Materials for Envir. Geology Coast Field Trip (4-10-05)

Learn the starred part of stratigraphic section for coast field trip.

STRATIGRAPHIC TIME CHART FOR TERTIARY UNITS

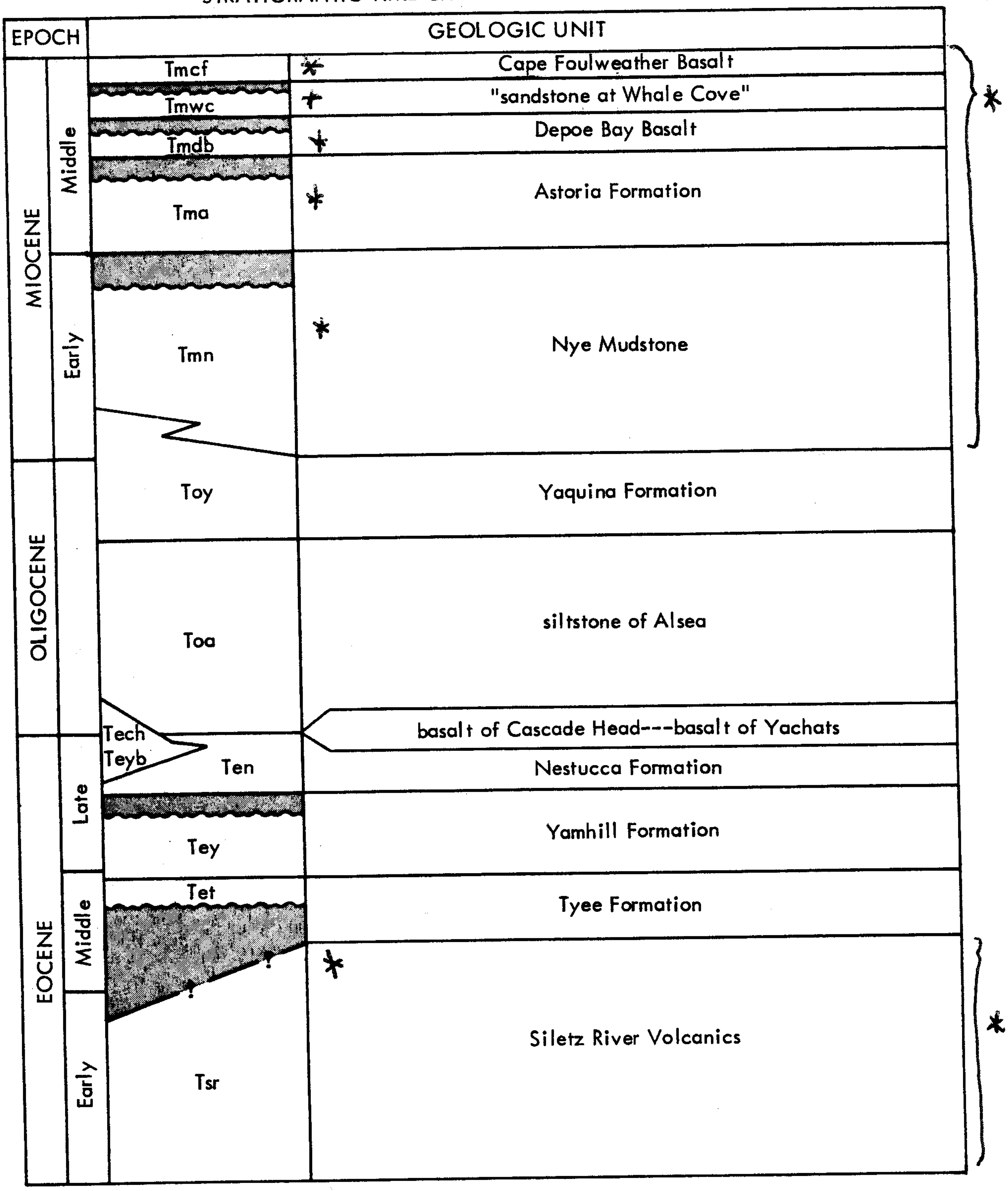
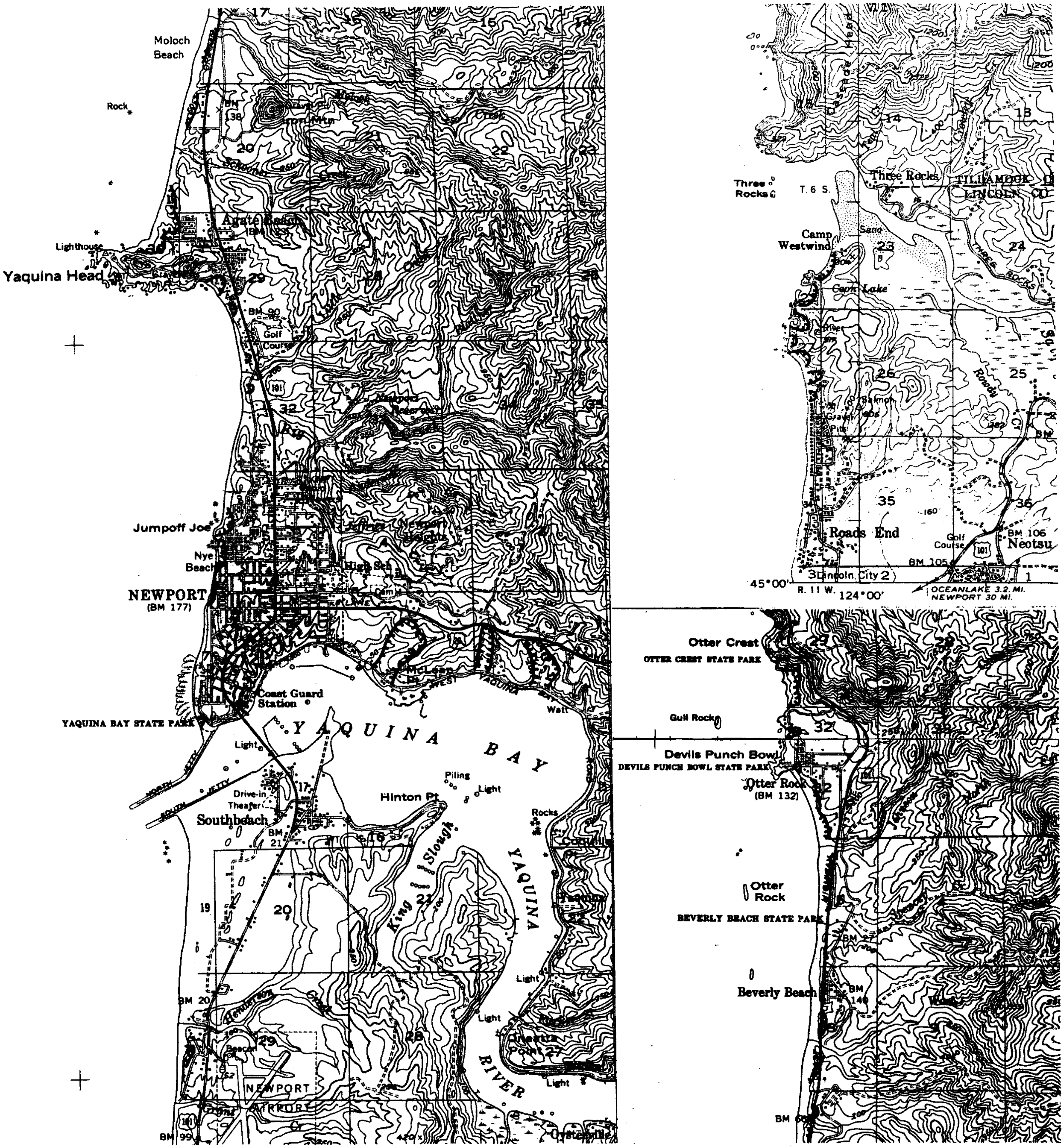


Figure 3. Chart showing the stratigraphic positions, map symbols, and relative ages of the bedrock formations in Lincoln County.



ADDENDUM TO BULLETIN 81. ENVIRONMENTAL GEOLOGY OF LINCOLN COUNTY, OREGON
(Add to maps)

Active landslides in sections of coastal region of Lincoln County, Oregon

Oregon Department of Geology and Mineral Industries, Portland, Oregon
April 5, 1974

Transient Shorelines

The beaches, spits, headlands, and estuaries of coastal Lincoln County represent a natural balance between the interrelated processes of wave erosion, longshore drift, river transport of sediments, and landsliding. Beaches and spits are particularly sensitive to the migration of sand up and down the coast; marine terraces are sensitive, in turn, to the condition of the beaches protecting them from the sea. Headlands owe their presence to the relative hardness of the rocks of which they are composed, and estuaries record the world-wide rise in sea level of the last 20,000 years.

The features of the coastal strip are the result of a complex interplay of many processes with innumerable local variations. It is emphasized that the processes are continuing and that the coastal area, probably more than any other area, is subject to continuing change, be it natural or man-induced. Proper land-use management in these areas is needed to insure that future developments are intelligently keyed to the geologic conditions so as to minimize future losses.

Beach areas

Approximately 70 percent of the coastline of Lincoln County is made up of beaches. These include Lincoln Beach, Wecoma Beach, and Gleneden Beach in the Cape Foulweather quadrangle; the coastline between Otter Rock and Yaquina Head, and between Yaquina Head and Beaver Creek in the Yaquina quadrangle; and the strip between Seal Rocks and Yachats in the Waldport quadrangle (see Figure 20). Because beach areas span so much of Lincoln County coastline, an understanding of the processes which govern their formation and destruction is critically needed.

Beach areas represent a balance between erosion and deposition and constitute a natural protection of the inland areas from the ravages of the sea. Offshore bars trip the waves, shallow slopes dissipate their energy, and the flat back-beach areas normally above high tide accommodate most storm activity. The dunes, products of wind-blown beach sand, constitute a final protection against exceptionally high storm waves and tides.

Wind waves: Waves generated by the wind are instrumental in determining the profile and local configuration of beaches. In response to seasonal storm activity, the beaches undergo cyclic variation in their form. In general, steep intense winter waves erode the beach, cutting into dune areas, whereas the gentler summer waves bring in sand, restoring the beaches to their former shape. Larger, unrecognized cycles and non-cyclic phenomena (such as tsunamis, discussed under "Ocean Flooding") also are important factors in beach stability.

Longshore drift: Longshore drift is the term applied to the direction of movement of sand along the coast as a result of tidal and wave action. Little is known of the longshore drift of the central Oregon coast. It is generally concluded, however, that the gentle northerly currents of long duration of the summer months dominate the brisk southerly currents of short duration during the winter months to give a net drift towards the south. Wind and swell movements (Kulm and Byrne, 1966), patterns of sedimentation adjacent to jetties (U.S. Army Corps of Engineers, 1971 a, b; Schlicker and others, 1972), and the presence of the south-flowing Japanese Current off the coast are consistent with this interpretation.

The presence of offsetting currents does not necessarily diminish the problems introduced by longshore drift. In fact, the operation of two-current systems introduces a hazard to the beaches which is doubly difficult to control. A consideration of this factor is discussed under "Topography" below.

Topography: Inlets and headlands which interrupt beach areas are significant to beach stability because they influence the supply of sand delivered to beaches by longshore currents. Tidal currents flowing in and out of inlets, such as estuaries, carry drifting sand seaward and temporarily remove it from the beach system.

In the undisturbed state, the effect of removing sand at inlets is balanced by longshore drift, and a series of bars and shallows insures that enough sand passes the inlet to supply the beaches farther along the coast. Man, however, can interrupt this balance by dredging the channel or constructing jetties.

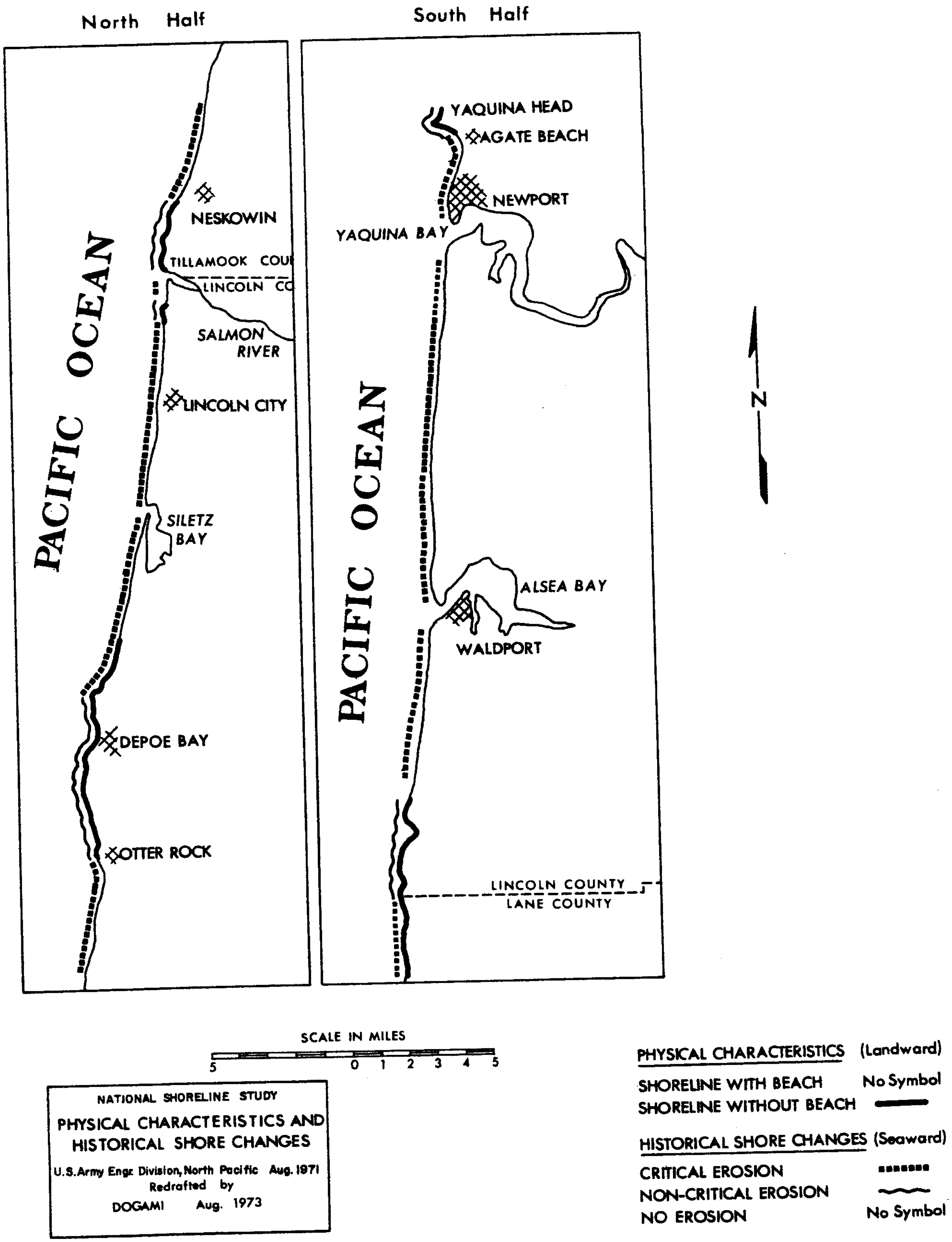


Figure 20. Shoreline map of Lincoln County.

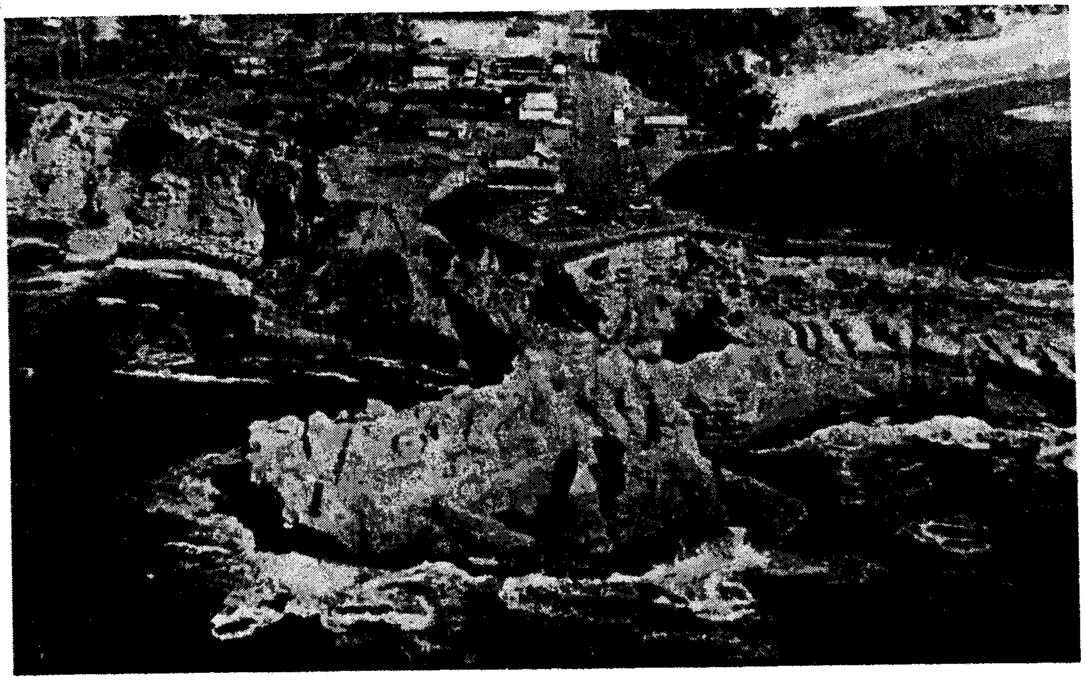


Photo 57. Devils Punch Bowl State Park at Otter Rock, a marine terrace on a sandstone headland. Wave erosion removes terrace sediments faster than the sandstone, continually reducing the margins of the park area.

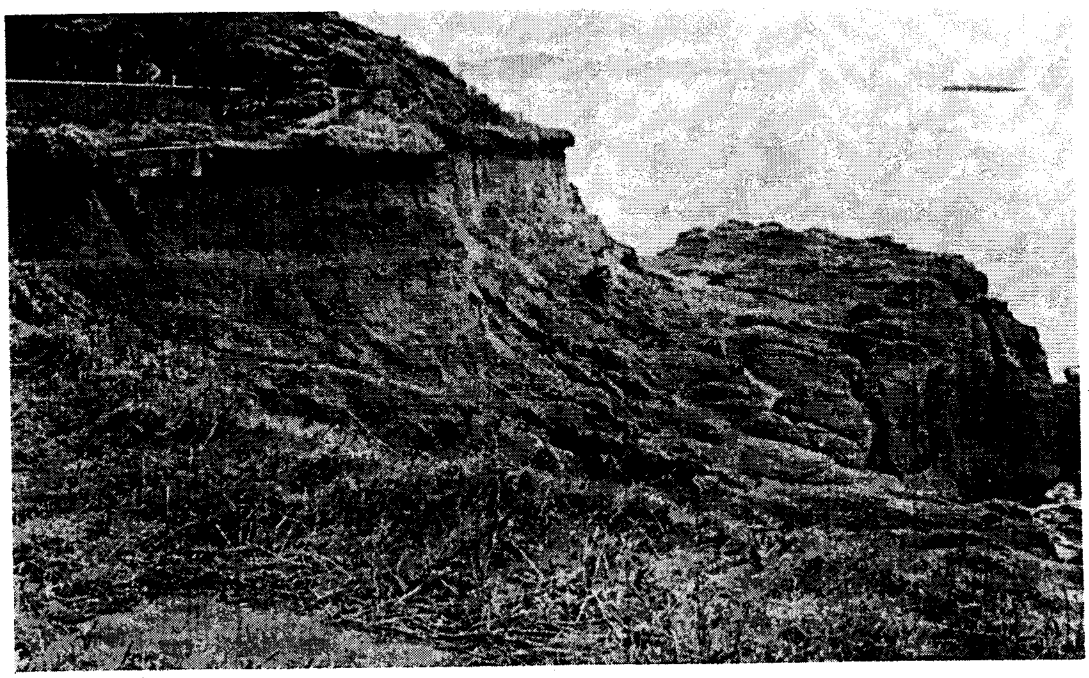


Photo 58. Close-up of Devils Punch Bowl area. Erosion has removed former stairway access to the Punch Bowl on right. Remains of old walkway projects from cliff at left.

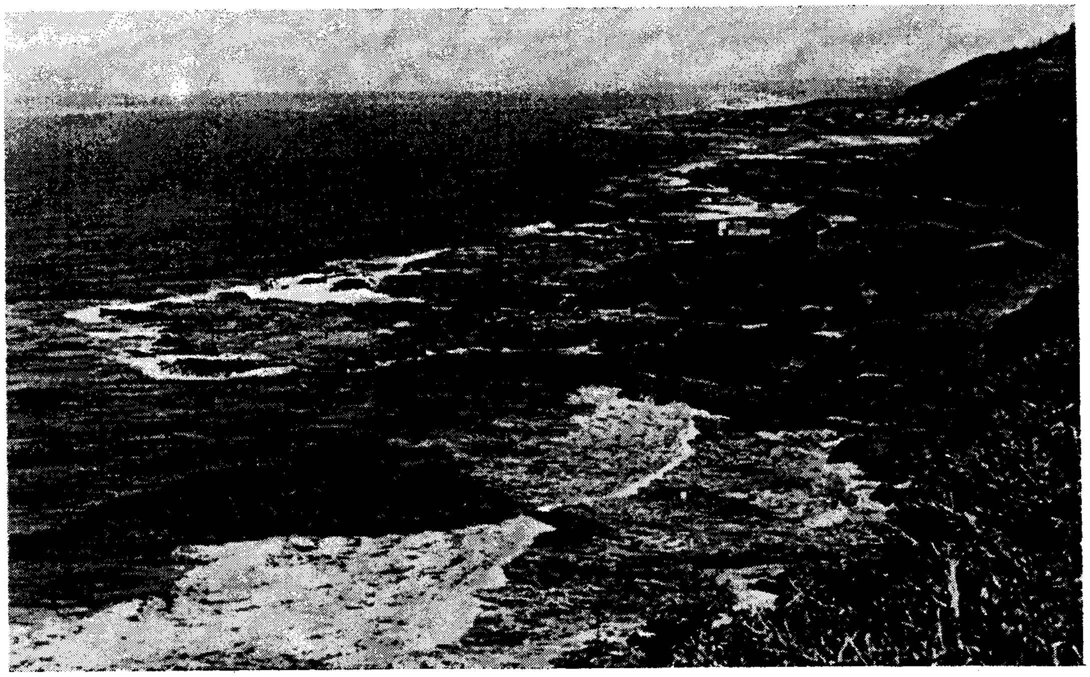


Photo 59. Wave-cut terraces on resistant basalt breccia at Cape Foulweather extend seaward. Basaltic rock is much slower to erode than sedimentary rock.

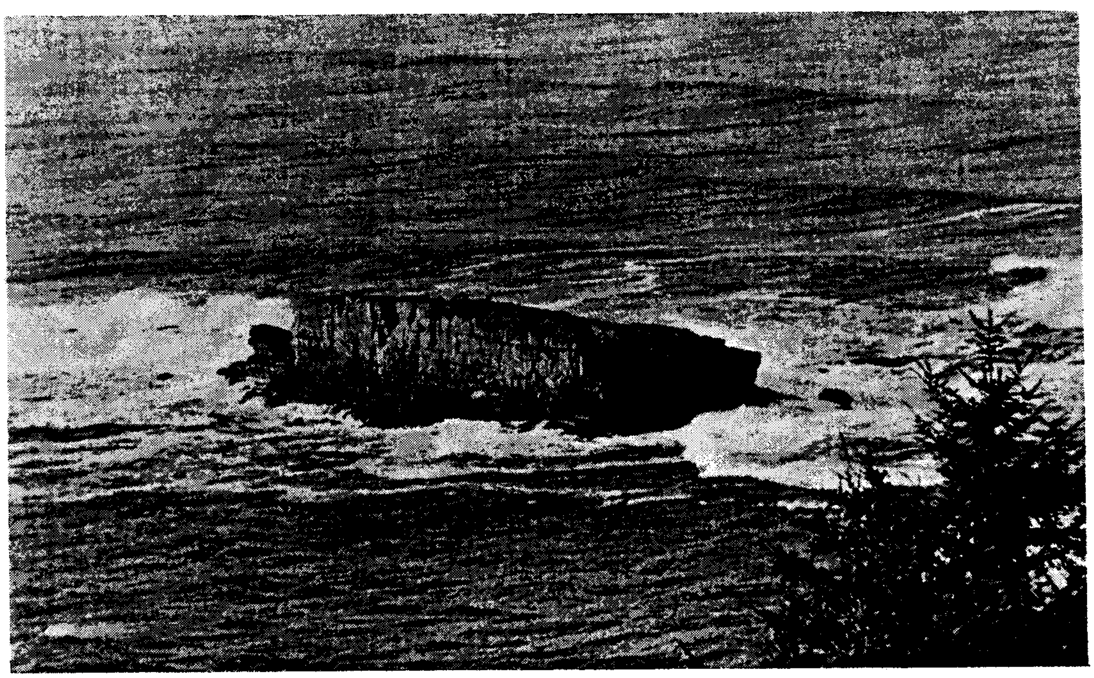


Photo 60. Basalt sea stack offshore from Cape Foulweather was once part of the headland. Erosion of less resistant rock between has left this isolated remnant.

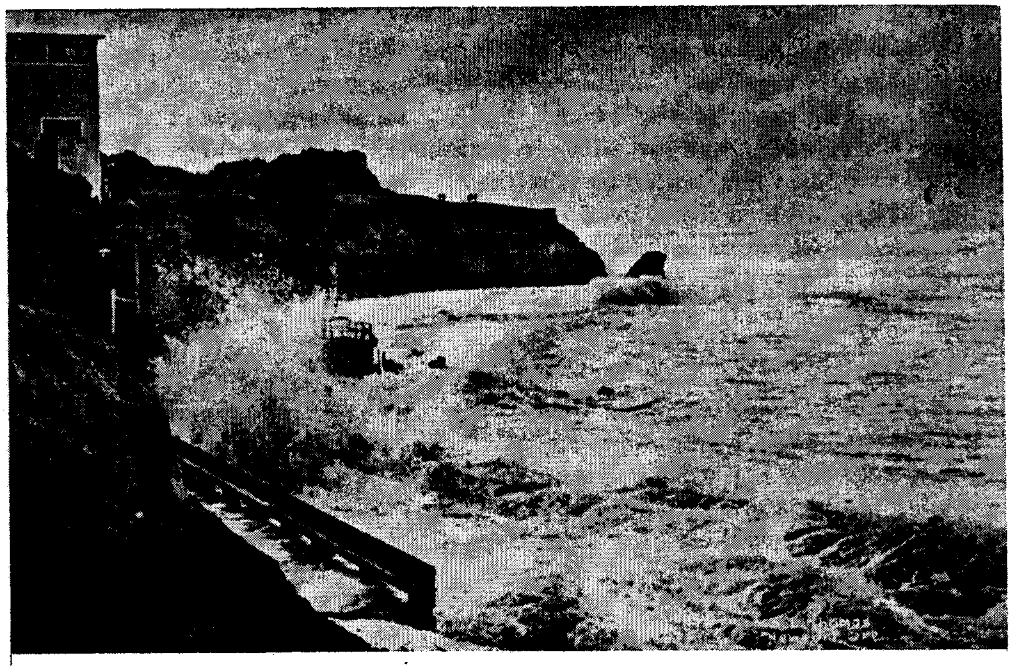


Photo 61. Nye Beach coastline about 1900. Photo taken from natatorium during storm at sea. (Courtesy of Lincoln County Historical Society)

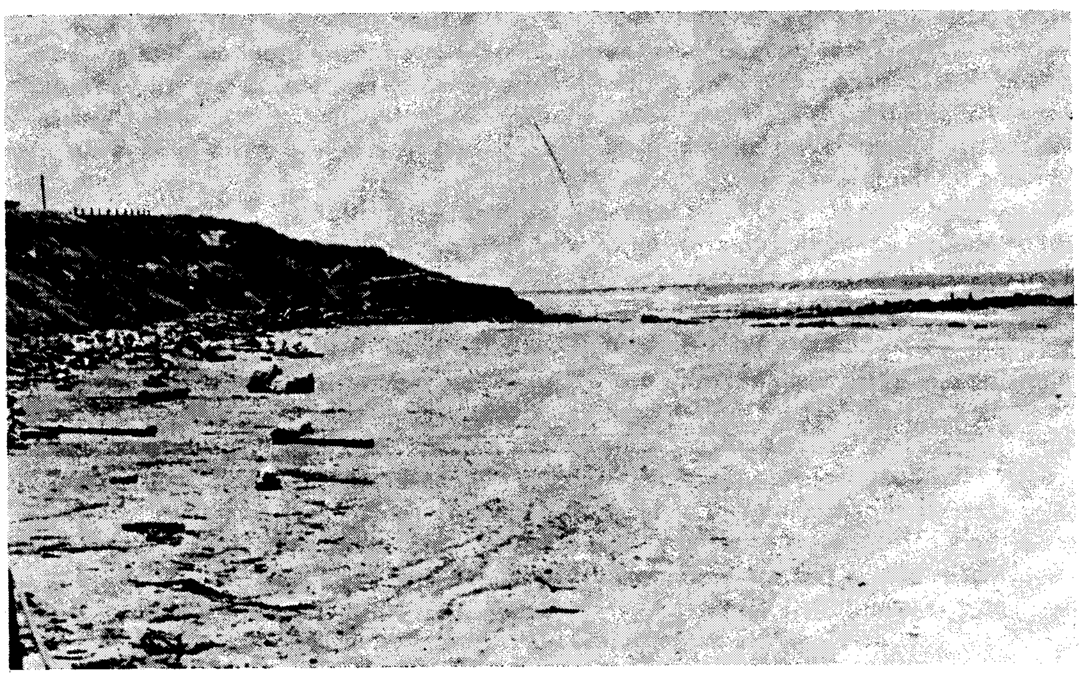


Photo 62. Photo taken from approximately same location in 1973 shows amount of recession of small headland and its terrace platform.

The result very commonly is the starving of beaches of sand and increased beach erosion. Bayocean at the mouth of Tillamook Bay is a case in point (Schlicker and others, 1972). Any proposed modifications of the shoreline should take into consideration the sand budget of adjacent beach areas. Large-scale removal of sand from the beaches should be discouraged in most instances.

Jetty construction or dredging operations will block sand migration both to the north and to the south and could conceivably contribute to beach instability in both areas. It is not uncommon elsewhere in coastal regions for beach sand to be transported by pipeline or barge from points of accumulation across dredged inlets to points of depletion on the other side. Modification of the coastal topography must proceed only after rigorous investigations of potential hazards are made and adequate provisions are made to preserve the flow of sand.

Sandspits and dunes

A sandspit is a point of land that projects from a beach and cliff area into an open body of water, usually between a bay and the ocean. Spits are a special class of beaches and are subject to the same processes, including longshore drift and wave and wind action. Most sand spits along the Oregon coast are topped by dunes, which become progressively lower and less stable toward the end of the spit.

Siletz Bay spit, projecting northward from the south shore of Siletz Bay and occupied by a part of Salishan, is the most notable sandspit in Lincoln County. Other spits include those at Yaquina and Alsea Bays.

The spit at Siletz Bay is undergoing critical sea erosion on its seaward side and is subject to a variety of other geologic hazards as well. Trough blowouts of its dunes are developing where the vegetative cover is insufficient. Most of the spit conceivably could be topped by high storm waves or tsunami waves. The scattered logs throughout much of the dune areas on the outer spit attest to the potential danger of storm waves.

Long-term residents of the area report that during the early 1900's the Siletz River passed through a channel at about the center of the spit. That channel subsequently became plugged with logs and sand, diverting the river northward. It is probable that the low spit has been breached at various places in the past.

During the high winter and spring tides of 1973, parts of the Siletz spit were attacked by the sea and in some places eroded back 75 feet or more. At least one house fell into the sea and the emergency placing of riprap was needed to preserve several others. The precise cause of the erosion has not been definitely identified, although the dominating factors probably included storm severity, the lateral migration of coastal landforms (a phenomenon discussed at length by Sonu, 1973), and natural variations in sand supplied by longshore currents and by the Siletz River.

A team of experts, including U. S. Army Corps of Engineers personnel, dispatched to the site at the request of Governor McCall concluded that at the present time parts of the spit are unsuitable for permanent construction. Properly engineered riprap and seawalls could conceivably stabilize the spit.

The dunes on the spit at the mouth of Yaquina Bay have undergone a relatively complex history and are presently stable in most areas. According to Cooper (1958), the deposits of sand south of the Bay fill the old channel of the Yaquina River and generally are stabilized by vegetation. The dune sand underlying parts of Newport was effectively cut off from its source of supply when the Yaquina River assumed its present course and it, too, is stable. As in all dune areas, preservation of the vegetative cover is recommended, especially in the dune fields south of Yaquina Bay. Excavation into stabilized dunes could expose loose sand to the wind and could initiate further dune activity.

At Alsea Bay, a blunt spit projects southward from the north bank into the estuary. With the exception of the foredune, all dunes on the spit were bulldozed flat for housing development. Preservation of the foredune and vegetation is essential to minimize wind erosion. Presently coastal erosion is critical on the seaward side. Wind erosion along the major dune axis is indicated by the centralized absence of vegetation and by the presence of half-buried trees on the landward side of the dune complex. Construction in the dune area could be hazardous. Leveling of dunes, especially foredunes, is contrary to presently accepted practices of dune management.

Because spits are subject to the same processes as beaches, they, too, must be regarded as transient features of a highly sensitive nature. Any major operations which interfere with the coastal sand budget could destroy parts or all of them. These include dredging of inlets and offshore bars, the construction of

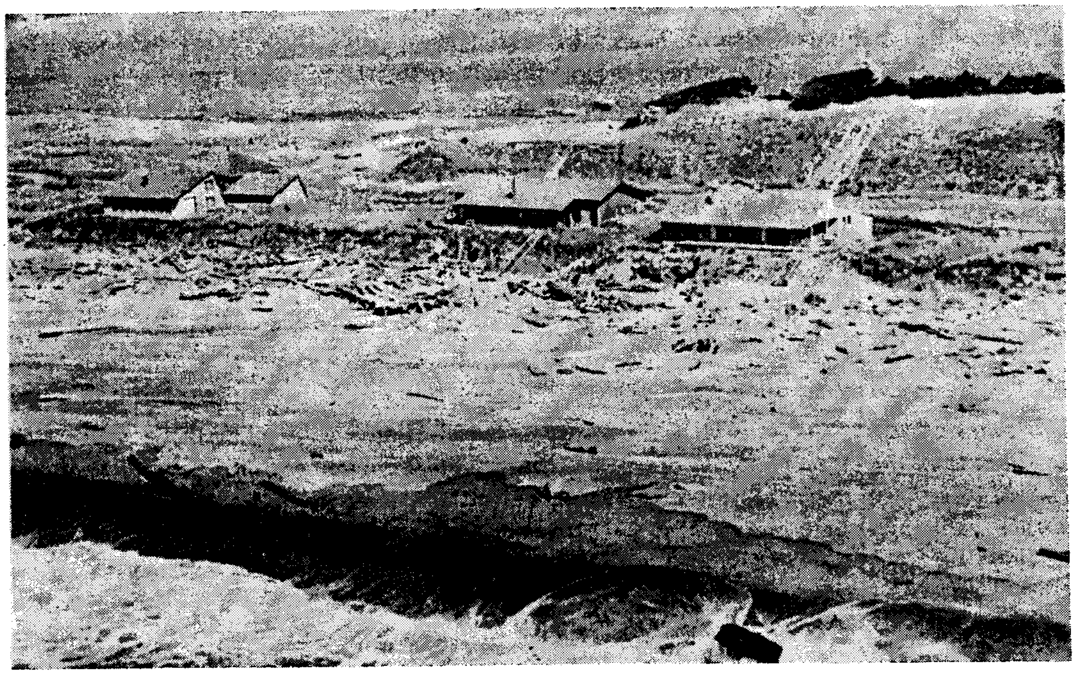


Photo 63. Some of the houses built on the low dunes of Siletz spit. Photo taken in fall of 1972 before severe erosion of spit by winter storms.

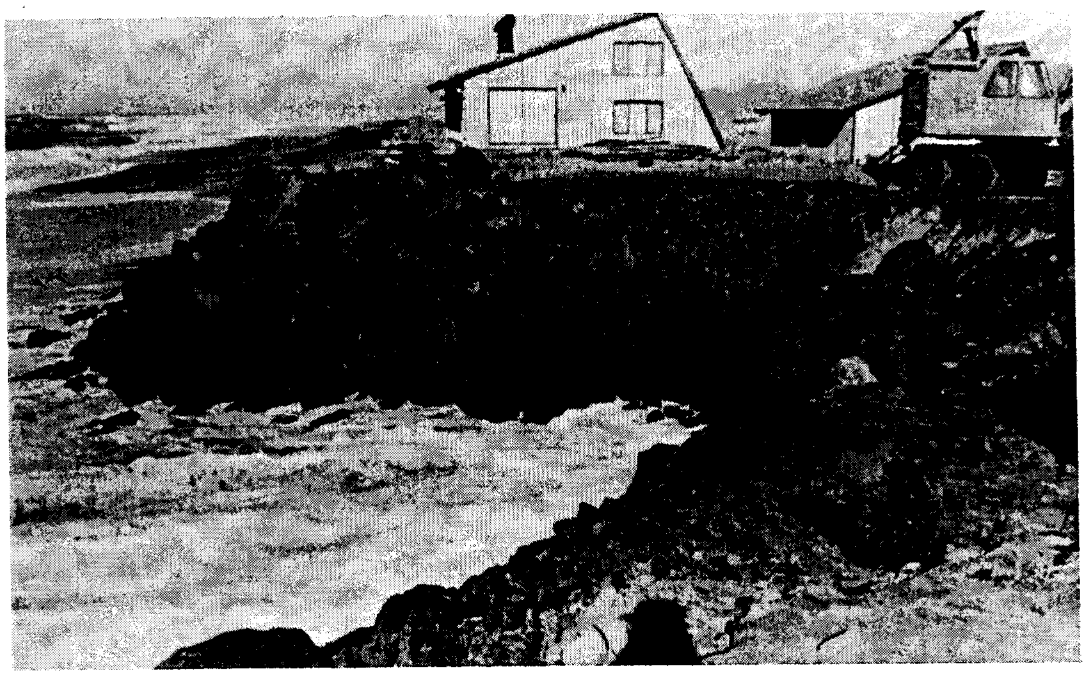


Photo 64. Close-up showing house on left side of above photo where riprap placed earlier at front of house was not sufficient to withstand later storms. Erosion continued to remove sand exposed at either end, requiring additional riprap.

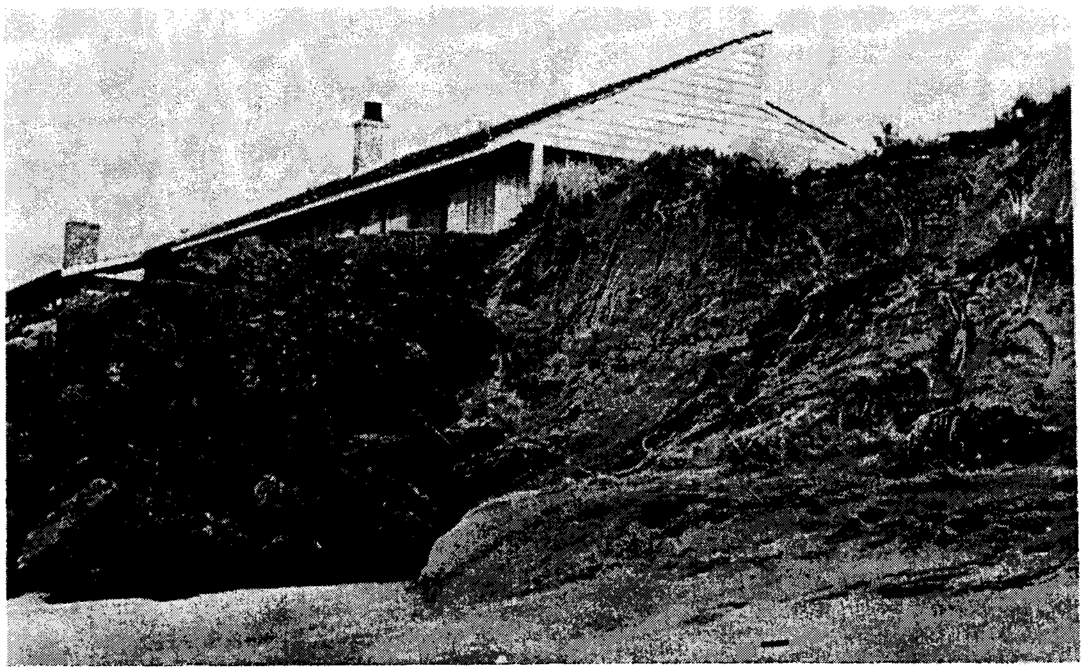


Photo 65. Close-up of house on right side of Photo 63 showing riprap placed to protect property from further storm-wave damage in December 1972.

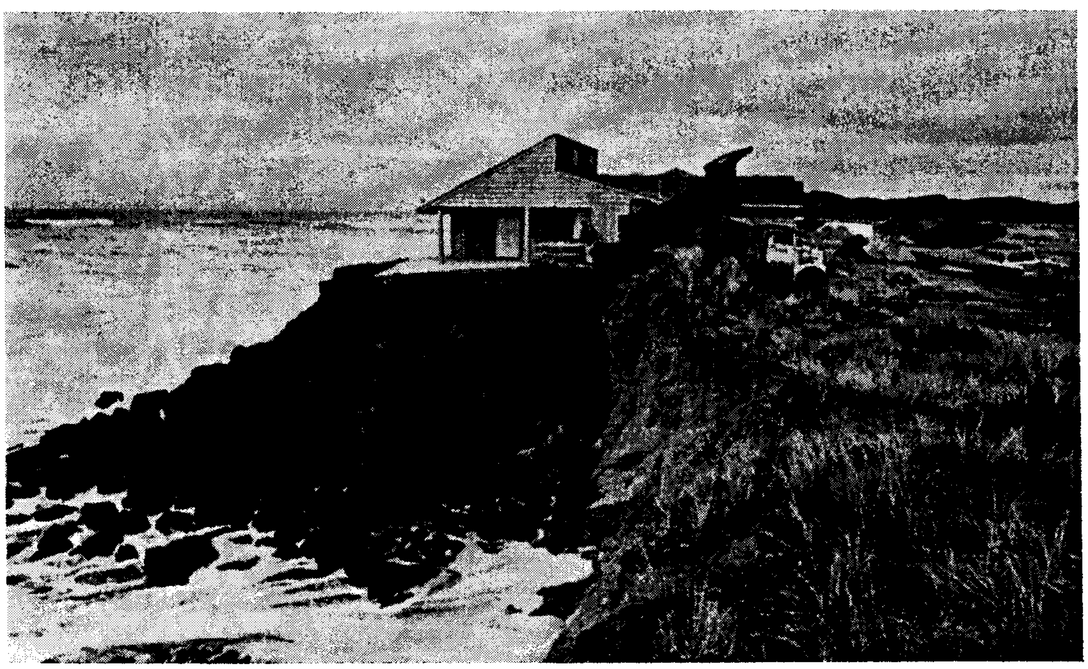


Photo 66. Same house as above after continued storms in January 1973 gouged out sand beyond the terminous of the riprap. Waves have already removed some of the basalt chunks used for riprap. See Photo 84, page 134, showing additional 1973 erosion.

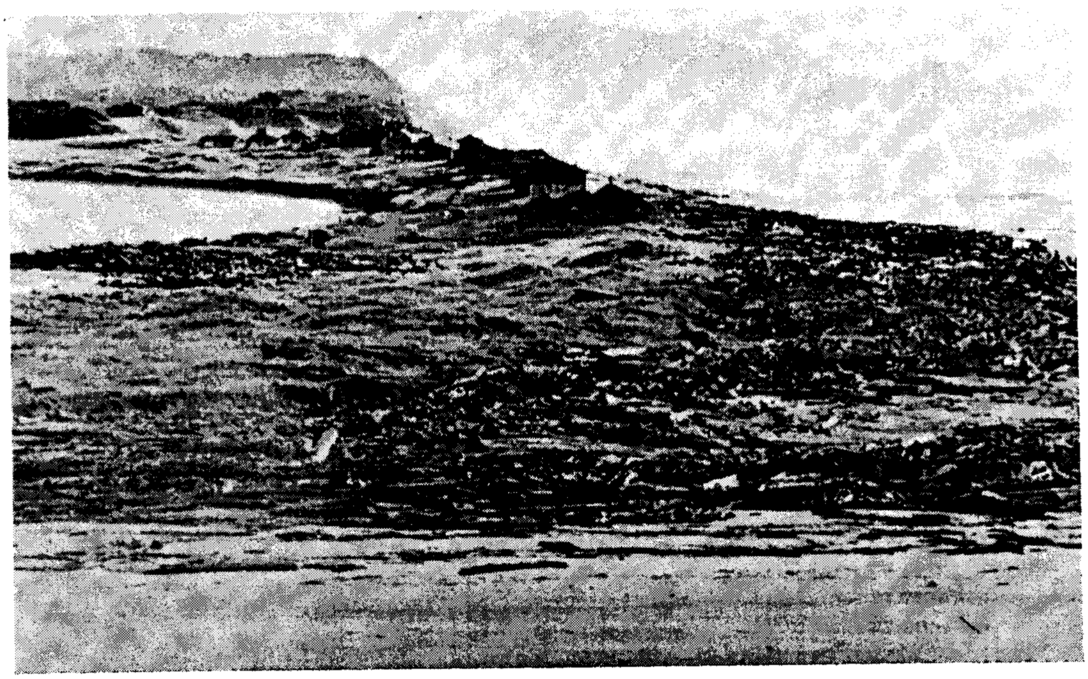


Photo 67. View looking south at Siletz spit showing erosion of inner margin of dune and masses of driftwood deposited by high seas.

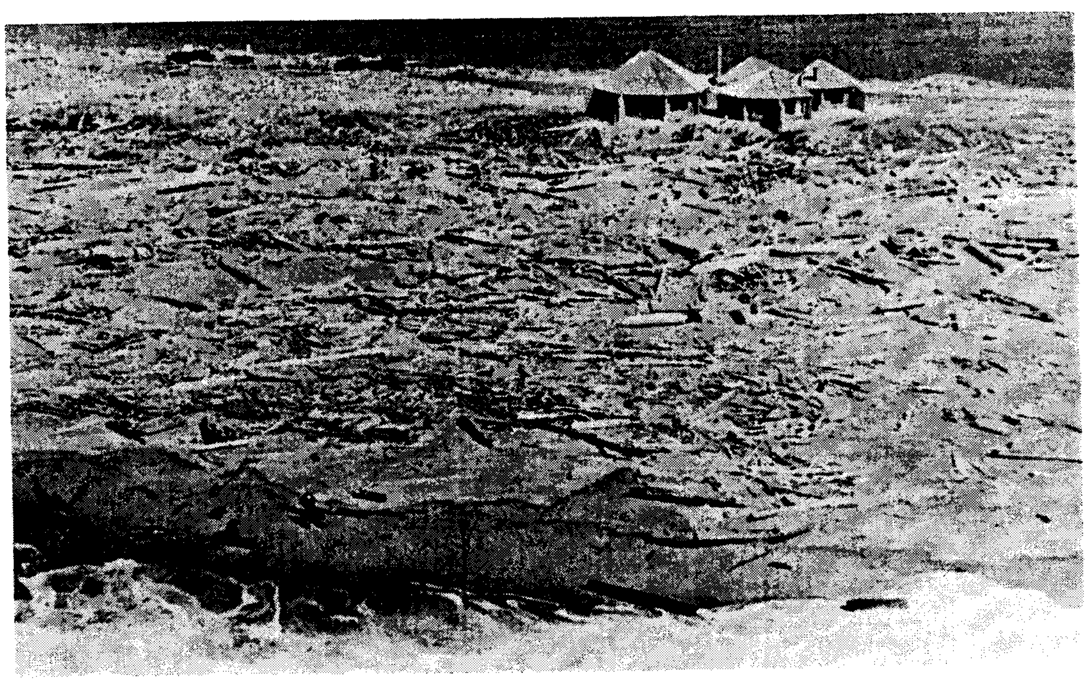


Photo 68. Logs scattered on Siletz spit indicate the level reached by recent storm waves. Photo taken during summer of 1972.

Photo 69. Dune grass planted to stabilize sand is no defense against the might of the ocean, which has eroded the dune, exposing buried logs carried in by previous storms.

Photo 70. Sawed logs buried under dune sands on Siletz spit indicate that burial postdates 1910, when logging began in upper Siletz River area.

Photo 71. All that remained of a house under construction on Siletz spit after winter storm waves destroyed it in 1973. (Photo by Lloyd E. Woolfe, Oregon Highway Department)

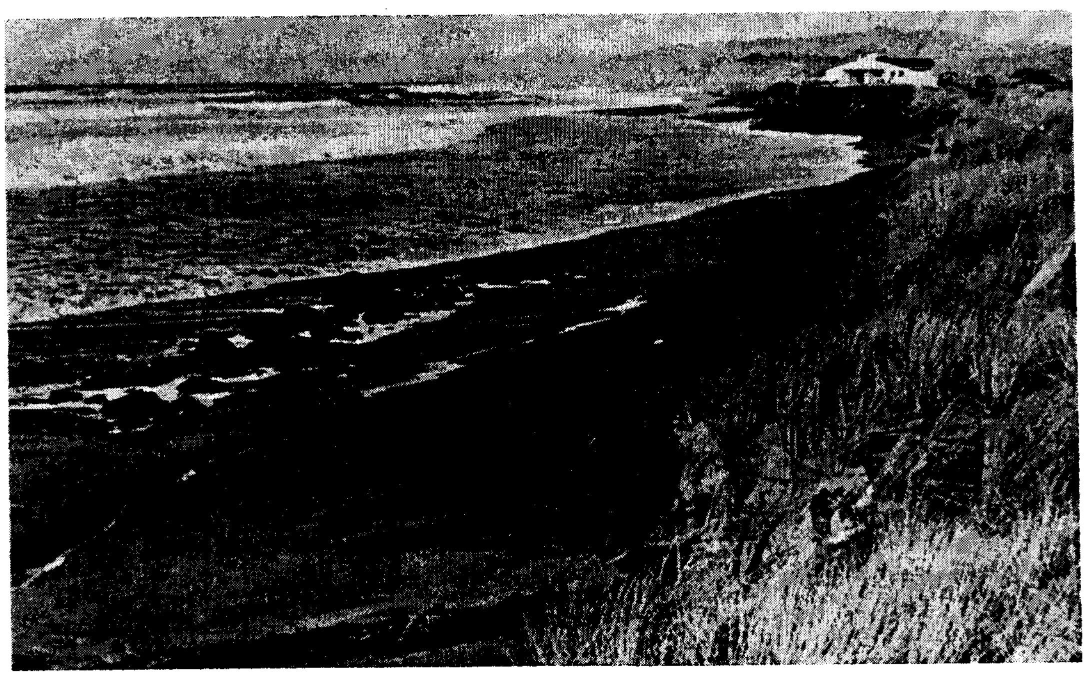


Photo 72. Even riprap placed along a lot frontage failed to prevent wave erosion of dune sand. Evidently at this site erosion worked behind riprap boulders.

promontories such as jetties, and the removal of vegetation. Indirectly, the overdraw of ground water could also lead to destruction by inducing salt water encroachment into the tap root areas of the trees which grow on the dunes in many areas.

Alternatively, development of the coastal strip should not be flatly condemned. Proper jetty construction and dredging, for instance, have contributed to the economic well-being of the Yaquina Bay area. Likewise, proper management of the ground water in the Clatsop dunes area to the north (Schlicker and others, 1972) is regarded as a realistic goal and an asset in the future development of that part of Clatsop County. It is emphasized, therefore, that what is needed in the beach and spit areas is a basic understanding of the processes that are operating and an appreciation of the magnitude of these processes in planning for future development. In evaluating specific projects, more detailed studies may be required.

Marine terraces

Marine terraces are elevated flat surfaces representing erosion or deposition by the sea along a former shoreline. Their present level may be a result of uplift, variations in absolute sea level, or both. A few terraces in Lincoln County are developed upon basaltic bedrock, as at Depoe Bay, Yaquina Head, and at Yachats. These areas are treated under the discussion of headlands below.

Elsewhere in the County, marine terraces are developed on bedrock of siltstone and sandstone, and the deposits are composed of semi-consolidated sand, clay, and gravel locally mantled by dune sand. Marine terraces generally lie immediately inland from beach areas and are present from Wecoma Beach to Lincoln Beach in the Cape Foulweather quadrangle, from Devils Punch Bowl to Seal Rocks (excluding Yaquina Head) in the Yaquina quadrangle, and from Seal Rocks to Yachats in the Waldport quadrangle. Elevations of terraces developed on sedimentary bedrock vary from 10 to 100 feet above sea level.

The seaward margins of the marine terraces are undergoing critical erosion as storm waves seasonally undercut the soft sediments and initiate a variety of landslides. Thus much of the terrace margin is unsuitable for development unless proper precautions are taken (see previous section on "Landslides").

The history of Jumpoff Joe, a small headland composed of sandstone overlain by terrace material, in north Newport points out the critical erosion of the terrace areas. Between 1880 and 1960, Jumpoff Joe was reduced progressively from a headland with a cave, to a headland with a tunnel, to a sea stack, and finally to a pile of rubble on the beach. In 80 years the headland and the terrace upon it retreated 167 feet (Shepard and Wanless, 1971) to give an average retreat of 2 feet per year.

With the headland thus reduced, the terrace to the north and south became increasingly subject to undercutting by the sea. Some of the most extensive terrace failures are immediately north of Jumpoff Joe. North and Byrne (1965) document between 35 and 490 feet of terrace retreat in northern Newport from 1902 to 1964 and between 40 and 220 feet of terrace retreat in southern Newport from 1912 to 1964. Average annual rates of retreat in this area have ranged between half a foot and 8 feet (Figure 21).

Since the beaches that front the terraces offer the only protection from the sea, it follows that whatever affects the stability of the beaches, be it dredging or jetty construction, also affects the terraces. Modifications of the coastal topography must proceed only after adequate geological engineering investigations are conducted.

As a general rule, the terraces with the narrowest beaches, the steepest slopes, and no exposed underlying bedrock are the most susceptible to undercutting and erosion. For these terraces, rates of retreat averaging several feet per year can be expected. For other terraces protected by wide beaches and underlain by exposures of bedrock, lesser rates of retreat are likely. Between Jumpoff Joe and Otter Rock, where bedrock dips up to 18° toward the west, massive slides are actively affecting large parts of the terraces, rendering them unsuitable for permanent development.

Headlands

Bold, natural promontories, or headlands, are formed in regions of coastal retreat where relatively resistant rock erodes more slowly than the adjacent terrain. The major headlands of Lincoln County consist of Eocene and Miocene volcanic and intrusive rock and include Cape Perpetua, Seal Rocks, Yaquina Head, and masses of volcanic rocks from Cape Foulweather to Government Point.

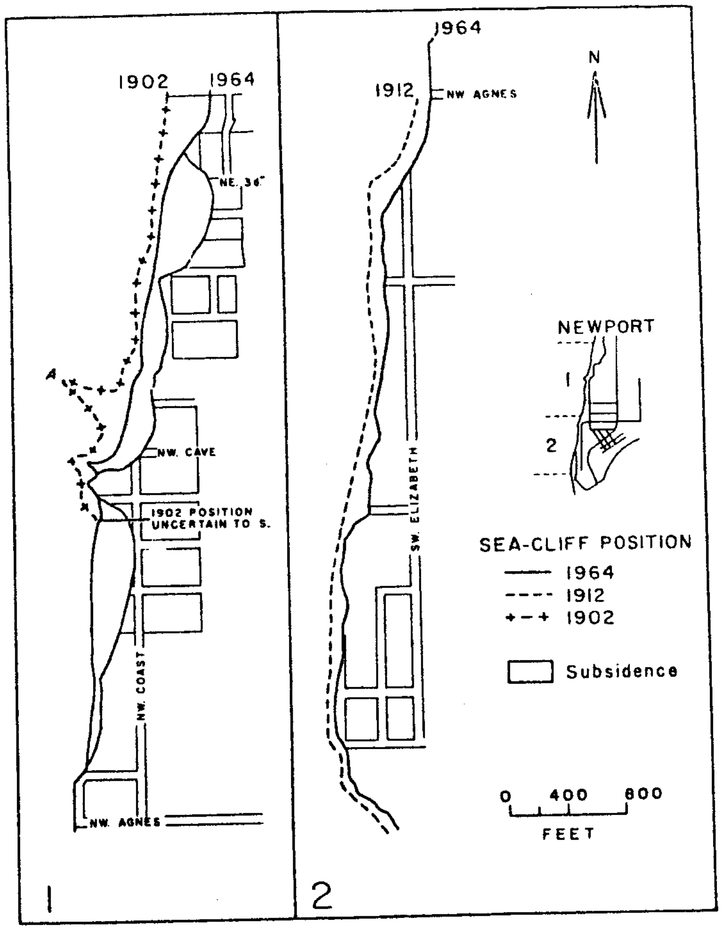


Figure 21. Coastal retreat at Newport, 1902-1964 and 1912-1964 (North and Byrne, 1965).

Although the volcanic headland areas are undergoing erosion, rockfall, and rockslide, the rate of retreat is negligible in most areas. Building on these headlands is not hazardous if the structures are placed sufficiently far back from the edge of the cliffs. Headlands in this category include Cape Perpetua, parts of Yaquina Head, and most of the Cape Foulweather area.

As waves approach the shoreline they are refracted towards areas of shallower water. In effect, they are concentrated on the headlands. In times of storm, rising tide, or high waves, dangers along the shore are most pronounced and beachcombers and boaters should avoid these areas. To the north at Cape Kiwanda 14 lives have been lost in the last 15 years by people unaware of the dangers posed by the headland areas.

Estuaries

The major rivers flowing through coastal Lincoln County from the Coast Range to the sea have been drowned by the post-Pleistocene rise in sea level to form estuaries. The Siletz, Yaquina, and Alsea Rivers empty into broad, partially alluviated bays; the valley of Beaver Creek is filled with sediment to form marshes; and the channel of Yachats Creek is uplifted to produce a series of alluvial terraces. In the northern part of the County the dendritic shoreline of Devils Lake suggests a former course of the lower Salmon River.

With the geologically recent rise in sea level, the gradients of the various streams were reduced and the capacities of the streams to carry sediment were diminished. Consequently the lower valleys became alluviated. Presently water depths are shallow and sediment thicknesses are great, probably exceeding 100 feet in places. As deposition and marsh growth have interacted, deposits of organic soil have developed

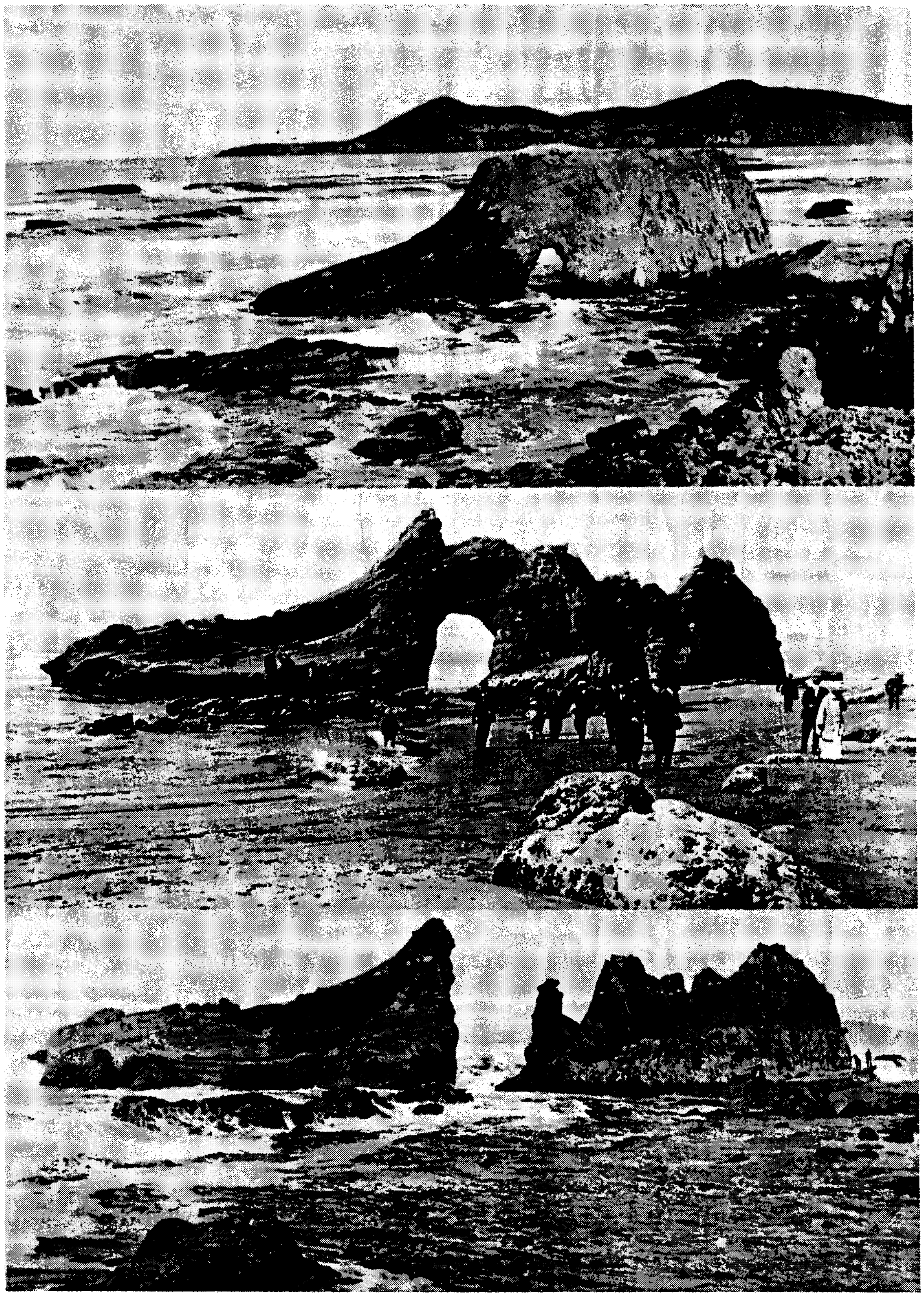


Photo 73. Jumpoff Joe in three stages of erosion: in 1900 (top), marine terrace remnant has a small arch; in 1913 (middle), surface eroded and arch enlarged; in 1926 (bottom), arch gone and outer rock an isolated sea stack. (Photos courtesy of Pacific Studio, Newport)

and are now present both at the surface and in the subsurface (see "Soft Compressible Soils", page 94). In the bay areas, adequate subsurface investigations should precede all moderate to heavy construction.

Use of the estuaries by seagoing vessels requires maintenance of adequate channels to the open sea. This in turn commonly requires dredging or the construction of jetties, as at Yaquina Bay. As discussed previously, however, modifications of coastal topography can have adverse effects on beach and terrace stability. It is recommended, therefore, that if dredging and jetty operations are anticipated in the future development of other estuaries, adequate engineering investigations should be completed beforehand.

The warm brackish waters of the estuaries constitute the major breeding ground for much of the marine life of the Oregon coastal area. It is imperative that the natural state be preserved as much as possible. Water quality and circulation must be maintained and marshlands must be preserved. Indiscriminate landfills and the introduction of pollution are not compatible with such an objective. In an ecological sense, the estuaries are among the most sensitive areas in Oregon and a continuation of in-depth studies is needed before proceeding with construction in these areas.

Earthquakes

Earthquakes in western North America are believed to be caused by the interacting motion of two large lithospheric plates, the North American Plate and the Pacific Plate. Off the Gulf of California, earthquake epicenters show that the locus of interaction of these two plates is associated with the East Pacific rise. North of the gulf, in southern California, the loci of earthquake epicenters appear to divide into two branches, according to Barazangi and Dorman, (1969).

The western branch, associated with the San Andreas fault system in California, passes out to sea in the vicinity of Cape Mendocino. Between Cape Mendocino and the northern end of Vancouver Island, the locus of epicenters is associated with the ridge-rise-transform fault system which exists off the coasts of northern California, Oregon, Washington, and Vancouver Island. From south to north the system comprises the eastern end of the Mendocino (or Gorda) escarpment, Gorda ridge, the Blanco fracture zone, Juan de Fuca ridge, Sovaco fracture zone, Explorer ridge, and the Queen Charlotte-Fairweather fault system. The Fairweather fault system and an associated major fault, the Denali fault, extend into southern Alaska.

The eastern branch of epicenters is less well defined, appearing as a broad zone or belt extending northward through Nevada, Utah, Wyoming, and Montana. The eastern earthquake zone either ends in northern Montana or is diffusely connected to the earthquake activity in the Puget Sound region. Oregon and parts of Washington and Idaho appear to be a relatively quiet island between the two zones of plate interaction. The major strain release associated with the interaction of the two plates occurs off the coast of the Pacific Northwest, east of Idaho, south of Oregon, and extends north-northwest from the Puget Sound region.

Earthquakes are products of deep-seated faulting and subsequent release of large amounts of energy. Vibrations radiating from the fracture are felt or recorded at the earth's surface as earthquakes. In some places, such as the San Andreas Fault in California, the fault producing the earthquake can be mapped at the surface, but in many instances the fault is buried (concealed) and cannot be observed at the surface. In Lincoln County, faults are numerous in the bedrock units. Snavely and others (1972 a, b, c) indicate a complex system of northwest- and northeast-trending normal faults, some of which have large vertical displacements. The age of faulting is not well established, but the youngest bedrock unit involved is late Miocene (15 m.y.). No faulting is present in the marine terrace deposits of late Pliocene to early Pleistocene, indicating that fault movement is at least older than 0.5 m.y. Although faulting is extensive in the County, no master earthquake-producing fault system is indicated.

Earthquake summaries by Berg and Baker (1963) and Couch and Lowell (1971) provide the historical earthquake data for Lincoln County. The data indicate that the recorded seismic history extends back only some 70 years to the late 1800's (Table 20). During this period seven earthquakes were reported: four at Newport with intensity ratings (Modified Mercalli) of IV; one at Waldport, intensity rating IV; one at Seal Rock, intensity rating III; and one at Alsea, intensity rating III (see Table 21 for Mercalli scale ratings).

Couch and Lowell (1971) have summarized information on seismic energy release in the entire Coast Range physiographic province of western Oregon. They report the seismic energy release for a 100-year period (1870-1970) as 6.4×10^{16} ergs per year, which they computed as approximately equivalent to one magnitude 5.0 earthquake (MMV) each decade. This compares with 2.6×10^{17} ergs per year for the same period at Portland, and an approximate earthquake level of one magnitude 4.8 (MMV) earthquake each year or one magnitude 5.2 (MMV-VI) each decade.

Couch and Deacon (1972) have attempted to evaluate the maximum level of seismicity to be expected in BPA service area (Oregon, Washington, Idaho, and western Montana). These studies indicate that for the Newport area a maximum intensity of VIII to IX could be produced from a distant earthquake epicenter near Port Orford. These studies also indicate that distant earthquakes, such as in the Gorda Basin off the southwest Oregon coast, could produce intensities of between VI and VII. Ground motion during earthquakes, from nearby earthquake epicenters as well as distant earthquakes, can affect not only buildings, bridges, and similar structures but also areas of potential land subsidence and landslides. Granular soils, especially thick sections of loose, saturated sand and gravel, will consolidate and subside as a result of shaking ground motion. Because subsidence is usually uneven, buildings on such ground may be tipped or destroyed. In regions of moderate to high relief with unstable slopes and saturated ground conditions (such as most of Lincoln County during winter and spring months), earthquake vibrations could start massive slope failure. In addition, fluid response in saturated lowlands soils could result in liquifaction as downslope flow, even on gentle slopes.

Table 20. List of earthquakes in the Lincoln County area *

Year	Date	Location	Intensity (Modified Mercalli)	Remarks
1897	January 26	Newport	IV	
1902	June 14	Newport	IV	
1916	January 4	Newport	IV	
1928	September 4	Newport (44.7° N-124.1° W)	IV	Felt for radius of 10 miles
1940	May 25	Waldport	IV	Felt at Toledo and Depoe Bay; small objects were moved at Waldport
1941	October 19	Seal Rock	III	
1957	March 22	Alsea	III	

* Data from Berg and Baker, 1963

GEOLOGIC HAZARDS

Landslides

Landslides occur in a mass of sloping soil or rock when the shearing stress exceeds the shearing strength. Such slope failures develop naturally through several processes: erosion undermines and oversteepens the slope; excessive rainfall increases the weight of the material in the slope; weathering decreases soil strength; and ground water leaches the elements that act as soil and rock binders.

Landslides can move rapidly, slowly, or intermittently depending upon the influence of the factors causing the instability. They may begin slowly and increase in velocity, or they may begin abruptly and decrease in velocity. Large landslides may continue to creep or move intermittently for many years.

Initial failure of a slope generally produces tension cracks in the ground. As movement continues, the cracks widen. Thick soil will tear apart and a small linear depression may form parallel to the crack. The types of landslides differ depending upon factors such as slope angle, depth to bedrock, and type of material involved in sliding. The various types of slides are discussed below.

Time tends to modify and obscure the surface features produced by the landslide. The tilted and bent trees are replaced by a new growth of straight and vertical trees, the drainage is reestablished, and sag ponds are drained. Ancient landslides may be recognized, however, by subtle differences in the morphology of the terrain. Gently sloping, rolling topography, the displacement of strata, and the deranged structure of the bedding all give evidence of a prehistoric landslide.

In Lincoln County much of the geologic terrain is susceptible to landsliding. Inland, where the topography is mountainous and streams cut deep canyons with steep slopes, several rock sequences, especially the siltstone and claystone formations, weather to produce residual soils and thick colluvium which fail when oversaturated by moisture or undercut by erosion. Along the coast, the sea cliffs composed of these rocks as well as unconsolidated terrace soils are constantly undercut by high tides and storm waves. Steep terrain, weak rock materials, high rainfall, weathering, and erosion combine to produce extensive slope failure throughout Lincoln County.

Investigations of landslides in Lincoln County was largely reconnaissance in scope, except in selective areas along the coast where more detailed site inspection was done. Landslide areas were identified by geologic field studies, by stereo viewing of aerial photographs of the entire area, and by study of topographic maps. In addition, automobile and foot traverses and air reconnaissance were conducted to study specific problems and to substantiate information developed by the other methods.

Classification of landslides

Landslides in Lincoln County can be classified according to age: (1) ancient landslides (no historical movement, probably several hundred years old); (2) recent landslides (historic movement but no current active movement); and (3) active landslides. They can also be classified according to five general types: (1) rotational slump slides in cohesive materials, (2) debris slides and mudflows in granular materials and cohesive soils, (3) bedding plane failures in rock units, (4) sloughing of vertical slopes, and (5) soil creep.

Rotational slump slides: This term refers to slump masses which move downslope on a curved basal slip plane and contain numerous back-tilted blocks. The resulting topography is hummocky, and some of the depressions fill up with water to form sag ponds and small lakes.

Rotational slump slides commonly occur in the thick residual soils that develop through weathering of the fine-grained sedimentary rocks of the Yamhill, Nestucca, Alsea, and Yaquina Formations. They also occur in more localized areas of the Tyee Formation and in unconsolidated marine terrace deposits.

Debris slides: Debris slides occur on steep slopes covered with granular rock fragments and soil; they tend to develop rapidly during heavy rainfall. Debris slides are easily reactivated by natural or man-made alterations in slope, water content, or surface runoff.

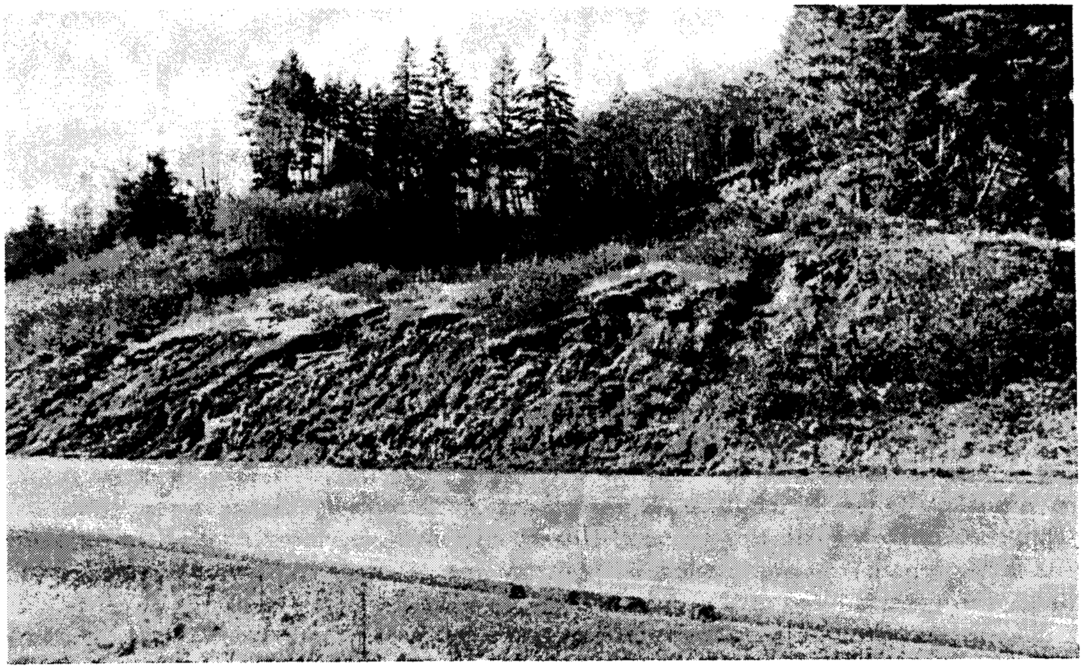


Photo 27. Landslide in roadcut of Highway 101 north of Salmon River. Headscarp of slide can be seen in background. Slide is in residual soils and weathered siltstone of Yamhill Formation.

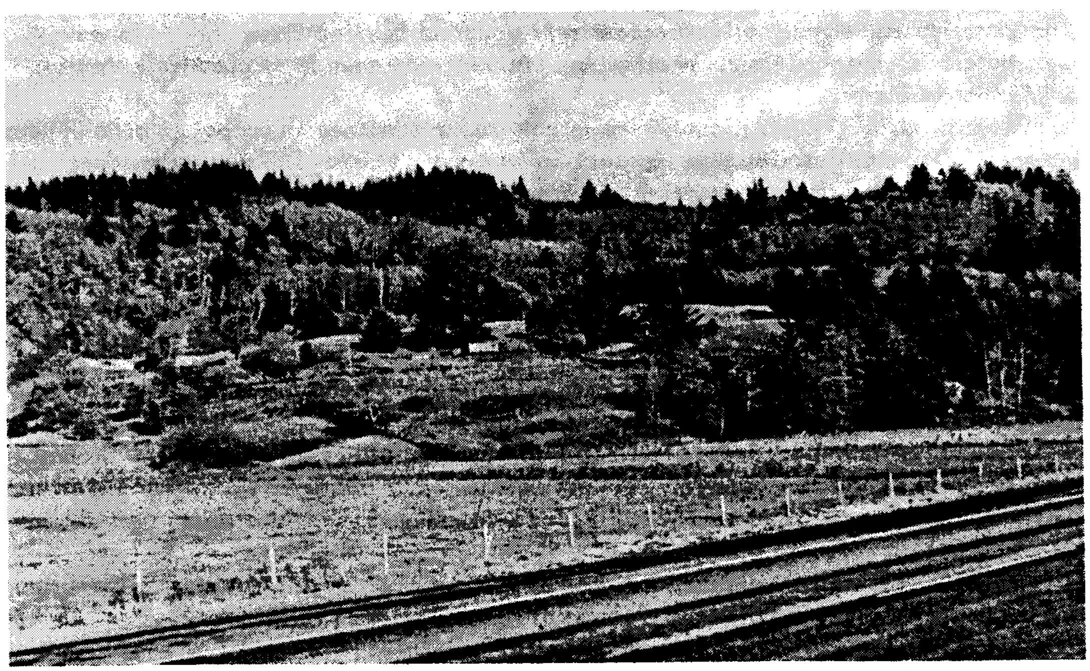


Photo 28. Topography characteristic of an old landslide in Yamhill Formation north of Salmon River on west side of Highway 101.

Bedding-plane slides: Bedding-plane slides occur where the bedding of rock units slopes toward a bluff, stream canyon, or man-made cut. Movement generally occurs along the water-saturated contact of the overlying material and the bedding plane when lateral support is removed by either erosion or excavation. Similar failures also occur on low-angle surfaces of slopes in residual soil or in the underlying weathered rock zone when shearing forces exceed shearing resistance.

In Lincoln County, bedding-plane failure occurs in coastal cliffs where siltstone and claystone beds of the Nestucca, Astoria, and Nye units dip toward the beach. Failure occurs at the water-saturated contact of marine-terrace deposits and the weathered bedrock unit. Inland from the coast, bedding-plane slides are characteristic of the Tyee Formation.

Sloughing of steep slopes: Sloughing of steep slopes is a slow but continuous process of slope retreat. It involves dune sand and marine terrace deposits in bluffs facing the ocean and soil or weathered rock along steep-sided stream canyons. Erosion is the primary cause of sloughing, but freezing and thawing of soils are contributing factors.

Soil creep: Soil creep is mass downslope movement of soils at an imperceptible rate. Typical soil creep is nearly continuous at a rate of about 1 foot in 10 years (Terzaghi, 1950). Although soil creep areas have not been differentiated in this study, they occur on hillsides in some localities. They can be an important factor in long-term slope stability, since they can render a structure totally useless.

Summary of landslides along the coast

Coastal landslides occur principally in the bluffs of the marine terraces and rarely in the volcanic headlands in Lincoln County. The general areas of coastal slides are described, but no attempt is made to analyze in detail any specific landslide. Further geologic and engineering studies will be required to determine the nature of slide areas, their potential for future movement (either naturally or as a result of proposed construction), possible damage to property or structures, and the method and effectiveness of slide correction. Coastal landslide areas from north to south are as follows:

Cascade Head landslide: North and Byrne (1965) indicate debris and slump landslides in volcanic rocks and associated sediments in six small embayments at Cascade Head. The largest landslide, according to North and Byrne, involves some 20 acres of pasture land that slumped into the sea in 1934.

Coastal terrace landslides: From Roads End to Lincoln Beach significant slump failures occur in the coastal terrace. The terrace is composed of elevated marine terrace deposits overlain in places by older stabilized dune sand. The deposits are soft to friable and are easily eroded. Some of the larger active slumps in the bluffs near Roads End just south of Cascade Head have caused damage to property. Sloughing is common in the steep and unstable slopes between Wecoma Beach and the mouth of Siletz Bay and on the south side of Siletz Bay to Fogarty Creek.

At Otter Crest, active slump failure occurs both north and south of the Devils Punch Bowl. From Otter Rock south to Yaquina Head, sloughing and slump failures are numerous along the bluff and occasionally threaten to undermine developed property. Bedrock strata of the Nye Mudstone and Astoria Formation underlie the terraces in this area and provide saturated surfaces along which sliding occurs. Large slump failures on both the north and south sides of Yaquina Head in the community of Agate Beach have damaged private property.

The Jumpoff Joe landslide at Newport is a classic example of a detached mass sliding on a seaward-dipping bedding plane. Both north and south of Jumpoff Joe, the heads of slides have moved landward several hundred feet and have cut off roads, damaged or destroyed houses, and disrupted the ground surface. The latest large movement, occurring in 1942 and 1943, involved a crescent-shaped section about 200 feet wide and 1,000 feet long (Allen and Lowry, 1943). More than 16 acres of land have been involved in the Jumpoff Joe slide area (North and Byrne, 1965).

South of Yaquina Bay, between Henderson Creek and Grant Creek, a large slump mass described by North and Byrne (1965) is 300 yards long and 200 yards wide. Present investigations indicate active slope movement onto the beach, but houses above the headscarp have not yet been affected by headward development of the slide. Numerous other types of slump failure and sloughing occur locally in the coastal terrace from Grant Creek to Alsea Bay.

South of Alsea Bay to Yachats the terrace is low; however, the soft terrace sands and overlying dunes can be attacked by ocean waves and actively eroded. Just north of Yachats, thin terrace deposits are underlain by basalt, which retards the rate of erosion considerably. At Yachats and to the south, where resistant basalt forms the slopes and headlands, erosion is minor. Terrace deposits overlying the basalt are thin and largely protected from wave erosion by the resistant basalt.

Summary of landslides in the upland areas

Large landslide slump failures are present in the upland areas of Lincoln County. They are most abundant in formations younger than the Tyee, particularly in the fine-grained units such as the Yamhill, Alsea, and Nestucca Formations and the Nye Mudstone. The predominantly sandstone strata of the Yaquina and Astoria Formations are less vulnerable to sliding in this area.

In the northern part of the County, large areas of ancient slump failure are present in the major drainage systems such as Schooner Creek, Drift Creek, Siletz River, the interior drainage in the hills between the Siletz and Yaquina Bays, and Devils Lake. From Yaquina Bay to Alsea Bay, landslides occur on the slopes of stream valleys, largely in the siltstone of Alsea. South of Alsea Bay, slump failures are locally present in the siltstone of Alsea and in weathered basalt of Yachats.

Most of the upland mountainous area of the County is underlain by relatively competent, resistant Tyee sandstone and basaltic and gabbroic intrusive rock. Locally on steep side slopes, residual soils, colluvium, and weathered rock will slide when saturated. Such landslides are generally tear-shaped masses which occur in bowl-like valleys tributary to major streams as well as on steep side slopes of the larger streams. Bedding-plane slides are common in the Tyee Formation, and range in size from small, or less than 10 acres, to massive hillside failure of more than 2 square miles. Large hillside slides in Tyee Formation are present south of Toledo in parts of secs. 29, 30, 31, T. 11 S., R. 10 W., on the north slope of Scott Mountain in parts of secs. 27, 28, 29, 32 and 33, T. 13 S., R. 9 W., and in the upper reaches of the Salmon River valley in the northwest part of the County.

It is emphasized here that many potentially unstable areas may exist in the upland areas of Lincoln County that are not shown on the map. For this reason, preliminary site investigations should be made to discover the possibility of slope problems prior to modifying slope or drainage for a construction project.

Catastrophic landslides

Catastrophic landslides are sudden or short-term movements of masses of material that create immediate danger to people or structures. For example, mudflows or slump-type landslides can move rapidly down slopes, block roads, crush buildings, and destroy power lines, bridges, and dams. A landslide moving into an already filled reservoir can cause overflow of the spillway and possible dam failure. Large blocks of land occupied by houses can move, tip, and break up. In 1951, a highway fill just east of Newport became liquid during heavy rains and formed a mudflow which destroyed an occupied house, fortunately without harm to the residents.

In some places, landslides of the past have moved into or across existing stream valleys. Probably the movement was slow and the stream was able to maintain its channel. However, there is always the possibility that some future landslide could temporarily dam a stream, impound the water, and then suddenly release it to the flood-plain areas downstream. Such potentially endangered areas include the following: the flood plain of the Salmon River from Rose Lodge east to the County border; on Big Creek in the NE$\frac{1}{4}$ of sec. 6, T. 8 S., R. 10 W., and the SW$\frac{1}{4}$, sec. 31, T. 9 S., R. 8 W., on the south side of the Alsea River flood plain in the N$\frac{1}{2}$ sec. 9 and south edge of sec. 4, T. 14 S., R. 9 W.; and in the flood plain of the Yachats River in the S$\frac{1}{2}$ of sec. 33, T. 14 S., R. 12 W.

There are a number of places along the coastal terrace of Lincoln County where houses have been destroyed by failure of the sea cliff; the slides at Jumpoff Joe are striking examples. In many places today, houses on the marine terrace situated within a few feet of the sea cliff could be involved in sudden slope failure. Because so much of Lincoln County's development is along the margin of the marine terrace where soft soil and weathered rock is being undermined by erosion at a rapid rate, catastrophic landslides are a serious potential hazard.

and are now present both at the surface and in the subsurface (see "Soft Compressible Soils", page 94). In the bay areas, adequate subsurface investigations should precede all moderate to heavy construction.

Use of the estuaries by seagoing vessels requires maintenance of adequate channels to the open sea. This in turn commonly requires dredging or the construction of jetties, as at Yaquina Bay. As discussed previously, however, modifications of coastal topography can have adverse effects on beach and terrace stability. It is recommended, therefore, that if dredging and jetty operations are anticipated in the future development of other estuaries, adequate engineering investigations should be completed beforehand.

The warm brackish waters of the estuaries constitute the major breeding ground for much of the marine life of the Oregon coastal area. It is imperative that the natural state be preserved as much as possible. Water quality and circulation must be maintained and marshlands must be preserved. Indiscriminate landfills and the introduction of pollution are not compatible with such an objective. In an ecological sense, the estuaries are among the most sensitive areas in Oregon and a continuation of in-depth studies is needed before proceeding with construction in these areas.

Earthquakes

Earthquakes in western North America are believed to be caused by the interacting motion of two large lithospheric plates, the North American Plate and the Pacific Plate. Off the Gulf of California, earthquake epicenters show that the locus of interaction of these two plates is associated with the East Pacific rise. North of the gulf, in southern California, the loci of earthquake epicenters appear to divide into two branches, according to Barazangi and Dorman, (1969).

The western branch, associated with the San Andreas fault system in California, passes out to sea in the vicinity of Cape Mendocino. Between Cape Mendocino and the northern end of Vancouver Island, the locus of epicenters is associated with the ridge-rise-transform fault system which exists off the coasts of northern California, Oregon, Washington, and Vancouver Island. From south to north the system comprises the eastern end of the Mendocino (or Gorda) escarpment, Gorda ridge, the Blanco fracture zone, Juan de Fuca ridge, Sovaco fracture zone, Explorer ridge, and the Queen Charlotte-Fairweather fault system. The Fairweather fault system and an associated major fault, the Denali fault, extend into southern Alaska.

The eastern branch of epicenters is less well defined, appearing as a broad zone or belt extending northward through Nevada, Utah, Wyoming, and Montana. The eastern earthquake zone either ends in northern Montana or is diffusely connected to the earthquake activity in the Puget Sound region. Oregon and parts of Washington and Idaho appear to be a relatively quiet island between the two zones of plate interaction. The major strain release associated with the interaction of the two plates occurs off the coast of the Pacific Northwest, east of Idaho, south of Oregon, and extends north-northwest from the Puget Sound region.

Earthquakes are products of deep-seated faulting and subsequent release of large amounts of energy. Vibrations radiating from the fracture are felt or recorded at the earth's surface as earthquakes. In some places, such as the San Andreas Fault in California, the fault producing the earthquake can be mapped at the surface, but in many instances the fault is buried (concealed) and cannot be observed at the surface. In Lincoln County, faults are numerous in the bedrock units. Snavely and others (1972 a, b, c) indicate a complex system of northwest- and northeast-trending normal faults, some of which have large vertical displacements. The age of faulting is not well established, but the youngest bedrock unit involved is late Miocene (15 m.y.). No faulting is present in the marine terrace deposits of late Pliocene to early Pleistocene, indicating that fault movement is at least older than 0.5 m.y. Although faulting is extensive in the County, no master earthquake-producing fault system is indicated.

Earthquake summaries by Berg and Baker (1963) and Couch and Lowell (1971) provide the historical earthquake data for Lincoln County. The data indicate that the recorded seismic history extends back only some 70 years to the late 1800's (Table 20). During this period seven earthquakes were reported: four at Newport with intensity ratings (Modified Mercalli) of IV; one at Waldport, intensity rating IV; one at Seal Rock, intensity rating III; and one at Alsea, intensity rating III (see Table 21 for Mercalli scale ratings).

Couch and Lowell (1971) have summarized information on seismic energy release in the entire Coast Range physiographic province of western Oregon. They report the seismic energy release for a 100-year period (1870-1970) as 6.4×10^{16} ergs per year, which they computed as approximately equivalent to one magnitude 5.0 earthquake (MMV) each decade. This compares with 2.6×10^{17} ergs per year for the same period at Portland, and an approximate earthquake level of one magnitude 4.8 (MMV) earthquake each year or one magnitude 5.2 (MMV-VI) each decade.

Couch and Deacon (1972) have attempted to evaluate the maximum level of seismicity to be expected in BPA service area (Oregon, Washington, Idaho, and western Montana). These studies indicate that for the Newport area a maximum intensity of VIII to IX could be produced from a distant earthquake epicenter near Port Orford. These studies also indicate that distant earthquakes, such as in the Gorda Basin off the southwest Oregon coast, could produce intensities of between VI and VII. Ground motion during earthquakes, from nearby earthquake epicenters as well as distant earthquakes, can affect not only buildings, bridges, and similar structures but also areas of potential land subsidence and landslides. Granular soils, especially thick sections of loose, saturated sand and gravel, will consolidate and subside as a result of shaking ground motion. Because subsidence is usually uneven, buildings on such ground may be tipped or destroyed. In regions of moderate to high relief with unstable slopes and saturated ground conditions (such as most of Lincoln County during winter and spring months), earthquake vibrations could start massive slope failure. In addition, fluid response in saturated lowlands soils could result in liquifaction as downslope flow, even on gentle slopes.

Table 20. List of earthquakes in the Lincoln County area *

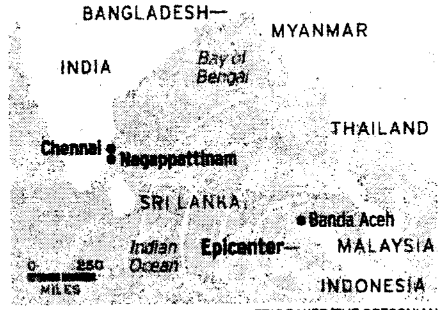
Year	Date	Location	Intensity (Modified Mercalli)	Remarks
1897	January 26	Newport	IV	
1902	June 14	Newport	IV	
1916	January 4	Newport	IV	
1928	September 4	Newport (44.7° N-124.1° W)	IV	Felt for radius of 10 miles
1940	May 25	Waldport	IV	Felt at Toledo and Depoe Bay; small objects were moved at Waldport
1941	October 19	Seal Rock	III	
1957	March 22	Alsea	III	

* Data from Berg and Baker, 1963

Clues in its wake

The Oregonian March 2 2005

Tsunami damage in India *offers grim lesson for future massive waves along the Northwest coast*



ERIC BAKER/THE OREGONIAN

By RICHARD L. HILL
THE OREGONIAN

The fatigued survivors along India's southeast coast told Oregon scientists of not one, but three horrifying waves that roared onto their beaches starting at 8:40 the morning of Dec. 26.

Most people survived the tsunami's first surge, but about 40 minutes later, a more powerful wall of water — in some places more than 15 feet high — sliced like a jagged knife across the coastline, leaving a swath of destruction. A half-hour later, another wave hit.

Although southeast India is nearly 1,000 miles away from the magnitude 9 quake that triggered the tsunami, more than 16,000 people died and thousands of homes and fishing boats were destroyed.

Four Oregon scientists who recently surveyed the devastation in India say what they saw and heard from survivors has grim implications for the Northwest. A large tsunami-generating earthquake only a few miles off the Northwest coast, which has a history of such quakes, could have more dire results than what India experienced.

Curt Peterson, a geology professor at Portland State University, said the ravaged landscape is what he had expected after spending years uncovering the traces of ancient giant tsunamis along Oregon's shores.

"It's what I had imagined for every single coastal community in California, Oregon and Washington many times over," Peterson said. "So it wasn't a shock to me, but it's a powerful reminder of what can happen here."

Peterson, Arun Chawla of Oregon Health & Science University's OGI School of Science and Engineering, and Harry Yeh and Solomon Yim of Oregon State University joined researchers from Korea, Japan and India to survey a 250-mile stretch of the Indian coast.

They are among hundreds of scientists who dashed to the crippled countries to take measurements before rain, wind and cleanup efforts erase the marks left by the most lethal tsunami

Please see TSUNAMI, Page C8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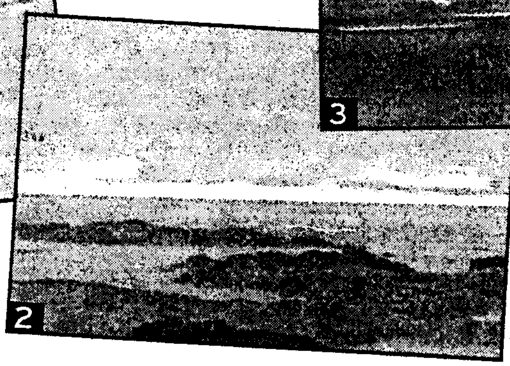
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Images left behind

A sequence of photos found in a victim's digital camera numbering 1 through 5 shows the Dec. 26 tsunami pushing ashore at Khao Lak, Thailand. In the first, tourists walk on the beach while water recedes, forming the first wave. The wave builds as it approaches shore, then crashes, obliterating the beachfront. The battered camera belonged to a vacationing Canadian couple and was found in late January by a missionary who came across it while walking littered beaches once dotted with shops, restaurants and bungalows

The Oregonian 3/2/05

Tsunami: Waves fling boats as far as a mile inland

Continued from Page C7

in history. They also want to get still-fresh accounts from survivors that could help the Northwest coast prepare for a similar catastrophe.

The earthquake and tsunami left 300,000 people dead or missing in southern Asia, making it one of the largest natural disasters in modern human history.

The quake — the third largest ever recorded — was felt in India, and the tsunami arrived two hours later. Waves undermined buildings by scouring out soil around and beneath the structures. Water also built up pressure inside houses, bursting walls that caused roofs to collapse. Almost all wood-frame and straw structures were destroyed and about half of the unreinforced masonry buildings collapsed.

Buildings near each other funneled water down alleys, forcing relatively shallow water to rise high enough to kill people.

Chawla, a coastal engineer at OGI, said the waves flung boats as far as a mile inland in low-lying areas.

"If there is a take-home message from this, it's to get away from the coast if you feel an earthquake," he said. "That's the key: The farther and higher you go inland, the better."

Battered by debris

Peterson said there was an "amazing" amount of devastation on the first 300 yards of the beach. One of the possible lessons is that a developed area may be more dangerous than a natural environment because logs and other debris can destroy buildings.

"When the first wave came in, it picked up a lot of stuff off the beach — trees, beams, canoes and big fishing boats," Peterson said. "When the second wave came in, it bore all that material in front of the wave and acted like a battering ram. That's what I think killed so many people."

Yeh, an OSU professor of ocean engineering and a veteran of tsunami surveys in several countries, said although the waves reached an average height of about 13 feet on the India coast, even a wave 5 feet high "was more than sufficient to kill adults."

The Oregon scientists say that the Northwest could be hit by the much heavier devastation experienced on Sumatra's coastline, only a few dozen miles from the powerful earthquake's epicenter.

Geologists with the U.S. Geological Survey say the quake triggered a 90-foot-high tsunami in Sumatra — six times taller than the tsunami that struck India.

What's troubling to the scientists is that the fault zone off Sumatra is a geologic twin to the Cascadia Subduction Zone, a 750-mile-long fault zone that runs 50 to 150 miles off the coast from Northern California to British Columbia. It's where the Juan de Fuca Plate plunges, or subducts, beneath the North American Plate. The plates lock up as they inch past each other, creating enormous pressure that is released in magnitude 9 earthquakes.

ON THE WEB

More information about earthquake and tsunami hazards and how to prepare for them can be found at:

- www.oregongeology.com
- www.pnsn.org/HAZARDS/CASCADIA/cascadia_zone.html
- www.pmel.noaa.gov/tsunami

Last big one in 1700

About 20 tsunami-triggering earthquakes have rocked the Northwest coast in the past 10,000 years, the last one in 1700. Scientists say they'll undoubtedly happen again. In addition, waves from distant places can be lethal, as Oregonians discovered in 1964 when a magnitude 9.2 subduction-zone quake off Alaska caused a tsunami that damaged coastal cities and killed four children at Beverly Beach north of Newport.

The relatively small breaking waves that Oregonians are accustomed to seeing during storms are different than tsunamis, where the ocean rises and surges ashore. "Storm waves pound the shores," Yeh said, "but tsunamis sweep the coastline. It's a powerful flow where people live, and people are not prepared for those kinds of conditions. That's why they were so devastated."

Chawla, a specialist in computer models that estimate the movements of tsunamis, said the information from the surveys will help refine computer simulations. He said a better understanding of tsunamis' impacts "will teach us how to protect ourselves from such an event if it was to occur in the Northwest."

Peterson said a group of Oregon scientists hope to go to Sumatra to see how the quake and tsunami affected the closest shoreline, which would give them a better idea of what could result from a quake off the Northwest coast.

Yim, an OSU professor of structural and ocean engineering, said he was interested in seeing the effects on buildings to determine how design codes might be updated. "The good thing is that our buildings are better, although the wave run-up on the Oregon coast would be similar."

The devastation wasn't a shock, said Yim, who took his first direct look at a tsunami's effects. "But it's a very emotional feeling to walk over an area where thousands of people have died."

Like Yim and Peterson, it also was Chawla's first such experience.

"It was overwhelming in many ways," said Chawla, a native of India. "It was sad to see the devastation, and it affected me even more because it's my own country."

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Scientists study quake clusters to try to see region's future

The pattern of magnitude 9 earthquakes off the West Coast could be ominous

By RICHARD L. HILL
THE OREGONIAN

The last enormous tsunami-triggering earthquake off the Northwest coast, 305 years ago, may have been the first in a recurring cluster of quakes, new research indicates. If so, a magnitude 9 earthquake and tsunami similar to the recent catastrophe in the Indian Ocean could be imminent.

Marine geologist Chris Goldfinger of Oregon State University and his colleagues have identified about 18 large earthquakes in the past 10,000 years, nearly all of them magnitude 9, that hit the coast from Northern California to British Columbia. Four of them occurred in the past 1,300 years, including the most recent in January 1700.

In new research, Goldfinger has found that the earthquakes appear to have occurred in clusters of from two to five quakes. The average time between earthquakes in a cluster is about 300 to 400 years, but the shortest interval is only 200 years.

If the pattern holds, the Northwest could be due for another powerful earthquake, though no one can be sure when it might happen.

In the past two decades, scientists have discovered dozens of sites on the Northwest coast that have been hit by large earthquakes and tsunamis. They agree the 1700 quake was a magnitude 9, which triggered a tsunami that slammed into the coast and swept all the way to Japan.

Scientists have been studying offshore earthquakes to determine whether there is a pattern that would give a better idea about when the next one might happen.

Goldfinger cautions, however, that the geologic record is complex, and there are other interpretations of the evidence. He said past cycles may not apply to what's happening offshore now. The 1700 earthquake also may have been the end of a cluster and the start of a quiet period in which a quake doesn't occur for another 500 to 1,000 years.

However, "based on the entire record, it appears more consistent to see 1700 as the start of a new cluster," Goldfinger said.

The study lists three quakes in the

Please see QUAKE, Page C8

Quake:
Scientists stress complexity of the analysis

Continued from Page C7

2,000 years before the 1700 earthquake — in 1500, 1150 and 750. The quakes in 1150 and 750 also appear to be magnitude 9 that ruptured the entire coast because there is evidence for them at several locations.

Signs of the 1500 earthquake were not seen at all the sites, leading the researchers to think it may have been weaker than magnitude 9, but still strong.

The 1500 quake "leads to a bit of complexity when evaluating where we are in the cycle," Goldfinger said. In most cases, the long gaps between the large earthquakes are partially filled by smaller quakes that did not rupture the entire subduction zone.

Goldfinger said if the smaller 1500 quake is interpreted as a small gap-filling event, that "would mean the 1700 earthquake was the start of a new cluster, not the end of an old one, which is the alternate interpretation."

Five years ago in a research cruise, Goldfinger and Hans Nelson of Texas A&M University collected and examined core samples of turbidites — deposits of mud and sand on the ocean floor caused by earthquake-generated landslides — off the Northwest coast. They indicated magnitude 9 quakes have repeatedly rocked the region in the past 10,000 years.

Goldfinger, Nelson and Joel Johnson of OSU have been working to correlate the dates from the turbidites with dates from shore evidence of earthquakes and tsunamis. Goldfinger's team is the first to compile and correlate the dates of earthquakes from ocean-floor and land sites.

The quakes occur in the Cascadia Subduction Zone, which runs the length of the Northwest coast about 50 to 150 miles offshore. The quake-prone area is where the Juan de Fuca Plate, as it moves eastward, plunges beneath the North American Plate.

Brian Atwater, a geologist with the U.S. Geological Survey at the University of Washington, said the evidence of past large earthquakes from the ocean floor "is vital" in looking at what the subduction zone has done in the past. But he's skeptical there's enough evidence from both onshore and offshore records to show clusters.

Atwater has discovered sites along the Southwest Washington coast that were hit by prehistoric quakes. "There's a fair amount of difference between the interpretations from both onshore and offshore studies about pattern repetition, or at least the ages of individual events," he said. Also, there are uncertainties as to how powerful many of the past earthquakes have been.

"You face daunting odds in being able to demonstrate it (clusters)," he said. "It's very, very tough to do."

Goldfinger and his colleagues have submitted their latest findings about the earthquake clusters to a peer-reviewed journal.

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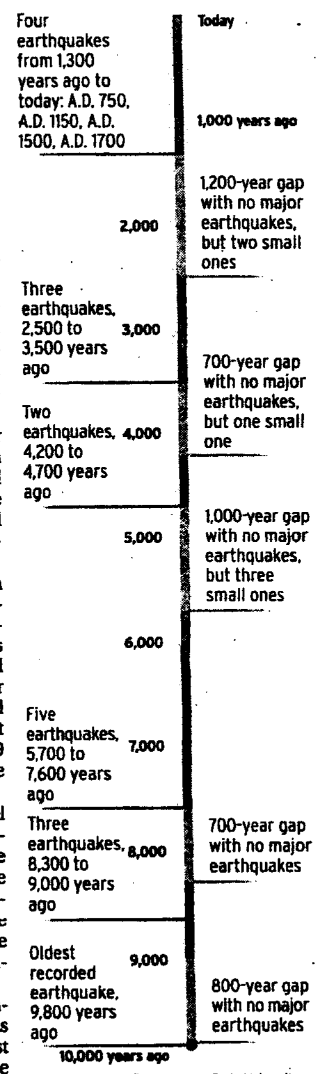
BIG QUAKES OF THE PAST

Seafloor deposits of mud and sand from quake-generated landslides show that powerful quakes have rocked the Northwest coast over thousands of years. Geologists say these may give clues about when future quakes could hit.

These are earthquakes off the Northwest coast during the past 9,800 years:



Source: Chris Goldfinger, Oregon State University
MICHAEL MODE/THE OREGONIAN