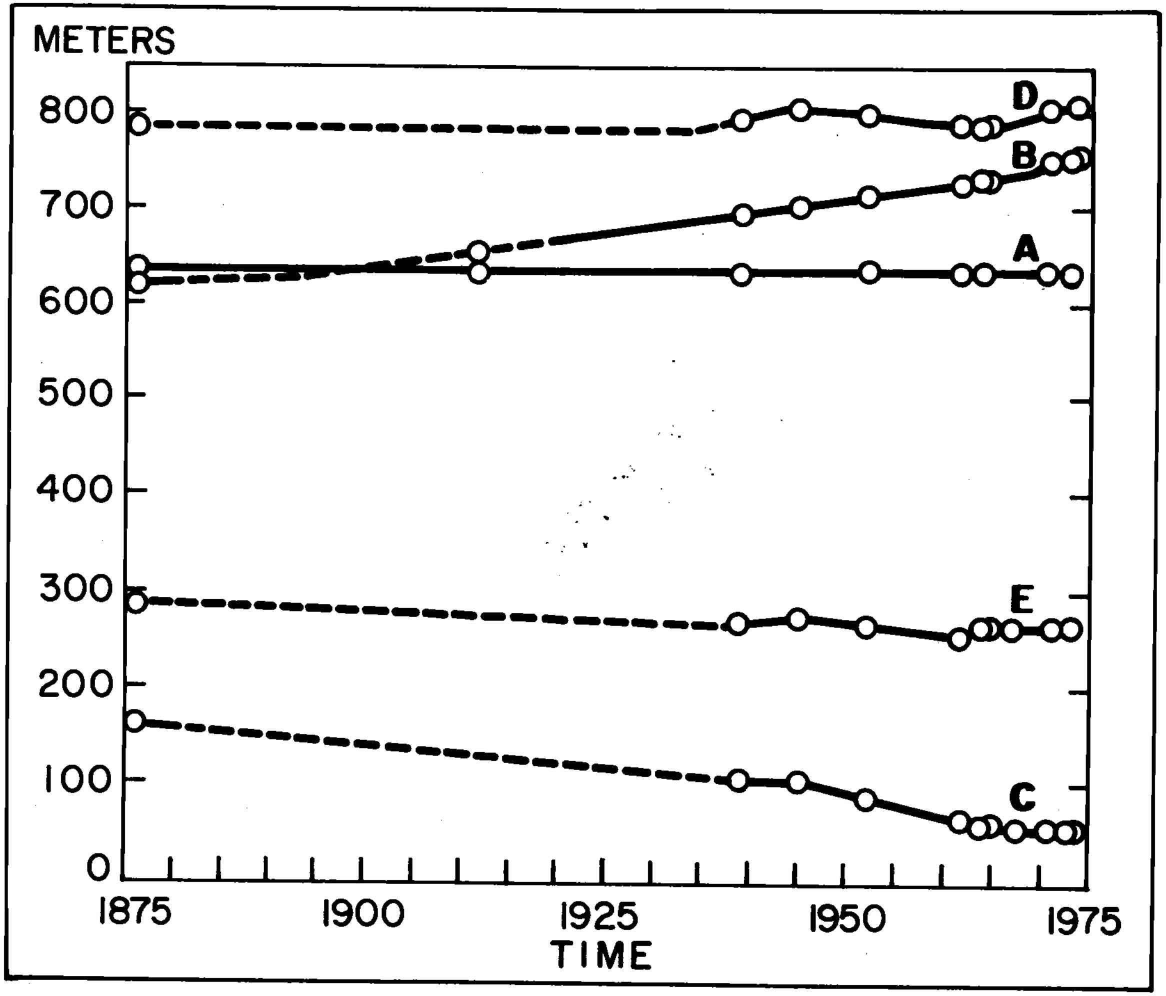


Figure 10. Graph of comparative erosion measurements.

in 99 years. Since the east end of B was fixed, this change has occurred through erosion of the sand spit on the bay side. It is quite convenient that the section line along which B was measured crosses the eastern shore of the spit at or near the point of maximum erosion. Between 1912 and 1965 the rate of erosion was nearly constant at a little over 1.4 m/yr. The eroding shoreline was riprapped prior to 1971 and again in early 1974; these actions are reflected in the data by a level spot separating two sharp increases (Figure 10). Prior to 1912, the average rate of erosion was approximately 0.9 m/yr, but the actual rate in 1875 and the time at which it began to increase cannot be determined. If the 1912 to 1965 line is extrapolated backward, it intersects the 1875 value (622 m) at 1891. This means that if the rate was zero or quite small in 1875, it must have started to increase about the time the area was settled and logging began. Even if the erosion rate was 0.9 m/yr after 1875, there had to be a significant increase around 1910 when logging began on the upper Siletz River.

The width (C) of the sand spit along the north side of Section 3 has decreased by over 110 m in 99 years due to the erosion on the bay side of the spit. The total erosion (135 m) is about 25 m greater than the decrease in width indicating 25 m of accretion on the seaward side of the foredune. Periods of accretion show up as level spots in the generally declining C curve of Figure 10. When the C and D curves are analyzed together it is apparent that the 25 meters accretion of the foredune is a cyclic phenomenon rather than a long-term trend. D is the distance from a house in Cutler City on the east side of the bay to the seaward edge of the foredune on the sand spit. In Figure 10, the D curve shows that the foredune at the point of measurement has gone through approximately 1.25 cycles of accretion and erosion since 1939 with a total variation of 20 to 25 m. A period of maximum accretion occurred in the mid-1940's followed by a steady decline through the 1950's with a minimum in 1964 nearly the same as the 1875 value. The erosion through the 1950's was noted by Dicken (1961) who stated in reference to Siletz Spit that the sea cliffs formed in the foredunes had apparently been pushed back slightly during the 20 years prior to his observation. The dune may now have reached another point of maximum accretion, but the short time span of the data makes it impossible to predict with any certainty the time or amplitude of the next erosional cycle. In any case, the homeowners in the area will undoubtedly riprap the foredune as soon as erosion begins. One thing is certain, since 1910 when logging began on the upper Siletz River the dune has eroded back at least once beyond the 1962-65 limit. This is demonstrated by the discovery of buried saw-cut logs protruding from the eroded sea cliff after the recent episode of erosion (Figure 11).

The last measurement, E, is the width of the sand spit along the south side of Sections 3 and 4 in Township 8 South. The data

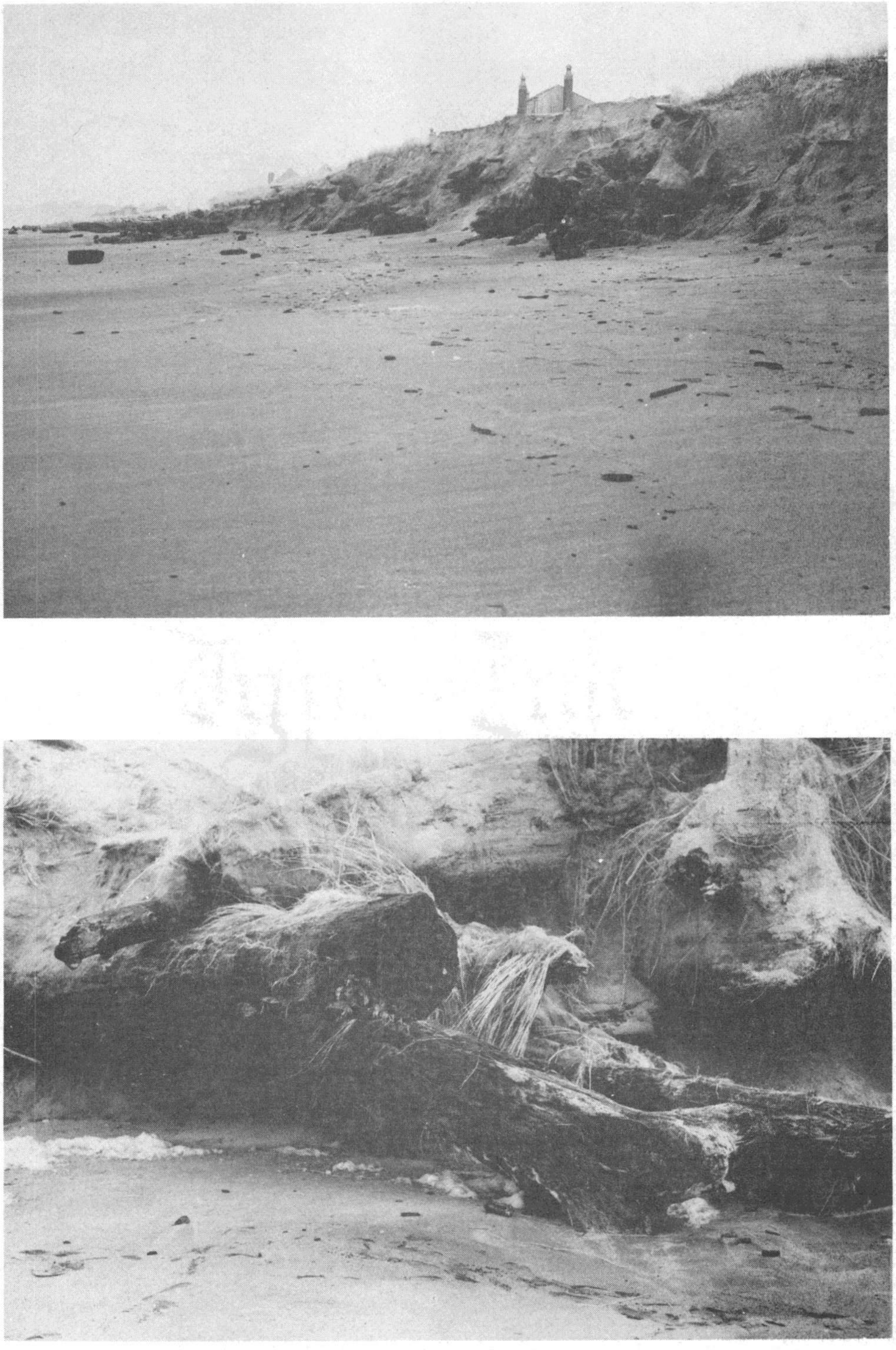


Figure 11. Saw-cut logs protruding from erosion scarp in foredune.

shows a slight decrease in width since 1875 but no significant change since 1939. The 1875 value may be in error because of the difficulty involved in measuring horizontal distances across the high dunes in the area. There was one episode of slight erosion since 1939 coinciding with the erosion on the northern section line.

In addition to the quantitative analysis of erosion by measurements along the two section lines, we made a detailed qualitative study of the whole spit using aerial photographs. The cycle of erosion and accretion described above occurred everywhere on the spit but at different times; accretion would be occurring at one point while erosive processes would be at work only a few hundred meters down the beach. There generally appeared to be an overall predominance of one process or the other. This is understandable since in a year of high wave energy there would be a predisposition toward erosion, but areas protected by a wide beach or large offshore bar would be unaffected, and the opposite would be true during low energy years. The following sequence of events is typical of the many cycles observed: (1) high waves eroded a vertical scarp in the seaward edge of the foredune; (2) subsequent high tides deposited drift logs at the base of the scarp; (3) lower energy waves built a broad, high "summer" berm; (4) the logs behind the berm trapped sand that was either blown off the berm or washed over it at high tide; (5) as the sand piled up around and seaward of the logs, waves could no longer reach them, and wind-blown sand continued the burial process; (6) this went on for several years if not interrupted by another serious erosion episode until by the slow addition of sand and occasional logs the pile grew above the reach of the highest normal storm waves; (7) at that point dune grass established itself or was planted; and (8) erosion again occurred to repeat the cycle. In some cases homes were constructed during stage (7) of the cycle when the dunes were at their maximum, only to be threatened and in one case destroyed when erosion returned. Figure 12 illustrates the above steps in the cycle of erosion and accretion.

Photographic coverage for the period between 1939 and 1962 is incomplete but the available evidence indicates general progradation of the foredune through the early 1950's followed by erosion along most of the spit in the early 1960's. Rebuilding began immediately and continued at least through 1967. The erosion that occurred since 1970 has been well documented by ground surveys and aerial photography because it threatened many of the houses built on the foredune. Figure 13 shows the areas where there has been serious erosion since 1970. In 1970-71 erosion occurred along a 670 m section of the foredune at the south end of the spit. Fifteen meters of the dune face were removed at the south end of the Park which equaled or exceeded the erosion there in 1962. Farther south there were only 6-9 m lost from the part of the foredune that had been built-up since 1962.

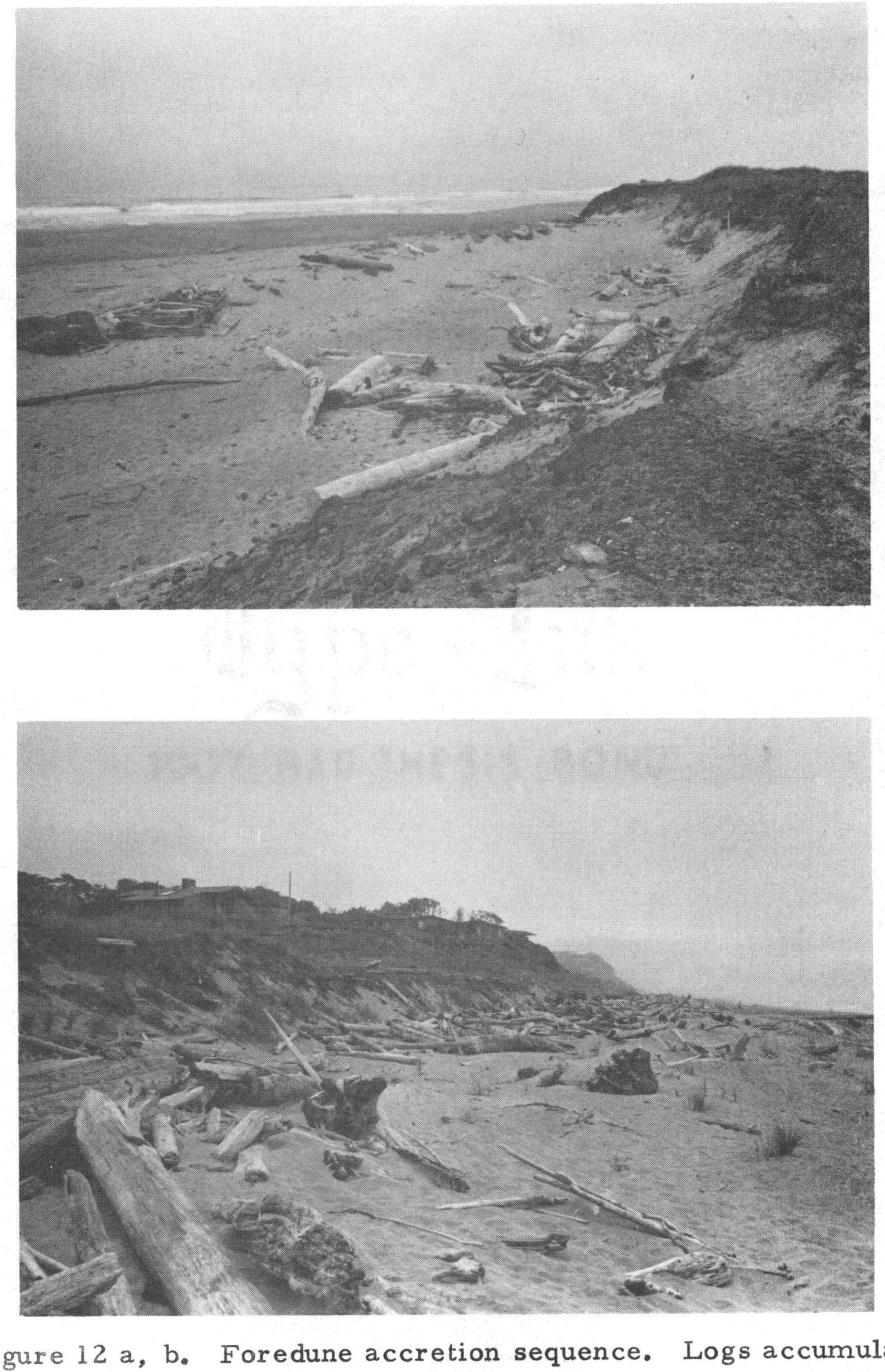


Figure 12 a, b. Foredune accretion sequence. Logs accumulating at base of erosion scarp and trapping wind-blown sand.

Figure 12 c. Foredune accretion sequence. Dune grass becoming established on built-up pile of sand and logs.

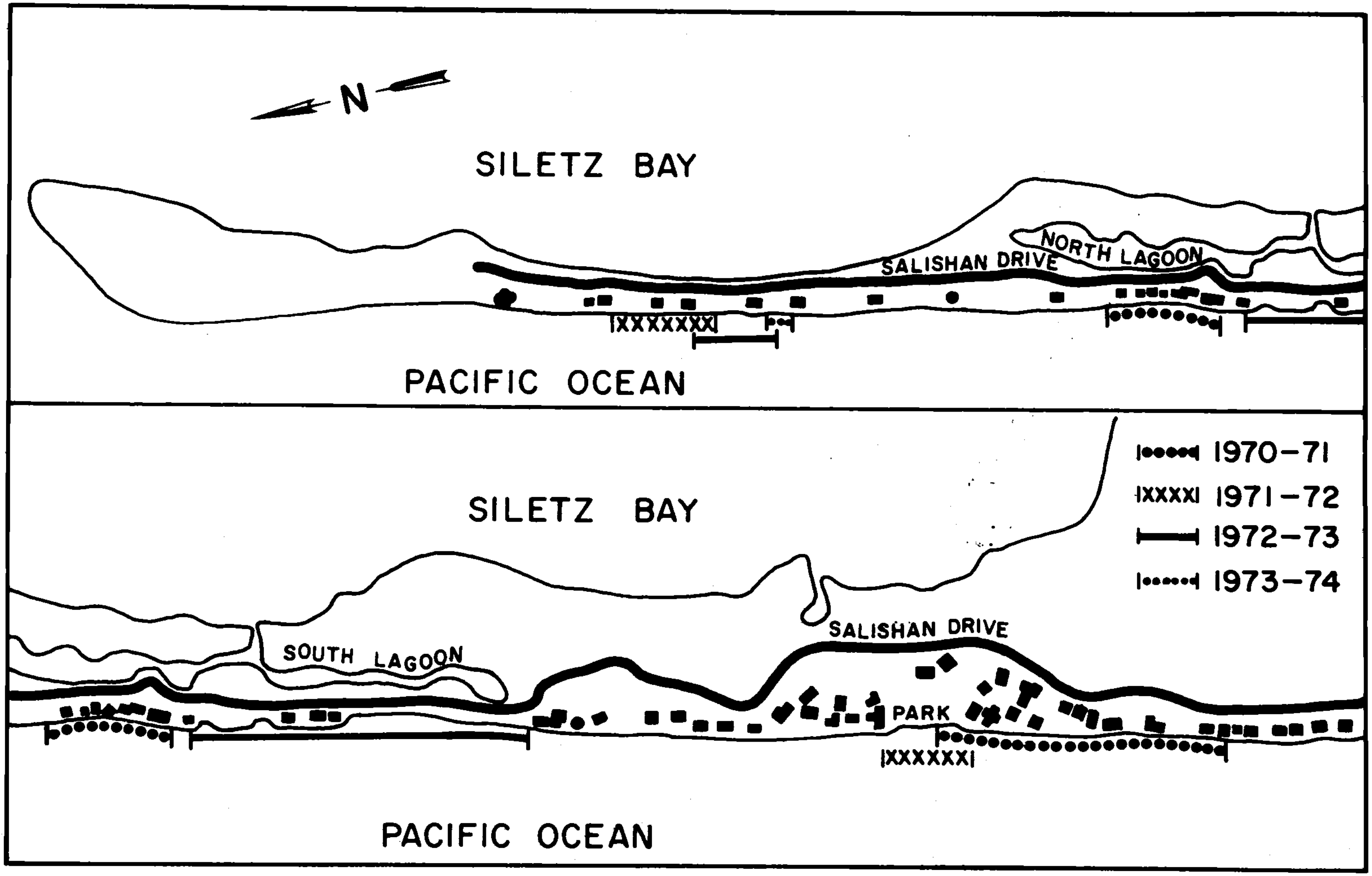


Figure 13. Areas of erosion on Siletz Spit since 1970.

Nevertheless, the three southernmost houses were riprapped. In 1970-71 waves also attacked a 200 m stretch of foredune seaward of the northern lagoon causing minor damage. Only a small part of a high grassy pile of sand and logs that had formed since 1962 was eroded before the entire area was riprapped to prevent further loss.

During the winter of 1971-72 very minor erosion occurred on the narrow portion of the spit. Again only the sand and logs that had accumulated since 1962 were affected, and in July 1972 the erosion scarp was about 20 m seaward of the 1962 scarp. Riprap was emplaced in front of two houses built on the 1962 erosion line. In the northern lagoon area there was some rebuilding of the foredune where it had been eroded the previous winter. Farther south, the Park suffered serious erosion; the foredune retreated 20 m from its 1971 position to a point about 10 m landward of the 1939 erosion scarp. Sawed logs protruding from the top of the new scarp indicate that high waves had washed even farther inland sometime in the past. Long sections of the foredune were riprapped both north and south of the eroded portion, but the Park was left unprotected because there were no homes there.

The severest and most publicized episode of erosion occurred during the winter of 1972-73. One partially built house was lost (Figure 14), three others had to be riprapped on three sides (Figure 15), and it was feared that the spit would be breached. Oregon

Figure 14. Remains of house destroyed by waves, January 18, 1973.

Figure 15. **Aerial view of eroded area, February 8, 1973.**

Governor McCall ordered an emergency study but decided not to involve state funds as only private property was threatened and the breaching may have served to clean the south end of the bay of accumulated mud and logs. The worst erosion took place along a 650 m long stretch centered on the southern lagoon. Figures 15 and 16 are respectively an oblique aerial photograph looking north along the eroded area and a diagram of the most severely damaged portion showing the location of the base of the foredune before and after the erosion. The maximum erosion occurred just south of lot 229-A and amounted to about 30 m within a three week period. Storm waves pushed the edge of the foredune back 20 m east of its 1962 position. South of the destroyed house, the erosion did not reach the 1962 dune line which shows up on Figure 15 as a faint line separating the light grass near the edge of the dune from the slightly darker grass nearer the road in the right and middle foreground.

The winter of 1972-73 also produced some erosion farther north on the sand spit. A new house constructed in late 1972 just south of the 1971-72 erosion was riprapped to prevent the loss of its dune protection. At the Park, which was the hardest hit area in 1971-72, natural recovery began with the accumulation of a large pile of logs seaward of the erosion scarp (Figure 12b).

The 1973-74 storm season proved to be quite mild with only a small amount (3 to 4 m) of additional erosion along the narrow portion

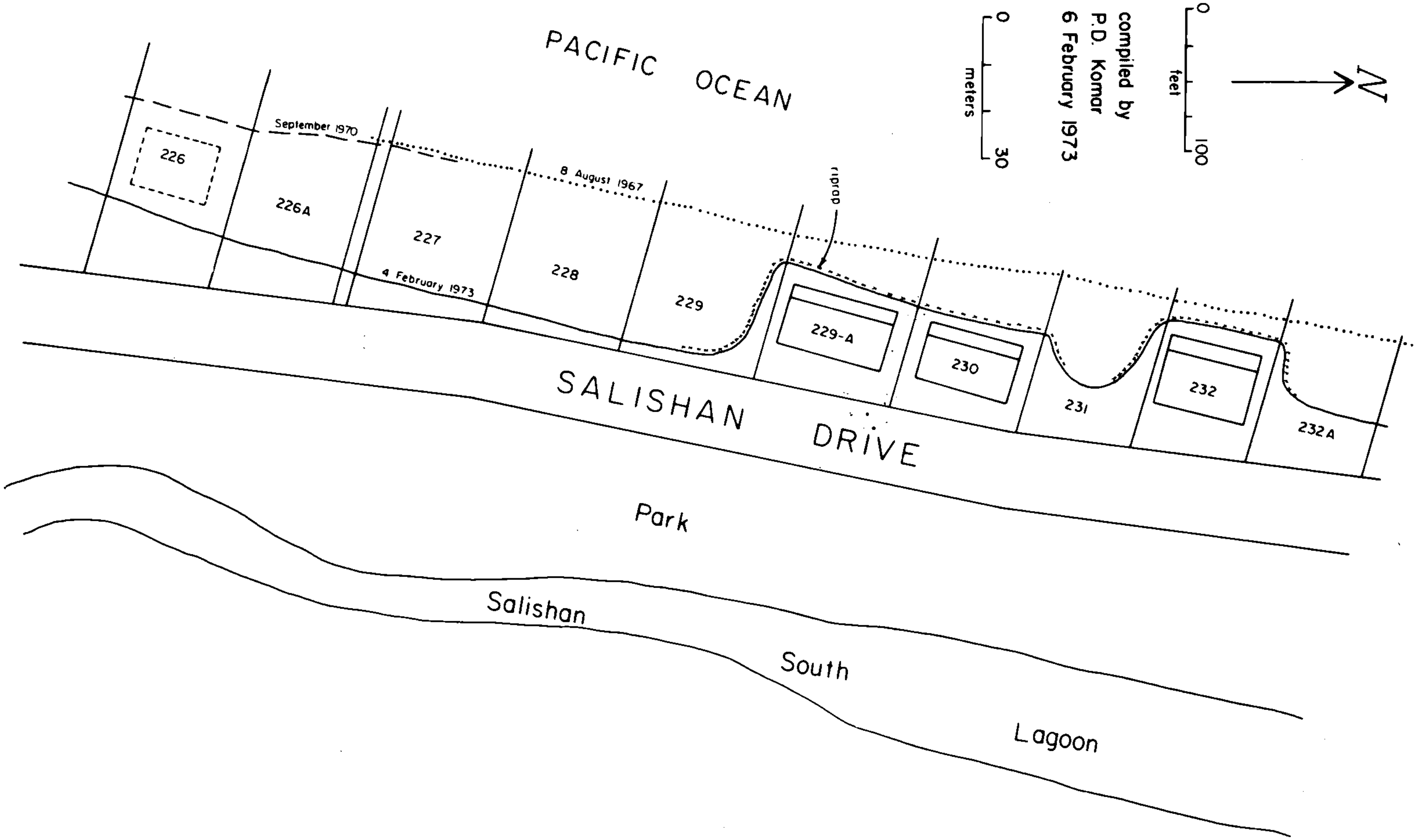


Figure 16. Position of foredune before and after the erosion in 1972-73. House on lot 226 was destroyed in January, 1973.

of the spit just south of the new house that was threatened the year before. Recovery continued along the remainder of the spit with some help from man. Heavy equipment was used to rebuild and riprap the foredune south of lot 229-A. Riprap is presently almost continuous from about 370 m south of Siletz Spit to the north end of the large group of houses seaward of the northern lagoon. The only gaps occur at the Park and just south of the group of houses opposite the north lagoon. Three houses on the narrow portion of the spit are also riprapped as is a 600 m long section of shoreline on the bay side of the spit opposite Cutler City.

Sedimentation Within Siletz Bay

Comparison of aerial photographs taken in 1939 and 1973 was made to study the rate at which the estuary is being filled with sediment. The principal indicator of sedimentation is the expansion of marshland; no direct field measurements of sedimentation rates were made. There has been no apparent change in the northern part of the bay where strong tidal currents remove all sediment finer than medium sand. Tidal flood currents carry beach sand into the bay, depositing it temporarily in three or four crescentic bars north of Cutler City. The same flood currents move sand along the bars and dump it into the main channel where ebb tide currents can transport it back to the ocean, preventing any net accumulation of sand within the estuary.

On the Drift Creek Delta south of Cutler City, the effects of siltation are evident. A 1931 survey (U. S. Army Corps of Engineers, 1931) shows Drift Creek flowing westward along the south side of Cutler City, then turning toward the northwest before joining the main Siletz River channel. Three years later according to another survey, Figure 17, Drift Creek had shifted southward on the mud flats and developed three west and northwest oriented channels across the outer delta. This general drainage pattern is evident in the 1939 aerial photograph (Figure 4). By 1971 (Figure 1), the outer delta had been built upward enough to deflect the Drift Creek flow southward into the Siletz River channel.

In the southern part of Siletz Bay, the marsh has prograded significantly between 1939 and 1973 (Figure 18). Carl Johannessen (Dicken, 1961) used aerial photography to study shoreline changes in Oregon estuaries and found that certain patterns such as circular colonies of marsh plants on otherwise bare mud flats indicate areas of rapid marsh expansion. Most of the new marsh shown in Figure 18 contained small isolated circular colonies in 1939. When the circular patches coalesce, they produce a distinctive blotchy pattern indicative of a young marsh. In 1939 this pattern was evident on much of the marsh west of Highway 101 except for the Y-shaped section along the south side of the main Siletz River channel. To determine the

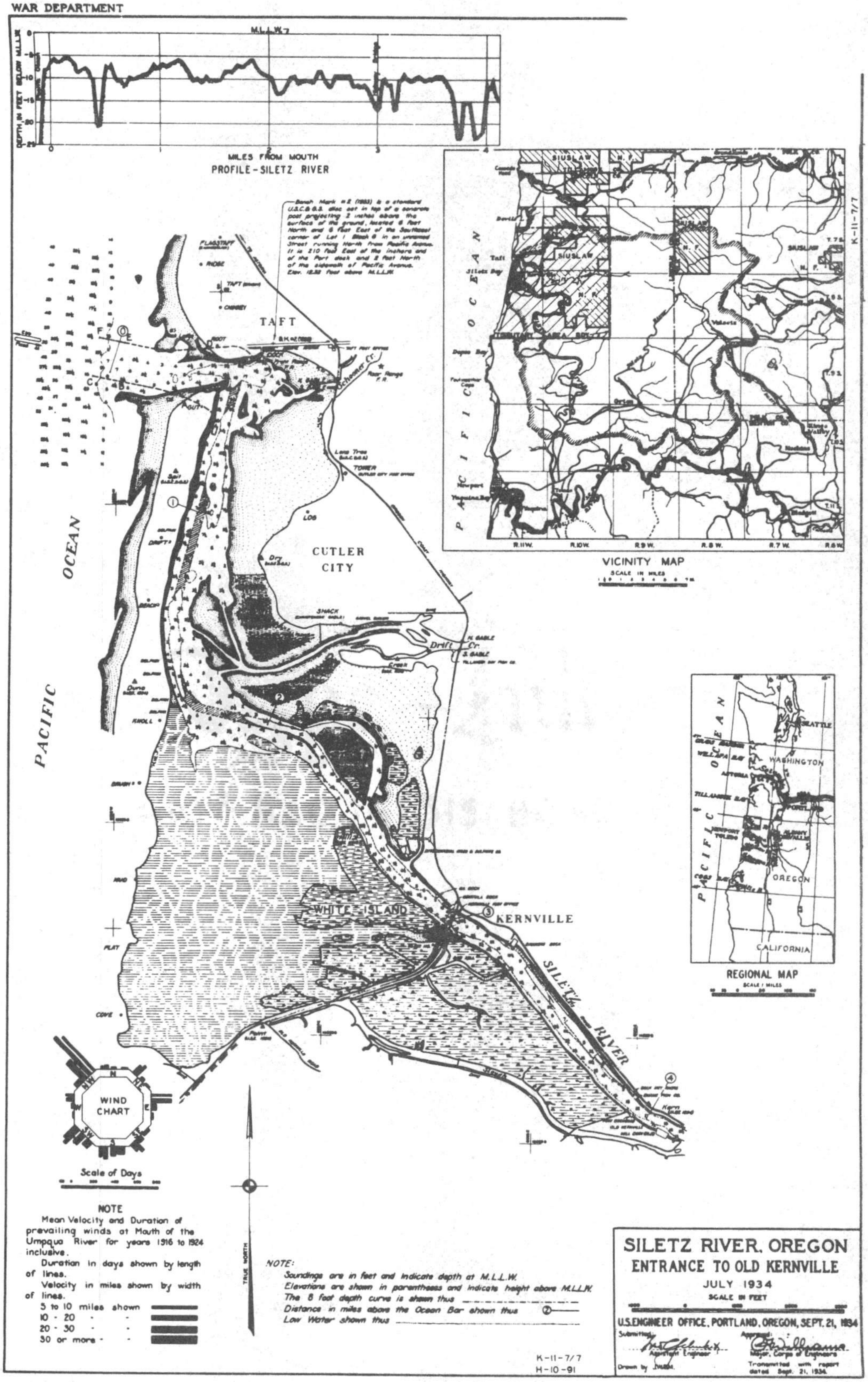


Figure 17. Survey of Siletz Bay and Spit in 1934
(U. S. Army Corps of Engineers)

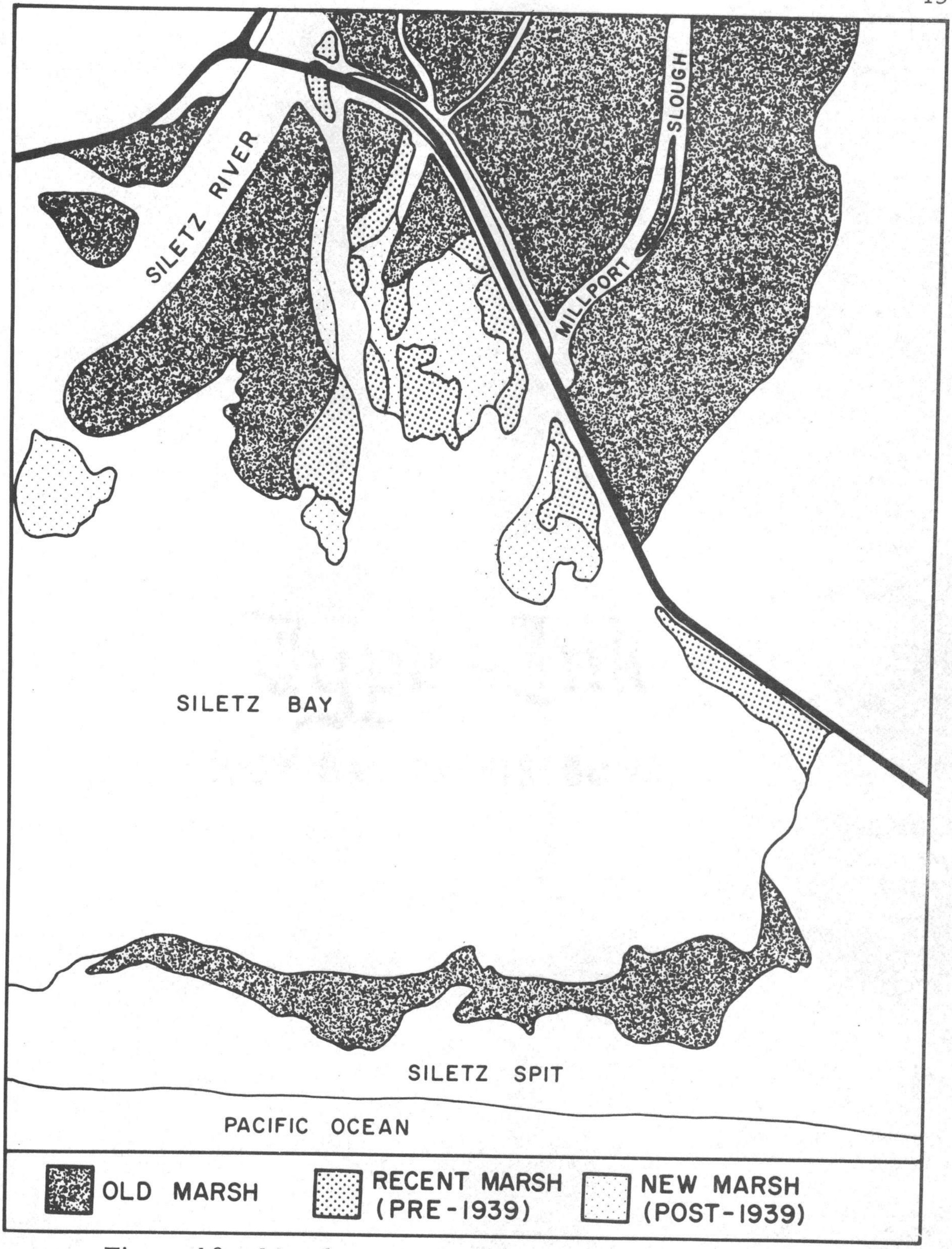


Figure 18. Marsh expansion in the southern portion of Siletz Bay.

approximate age of the young marsh in 1939, its pattern was compared with that of the post-1939 marsh. By 1962 the post-1939 growth had produced a pattern very similar to that seen in 1939 indicating that the young marsh areas in 1939 may have been less than 25 years old. The total area of marshland formed in Siletz Bay since 1900 is about 0.28 square kilometers (70 acres). The rate of marsh expansion in this century has probably been 4000-5700 square meters (1.0 - 1.4 acres) per year. On the 1875 survey plats (Figure 7) and the 1912 tidelands survey (Corvallis and Eastern Railroad Co., 1912) the extent of marshland is not much different from the limit of old marsh in Figure 18. This is another line of evidence suggesting a sudden increase in the siltation rate when the area was settled, creating rapid marsh expansion.

A final argument indicating rapid sedimentation since 1900 is provided by a U. S. Army Corps of Engineers sketch map dated 1897 (Figure 19) which shows much less extensive tidal flats than currently exist and no delta at the mouth of Drift Creek.

CHAPTER IV. CAUSES OF CHANGES WITHIN THE BAY AND ON THE BAY-SIDE OF THE SPIT

It seems likely that there is a relationship between the influx of white settlers into the Siletz Bay area, starting about 1895, the logging along the Siletz River, the sudden increase in the erosion rate

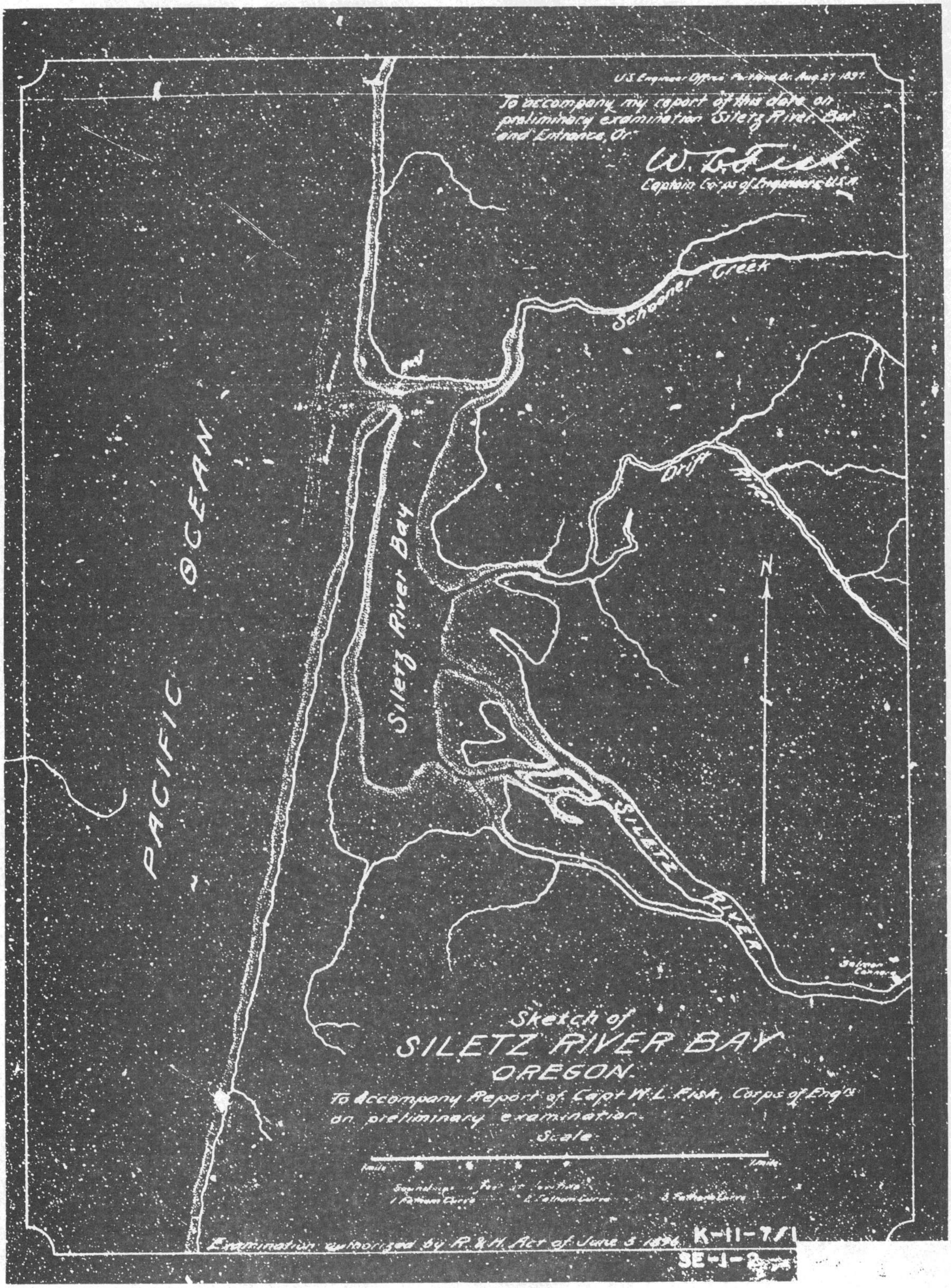


Figure 19. Sketch of Siletz Bay and Spit in 1897.
(U. S. Army Corps of Engineers)

on the east side of Siletz Spit that occurred between 1890 and 1910, and the acceleration in the rate of marsh growth that apparently took place sometime between 1900 and 1920. The onset of cultivation and logging would have increased the sediment load and river discharge causing an increase in the siltation rate within the bay and possibly a shift in the current pattern. The occurrence of an actual current shift in the late 1890's is suggested by the observation of a member of the Parmele family who homesteaded on Drift Creek in 1897 (North Lincoln News Guard, 1966). He stated that during their first year the family took a great many clams from the mud flats at the mouth of Drift Creek but that the clams disappeared the next year when the channel began shifting to the south. The channel migration could have been caused by rapid sedimentation on the Drift Creek delta south of Cutler City. A sudden influx of silt could also account for the disappearance of the clams. Additional evidence for a change in the Drift Creek delta after 1875 is the existence of a small parallel secondary channel or slough that cut through a piece of marshland south of the main channel of Drift Creek. Hurlburt reported the marshland but did not mention any secondary channels in his 1875 field notes. The slough is presently about one chain (20 m) in width and would hardly have escaped mention by Hurlburt if it had been as large in 1875. Therefore it must have formed or enlarged greatly sometime after 1875.

By the time white settlers arrived, Siletz Bay had been in existence for some 3000 years or more and had probably achieved a state of near equilibrium between the supply of sediments and the energy available to remove it from the bay. In this state, the bay would have been filling very gradually mainly due to sedimentation along the fringes of the slowly advancing marsh. However, if the equilibrium is upset by an increase in the sediment supply without any corresponding change in wave, tidaly, or current energy dissipation, sediment accumulation will occur in areas where the rate of energy dissipation is insufficient to remove all of the incoming material. This is apparently what happened in Siletz Bay around the turn of the century. Rapid sedimentation raised and extended the tidal flats of the Drift Creek delta located south and west of the Cutler City peninsula. The outer edge of the delta appears to be a separate bar in aerial photographs because the former northwest flowing Drift Creek channel mentioned in the previous chapter isolates it from the inner delta. This bar restricts the flow of the Siletz River to a narrow channel along the east side of the sand spit during all except the highest portion of the tidal cycle. The bar has remained stationary but appears to have grown upward as indicated by the greater clarity and detail of its outlines in more recent photographs (for example, Figures 1 and 4). Meanwhile the channel between the bar and the spit widened by more than 45 m from 1945 to 1971 due to erosion of the spit. The rate of erosion would probably have declined as the channel widened if the spit were not located outside of a sharp bend. According to an 1897 map of the U. S. Army Corps of Engineers (Figure 19) it appears that prior to the period of rapid sedimentation, the bar or outer delta was much smaller or non-existent and the Siletz flowed over and on either side of it. In Figure 1 and the 1934 survey of Figure 17 the remnant of a deep channel is evident between Cutler City and the north end of the bar. If this channel originally extended to the southeast it would have intersected the Siletz River where the river turns westward toward the sand spit. This suggests that the Siletz River formerly flowed through the estuary in a northwesterly direction along a channel that has been buried by deposition at the mouth of Drift Creek. At present the northwest flow through the upper bay is deflected westward in the middle bay by the Drift Creek delta and then northward by the sand spit. In short, rapid progradation of the Drift Creek delta has apparently caused the sudden increase in the erosion rate of the east side of Siletz Spit by deflecting the main flow of the Siletz River toward the spit.

In addition to increasing stream sediment loads, logging probably increased the number of drift logs on the beach by a significant factor. These logs trap sand and allow the foredune to build upward so that washovers by storm waves are rare. Therefore, prior to the onset of logging the dunes may have been lower and washovers more frequent. Waves washing over the spit could have carried enough beach sand into the bay to replace that removed by the river, thus preventing any net erosion.

Subsequent changes in the fresh water drainage pattern brought about by damming of the sloughs that formerly discharged into the southern part of the bay have undoubtedly contributed to both erosion and deposition. The secondary channels of the Siletz River were all blocked by man-made causeways between 1926 when Highway 101 was constructed and 1963-64 when the Siletz Keys landfill was built. Millport Slough, the largest and southernmost of these channels, was dammed in 1951 (Rauw, 1974). The slough blockages have reduced the stream current energy available for removal of sediment in the southern part of the bay, especially during periods of high runoff when the sediment input is greatest. This has further disrupted the energy-sedimentation equilibrium discussed above, allowing rapid siltation to occur as evidenced by the continued fast rate of marsh expansion on the southeast side of the bay. In addition, the damming of the sloughs has confined the total discharge of the Siletz River to the main channel thereby enhancing the current's erosive power at the same time that it should have been reduced by the widening of the channel.

Other factors that may contribute to the erosion and deposition problems are diking of the higher marshlands for agricultural use and stabilization of the dunes on the sand spit. Dicken (1951) stated that "the diking of the lands adjacent to the estuarine streams ... has contributed to the additional transport of sediment into the mud flats and undiked marshes, thereby filling the estuaries." Before large scale planting of dune grass during the 1950's that stabilized the sand spit, a large moving dune existed on the spit just south of the narrowest portion (Figure 4). During the winter, strong southwest winds probably blew sand from this dune into the main channel where it served as a buffer protecting the spit from erosion. The protective effect may have been significant prior to the deflection of the main flow toward the sand spit but was negligible afterward because the spit was being actively eroded for at least 50 years before the dune disappeared.

CHAPTER V. BUDGET OF SAND ON SILETZ BEACH

In the long term, the beach at Siletz Spit must be eroded and shifted landward as the cliffs to the north and south are gradually eroded. These cliffs composed of semi-consolidated Pleistocene dunes and marine sands erode much more slowly than the low unconsolidated dunes on the spit. Therefore, high waves will frequently erode the foredune back 20 to 30 m landward of the cliff line in a single winter. However, in subsequent years the sea piles logs and sand in the eroded areas rebuilding the foredune until it is once again in line with the cliffs. Consequently, along the ocean side of Siletz

Spit natural erosion is essentially a reversible process over periods of 10 to 20 years. In our analysis of the aerial photographs, we identified several cycles of erosion, deposition, and re-erosion that occurred independently at various locations along the beach. The presence of buried drift logs underlying most of the foredune indicate that the cycle of erosion and deposition has been repeated many times in the past.

Since the long term erosion of the sand spit depends on the retreat of the adjacent cliffs, it is necessary to analyze the factors affecting cliff erosion. Along most of the Oregon coast, sand beaches protect the cliffs from wave attack. The wider the beach at high tide, the greater the degree of protection provided. The width of the beach depends on the sediment budget, that is, the rate at which sand is supplied to the beach minus the rate at which wave action removes sand. If the sediment budget is balanced, the beach is in equilibrium and will maintain a constant average width for a given mean sea level. A deficit budget results in the disappearance of the beach if the cliff is very resistant to erosion, but if the cliff is easily eroded, it will retreat in order to make up the deficit in the sand supply. A surplus of sand causes progradation of the beach. Along the coast of Oregon from the Columbia River to Coos Bay, 76% of the shoreline shows evidence of erosion while progradation is occurring only in the Clatsop Plains area just south of the Columbia (Byrne, 1963).

Therefore, the majority of the cliffs on the northern Oregon coast are being actively eroded to supply the beaches with sand.

In calculating a coastal sediment budget, one generally divides the shoreline into cells separated by headlands, jetties, or other barriers to longshore sand transport. For the purposes of this study, we limited our attention to the 24 kilometers of coastline between Government Point to the south and Cascade Head to the north of Siletz Bay, and assumed that the transport of sand around the two headlands is negligible. Our study included consideration of the net onshore-offshore transport, net longshore transport, river input, and cliff erosion input of sand.

Onshore-Offshore Exchange

The most difficult of the potential sources of beach sand to evaluate is the net onshore-offshore transport. We made a series of three-dimensional beach surveys on Siletz Spit between February 1 and May 8, 1974, which give some indication of the magnitude of gross seasonal onshore-offshore movement of sand between the beach berm and offshore bar. During the survey period the transport was mainly in the onshore direction, producing a total accretion of over 37,000 cubic meters along the 400 m stretch of beach covered by the surveys. Figure 20 illustrates the changes in the beach profile that resulted from the accretion. A rip current prevented formation of the

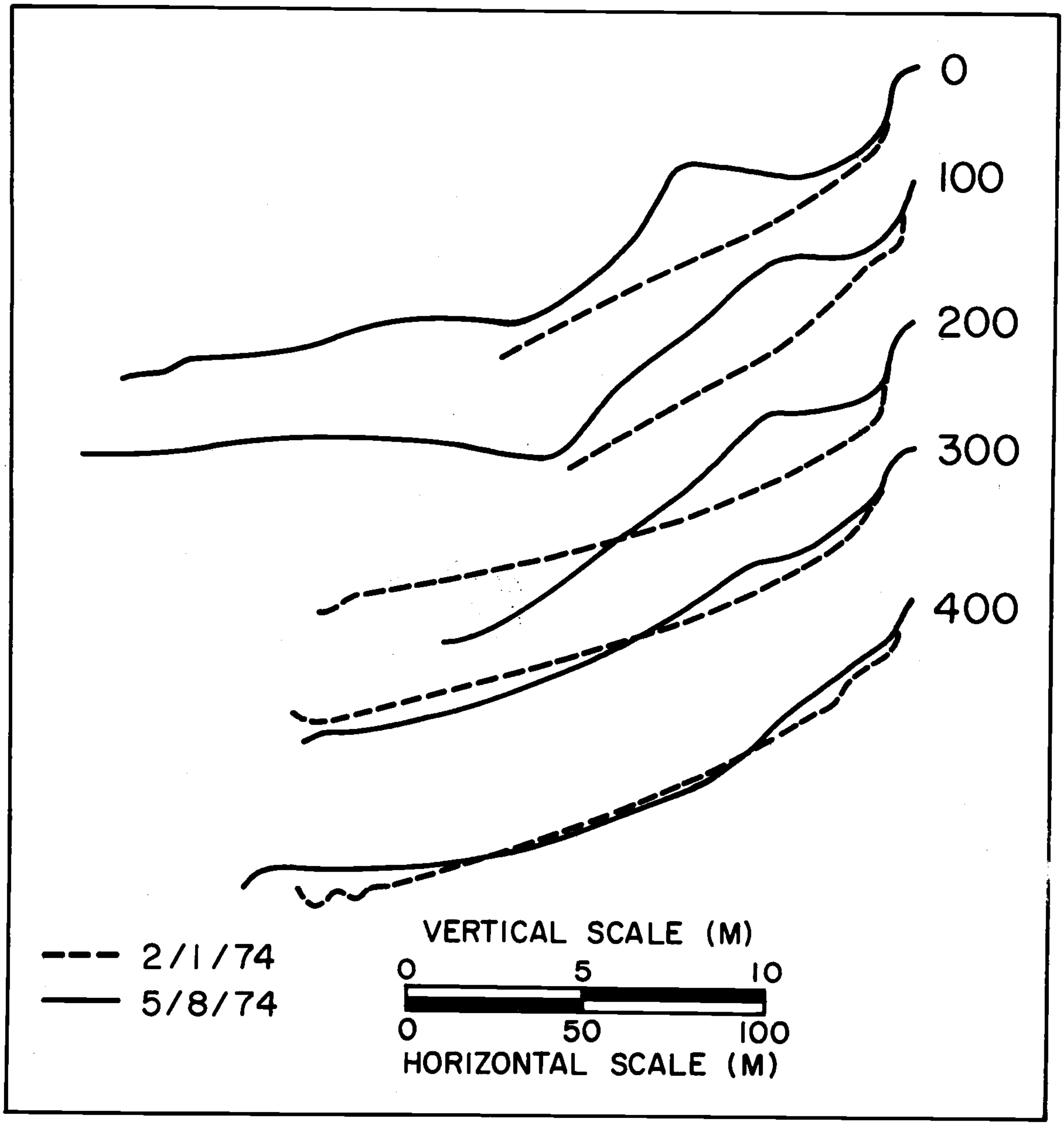


Figure 20. Comparative beach profiles, February 1 and May 8, 1974.

normal wide "summer" berm at the 300 and 400 meter profiles. Obviously if onshore transport continued at this rate, rapid progradation of the beach would result. Progradation is not occurring so that the observed accretion must be balanced by an offshore transport of similar magnitude during periods of high wave energy which generally occur in November through January. This offshore shift of sand during the winter months followed by an equal onshore shift during the summer months of lower wave activity is well documented on other beaches throughout the world. The onshore-offshore seasonal shift of sand does not constitute a source or loss of beach sand in the long term since there is a balance. More important to our budget of sediments is a permanent exchange with sands in deeper water beyond the outer bar. Sands may be coming ashore from the inner shelf area, thus contributing to the total amount of sand on the beach, or sands may be moving offshore from the beach to the shelf area and therefore being a loss. As opposed to the seasonal shift from beach berm to bar which can easily be measured with repeated beach profiles, a long-term exchange with the shelf area is almost impossible to detect unless very large. The available evidence from the mineralogy of offshore shelf sands (Roush, 1970; Scheidegger et al., 1971) and changes in water depth indicate that any exchange in sand between the beach and shelf must be very small, especially small when compared to the amount of sand provided by river runoff and cliff erosion.

Longshore Transport

The net longshore transport of sand along the beach is also difficult to evaluate since it appears to be a very small quantity. Clues to the direction of net drift are the orientation of sand spits which typically grow in the direction of net transport, beach erosion at the updrift end of a cell, beach progradation at the downdrift end where the transport is blocked by a headland or other obstacle, and in some rare instances by a progressive fining of beach grain size in the direction of transport. Along the Oregon coast nearly as many spits grow south as north, in many cases in close proximity to one another and under the same wave conditions. Therefore the direction of spit extension is a poor indicator of net sand transport along the Oregon coast. Erosion at one end of a cell and accretion at the other end is not evident. Dicken (1961) notes that the beach is skewed 56% south but attributes this to the lower resistance of the shoreline on the south rather than to the dominant wave direction.

Some evidence of longshore transport was provided by the beach surveys on Siletz Spit coupled with repeated aerial photographic coverage supplied by the Oregon Air National Guard between February 2 and June 10, 1974. By correlating the surveys and photographs, we were able to plot the longshore movement of the large rhythmic cusp features commonly seen on Siletz Spit (Figure 21). The topographic

Figure 21. Aerial photograph of rhythmic beach topography on Siletz Spit, February, 1973.

features in the survey area shifted 300 m to the north on the average between February 2 and March 28 under the influence of predominantly southwest winds and waves. Later as the winds shifted to the northwest, the topography began to move southward. This sequence of events suggests that the longshore transport is to the north during the winter when the winds are generally out of the southwest and to the south during the summer when northwest winds predominate. Terich and Komar (1973) reached the same conclusion in their analysis of sand accumulation around the jetty at Tillamook Bay, and further concluded that the winter and summer transports are nearly balanced resulting in a negligible net longshore movement of sand along the beach.

Analysis of the heavy mineral content of sands on the beach, and within the bay and river has been performed by K. Scheidegger at our request. The heavy minerals may serve as natural tracers of the sand movement and as indicators of the sources of the sands. The locations of the ten sand samples used in the study are shown in Figure 22 and their heavy mineral assemblages and median grain sizes are listed in Appendix B. Sample 1 from the Siletz River above tidewater has an almost monomineralic clinopyroxine heavy mineral assemblage similar to those found in other north Oregon Coast Range drainages (Scheidegger et al., 1971). This assemblage reflects derivation from a basaltic igneous source-rock, the Siletz River

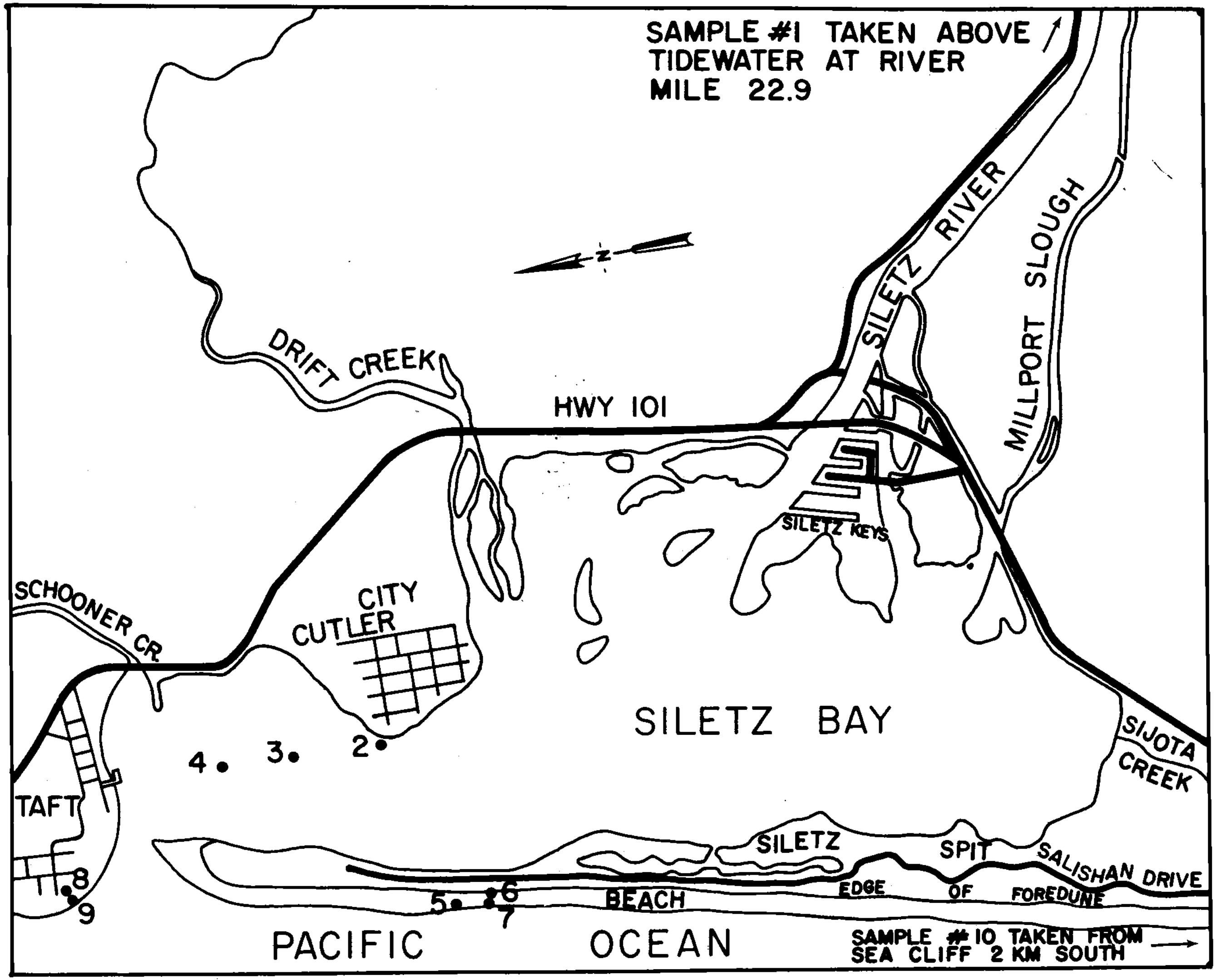


Figure 22. Map of Siletz Bay showing sand sample locations.

Volcanics. The other nine samples were taken from Siletz Bay, Siletz Spit, and the marine terraces north and south of the bay. Each of these, except sample 9 which is anomalous, has an assemblage containing 85-95% clinopyroxenes like other beach and nearshore samples from the area (Scheidegger et al., 1971). All of the samples except the one from the Siletz River contain varying amounts of amphiboles, epidotes, garnets, hypersthene, and other heavy minerals not generally found in the Siletz River. The low percentages of hypersthene and the presence of metamorphic minerals such as blue-green hornblende, epidotes, garnets, staurolite, and glaucophane indicate the influence of a metamorphic provenance on the overall assemblage. These metamorphic minerals have come from the Klamath Mountain area of southwestern Oregon and northwestern California and not from the Columbia River which carries a high percentage of hypersthene. The presence of glaucophane in two of the samples confirms the Klamath Mountains as the source of the metamorphic minerals (Scheidegger et al., 1971). Scheidegger et al. (1971) found glaucophane in the outer shelf sands but not on the inner shelf which indicates that there was a net northward transport of sand in the past during lowered sea level but that this transport halted as the shoreline shifted eastward with rising sea level. The absence of glaucophane on the inner shelf also rules out any exchange of sand between the outer shelf and the beach. Our heavy mineral analysis shows that the glaucophane on Siletz beach comes from the Pleistocene marine terrace deposits which were laid down during a period of higher relative sea level prior to the last glaciation. The mineralogical evidence argues against any significant net longshore drift at the present time.

The presence of metamorphic minerals in the Siletz Bay samples is evidence that beach sands are being carried into the estuary and therefore lost from the beach. The transport of ocean sands into estuaries has been well documented at other estuaries including Yaquina Bay to the south (Kulm and Byrne, 1966; Meade, 1969, 1972). This transport from beach to estuary is particularly enhanced if at sometime during the year the estuary circulation is well stratified with fresh water at the surface and a salt-wedge close to the bottom. Under such conditions the near bottom currents actually flow from the ocean inward to the estuary to replace the salt water lost from the salt-wedge through mixing with the surface layer. Burt and McAlister (1958) and Rauw (1974) found that this two-layered circulation occurs in the Siletz estuary during the late fall and winter when fresh water runoff is high. Unless an estuary is dredged periodically, an equilibrium between incoming and outgoing transport should eventually be established such that the estuary does not continue to act as a sink for the beach sands. From the close similarity of the heavy mineral assemblages in the beach and estuary samples, the indication is that the input of sand by the Siletz River is small compared to the amount of beach sand carried into the bay by tidal currents and two-layered estuarine circulation.

Previous heavy mineral analyses and those done for this study contain firm evidence that the Columbia River provides no sand input to the beach fronting Siletz Spit, the coastal cell between Government Point and Cascade Head. The analyses also indicate that if a net longshore transport exists, it is definitely not to the south.

For our sediment budget calculations we have assumed that any net changes in the amount of sand on the beach due to longshore drift are negligible compared to changes caused by the other factors. This means that little or no sand is by-passing Government Point and Cascade Head so that the beach behaves as a large pocket beach with only internal sources and losses of beach sand.

River Source

The Siletz River and smaller streams entering the bay are a potential source of sands to the spit. There are a number of methods for calculating the sediment load carried by a river, but unfortunately they tend to disagree with one another so there is a large uncertainty in the evaluation. In addition, equations based on stream parameters give the maximum load that can be carried by a given flow condition without regard to whether or not the sediment source is sufficient to utilize the total carrying capacity of the stream. Langbein and Schumm (1958) have developed an empirical graph for estimating stream loads from the drainage area and effective rainfall rather than directly from the stream flow conditions. We utilized both the equations for evaluating the sediment transport, and the empirical methods of Langbein and Schumm (1958).

Of the many stream-load equations available, we chose one of the simpler ones, that developed by Schoklitsch (see discussion in Graf, 1971). The Schoklitsch equation relates the bed-load sediment transport to the river discharge through the equation

$$G = 2500\, S^{3/2}\, (q - q_{cr})\, W \qquad (1)$$

where G is the bed-load transport in kilograms/second, W is the width of the stream channel, q is the stream discharge per unit channel width, q_{cr} is the critical discharge required to initiate bed-load movement, and S is the slope of the energy grade line of the river. The critical discharge q_{cr} is a function of the slope S, the critical water depth D_{cr}, and the roughness factor n according to the equation

$$q_{cr} = \frac{1}{n}\, (D_{cr})^{5/3}\, S^{1/2} \qquad (2)$$

The roughness factor can be determined from the sediment grain diameter d by

$$n = 0.0525\, d^{1/6} \tag{3}$$

Finally, the critical depth is obtained from the equation for critical shear stress

$$(\tau_o)_{cr} = \rho g D_{cr} S = 0.000285\, (\rho_s - \rho)\, g\, d^{1/3} \tag{4}$$

when g is the acceleration of gravity, ρ is the density of water, and ρ_s is the sediment density. Equation (4) is suggested by Schoklitsch for use when the grain diameter of the 40% finer fraction d_{40} is between 0.1 and 3.0 millimeters.

In apply equation (1) we took d_{40} to be 0.36 millimeters and calculated the 20 year (1951-1970) average monthly discharges for the Siletz River using data from the U. S. Geological Survey (1963, 1971, 1972) Water Supply Papers which give the discharge at river mile 42.6. To obtain a value for the monthly discharge at the mouth we compared the average annual discharge of 1,140,000 acre-feet per year at mile 42.6 with the value of 1,400,000 acre-feet per year (Percy *et al.*, 1973) at the mouth. Since these two values have a ratio 1.23, we multiplied the average monthly discharges by this factor. The slope of the energy grade line was approximated by the river's surface slope which is about 0.000077 for the tidewater portion of the Siletz based on a surface elevation of eight feet above mean sea level at the head of tidewater, river mile 19.75 (U. S. Geological Survey, 1926). The width of the river channel is about 120 m where it enters the bay. To convert the results of equation (1) from kg/sec to m^3/sec we used 2.65 gm/cm^3 for the density of the quartz sediment grains and assumed a porosity of 45% for the resulting deposit. These figures yield a total bed-load of about 1420 cubic meters per year for the Siletz River.

The U.S.G.S. Water Supply Papers do not give any discharge data for the Salmon River so we used the Siletz River monthly discharges reduced by a factor equal to the ratio of the annual discharges for the two rivers from Percy et al. (1973). The width of the Salmon River is about 40 m and its slope was estimated to be 0.00036. These values yield an annual bed-load transport of 6,040 cubic meters. Note that the greater slope of the Salmon River more than compensates for its smaller discharge and width relative to the Siletz River.

The second method used to calculate river sediment input is that of Langbein and Schumm (1958) which relates annual sediment load to the drainage area and effective rainfall. The effective rainfall is equal to the observed annual river discharge divided by the drainage area. Figure 23 shows sediment yield curves adapted from Langbein and Schumm (1958) using their average bulk density of 962 kilograms per cubic meter; the curves are normalized for a drainage area of 100 square kilometers. To convert the data for use with different sized watersheds, Langbein and Schumm (1958) multiply by a correction

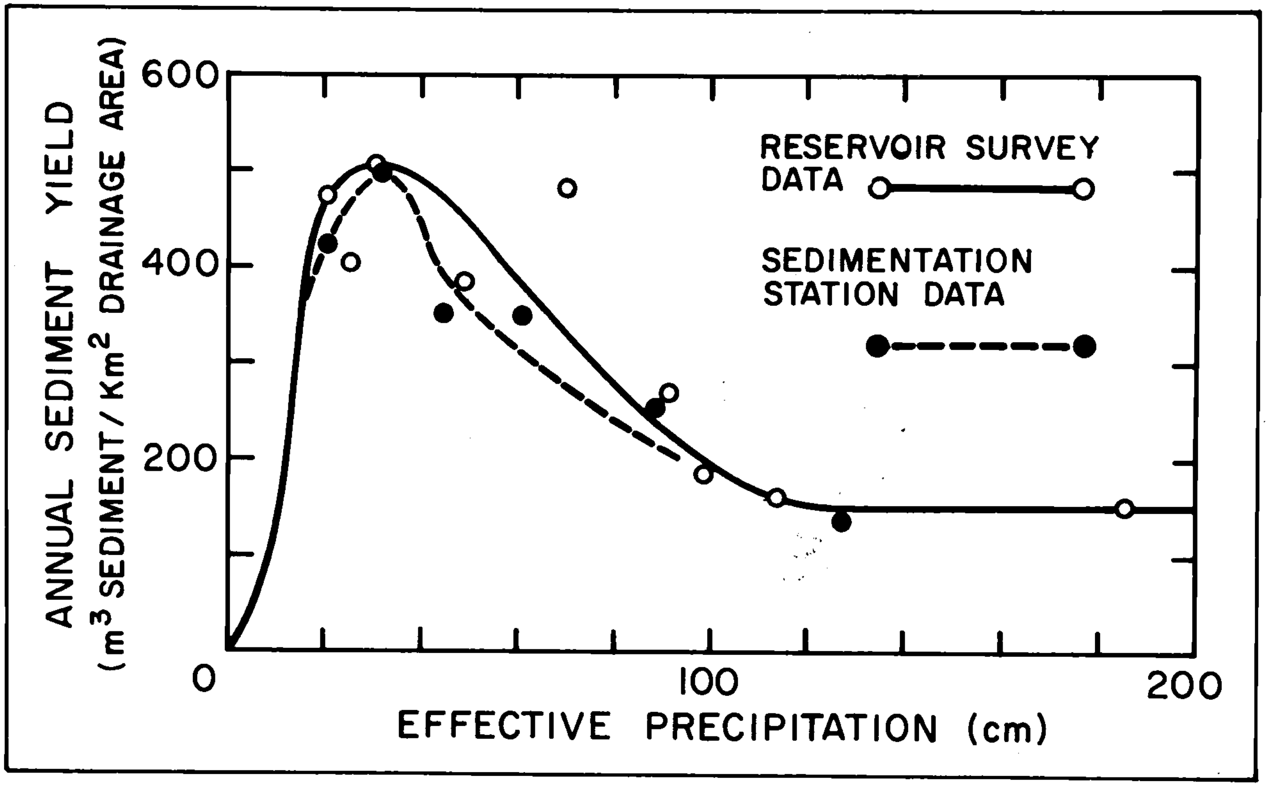


Figure 23. Climatic variation in sediment yield. After Langbein and Schumm, 1958.

factor based on the 0.15 power rule of Brune (1948). This factor is

$$\left(\frac{100\ \text{km}^2}{\text{area of watershed}} \right)^{0.15} \qquad (5)$$

The curves in Figure 23 level out at 154 cubic meters per square kilometer for an effective rainfall greater than 130 cm. The effective precipitation of the Salmon and Siletz Rivers is approximately 216 and 285 cm respectively, based on their drainage areas and annual discharges (Percy et al., 1973). The Siletz basin covers 797 square kilometers of which 44 drain into Valsetz Lake where bed-load sediments are trapped. Using Figure 23, the total annual sediment load is

$$\left(\frac{154\ \text{m}^3}{\text{km}^2} \right) \times \left(\frac{100}{753} \right)^{0.15} \times 753\ \text{km}^2 = 85,660\ \text{m}^3 \qquad (6)$$

Because the bulk density used by Langbein and Schumm (1958) is about two-thirds of what we used in our discussion of the Schoklitch method, we must multiply 85,660 by 0.67 to make the results comparable. Assuming that only 15% of the total sediment load is coarse enough to remain on the beach, the annual sand input by the Siletz River is 8,600 cubic meters. Similar calculations for the Salmon River, which has a watershed area of 194 square kilometers, give an annual bed-load yield of 2720 cubic meters. These figures are nearly in proportion to the discharges and drainage areas of the two rivers and therefore seem more reasonable than the results obtained using the Schoklitsch equation.

A third estimate of river input to the sediment budget was derived from the annual sediment loads of 67,000 metric tons for the Siletz River and 12,700 metric tons for the Salmon River determined by Percy et al. (1973). As before, we take only 15% of the total load as being the coarse fraction, the finer sediment being principally carried offshore into deeper water. Converting to volumes of sediments, the results are 6940 cubic meters for the Siletz River and 1310 for the Salmon River. These results are close to those above determined by the Langbein and Schumm (1958) graph. This is understandable since Percy et al. (1973) also based their sediment load values on watershed area and precipitation, the same factors as in the Langbein and Schumm method. In addition, Percy et al. estimated corrections for topography and type of vegetation cover so that their results may be more accurate. However, because of the assumptions involved, in all three approaches to estimating the sediment yield from the rivers we are probably dealing only with order of magnitude accuracies.

In deciding which figures to use for our sediment budget, we first discarded the results from the Schoklitsch equation because they are not consistent with the relative sizes of the sediment source areas and because of the disparity between them and the other sets of values. Then we chose the larger of the remaining yields, rounding them off to 9000 and 3000 cubic meters per year so that these figures are an estimate of the maximum river input to the sediment budget. A few small creeks empty into the ocean south of Siletz Bay, but these have very small drainage areas and generally flow through swamps before reaching the shore. Their coarse sediment input to the beach is therefore considered as being negligible.

Cliff Erosion Input

The final potential source of beach sand to be considered is the erosion of the cliffs behind the beach. Most of the coast between Government Point and Cascade Head is backed by actively eroding cliffs (Figure 24) as evidenced by the lack of permanent vegetation on the cliff face and noticeable changes even during a single year.

The rate of cliff erosion was determined by comparison of detailed measurements on aerial photographs taken in 1945 and 1973. Most of the areas where erosion is obvious show three meters or more of erosion between the two sets of photographs. Unfortunately, as noted by Dicken (1961), the resolution of the photography and accuracy of the measurements makes it nearly impossible to detect erosion on the order of two meters or less. By computing the erosion rate for the areas of obvious erosion and estimating the percentages of the total cliff that these areas represent, we arrived at an annual sand input of 11,000 to 15,000 cubic meters. The steepness of the cliff face and lack of vegetation indicate that it is actively eroding along

Figure 24. Actively eroding cliff south of Siletz Spit.

most of the coast althought there may be no obvious change since 1945 on the aerial photographs. In fact, erosion rates up to 5 cm/year may be undetectable on aerial photography over the 30 year coverage. An average rate of 3 cm/year seems reasonable for the areas of slow erosion and this adds approximately another 6000 cubic meters to this source, which when added to the input from fast eroding areas gives a total of 21,000 m^3/year. Comparison of the grain sizes of beach sands and marine terrace sands which form the cliffs indicates that only about 75% of the cliff sand is sufficiently coarse to remain on the beach, the rest drifting offshore. Therefore the net sand input from cliff erosion is estimated at being approximately 16,000 m^3/year.

Total Sediment Budget

Any estimate of the total amount of sand being lost or gained by the beach at Siletz Spit in a single year must be highly uncertain. One of the principal potential sources of sand are the Siletz and Salmon Rivers, but the former enters Siletz Bay and we cannot be certain whether the sand actually reaches the beaches or is trapped within the bay. We have already seen that analyses of the heavy minerals within the sands indicate that beach sand is moving into the bay. However, this does not preclude the possibility that river sand is finding its way through the bay and out onto the beach. The river source remains an uncertain contribution to the beach sand budget and only more detailed study might resolve this problem. A somewhat comparable situation is found at Yaquina Bay to the south, and a careful study of the sediments there indicates that river sands are not reaching the beaches (Kulm and Byrne, 1966). This may prove to be the case at Siletz as well.

If we assume that all the sand from the Siletz and Salmon Rivers does reach the beach, then the annual supply from all sources is 28,000 cubic meters. Since in arriving at this figure we have used the higher of the two sets of river sediment yield estimates and have also probably overestimated the percentage of cliff that is experiencing rapid erosion, this 28,000 m^3/year must be viewed as a maximum potential input. The actual supply may be more on the order of half this maximum estimate. Even with this maximum value, it is clear that when spread out over the 24 km of beach between Government Point and Cascade Head the contribution to any unit length of shoreline is very small. At this rate of input there would be no observable change in the size of the beach since settlement by white man, especially since onshore-offshore annual shifts between beach berm and bar involve much greater quantities. "Old-timers" reports of the beach being much wider at present than during their childhoods must therefore be discounted.

A U. S. Army Corps of Engineers (1972) report to the State of Oregon at the time of severe erosion on Siletz Spit indicated appreciable beach accretion between 1939 and 1973. This analysis was faulty as it was based on aerial photographs and they mistakenly compared the shoreline position in 1973 with the cliff line (not the shoreline) in 1939. A restudy of these aerial photographs and others show no systematic increase or decrease in the size of the beach. Any small net change that might have occurred was masked by annual beach profile changes from one season to the next and by variations in the water levels with the tides.

The continued erosion of sea cliffs over thousands of years argues against any significant long-term accretion of the beach. With accretion the beach would widen and therefore offer protection to the cliffs from wave attack. With continued accretion cliff erosion would eventually cease. Instead, it is more reasonable to assume that the beach at Siletz is approximately in a state of equilibrium with its sand sources and losses so that the total quantity of sand on the beach remains nearly constant. The 16,000 m^3/year of sand supplied by erosion of cliffs plus any contribution that may be gained from the rivers is probably lost through sand abrasion and offshore movement to the deeper waters of the shelf. Since all of the contributions and natural losses of beach sand are small, it is impossible to attempt any accurate assessment of a sedimentary budget.

Sand Mining

The sand budget discussed in the preceeding section included only natural losses and gains of beach sand. An important factor in the Siletz Spit area is the mining of beach sand between 1965 and 1971 by Oceanlake Sand and Gravel Company of Lincoln City, Oregon. A reported 84,500 cubic meters of sand was removed from the beach at the mouth of Schoolhouse Creek (State of Oregon, Division of State Lands, 1973), 2 km south of Siletz Spit. During those seven years the natural sources of sand supplied some 112,000 cubic meters to a maximum of 196,000 cubic meters of sand. Therefore, sand mining removed 43% to 75% of the new sand supplied to the beach. But natural processes probably continued to operate, removing sand offshore. Prior to sand mining, we saw that there was an approximate balance between losses and gains of beach sand. With sand mining the probability is that the equilibrium is upset, the beach sand losses being greater than the gains. The result would be a progressive decrease in the quantity of sand in the littoral zone and the overall size of the beach.

One of the important attributes of a beach is that it serves as a buffer between the wave energy and the coastal property. With an adequate beach the waves break well offshore and dissipate their energy before washing against the sea cliffs or other property. With a wide beach the wave swash may not even reach the cliffs.

Any loss in beach sand as in the case of sand mining at Schoolhouse Creek will act to diminish the beach size and therefore increase the potential for property erosion. The greater the amount of sand removed, the greater the probability for coast erosion. The precise response of the beach to the sand mining is difficult to evaluate, however. The greatest initial effect would be felt in the area immediately surrounding the removal site. Sand transport processes would tend to move sand alongshore to the removal area in order to replace the sand lost so that eventually the effect would be felt over the full 24 km of beach between Government Point and Cascade Head. However, by this delayed stage only a small effect would be expected as each unit length of shoreline would need to yield only a small amount of sand to replace that removed by mining. The significant consequences to mining would be felt close to the removal site and soon after removal, before replacement is accomplished by the littoral processes. Therefore, important to the effects on beach mining on local coastal erosion is the rate at which the sand is removed as well as the total quantity mined.

The removal of sand from the beach at Schoolhouse Creek may or may not be an important factor in the erosion experienced at Siletz Spit. We have already seen that the historic evidence indicates that erosion is largely a natural process as similar episodes of erosion occurred in the past prior to beach mining. However, we can also be certain that beach mining is an aggravating factor and if continued would lead to more severe episodes of sand spit erosion as well as erosion of the cliffs surrounding the removal site where homes are already precariously close to the cliff edge.

CHAPTER VI. LONG TERM SEA LEVEL CHANGES

An additional cause of long term erosion may be rising sea level. Hicks (1968, 1972) notes that the general trend in sea level has been upward since 1946 with a possible leveling off during the last decade. However, several cities on the west coast of North America have registered drops in sea level because of tectonic activity. Therefore, we cannot be certain how the relative sea level is changing on the Oregon coast. Tide records for Newport, Oregon, do not extend back far enough to demonstrate any long term trends (Pittock, personal communication).

One additional factor favoring erosion during the winter is the seasonal variation in sea level on the Oregon coast. Pattullo (1960) reported a maximum positive deviation from mean sea level of 24 cm in January 1958 at Crescent City, California, and 19 cm at Sitka, Alaska. The maximum negative deviations occurred in July. Analysis of tide records from South Beach, Oregon, for the years 1967-1973 indicates that the average seasonal variation in sea level between

December-January and June-July is on the order of 30 cm with a maximum of about 45 cm (Pittock, personal communication). Pattullo (1963, 1966) discusses various causes of the seasonal shift. The effect of the higher winter sea level is to increase the vulnerability of the foredunes and cliffs to wave attack.

CHAPTER VII. WAVE ACTION AND SPIT EROSION

Of major importance to the long-term erosion or growth of Siletz Spit is the budget of sediments already discussed. Of greater short term concern to the property owners on the spit and those concerned with preservation of the estuary is the annual cycle of erosion which is governed by the energy of the waves reaching the beach, the nearshore and beach topography, tides, and winds.

Because intense storms occur close to the Oregon coast during the late fall and winter the waves are generally highest then and therefore contain the most energy. During the summer months the offshore winds are weaker and so do not produce as large waves, and many of the waves come from very distant storms in the far south Pacific. Therefore on the Oregon coast there is an annual cycle of wave energy level. The beach responds to these changing wave conditions with an annual cycle of its own. During the winter months when the waves are large, sand shifts off the exposed portion of the beach (called the beach berm) and moves offshore to form offshore bars. During summer months of reduced waves the sand again returns to the exposed portion of the beach and forms a wide berm. The relationship between storm cycles and beach erosion and accretion has been extensively studied by Shepard (1950) in California, Fox and Davis (1973, 1974) on Lake Michigan and the Oregon coast, and by Harrison (1970), Dolan (1966, 1971), Sonu and Van Beek (1971) and Sonu (1973) on the Atlantic coast. Under storm waves sand moves offshore from the berm to the bars. Between storms smaller waves cause the bars to migrate shoreward until they become welded to the beach. The frequent storms that dominate the winter months cause the loss of sand from the beach berm to the offshore bars. During the summer, intervals between storms are generally longer and the storms milder so that a net accretion of sand occurs.

To determine the conditions under which wave erosion will occur on Siletz Spit, we correlated wave information with erosional episodes and with the results of beach surveys made during the later winter and spring of 1974. Significant wave heights and periods, determined from records made at the Oregon State University Marine Science Center at Newport (Creech, 1973), were used to calculate wave energy flux and wave steepnesses according to the following equations:

$$\text{energy density} = \frac{1}{8} \quad g H^2 \left[1 - 4.93 \frac{H^2}{L^2} \right] \qquad (6)$$

$$\text{group velocity} = \frac{1}{2}\ \frac{L}{T}\left(1 + \frac{4\ \ D/L}{\sinh(4\ \ D/L)}\right) \qquad (7)$$

$$\text{energy flux} = (\text{energy density}) \times (\text{group velocity}) \qquad (8)$$

where g is the acceleration of gravity, ρ the water density, D the water depth, H the wave height, L the wave length, and T is the wave period. Since we used the significant wave height rather than the root-mean-square (rms) height, the calculated value is twice the average energy density (Michel, 1968). Equation (7) is the small amplitude wave theory solution for the velocity of energy propagation while equation (6) takes into consideration the effects of large wave steepness on the wave energy density (Ippen, 1966).

The beach surveys consisted of nine profiles spaced 50 meters apart along the northern third of the spit. Surveys were made in the same location on February 1, March 28, April 25, May 7, and May 8, 1974. A computer program developed by William Fox produced contour maps and erosion-deposition maps from the survey data. As stated earlier, the contour maps showed a northward migration of beach topography through March. The erosion-deposition maps indicated steady deposition from February 1 to April 25, amounting to a net accretion of about 21,000 cubic meters of sand on a strip of beach 400 meters long by about 130 meters wide. Betwen March 28 and April 25, the longshore drift switched from north to south, the offshore bars migrated shoreward, and a rip current cell developed in the northern half of the survey area. The rip current removed about 7800 cubic meters of sand so that the measured net accretion between March and April was only 5,500 cubic meters. Because the longest March profile was only 145 meters and the bars surveyed in April were out beyond 150 meters, the large amount of accretion represented by the shoreward migration of the bars could not be measured. Between April 25 and May 7, the rip cells and bars shifted about 100 meters to the south, and the bars built upward resulting in a net deposition of over 16,000 cubic meters within an area 400 meters long and an average width of 200 meters. The total measured accretion between February and May was over 37,000 cubic meters.

It is important to note that even during this period of general accretion of the beach, the rip current caused severe erosion wherever it happened to be located while deposition occurred on either side of it. This effect is evident in the 300 and 400 meter profiles of Figure 20. Rip current cells usually migrate along the beach, but occasionally a large rip becomes stabilized in one location. This happened during the winter of 1972-1973 when high wave energy was causing general erosion of the beach and resulted in extensive erosion of the foredune where the rip current had cut into the protective beach. This incident will be discussed further later in this report.

Serious erosion of the foredune on Siletz Spit occurred during the winters of 1970-71, 1971-72 and 1972-73, but there was very little erosion during the 1973-74 winter. The wave energy flux for the latter three periods is plotted in Figure 25. To smooth out the irregularities in the energy curve, we plotted the three-day moving average of the energy flux. Only the data for November through January were used because the major storms usually occur during those three months. Analysis of Figure 25 shows that there were fewer large storms during the winter of 1973-74 than during the two preceeding winters.

During the winter of 1971-72, the foredune was badly eroded in places along the southern third of the spit. The wave energy plot (Figure 25) shows four large storms and two smaller ones that probably contributed to the damage. Erosion was localized, occurring wherever rip currents caused embayments in the beach berm so that waves could reach the dunes.

The largest storm obviously occurred on December 24-25, 1972. It was this storm that initiated the erosion that nearly destroyed the houses on lots 229-A, 230, and 232, and required major riprap installation (Figures 16 and 26). A significant wave height over seven meters high was recorded by the OSU Marine Science Center at 7:00 A.M. on December 24, and six hours earlier the significant wave height was 6.4 meters. High tide occurred around 3:25 A.M. and therefore greatly enhanced the destructive capability of these large

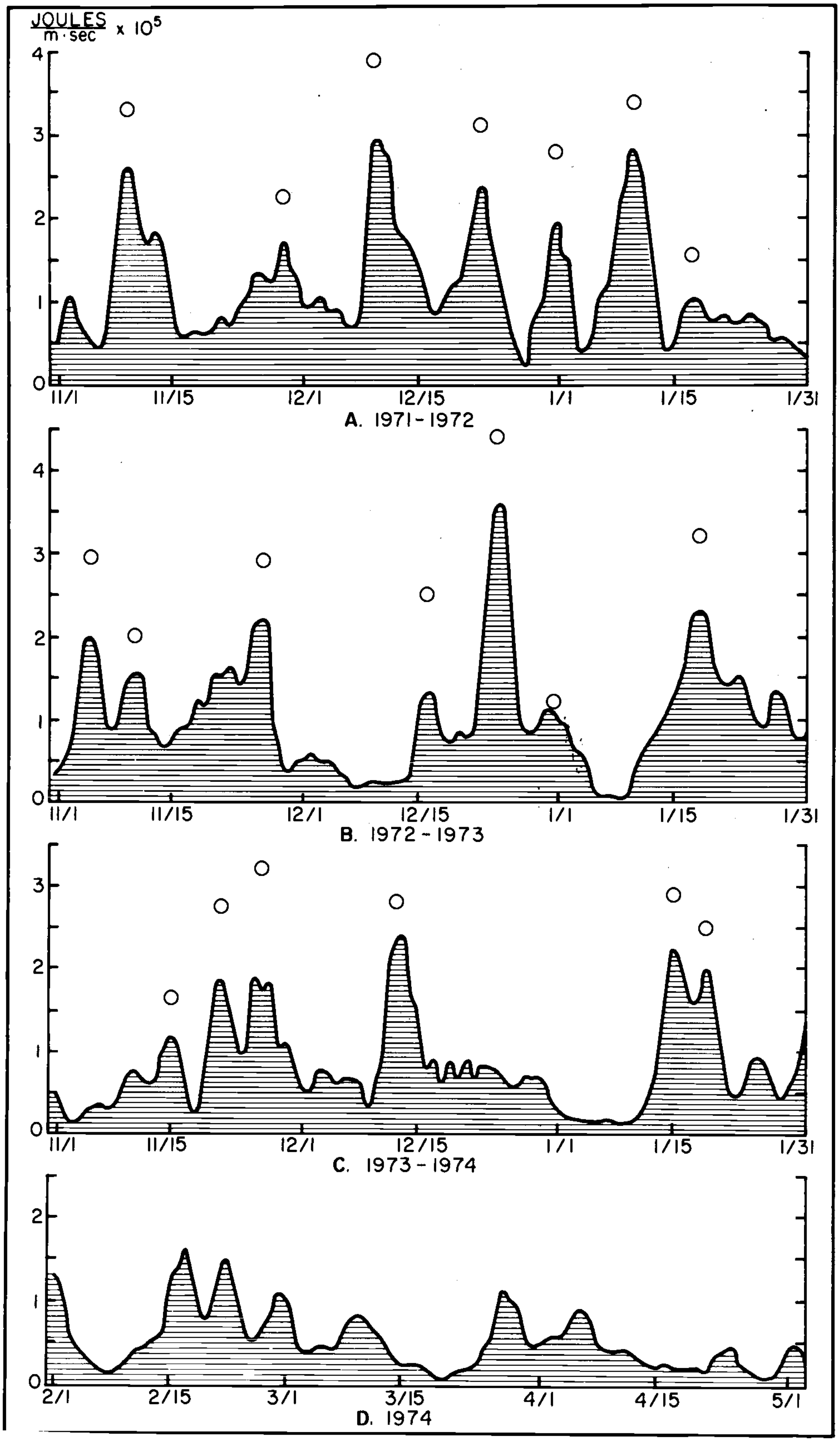


Figure 25. Wave energy flux smoothed by three-day moving average. Peak one-day averages indicated by ○ .

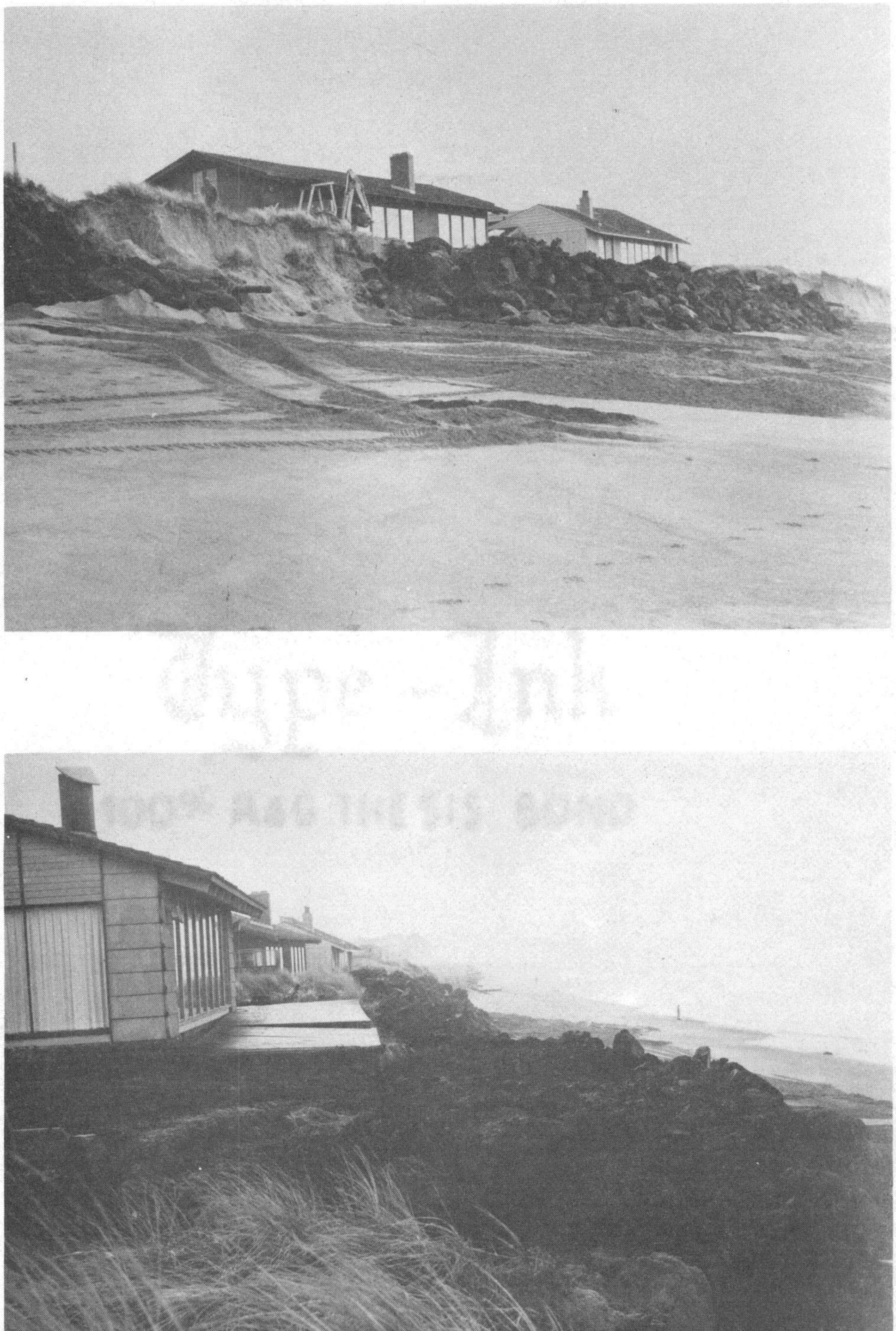


Figure 26. Houses riprapped after storm on December 24, 1972.

waves. Three storms in November 1972 had removed the summer buildup of beach sand on the berm so that the December storm together with high tides was able to attack the foredune directly. The actual location of the erosion was determined by the nearshore and beach topography. Seaward of the erosion area no offshore bar was present and the beach berm itself was almost entirely removed by the stabilized rip current discussed above (Figure 15). The second worst storm of the 1972-73 winter coincided with a high spring tide on January 18. The combination of high waves and tides resulted in very severe erosion of the foredune. Riprap protected the fronts of the three houses endangered by the December storm, but the dune on both sides retreated almost to the road. A partially constructed house on lot 226 that had not been riprapped fell into the sea (Figure 14). During the late winter and spring the large embayment and rip current cell migrated 180 meters northward causing a corresponding shift in the center of maximum erosion for that period.

Only minor erosion occurred on Siletz Spit during the 1973-74 winter even though a number of storms appear on the energy graph (Figure 25). These storms are generally smaller than those of the previous two winters and they occurred less frequently than in 1971-72. Table 3 gives the number of days on which the average daily energy flux exceeded certain limits for the four periods graphed in Figure 25. This information indicates that the first two winters were

TABLE 3. NUMBERS OF DAYS HAVING AVERAGE WAVE ENERGY FLUXES BETWEEN GIVEN LIMITS DURING FOUR 92 DAY PERIODS SINCE 1971.

Dates	Energy Flux Limits in Joules/Meter/Second Times 100,000								
11/1 to 1/31	0.0 to 0.49	0.5 to 0.99	1.0 to 1.49	1.5 to 1.99	2.0 to 2.49	2.5 to 2.99	3.0 to 3.49	3.5 to 3.99	4.0 to 4.49
1971-72	20	30	17	10	6	4	4	1	0
1972-73	23	28	19	13	3	3	1	0	2
1973-74	37	25	18	4	3	4	1	0	0
2/2 to 5/6/74	59	22	6	4	1	0	0	0	0

quite comparable in terms of wave energy while the third winter was significantly milder.

We had hoped to use the beach survey data to determine the critical level of wave energy flux that will cause net erosion of the beach. However, the low energy conditions that prevailed during the spring of 1974 (Figure 25d) produced a net accretion of sand on the beach berm. We can make a rough estimate of the critical energy flux by comparing the energy curves in Figure 25 and analyzing the information in Table 3. The number of days having an average energy flux greater than 1.5×10^5 joules/sec/m appears to be a significant factor. The removal of beach sand undoubtedly begins at a lower energy level, but storms must have a certain strength and frequency in order to erode the beach faster than it can be built up during quiet periods between storms. Once the protecting beach has been removed, storm waves can attack the dunes and cliffs at high tide. It is probably safe to assume that when the percentage of days with energy flux greater than 1.5×10^5 exceeds 20% of the total, erosion of the foredunes is likely and when the average energy flux is below 5.0×10^4 more than 50% of the time then net accretion will occur.

CHAPTER VIII. RECOMMENDATIONS FOR CONTROLLING EROSION

It is clear from our earlier discussions that there is a steady long-term erosion of the coast resulting in a retreat of the sea cliffs and thus an erosion or shifting landward of Siletz Spit. Superimposed on this long term retreat of the spit are cycles of foredune erosion that recur over periods of decades. Since settlement by white man, there has been an interference in these natural processes, especially within the past few years. Our discussion in this chapter is concerned mainly with preventing or eliminating any increase in the erosion rate caused by man's interference in the natural beach processes.

Most man-caused beach erosion results from tampering with the natural sediment budget. If this takes the form of groins or breakwaters which interrupt the longshore transport of sand or dams which trap stream sediments, the problem is major and not easily solved. Such is not the case at Siletz Spit. At Siletz Spit the main activity upsetting the sediment budget has been sand mining at the mouth of Schoolhouse Creek. The adverse cumulative effect of such activity has already been discussed. The amount of sand removed prior to the expiration of the mining permit in 1971 is small relative to the total volume of sand on the beach but the impact would be felt strongest close to the removal site. In an attempt to restore the proper quantity of sand to the beach, there results an increase in the erosion rates of the sea cliffs and dunes on the spit. With time the situation will correct itself so long as there is no additional sand mining. Man's impact on the sand budget can therefore be easily rectified by prohibiting any further mining.

Another activity that is a potential long-term source of difficulty is the practice of placing riprap or building seawalls at the base of the sea cliff to prevent erosion by wave attack. Our sediment budget calculations indicate that the cliff erosion is probably the largest source of beach sand for this portion of the coast so that if a significant section of the cliff is protected from erosion this source will be lost and the unprotected areas will be eroded faster to maintain the necessary total supply. At present about 15% of the sandy cliffs between Cascade Head and Government Point are artificially protected in some way. If the beaches are to be preserved for recreation and as a natural buffer against storm waves, the spreading use of riprap and seawalls must be discouraged.

The best anti-erosion measures for the sand spit itself vary depending on how the spit is to be used. If its present use as a coastal site for vacation homes is continued, as seems likely, then the present erosion prevention techniques of planting dune grass to stabilize the dunes and riprapping the foredune to protect it from waves are appropriate measures. However, the homeowners, especially those who have built on the foredune, should be made aware of the high risks and potential expenses involved. Riprap which is very effective in protecting the dune under normal conditions, can be easily undermined and washed away by a series of severe storms, the waves reflecting from the riprap accelerating the erosion of the beach. Dune grass stabilizes dunes with a protective cover of vegetation and a dense mass of deep, intertwined roots. The grass also builds dunes by trapping blowing sand; it can accumulate up to four feet of sand in one year (Jagschitz and Wakefield, 1971). Unfortunately, when attacked by storm waves highly stabilized dunes act as a rigid seawall in that they absorb the full energy of the waves rather than allowing them to wash over the top, and severe erosion can result. Since there is no washover, the eroded sand is carried offshore where it may be permanently lost. This is what happened when Hurricane Ginger hit the Cape Hatteras National Seashore in 1971 (Dolan and Godfrey, 1973). Another useful procedure not yet tried on Siletz Spit is beach nourishment. This involves providing an artificial supply of sand to replace that sand which is removed by longshore or offshore transport. Numerous technical memoranda (see list in Ippen, 1966) have been published giving details on the procedures and results of many actual cases. It may be feasible to maintain a stockpile of sand on Siletz Spit for beach nourishment in endangered areas.

If the sand spit were considered merely a barrier separating the ocean from Siletz Bay, the measures against erosion would be entirely different from those outlined above. To be an effective barrier the spit would have to resist breaching with a minimum of maintenance. Occasional washovers would be allowed and further study might even indicate that they would be beneficial to the estuary. Dolan et al. (1973) and Dolan and Godfrey (1973) have shown that barrier islands and spits can best resist storm wave erosion in their natural state consisting of low, unstabilized foredunes backed by overwash flats that slope gently landward. Large waves can wash over the low dunes without doing any permanent damage, and the transport of sand from the beach to the overwash flats is the natural mechanism of landward migration in response to rising sea level. Although it is not known if sea level is rising in the Siletz Bay area, occasional washovers on the northern third of the spit would be beneficial because they would replace the sand that is eroded from the east side of the spit by the river. To return Siletz Spit to its natural state would require considerable money and effort, and the cooperation of the residents there. This is not a likely alternative to maintaining the present situation even though it probably would have been the best utilization of Siletz Spit.

On the bay side of the spit there is a long history of steady erosion which could eventually breach the spit. The affected areas have been riprapped, but the riprap is lying on a tidal sand flat and could be easily undermined. Since riprap is probably the best protection in this case, it should be properly emplaced with a deep foundation. The erosion problem could be alleviated by changing the circulation pattern within the bay. One way of achieving this would be to open up Millport Slough and the other sloughs that flow into the south end of the bay so that the discharge through the main channel would be reduced. Besides reducing erosion to the spit, opening the sloughs would improve the overall water quality within the bay. In its present state little water replacement is achieved in the south end of the bay and it has become stagnated with accumulations of mud and old logs. Another change that would reduce spit erosion is the dredging of the sand bar in the main channel southwest of Cutler City. This would widen and straighten the channel so that the full force of the flow would no longer be directed toward the spit. The dredge spoils could be used for beach nourishment on both sides of the spit.

It is too late to reverse the development of Siletz Spit, but the lessons learned there and at Bayocean should be carefully considered before any further development is allowed on Oregon's sand spits. Natural beaches and sand spits usually exist in a state of long term dynamic equilibrium developed over thousands of years. Any attempts by man to interfere with or improve upon this natural system should be permitted only after very careful study of all the factors involved. Because our knowledge of these factors is incomplete, non-interference is generally the safest and least expensive method of dealing with natural coastal erosion.

CHAPTER IX. SUMMARY

Siletz Bay was formed by the drowning of the Siletz River valley during the rise in sea level after the end of the last glacial epoch. As the drowned valley filled with sediment, a barrier sand spit grew across the mouth of the bay, leaving only a narrow opening at the north end. The bay continued to fill until an equilibrium situation was reached in which the energy of the natural estuarine circulation was just sufficient to remove sediment as fast as it accumulated.

This equilibrium condition apparently existed until white settlers began to homestead the area in the 1890's. The available evidence suggests that cultivation of the land and logging greatly increased stream sediment loads and water runoff around the turn of the century causing rapid siltation in the bay. The diking of marshland and the damming of the Siletz River sloughs, which reduced drainage through the southern part of the bay, both contributed to the sudden increase in sediment deposition. One result of this deposition was progradation of the Drift Creek delta into the Siletz River channel deflecting the main flow so that it began to erode the east side of Siletz Spit. Since 1912 the river has cut 105 meters into the sand spit at a nearly constant rate of 1.4 meters per year. Siltation has also resulted in marsh expansion in the southern end of the bay amounting to about 0.28 square kilometers since 1900.

On the ocean side of Siletz Spit there is no evidence of long term erosion. Aerial photography back to 1939 shows three episodes of foredune erosion in the late 1930's, the early 1960's, and early 1970's separated by periods of dune building. The spit was developed in the late 1960's during a period of general accretion so that many homes were built on the foredune along the 1962 erosion scarp but several meters back from the present edge of the accreting dune. During the recent erosion, the homeowners riprapped much of the dune that had formed since 1962, but erosion landward of the 1962 scarp did occur in two places in 1972 and 1973. The 1972 erosion area is recovering naturally and in the 1973 area the property owners have filled and riprapped the eroded portion of the foredune.

Wave energy studies and beach surveys show that foredune erosion requires a combination of (1) several large storms spaced closely enough to prevent much rebuilding of the beach between storms, (2) high spring tides coincident with storms, and (3) erosion of the beach and offshore bar by rip currents. Given a series of large storms, one can expect erosion landward of any large rip current cell, especially if the cell has stabilized in one location and if spring tides coincide with high waves.

Protective measures employed on Siletz Spit are riprapping and dune stabilization by dune grass. On the outer banks of North Carolina, stabilized dunes recover from serious storm erosion much less rapidly than natural dunes. Whether this holds true for the barrier spits on the Oregon coast is a matter that requires further study. In any case, beach nourishment is probably a safer and more natural method of protecting against erosion.

BIBLIOGRAPHY

Brune, G. 1948. Rates of sediment production in mid-western United States. Soil Conservation Service TP-65. 40 p.

Burt, W. V. and B. McAlister. 1958. Hydrography of Oregon estuaries, June 1955 to September 1958. Office of Naval Research 58-6, School of Science, Oregon State University, Corvallis, Oregon.

Byrne, J. V. 1963. Coastal erosion, northern Oregon. In: T. Clements (ed.), Essays in Marine Geology in Honor of K. O. Emery. University of Southern California Press, Los Angeles. p. 11-33.

Corvallis and Eastern Railroad Company. 1912. Section maps of tide and marsh lands on Yaquina, Alsea, and Siletz Bays in Benton (now Lincoln) County, Oregon. Surveyed 1912. Lincoln County Surveyor's Office, Newport, Or.

Creech, C. 1973. Wave climatology of the central Oregon coast: Technical Report NOAA Sea Grant project 04-3-158-4. OSU Marine Science Center, Newport, Or. 19p.

Curray, J. R., F. P. Shepard, and H. H. Veeh. 1970. Late Quaternary sea-level studies in Microneasia: Carmarsel Expedition. Geol. Soc. America Bull. 81, p. 1865-1880.

Dicken, S. N. 1961. Some recent physical changes of the Oregon coast: ONR Report project NR 388-062. University of Oregon, Eugene, Or. 151 p.

Dolan, R. 1966. Beach changes on the outer banks of North Carolina. Annals Assoc. American Geog. 56, p. 699-711.

Dolan, R. 1971. Coastal landforms: crescentic and rhythmic. Geol. Soc. America Bull. 82, p. 177-180.

Dolan, R. and P. J. Godfrey. 1973. Effects of hurricane Ginger on the barrier islands of North Carolina. Geol. Soc. America Bull. 84, p. 1329-1334.

Dolan, R., P. J. Godfrey, and W. E. Odum. 1973. Man's impact on the barrier islands of North Carolina. American Scientist. 61, p. 152-162.

Fox, W. T. and R. A. Davis, Jr. 1973. Simulation model for storm cycles and beach erosion on Lake Michigan. Geol. Soc. America Bull. 84, p. 1769-1790.

Fox, W. T. and R. A. Davis, Jr. 1974. Beach processes on the Oregon coast, July, 1973: ONR Technical Report number 12 project NONR-388-092. Williams College, Williamstown, Ma. 85 p.

Graf, W. H. 1971. Hydraulics of Sediment Transport. McGraw-Hill Book Company, New York. 513 p.

Harrison, W. 1970. Prediction of beach changes. In: C. Board, et al. (eds.), Progress in Geography; International Reviews of Current Research, Volume 2. VIMS Contribution 341. p. 207-235.

Hicks, S. D. 1968. Long-period variations in secular sea level trends. Shore and Beach. 36, p. 32-36.

Hicks, S. D. 1972. On the classification and trends of long period sea level series. Shore and Beach. 40, p. 20-23.

Hurlburt, J. A. 1875. Field notes and survey plats of fractional townships 7 and 8 south range 11 west Willamette meridian in the state of Oregon. U. S. Bureau of Land Management, Portland, Or.

Ippen, A. T. (ed.) 1966. Estuary and Coastline Hydrodynamics. McGraw-Hill Book Company, New York. 744 p.

Jagschitz, J. A. and R. C. Wakefield. 1971. How to build and save beaches and dunes: preserving the shoreline with fencing and beachgrass. University of Rhode Island College of Resource Development, Rhode Island Agricultural Experiment Station, Kingston, Rhode Island. Bulletin 408, 12 p.

Kerry, A. A. 1951. Sawmilling and logging on the Siletz. In: E. M. Nelson (ed.), Pioneer History of North Lincoln County, Oregon, Volume I. Telephone Register Publishing Company, McMinnville, Oregon, p. 25-26.

Kulm, L. D. and J. V. Byrne. 1966. Sedimentary response to hydrography in an Oregon estuary. Marine Geology. 4, p. 85-118.

Langbein, W. B. and S. A. Schumm. 1958. Yields of sediment in relation to mean annual precipitation. Transactions: American Geophysical Union. 39, p. 1076-1084.

Lincoln County Historical Society. 1948. Lincoln County Lore from the Journal of Lieut. Theodore Talbot, U. S. A., on his Journey through Lincoln County and along the Oregon coast in 1849. Publication 1. Newport, Or. 14 p.

Meade, R. H. 1969. Landward transport of bottom sediments in estuaries of the Atlantic coastal plain. Jour. Sed. Pet. 39, p. 222-234.

Meade, R. H. 1972. Transport and deposition of sediments in estuaries. Geol. Soc. America Memoir 133. p. 91-120.

Michel, W. H. 1968. Sea spectra simplified. Marine Technology. 5, p. 17-30.

Milliman, J. D. and K. O. Emery. 1968. Sea levels during the past 35,000 years. Science. 162, p. 1121-1123.

North Lincoln News Guard. 1966. Pioneer Days. February 3, 1966. Lincoln City, Or.

North Lincoln News Guard. 1970. Kernville history. August 27, 1970. Lincoln City, Or.

North, W. B. and J. V. Byrne. 1965. Coastal landslides of northern Oregon. The Ore Bin. 27, p. 217-241.

Oregon Journal. 1945. The ghost of old Kernville. November 4, 1945. Portland, Or.

Oregon State Highway Department (OSHD). 1970. Foundation information for Highway 101 bridge over the Siletz River at Kernville Interchange.

Pattullo, J. G. 1960. Seasonal variation in sea level in the Pacific Ocean during the International Geophysical Year, 1957-1958. Jour. Marine Research. 18, p. 168-184.

Pattullo, J. G. 1963. Seasonal changes in sea level. In: M. N. Hill (ed.), The Sea, Ideas, and Observations on Progress in the Study of the Seas. 2, p. 485-496.

Pattullo, J. G. 1966. Mean sea level. In: R. W. Fairbridge (ed.), Encyclopedia of Oceanography. Reinhold Publishing Corp., New York. p. 475-479.

Percy, K. L., D. A. Bella, P. C. Klingeman, C. K. Sollit, J. B. Kennedy, and L. S. Slotta. 1973. Descriptions and Informations Sources for Oregon Estuaries. Oregon State University, Water Resources Research Institute, Corvallis, Or. WRRI-19-I. 190 p.

Rauw, C. I. 1974. Seasonal variations in tidal dynamics, water quality, and sediments in the Siletz estuary. M. S. Thesis, Department of Civil Engineering, Oregon State University, Corvallis, Or. 174 p.

Roush, R. C. 1970. Sediment textures and internal structures: A comparison between central Oregon continental shelf sediments and adjacent coastal sediments. M. S. Thesis. Corvallis, Oregon State University. 75 numb. leaves.

Scheidegger, K. F. 1974. Results of heavy mineral analysis of Siletz sand samples. Written Communication.

Scheidegger, K. F., L. D. Kulm, and E. J. Runge. 1971. Sediment sources and dispersal patterns of Oregon continental shelf sands. Jour. Sed. Pet. 41, p. 1112-1120.

Schlicker, H. G., R. J. Deacon, G. W. Olcott, and J. D. Beaulieu. 1973. Environmental geology of Lincoln County, Oregon. State of Oregon Department of Geology and Mineral Industries, Portland, Or. Bulletin 81. 171 p.

Shepard, F. P. 1950. Beach cycles in Southern California. U. S. Army Beach Erosion Board Technical Memo. No. 20.

Sonu, C. J. 1973. Three dimensional beach changes. Jour. Geology. 81, p. 42-64.

Sonu, C. J. and J. L. Van Beek. 1971. Systematic beach changes on the outer banks, North Carolina. Jour. Geology. 79, p. 416-425.

State of Oregon Division of State Lands. 1973. Volume of sand mined annually from Lincoln Beach by Oceanlake Sand and Gravel Co. between 1965 and 1972. Written communication.

Terich, T. A. and P. D. Komar. 1973. Development and erosion history of Bayocean Spit, Tillamook, Oregon. Oregon State Univerisyt, School of Oceanography, Corvallis, Or. Reference 73-16. 145 p.

U. S. Army Corps of Engineers. 1897. Sketch of Siletz River Bay, Oregon. U. S. Engineer Office, Portland, Oregon. August 27, 1897.

U. S. Army Corps of Engineers. 1931. Survey of Siletz River, Oregon, entrance to Old Kernville, July, 1931. U. S. Engineer Office, Portland, Oregon.

U. S. Army Corps of Engineers. 1934. Survey of Siletz River, Oregon, entrance to Old Kernville, July, 1934. U. S. Engineer Office, Portland, Oregon.

U. S. Army Corps of Engineers. 1972. Siletz Bay, Oregon; erosion problem. letter CEREN-EV (14 JAN 72) 1st Ind. from: Coastal Engineering Research Center, Evaluation Branch, Washington, D. C. to: District Office, Portland, Or.

U. S. Army Corps of Engineers. 1973. Siletz River, bar and entrance. Department of the Army, Portland District Corps of Engineers, Portland, Or.

U. S. Geological Survey. 1926. Plan and profile of Siletz River, Oregon, and South Fork from head of tide to mile 57. Sheet C.

U. S. Geological Survey. 1963. Water-Supply Paper 1738. U. S. Government Printing Office, Washington, D. C. 327 p.

U. S. Geological Survey. 1971. Water-Supply Paper 1935. U. S. Government Printing Office, Washington, D. C. 957 p.

U. S. Government Survey. 1972. Water-Supply Paper 2135. U. S. Government Printing Office, Washington, D. C. 1036 p.

APPENDIX A. AERIAL PHOTOGRAPHY

Date	Agency[1]	Film Identification	Frames
5/3/39	USCE	Cape Foulweather Quad. roll 107	2689-2694
7/17/39	USCE	Cape Foulweather Quad. roll 179	10019 10021 10023
9/14/45	?	VV16PLM 1 16 PS 5M 151	32-41
10/5/52	USDA	Lincoln County, Or., DFL-13H	10-13
6/6/62	USCE	62-681 NPP roll 545	
7/6/62	OSHD	LIB 3	3-1 - 3-4
10/4/64	OSHD	LIB 8	1-5 - 1-8
9/23/65	OSHD	OC - 1	10-23 - 10-31
7/26/66	OSHD	LIB 10	3-4 - 3-7
9/3/67	OSHD	OC - 3	R23-14 - R23-23
1/5/71	?	?	?
8/6/71	Carto	OC - 13	10-6 - 10-10
5/24/72	USDA	Lincoln County, Or., A21 4104	172-50 - 172-60
7/17/72	USCE	CE NPP	2054-2055 2057-2058
2/6/73	Carto	OSU - OC	5-1 - 5-12
2/8/73	USCE	CE NPP USCE - 73	OBL 1-3 OBL 1-11
4/8/73	OSHD	OC - 16	1-7 - 1-16
5/11/73	Carto	OC - 17	7-8 - 7-10

----

[1] USCE = U. S. Army Corps of Engineers
USDA = U. S. Department of Agriculture
OSHD = Oregon State Highway Department
Carto = Carto-Photo Corporation, Eugene, Oregon

Appendix A. continued

Date	Agency[1]	Film Identification	Frames
2/2/74	ANG	OSU beach photography for William Fox and Campbell Rea	
3/2/74	ANG	"	
3/15/74	ANG	"	
4/26/74	ANG	"	
6/9/74	ANG	"	
9/5/74	W. W.	OSU coastal photography	V22-V26

----

[1] ANG = Oregon Air National Guard, 1042nd M. I. Co.
W. W. = Western Ways Incorporated, Corvallis, Oregon

APPENDIX B. HEAVY MINERAL ANALYSIS OF SAND SAMPLES

Mineral	Sample Number and Percent Composition										
	Columbia River	river 1	2	3	4	5	6	7	8	9	10
Actinolate	0.6									0.6	
Glaucophane								0.3		0.3	
Hornblend											
Balsaltic	3.7		0.7	0.7		0.7	2.2	0.3	0.4	0.3	0.7
Blue-green	5.0	0.4	1.8	2.2	1.1		1.4	1.7	0.4	15.4	1.0
Brown	4.5		1.4				0.8	0.7		5.8	0.7
Green	7.7		2.8	0.7				0.3		13.5	0.3
Apatite	0.2										
Epidote Group											
Clinozoisite	0.3		0.3	0.7						1.9	
Epidote	1.1		2.0	0.7		1.4	0.8	0.3		2.6	1.7
Garnet	2.0										
Clear			1.0	3.4	0.4	0.7	0.8	1.4	0.4	1.9	6.1
Pink			1.0	1.1	0.7			1.4		0.3	2.0
Salmon				1.1							2.7
Glass (volcanic)					0.7						
Kyanite	0.2										
Olivine	1.2			0.4						0.3	

(continued on next page)

Appendix B. continued

Mineral	Columbia River	river 1	bay 2	bay 3	bay 4	beach 5	beach 6	beach 7	terrace 8	terrace 9	terrace 10
	Sample Number and Percent Composition										
Orthopyroxene											
Enstatite	0.2										
Hypersthene	37.5	0.4	0.3	4.8	1.5	1.4		3.0	1.2	19.2	1.7
Clinopyroxene											
Augite	30.5	26.5	10.3	11.2	8.9	9.2	9.0	13.2	10.8	3.6	10.2
Diopside		72.3	77.4	72.6	87.4	85.2	85.0	77.4	86.8	33.3	72.6
Ti Augite	1.2										
Rutile	0.1										
Sillimanite	0.1										
Sphene	0.3										
Spinel	0.1										
Staurolite	0.1	0.4	0.7			0.7				1.0	
Tourmaline	0.1										0.3
Zircon	0.1										
Median Grain Size - ϕ_{50}		2.05	1.72	1.74	1.17	1.51	1.30	1.57	1.77		1.76

Heavy mineral compositions determined by Scheidegger (1974).