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COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY, OREGON: SEASIDE TO CAPE FALCON

By

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NOTICE

The results and conclusions of this report are necessarily based on limited geologic and geophysical data. At any given site in any map area, site-specific data could give results that differ from those shown in this report. **This report cannot replace site-specific investigations.** The hazards of an individual site should be assessed through geotechnical or engineering geology investigation by qualified practitioners.

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EXECUTIVE SUMMARY

The coast of southern Clatsop County, Oregon, has a notorious history of large deep seated landslides that have severely impacted coastal development. For example, in February, 1961, heavy precipitation destabilized a 3,000-ft-long by 1,000-ft-wide landslide that closed Ecola State Park. Perhaps more famous is the February 3, 1974, Silver Point landslide that involved over 2 million cubic yards of material, vertically displaced U.S. Highway 101 by 35 ft and laterally shifted houses near the landslide toe 50 to 80 ft westward. The results of mapping historically active landslides and those that failed prehistorically, as well as studying the coastal processes that lead to shoreline change and contribute to chronic bluff erosion, can be used to forecast the impacts of future erosion and potential slope failure. This report describes the methods and results used to develop a GIS map database that delineates the coastal geology of southern Clatsop County and defines coastal erosion hazard zones for use by county and local planners.

The method used to map erosion hazard zones for bluff-backed shorelines incorporates coastal geologic mapping, the slopes of repose for talus of bluff materials, historical bluff erosion rates, and empirical estimates of maximum landslide block widths. The hazard zones are defined by three scenarios of bluff erosion that have decreasing relative likelihood over a 60- to 100-yr period.

Hazard zones on dune-backed beaches are derived using a geometric model that predicts the landward extent of erosion caused by storm waves and extreme tides that exceed the elevation of the junction between the beach and dune. Three scenarios of varying severity are used to model erosion hazard zones on dune-backed shorelines. The worst scenario that we considered incorporates land subsidence caused by a Cascadia subduction zone earthquake.

The active-hazard zone for southern Clatsop County encompasses areas of coastal bluffs and dunes undergoing active erosion, whether by extreme wave erosion, nearshore sediment transport, gradual erosion, or mass wasting processes. On dune-backed shorelines, the active-hazard zone reflects the zone of historical beach variability and dune and backshore areas where shore processes regularly modify and reshape ephemeral landforms. On bluff-backed shorelines the active hazard zone includes the beach, bluff toe, and escarpment, all seaward of the top edge of the bluff. The active-hazard zone also incorporates active and potentially active landslides that intersect the bluff top edge.

The high-, moderate-, and low-hazard zones may be viewed as potential areas of future expansion of the active-hazard zone. Lateral distances to the landward edge of erosion hazard zones vary from 20 to 400 ft for the high-hazard zone, 45 to 555 ft for the moderate-hazard zone, and 70 to 710 ft for the low-hazard zone. Riprap placed along nearly 50 percent of the shoreline fronting Cannon Beach will likely require ongoing monitoring and maintenance to mitigate future erosion, particularly if sea level rise begins to accelerate over the next century. Areas underlain by active or potentially active landslides may experience future mass movement, particularly during winter storms characterized by high rainfall. Areas of particular concern include active landslides within Ecola State Park; the area west of Tolovana Hill, including the S-Curves landslide in Cannon Beach; landslides at Silver Point; areas at the southern end of Arcadia Beach north of Hug Point; and the entire Falcon Cove community. Site-specific investigations of geologic hazards should be required in these areas before building permits are issued.

INTRODUCTION

This report describes and documents the methodology and results used to establish erosion hazard zones from Seaside to Cape Falcon along the southern Clatsop County, Oregon, coastline. The results of this investigation build on prior coastal erosion hazard and landslide hazard evaluations performed by the Oregon Department of Geology and Mineral Industries (DOGAMI) (Allan and Priest, 2001b; Priest and Allan, 2004). The project was funded by Oregon Department of Land Conservation and Development (DLCD) intergovernmental agreement DLCD PS07029 and PS07068. The product of this effort is a digital Geographic Information System (GIS) database that includes:

- Maps depicting four erosion hazard zones, including active, high, moderate, and low hazard;
- A 1:4,800-scale geologic map compiled from existing geologic maps (Schlicker and others, 1972; Niem and Niem, 1985;) and mapping completed for this study;
- Digitized landslide-related scarps mapped by Ross (1976, 1977); and
- Polylines that locate the top edge and base of coastal bluffs mapped on the basis of GPS surveys, field reconnaissance, and interpretation of stereo-paired aerial photographs.

When combined with the erosion hazards database for the northern Clatsop County coast (Allan and Priest, 2001a), the information presented here completes a seamless digital database that depicts erosion and landslide hazards for the entire Clatsop County coastline. Together, digital data from Clatsop County (Allan and Priest, 2001a; this study) Tillamook County (Allan and Priest, 2001b) and Lincoln County (Priest and Allan, 2004), cover much of the northern Oregon coast. Mapping completed for this study updates preliminary mapping by Allan and Priest (2001b) for a small area in northern Tillamook County, north of Cape Falcon.

The purpose of the project is to provide a uniform set of modern geologic hazard maps for use by county and city planners to address the objectives of goals 7 (Natural Hazards), 17 (Coastal Shorelands), and 18 (Beaches and Dunes) of Oregon's Statewide Planning Goals (DLCD, 2006). These goals establish guidelines for developing comprehensive land-use plans for shoreland, beach, and dune environments, including areas subject to river and ocean flooding, mass movement (landsliding), erosion, and other natural hazards. Coastal "shorelands," as defined by DLCD, refers to "lands contiguous with the ocean, estuaries and coastal lakes."

Background

The erosion and landslide hazard maps for Clatsop County provided with this report make available a complete GIS dataset for the county's coastline that enables county and city governments to use more accurate, updated maps to implement natural hazards-related land-use ordinances. For example, section 4.040 of Clatsop County's land-use and development regulations (ordinance 80-14) identifies the Geologic Hazards Overlay District with the intent to "…minimize building hazards and threats to life and property that may be created by landslides, ocean flooding and erosion, weak foundation soils, and other hazards as identified and mapped by the County" (Clatsop County Land Use Planning Division, 2007, p. 4-244).

Potentially hazardous areas identified by the County include those underlain by active landslides or landslide-related topography, areas prone to attack by ocean waves, and areas with compressible soils delineated in the Soil Survey of Clatsop County (Smith and Shipman, 1988). Currently, the County uses maps created in the 1970s to delineate areas subject to landslide hazards, including DOGAMI Bulletins 74 and 79 (Schlicker and others, 1972; Beaulieu, 1973) and a geologic hazards report for southern Clatsop County by Ross (1978). The City of Cannon Beach maintains and periodically updates a "master map" that delineates areas of natural hazards used to issue building permits required by zoning ordinances. To date, the City relies on geologic hazard maps completed by Ross (1977) to aid in the development of a comprehensive land-use plan. For areas with potential geologic hazards, both Clatsop County (2007) and the City of Cannon Beach (2006) require a site-specific investigation by a certified engineering geologist or a registered professional geologist and a geotechnical report in order to obtain the necessary permits to develop or build on a site.

Study Area

The study area extends about 20 miles (~32 km) along the southern Clatsop County coastline, from Seaside in the north to Cape Falcon in the south (Figure 1). Coastal geology of the area was mapped within 1,500 to 4,000 ft landward of the Pacific Ocean shoreline in order to encompass areas defined by Goals 17 and 18 as Oregon's coastal shorelands, beach, and dunes. The northern part of the study area includes the cities of Seaside and Cannon Beach. The

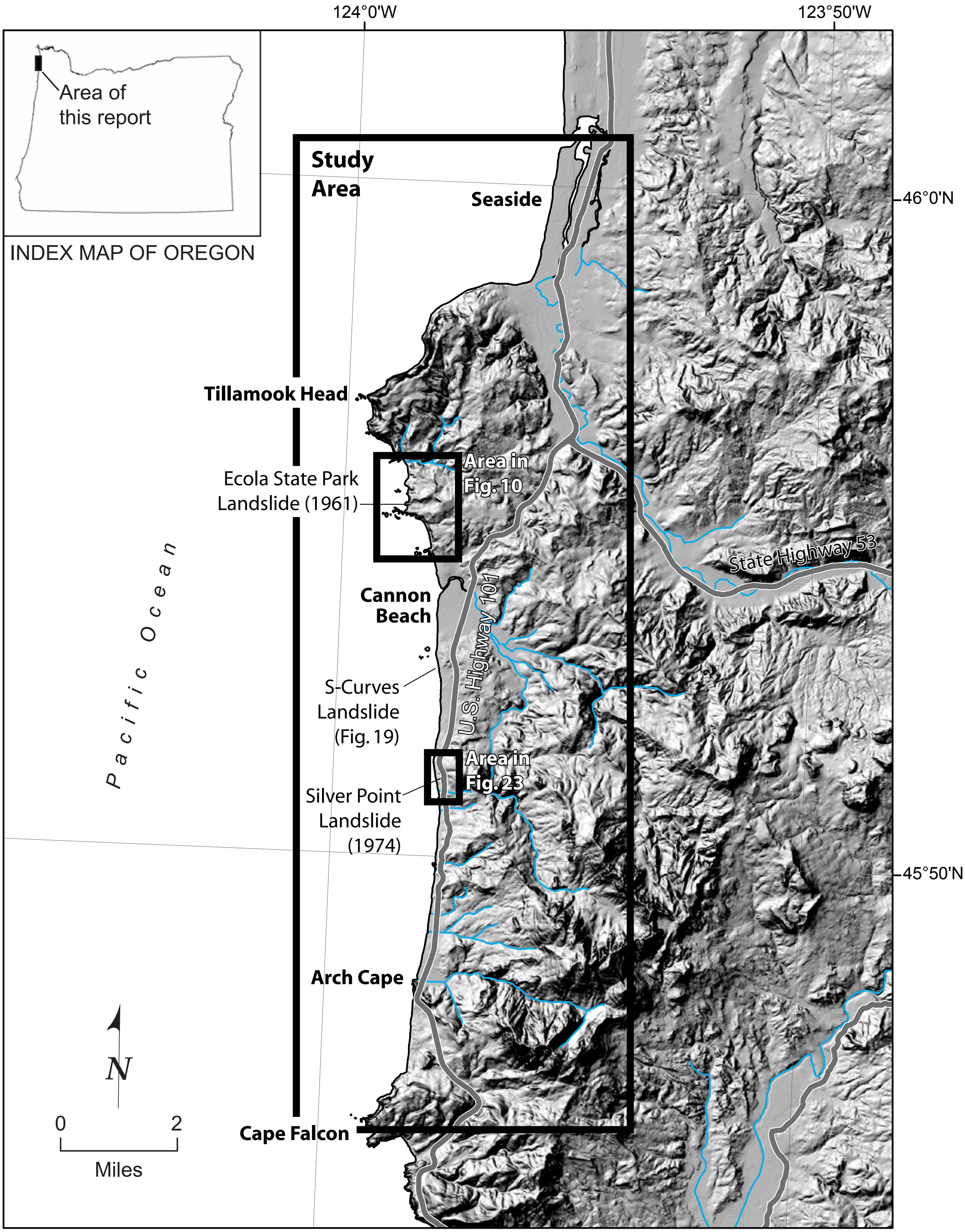


Figure 1. Southern Clatsop County, Oregon, study area from Seaside in the north to Cape Falcon in the south.

southern part of the county includes the unincorporated coastal communities of Arch Cape and Cove Beach. A 2006 economic assessment of the Oregon coast (The Research Group, 2006) indicates retired citizens bring in the largest component of personal income in Clatsop County. In addition, the timber industry, commercial fishing, and tourism together comprise about 30 percent of total personal income for the county.

Sea stacks, steep headlands, and long, narrow beaches of southern Clatsop County reflect the underlying geology and dynamic processes that form the coastal landscape. Stream incision and mass wasting have sculpted Tertiary mudstone and sandstone of the Astoria Formation that forms forested foothills along the coast (Schlicker and others, 1972; Niem and Niem, 1985). Invading and deforming the sedimentary rocks are dikes and sills of basalt that form the prominent headlands of Tillamook Head and Cape Falcon. Compositional similarities between coastal basalts and the Columbia River Basalt Group indicate the lava erupted in the Miocene from vents on the Columbia Plateau and flowed westward into the sea, where they invaded soft sediments of estuarine and deltaic environments (Beeson and others, 1979). Locally, resistant sandstone forms striking sea cliffs 70 to 120 ft high at Hug Point (Niem, 1975). Late Pleistocene coastal terraces consisting of beach, estuarine, and alluvial deposits form the lowlands upon which the communities of Cannon Beach and Arch Cape are developed.

Evidence of historical erosion to the southern Clatsop County shoreline includes steep sea cliffs that back much of the length of the shoreline and shore protection structures placed by local property owners to mitigate further loss of land. For example, nearly 50 percent of the shoreline fronting Cannon Beach is protected by engineered structures, including sea walls and riprap. From observations during beach surveys, most of the Arch Cape shoreline also is protected, although much of the riprap or sea walls are buried by cobbles or beach sand. Perhaps of greater impact than shoreline erosion is the periodic collapse of coastal bluffs involved in shallow- and deep-seated landslides that are common along the southern Clatsop County coast. The following large historical landslides have had costly impacts to the built environment.

Historical Landslides of Southern Clatsop County

In February 1961 heavy precipitation caused movement of a large (more than 61 acres) landslide that closed Ecola State Park (Figure 2) (Schlicker and others, 1961). Recurrent movement over several years following 1961 (Carson and Hankel, 1975) has tilted trees, cracked pavement, and formed intermittently drained sag ponds. Movement in 1961 involved an area approximately 3000 ft long and 1000 ft wide that started at an elevation of 240 ft and tapered seaward, resulting in a maximum horizontal displacement of about 100 ft. Schlicker and others (1961) mapped other large, active landslides nearby at Bald Point and along bluffs backing Crescent Beach.

The February 3, 1974, Silver Point landslide (~16.5 acres) involved over 2 million cubic yards of material, extended along an 800-ft section of the shoreline, reached 1200 ft upslope from the beach, and resulted in seaward translations of the slide toe and surface features from 50 to 80 ft (Figure 3) (L. R. Squier, Inc., 1974). Ground deformation included 35-ft vertical displacement of the highway. The slow-moving landslide damaged or destroyed at least four houses, closed the Oregon Coast Highway for several days, and resulted in reconstruction costs over $1 million. Mapping and analyses by L. R. Squier, Inc. in 1974 support the interpretation that the Silver Point landslide resulted from excessive precipitation during the months preceding the landslide compounded by progressive weathering and deterioration of the materials underlying the slope with time (L. R. Squier, Inc., 1974).

Intermittent movement of the S-Curves landslide (~2.3 acres) in Cannon Beach has been noted since 1995 (Horning, 2004). In the winter of 1997-1998 a strong El Niño brought warmer sea surface temperatures, raised sea level along the Oregon coast by 1.5 to 2 ft (Komar, 1998), and removed sand from the toe of the landslide. According to Horning (2004), erosion of 6 ft of beach sand at the toe contributed to failure of a rotational slump that uplifted mudstone bedrock approximately 8 ft along a curved failure plane that reach the surface about 25 ft west of the bluff. Fluctuating ground water levels also contribute to movement of the S-Curves landslide. Conclusions of an investigation of the S-Curves landslide (White and Rondema, 2003), based on ground surveying, inclinometer data, ground water fluctuation, and rainfall records, correlate landslide movement with rainfall intensity and duration.

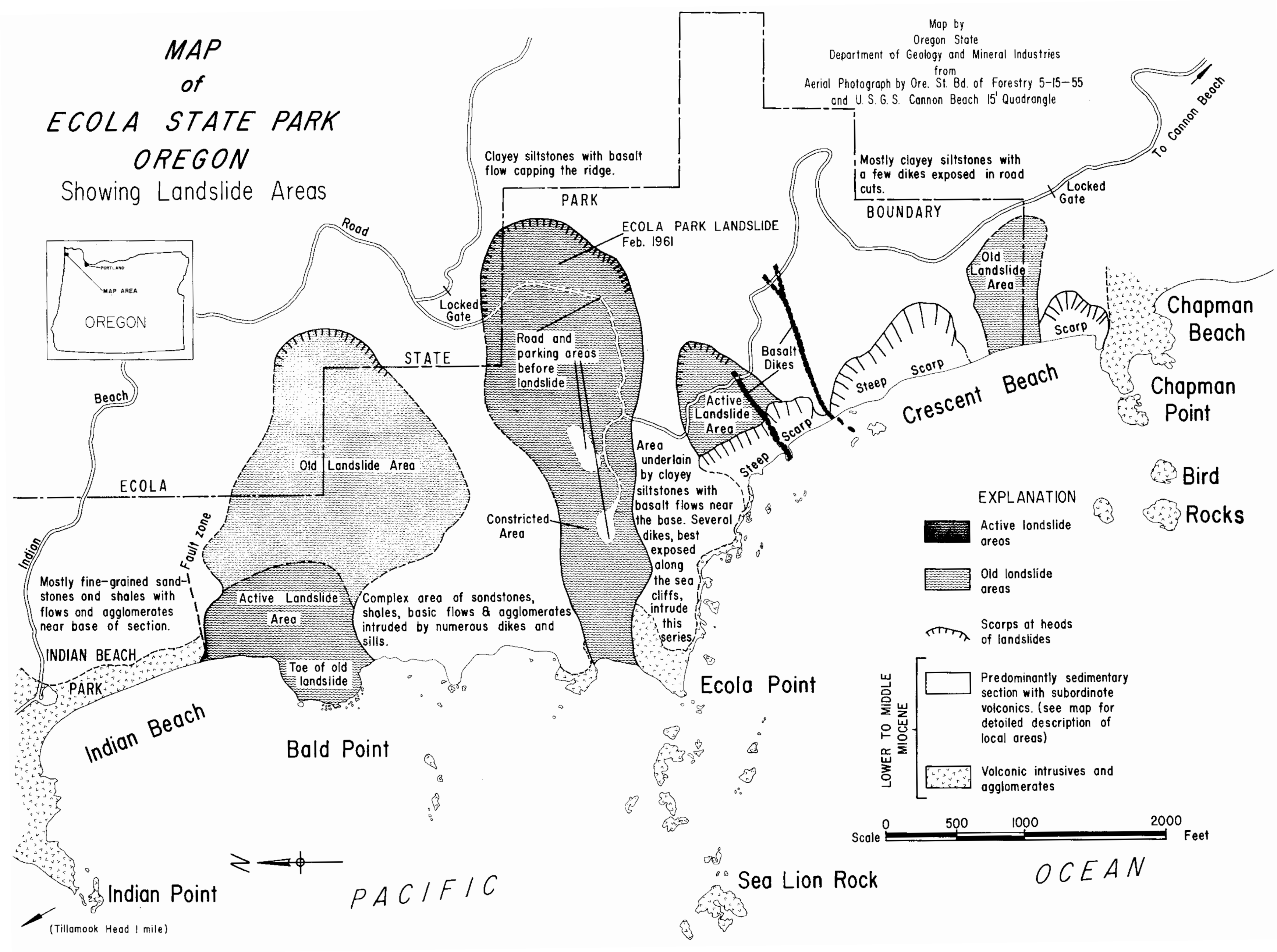


Figure 2. Ecola State Park geologic map (Schlicker, 1961).


UPPER SCARP
MAIN SCARP
DIAGONAL CRACK
35'
U.S. Highway 101
OUTCROPPING
NORTH PORTION
SOUTH PORTION

METHODOLOGY

Initial development of the GIS database involved compilation of various maps, aerial photographs, and remote sensing images. Compiled imagery and maps include scanned 1939 and 1967 vintage aerial photographs, 0.5- to 1-m resolution black-and-white and color orthorectified imagery, scanned geologic and topographic maps of the southern Clastop County study area (Schlicker and others, 1972; Niem, 1975; Ross, 1977, 1978; Niem and Niem, 1985), and digital soil survey maps (Smith and Shipman, 1988) (Table 1). Orthorectified imagery and digital raster graphics are available at the Oregon Geospatial Data Clearinghouse website (http://www.oregon.gov/DAS/EISPD/GEO/sdlibrary.shtml; accessed 2006). Scanned maps, aerial photographs, and other digital data were obtained from state, county, and local sources. For example, 2-ft topographic contours derived from 2004 aerial photographs were provided by the City of Cannon Beach. The compilation also includes high-resolution topographic data collected by light detection and ranging (lidar) technology in 2002 along a 2,500-ft- (760-m) wide coastal strip (National Oceanic and Atmospheric Administration Coastal Services Center website: http://www.csc.noaa.gov/crs/tcm/; accessed 2006).

The following sections summarize the approaches used to map erosion hazard zones along the southern Clatsop County shoreline. Our approach has been adapted from similar studies completed for the Clatsop Plains, Tillamook County, and northern Lincoln County (Allan and Priest, 2001a, 2001b; Priest and Allan, 2004).

Figure 3. (Facing page) Oblique aerial photograph of the Silver Point landslide taken February 5, 1974 (L. R. Squier, Inc., 1974). The report by L. R. Squire, Inc. (1974) noted that the toe of the landslide consisted of two coalescing tongues of slide material, a northern and southern lobe, that both overrode the beach. The lateral width of the entire landslide at the beach was approximately 900 ft. The diagonal crack (middle left of photograph), a discontinuity in the roadway that required periodic maintenance to repair chronic south-side-down slip, ultimately accommodated 35 ft of vertical displacement. The main head scarp began forming on February 3, 1974. L. R. Squier, Inc. (1974) speculated that a secondary scarp ("upper scarp"), uphill of the main scarp, formed during the main slide, which occurred on February 4. Measured from the upper scarp to the slide toe, the maximum length of the Silver Point landslide was approximately 1,200 ft.

Table 1. Maps and imagery compiled for geologic mapping and erosion rate assessments for the southern Clatsop County, Oregon, study area.

Year	Imagery	Scale	Source
1939	scanned, black and white, stereo-paired aerial photographs (Project OC & SW)	1:10,500	U.S. Army Corps of Engineers
1961	geologic map of the Ecola State Park landslide area	1:12,000 (approx.)	Schlicker and others (1961)
1967	scanned black and white, stereo-paired aerial photographs (Project OC-3)	1:6,000	Oregon Department of Transportation
1972	scanned engineering geology and geologic hazard maps of coastal Clatsop County, Oregon	1:24,000	Schlicker and others (1972)
1977	geologic hazard maps, Cannon Beach, Oregon	1:1,200	Ross (1977)
1978	maps of geologic hazards from Silver Point to Cove Beach, Clatsop County, Oregon	1:2,400	Ross (1978)
1975	scanned black and white, stereo-paired aerial photographs (Project ORE. COAST – 75)	1:9,600	unknown
1985	geologic map of the Astoria Basin, Clatsop and northernmost Tillamook Counties, northwest Oregon	1:100,000	Niem and Niem (1985)
1994	black and white, stereo-paired aerial photographs (Project WAC-94OR)	1:24,000	WAC Corporation
1997	digitized soil survey maps for Clatsop County	1:24,000	Natural Resources Conservation Service, U.S. Department of Agriculture
2000	black and white, digital orthophoto quadrangle (1-m ground resolution)	1:12,000	Oregon Geospatial Data Clearinghouse
2002	topographic contour maps derived from light detection and ranging (lidar) surveys	na (±0.5 ft vertical data)	National Oceanographic and Atmospheric Administration
2004	digital 2-ft elevation contours	na	City of Cannon Beach
2005	true color, digital orthoimagery (0.5-m ground resolution)	1:6,000	Oregon Geospatial Data Clearinghouse
various	USGS 7.5-minute quadrangles, digital raster graphics	1:24,000	Oregon Geospatial Data Clearinghouse

na means not applicable

Bluff-Backed Shorelines

We delineate four coastal erosion hazard zones for bluffs of southern Clatsop County (Figure 4) following the methodology of Allan and Priest (2001b) and Priest and Allan (2004). The active hazard zone includes areas presently exposed to wave erosion and active mass movements. Three additional hazard zones are defined by high-, moderate-, and low-hazard scenarios that predict expansion of the active hazard zone by coastal processes that drive bluff-top retreat (Figure 4). The high-hazard zone represents the minimum amount of erosion expected within the next several decades; the low-hazard zone represents the maximum amount of erosion expected over a century. Defining hazard zone boundaries relies on the evaluation of several geological parameters including historically derived bluff erosion rates, estimated dimensions of block landslides, and empirically determined slopes of repose for talus of different bluff materials. The hazard zones depict a series of scenarios that increase in severity but decrease in likelihood and incorporate gradual erosion as well as episodic bluff failure. For example, the scenario used to delineate the high-hazard zone assumes gradual erosion at measured historical erosion rates over a period of 60 years; however, individual erosion events may include episodes of rapid bluff retreat that span tens of feet during a single storm, which can severely impact local areas but produce relatively small effects to the regional coastline. More severe but less probable scenarios used for the moderate- and low-hazard zones assume gradual erosion over 60 to 100 years in addition to episodic large erosion events, including landslide block failures.

The four erosion hazard zones are explicitly defined as follows:

1. *Active-Hazard Zone* – On bluff-backed shorelines, the active-hazard zone includes areas undergoing active erosion, whether by wave attack or mass wasting processes including all active or potentially active coastal landslides impacting bluffs. The active-hazard zone encompasses all areas seaward of the bluff top including the beach, foredunes, and the bluff escarpment.
2. *High-Hazard Zone* – Depicts width of bluff retreat caused by gradual or episodic erosion over a period of 60 years on the basis of the mean erosion rate estimated from historical data. This scenario also assumes the bluff slope reaches and maintains an empirically determined angle of repose for talus of the bluff material.
3. *Moderate-Hazard Zone* – Represents the intermediate hazard zone with a landward boundary defined by the average distance between the high- and low-hazard zone boundaries. The purpose of this zone is to depict possible erosion scenarios, more extreme but less likely than scenarios encompassed by the high-hazard zone that may include combined processes of landslides, subaerial weathering and episodic bluff erosion over a period of 60 to 100 years.

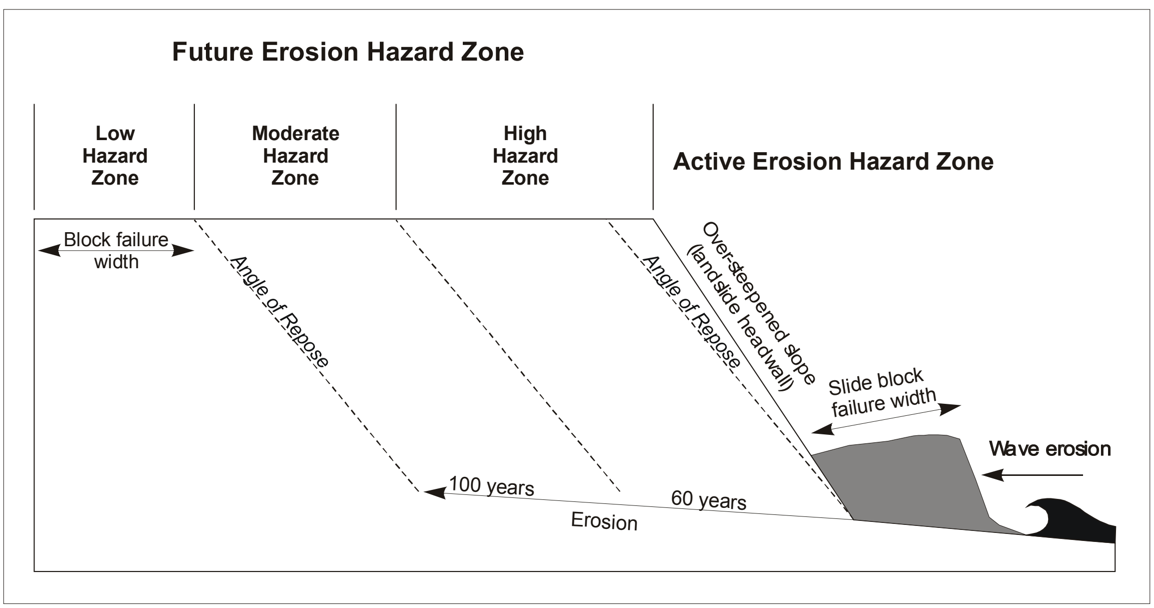


Figure 4. Schematic illustration of block failure on a bluff, angle of repose, and erosion rate in relation to possible hazard zones. These factors can be combined in a variety of different ways to produce hazard zones.

4. *Low-Hazard Zone* – Encompasses the most severe scenario for bluff retreat over a period of 60 to 100 years including maximum estimated landslide block widths, bluff retreat to an ideal slope of repose, and bluff erosion at a rate equal to the mean historical erosion rate plus one standard deviation from the mean and error from measurement uncertainty.

Because of their regional scope, maps depicting erosion hazard zones are not intended for site-specific use. More detailed, site-specific investigations are necessary to provide accurate assessments of the potential for bluff or dune erosion at a particular building site or proposed development. The following sections describe the bluff retreat model and define the parameters used to estimate erosion hazard zones for dune- and bluff-backed shorelines in southern Clatsop County.

The Bluff Retreat Model

Episodic landsliding and gradual retreat of coastal bluffs threaten coastal communities, numerous roads and highways, and state park property along hundreds of miles of the Oregon coast (Komar, 1997). Prior erosion hazard zone evaluations by DOGAMI (Allan and Priest, 2001b; Priest and Allan, 2004) have relied on a conceptual model of bluff retreat that defines four erosion hazard zones by evaluating a number of empirical parameters including historical erosion rates, angle of repose of talus of the bluff material, and maximum block failure width measured at active landslides (Figure 4). Our methods also consider many physical parameters, summarized in Figure 5, that influence the processes that govern erosion of coastal bluffs.

For this regional evaluation of bluff erosion in southern Clatsop County, hazard zones are mapped by assessing the parameters related to local geology (e.g., bluff slope, height, structure, and composition) and historical bluff retreat rates within the context of the conceptual model of bluff retreat shown in Figure 5.

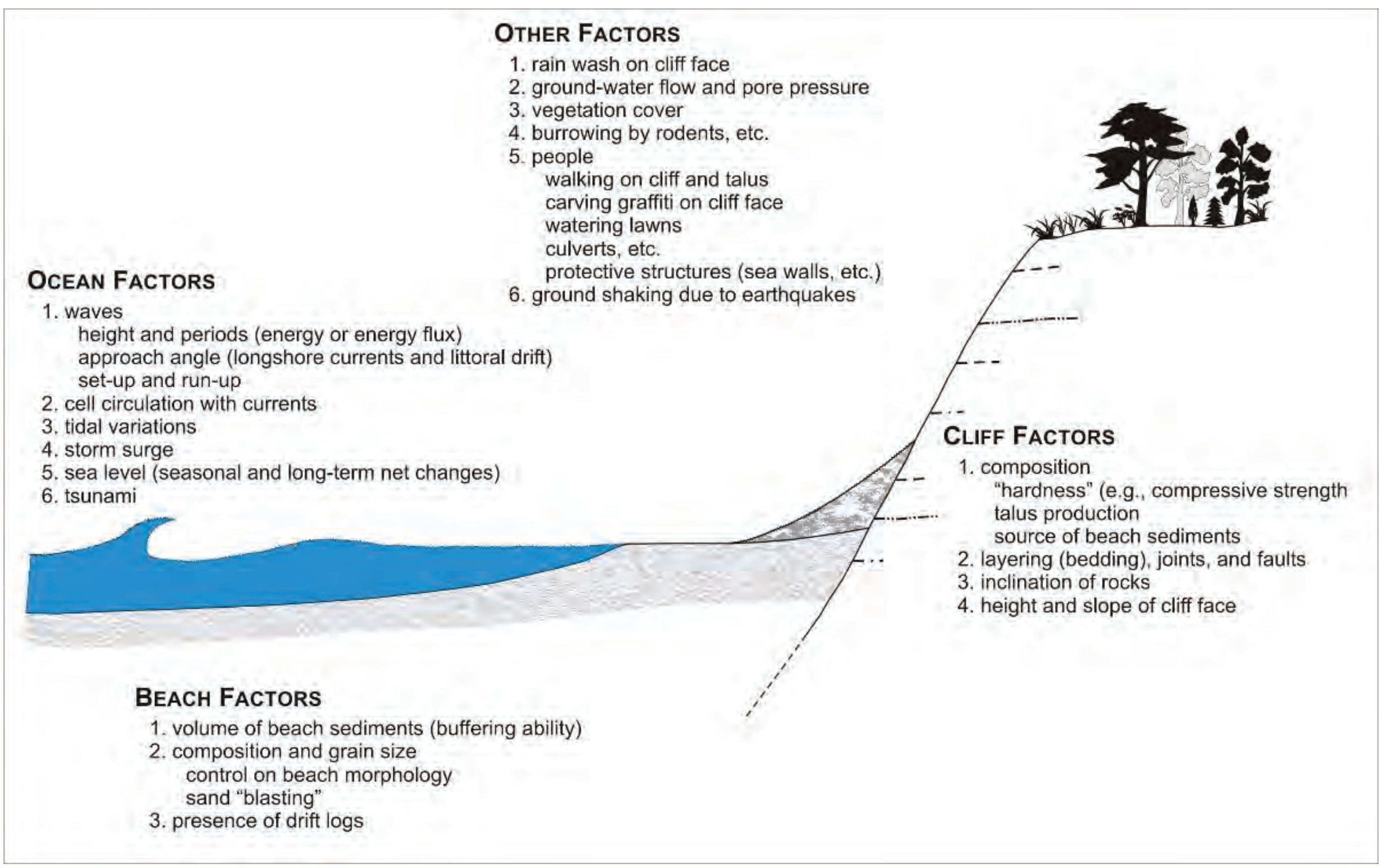


Figure 5. Factors important in sea cliff erosion (after Komar [1997]).

Mapping Technique for Bluff Erosion Hazard Zones

The mapping technique used in this study follows the approach established by Allan and Priest (2001b) and Priest and Allan (2004) for similar erosion hazard evaluations conducted for Tillamook County and northern Lincoln County, respectively (Figure 4). This section reviews the parameters used to estimate bluff erosion hazard zones for southern Clatsop County, including the slopes of repose for bluff materials found in the study area, historical erosion rates, and estimated maximum landslide block failure widths. This section also explicitly describes the procedure used to develop the bluff erosion hazard zones.

Parameters Used to Calculate Bluff Erosion Hazard Zones in Southern Clatsop County

Erosion hazard zone calculations use three parameters — erosion rate, the width of potential landslide block failures, and slope of repose — that relate to physical processes that control bluff erosion. The three parameters, and methods used to estimate them, are described below and ordered according to their relative importance to bluff erosion on the northern Oregon coast. Chronic abrasion by wind and ocean waves drives the retreat of most bluffs not involved in large landslides and prevents slopes from reaching stable angles of repose. Erosion of some bluffs is predominantly controlled by the dimensions of large rotational, translational, and complex landslides. Less common are bluffs beyond the reach of wave erosion along parts of the shoreline where the toes of bluffs are mantled by shallow colluvial aprons that achieve a slope of repose that reflects the strength of unconsolidated talus material and gradual retreat of the bluff by hillslope processes over longer periods of time.

Erosion Rate. The rate of landward retreat of the seaward edge of the bluff top reflects the combined activity of several processes, including localized slumping and block failure that degrade the bluff face, and erosion of the bluff toe caused by the force of wind and ocean waves. Table 2 shows erosion rate estimates used in this study to calculate the high- and low-hazard zones for bluff erosion based on erosion rate data for bluffs of Tillamook County (Allan and Priest, 2001b). Preliminary bluff-top erosion rates along the open coast of southern Clatsop County were estimated by comparing the bluff-top edge interpreted on 1939 and 1967 stereo aerial photographs to the bluff edge mapped on 2005 orthorectified imagery. Scanned 1939 and 1967 aerial photos were georegistered in the GIS by matching reference features (e.g., buildings, road intersections, and stable landmarks) common to the photograph and 2005 orthorectified imagery. The results of our analysis determined that the 1939 photographs were inaccurately registered due to too few reference features and apparent warping of the images. However, a reasonable erosion rate for bluffs composed of Quaternary deposits (–0.3 ± 0.3 ft/yr) was estimated at 40 sites using 1967 and 2005 aerial imagery. Because correcting the aerial photographs for radial distortion, relief displacement, or other sources of error was beyond the scope of this project, we assume the standard deviation of the measurements includes the potential uncertainty in the location of a feature on uncorrected aerial photographs. The preliminary erosion rate estimated for bluffs of Quaternary material in southern Clatsop County is similar to erosion rates estimated for bluffs of Quaternary material in Tillamook County (–0.25 ± 0.26 ft/yr; Allan and Priest,

Table 2. Estimated open coastal bluff-top erosion rates used to delineate hazard zones along bluff-backed shorelines in southern Clatsop County, Oregon.

Bluff Material	Erosion Rate	High-Hazard Zone Rate[1]	Low-Hazard Zone Rate[2]
Basalt (Miocene Grande Ronde Basalt)	–0.1 ± 0.3 ft/yr	–0.1 ft/yr	–0.2 ft/yr
Resistant sedimentary rock (e.g., Astoria Formation, Angora Peak sandstone; Cape Falcon conglomerate)	–0.1 ± 0.1 ft/yr	–0.1 ft/yr	–0.2 ft/yr
Interbedded mudstone (e.g., Astoria Formation, Cannon Beach member; Smuggler Cove formation)	–0.2 ± 0.3 ft/yr	–0.2 ft/yr	–0.4 ft/yr
Quaternary deposits (e.g., late Pleistocene coastal terraces, late Pleistocene to Holocene alluvial and colluvial deposits)	–0.25 ± 0.25 ft/yr	–0.5 ft/yr	–1.0 ft/yr

Note: Erosion rates from Table B2, Appendix B, of Allan and Priest (2001b).
[1]Erosion rate used to determine high-hazard zone for bluff-backed shorelines.
[2]Erosion rate used to determine low-hazard zone for bluff-backed shorelines.

2001b) and Lincoln County (–0.1 ± 0.2 to –0.5 ± 0.1 ft/yr [Priest and Allan, 2004; Witter and others, 2007]).

Width of Landslide Block Failure. Estimated maximum widths of hypothetical landslide block failures are used to estimate the low-hazard zones. The estimated maximum block failure widths used in this study (Table 3) come primarily from empirical data collected in Tillamook and Lincoln Counties (Allan and Priest, 2001b; Priest and Allan, 2004) with three exceptions. For southern Clatsop County, maximum landslide block widths were estimated for landslide areas on the north flank of Tillamook Head, in Ecola State Park, and at Silver Point (Table 3). The data are derived from interpretation of aerial photographs and field measurements of individual blocks within active landslides. Empirical relationships between maximum failure width and bluff height suggest that block width increases with bluff height but not in a linear fashion. The presence of seaward-dipping sedimentary rock also may influence the maximum block width. The data are used to develop worst-case bluff failure scenarios that incorporate the historical erosion rate (Table 2) after reaching the angle of repose for talus of the bluff material (Table 4).

Angle of Repose. Empirical estimates of repose angles for talus of various bluff forming materials are used to project the position of the bluff top as its slope reclines due to subaerial and hillslope processes (slumping, rills and gullies, soil creep). For consistency with previous studies, we use the slopes of repose[1] applied to erosion hazard evaluations of northern Lincoln County and Tillamook County (Allan and Priest, 2001; Priest and Allan, 2004) (Table 3). Field measurements of slope angles in these studies suggest that a 1:1 slope is an appropriate estimate for the slope of repose for the resistant basalt cliffs that occur at Cape Falcon and along the flanks of Tillamook Head. A lower slope of 1.5:1 was found to approximate the slope of repose for Tertiary sedimentary rocks and sediments underlying late Pleistocene marine terraces.

Table 3. Recommended maximum landslide block failure widths for coastal bluffs in southern Lincoln County, Oregon.

Bluff Material Causing Block Failure	Bluff Height (ft)	Maximum Block Failure Width (ft)
Basalt subject to rock falls and topples	<100	10
Basalt subject to rock falls and topples	≥100	50
Resistant sedimentary rock	<100	10
Resistant sedimentary rock	≥100	50
Smuggler Cove formation rocks associated with landslides on north flank of Tillamook Head	variable	500
Astoria Formation rocks associated with landslides in Ecola State Park	variable	300
Astoria Formation rocks associated with the Silver Point landslide	variable	250
Interbedded sandstone, mudstone	<60	bluff height/1.25
Interbedded sandstone, mudstone	>60	140
Quaternary deposits	<150	bluff height/1.25

Values from Allan and Priest (2001) and Priest and Allan (2004) except as noted in the text.

Procedure for Delineating Erosion Hazard Zones

The procedure used to define the widths of bluff erosion hazard zones in southern Clatsop County builds on the technique used by Priest and Allan (2004) and Witter and others (2007) for mapping bluff erosion hazard zones in Lincoln County. To delineate the landward boundary of the *high-hazard zone*, we estimate the amount of bluff top retreat caused by erosion projected over the next 60 years using historical erosion rates. Also included in the *high-hazard zone* is the amount of retreat expected once the bluff reaches a slope of repose appropriate for the bluff material. For the landward boundary of the *low-hazard zone*, the procedure considers the projected erosion over 100 years, the projected bluff top position at the appropriate slope of repose, and the maximum landslide block width determined from empirical studies (Allan and Priest, 2001b). Slope of repose calculations and block widths are referenced to the bluff toe. The landward boundary of the

Table 4. Angles of repose and slopes of repose by material type (Allan and Priest, 2001; Priest and Allan, 2004).

Bluff Material	Angle of Repose	Slope of Repose (Horizontal:Vertical)
Basalt	45°	1:1
Tertiary sedimentary rocks	34°	1.5:1
Holocene alluvial and colluvial deposits	34°	1.5:1
Pleistocene marine terrace deposits	34°	1.5:1
Holocene to late Pleistocene dune sand	34°	1.5:1

1 The slope of repose is equal to the cotangent of the angle of repose, or the ratio of the horizontal distance to the vertical height between the toe and top of the talus slope.

moderate-hazard zone is located halfway between the *high-* and *low-hazard zone* landward boundaries. Although the width of the *moderate-hazard zone* is not explicitly tied to the 60- to 100-year time span, its purpose is to represent a scenario of intermediate severity that may involve episodic bluff retreat related to slope failure or "hot spot" erosion.

The following step-by-step procedure applied by Witter and others (2007) for southern Lincoln County has been uniformly applied to develop consistent bluff erosion hazard zones for southern Clatsop County:

1. Determine bluff geology, structure, and extent of all landslides, including ancient (prehistoric) slides.
2. Using the most detailed data available (e.g., aerial photographs, lidar, GPS surveys), map the seaward edge of the bluff top or top edge of the active or potentially active landslide headwall. Exclude all mass movement hazard areas that are prehistoric (e.g., unit PHls [see Table A-1, Appendix A]) or potentially active but queried (e.g., PAls?). Everything seaward of this line is the *active-hazard zone*.
3. Using the empirically derived slope of repose for the bluff material (Table 4) and beginning at the bluff toe, determine the projected location of the bluff top (or projected landslide headwall position) resulting from subaerial weathering processes. On steep, near-vertical bluffs where the bluff toe cannot be distinguished from the top edge of the bluff, assume that the bluff toe is located directly below the bluff top.
4. Estimate the width of the *high-hazard zone* by summing (a) the distance between the bluff top and the projected bluff top at the slope of repose and (b) the product of the mean erosion rate of the bluff material (from Table 2) multiplied by 60 years. The *high-hazard zone* extends from the bluff top in the landward direction.
5. Estimate the width of the *low-hazard zone* by summing (a) the distance between the bluff top and the projected bluff top at the slope of repose (Table 4), (b) the product of the mean erosion rate (plus error) of the bluff material (from Table 2) multiplied by 100 years, and (c) the maximum block failure width from Table 3. The sum of these factors represents the landward boundary of the *low-hazard zone* for most bluffs.
6. Draw the *moderate-hazard zone* landward boundary halfway between the high- and low-hazard zone boundaries (i.e., sum the lateral distances to the high- and low-hazard zone boundaries and divide by 2).
7. Adjust the *low-* and *moderate-hazard zone* boundaries to encompass any intersected inland landslides to account for possible future expansion of the *active-hazard zone*. Use geologic judgment to incorporate the parts of inland landslides within the *low-hazard zone* boundary, including prehistoric (PHls) and queried potentially active (PAls?) mass movements that may be further destabilized by future coastal erosion.

Active-Hazard Zone for Dune-Backed Shorelines

The active-hazard zone (AHZ) for dune-backed shorelines (Figure 6) was mapped throughout the study area based on geomorphic observations derived from aerial photographs and National Ocean Service (NOS) T-sheets (e.g., 1870s era, 1920s era, 1999, and 2005), field mapping, and GPS surveys of the coastline. The AHZ is better constrained than the other coastal hazard zones evaluated in this investigation because its dimensions depend on easily identifiable coastal features that may be seen on modern aerial photos supplemented with current field data. On dune-backed beaches the AHZ distinguishes the zone of beach variability, a region in which beaches undergo considerable change (e.g., changes in the position of the shoreline relative to some known datum point). Thus, the AHZ represents the portion of beach that is known to have changed in recent times due to large wave events and changes in sediment supply. It is therefore the zone that can be expected to change in the immediate future. As a result, there can be no doubt that building within the active hazard zone represents considerable risk.

It is important to note that the AHZ as defined here should not be confused with the "active dune" or "active foredune" used by State regulators (e.g., OCZMA, 1979; DLCD, 1995). For example, OCZMA (1979) defines the "active foredune" as those dunes that possess insufficient vegetative cover to retard wind erosion, while Goal 18 (Beaches and Dunes) of Oregon's Statewide Planning Goals and Guidelines prohibits the residential and commercial development of beaches and active foredunes (DLCD, 1995).

Dune-Backed Shorelines

To predict the extent of possible future shoreline variability on dune-backed beaches, this study follows the approach of Allan and Priest (2001a), which uses an empirically derived geometric model (Komar and others, 1999) that accounts for multiple oceanographic factors that influence coastal erosion. The advantage of this technique is that it predicts the landward limit of erosion given inputs from various scenarios that depict possible oceanographic conditions of increasing severity. For example, the model can incorporate the effect of local relative sea-level rise, including the impact of earthquake-induced subsidence that would make shorelines more susceptible to erosion than past events reflected only in geomorphic observations.

Hazard zones on dune-backed beaches are derived using a geometric model (Komar and others, 1999) that predicts landward extent of erosion when total water level produced by the combined effect of extreme wave runup superimposed on the tide level exceeds the elevation of the beach-dune junction. Three scenarios define the inputs used to model erosion hazard zones on dune-backed shorelines:

- *Scenario 1* (high hazard) is analogous to the March 2-3, 1999, La Niña winter storm. This scenario is based on storm waves (wave heights ~47.6 ft [14.5 m] high) that occur over the cycle of an above average high tide, coincident with a 3.3 ft (1 m) storm surge. In this scenario the designated high-hazard zone was found to range from 102 to 280 ft (31 to 85 m).
- *Scenario 2* (moderate hazard) is one of two "worst case" situations in which a severe storm event (wave heights ~52.5 ft [16 m] high) is coupled with a large storm surge of 5.6 ft (1.7 m). Maximum potential erosion distances (MPED) estimated for this scenario varied from 145 to 474 ft (44 to 145 m).
- *Scenario 3* (low hazard) is the second "worst case" scenario and is similar to scenario 2 but incorporates 3.3 ft (1.0 m) of subsidence caused by a hypothetical Cascadia subduction zone earthquake. MPED estimated for scenario 3 ranged from 158 to 600 ft (48 to 183 m).

For a complete description of the methods used to develop erosion hazard zones on dune-backed beaches in Clatsop County, see Allan and Priest (2001a).

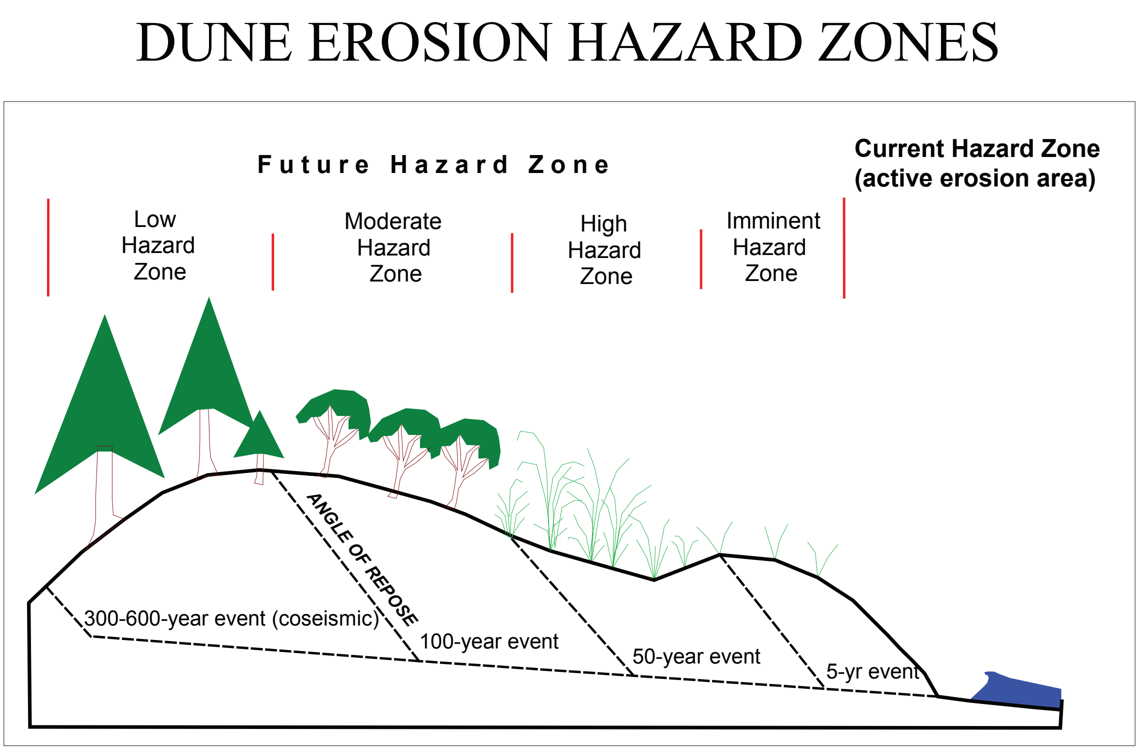


Figure 6. Schematic diagram showing possible dune erosion hazard zones.

RESULTS AND DISCUSSION

The results of the coastal erosion hazard evaluation for southern Clatsop County are included as GIS files in a digital database that accompanies this report. The database contains files that depict four erosion hazard zones for dune- and bluff-backed shorelines, coastal geology mapped at 1:4,800-scale, digitized location of the bluff-top edge and bluff base, and a digital compilation of landslide scarps mapped by Ross (1977, 1978). The files contain spatial information as well as attributes, including descriptions of each map unit and data sources. Also included as a product of this investigation are printable maps that depict the geologic map units (Appendix A) and erosion hazard zones (Appendix B) at 1:9,600 scale. The maps use 2005 digital orthophotographs (0.5-m ground resolution) of Clatsop County as a base map and identify major highways, county roads, city streets, and public parks and recreation areas. The following sections summarize the results of the project.

Active-Hazard Zone

The active-hazard zone for southern Clatsop County varies in width from less than one hundred feet on pocket beaches adjacent to the steep flanks of Tillamook Head and Cape Falcon to over 3,400 ft encompassing the active Ecola State Park landslide. On dune-backed shorelines, the active-hazard zone reflects the zone of historical beach variability. (i.e., the varying locations of the mean shoreline position derived from historical photographs and lidar data) as well as knowledge of the geomorphic character of the shore (e.g., open dune areas subject to shifting sands).

On bluff-backed shorelines the *active-hazard zone* includes the beach, bluff toe, escarpment, and any existing shore protection structures, all seaward of the top edge of the bluff. In addition, the *active-hazard zone* envelopes any active or potentially active landslides that intersect the seaward bluff edge. Because areas of historical mass movement and potentially active landslides cover approximately 25 percent of the southern Clatsop County coastline, the *active-hazard zone* encompasses considerable areas landward of the bluff edge. For example, along coastal reaches impacted by large historical landslides the *active-hazard zone* departs hundreds to thousands of feet inland from the bluff edge. As a result, the widest *active-hazard zones* occur along the north flank of Tillamook Head, at Ecola State Park, west of Tolovana Hill near the S-Curves landslide in Cannon Beach, at Silver Point, at the southern end of Arcadia Beach north of Hug Point, and along much of the Falcon Cove community.

Shore protection structures, including riprap and seawalls, armor 48 percent of the coast along Cannon Beach from the mouth of Ecola Creek to Silver Point. To the south, extensive shore protection also has been emplaced along the northern part of Arch Cape; however, field mapping confirmed that most of these structures have been buried by beach sand and cobbles. Mapped shore protection structures are included in the GIS database as “fill” and are shown graphically on geologic maps included in the GIS database and in Appendix A. Future retreat of these protected bluffs, as well as dunes fronted by riprap, likely will be minimal as long as the structures are properly maintained. Continued long-term rise in sea level along the coast projected over the next several decades together with future winter storms will damage the structures and decrease beach width. If the structures are not maintained, bluffs and dunes now protected by riprap will again be threatened.

Dune Erosion Hazard Zones

Estimates of maximum potential erosion distances (MPED) for dune-backed shorelines in southern Clatsop County have been derived by using the geometric model of Komar and others (1999) for each 330-ft section of beach according to the three scenarios described by Allan and Priest (2001a). Four areas were assessed, including dunes and the extensive cobble beach at Seaside, dunes between Chapman Point and Cannon Beach, the dune-backed beach at the southern end of Arch Cape, and a 570-ft-long cobble berm impounding a small lagoon at Cove Beach. Because the morphologies of the beaches varied significantly between these sites, specifically in terms of the beach-dune toe elevations and beach slopes, MPED data were combined in order to calculate average MPED values that characterized each of the four sites (Table 5). For each site the average of the MPED data presented in Table 5 was used to generate the high- (red zone), moderate- (orange zone), and low- (yellow zone) hazard zones shown on maps in Appendix B.

Considerable variability is expressed by the spread of the MPED data shown in Table 5. The widest erosion hazard zone was identified along the shore at Seaside, where the MPED for the high-hazard zone was determined to be ~280 ft (85 m) wide; MPED reached 710 ft (216 m) for the low hazard zone. This reflects the fact that much of the beach at Seaside is characterized by a gently sloping beach

Table 5. Maximum potential erosion distances (MPED) determined for dune-backed shorelines in southern Clatsop County.

	Hazard Zone Scenario	Minimum (ft)	Maximum (ft)	Average MPED (ft)
Seaside	high	186	343	280
	moderate	373	561	474
	low	490	710	600
Cannon Beach	high	83	173	151
	moderate	261	399	304
	low	374	556	395
Arch Cape	high	118	249	199
	moderate	235	388	336
	low	297	468	413
Cove Beach	high	86	116	102
	moderate	118	263	145
	low	150	308	158

(~1.4 degrees), while the elevation of the beach-dune junction is generally lower compared with other sites in Clatsop County. As a result, this site remains at risk from a significant event that could remove portions of the dune. In addition, Stembridge (1975) identified several years (e.g., 1939, 1958, 1960, and 1967) in which the community of Seaside was affected by severe coastal flooding and erosion hazards. Furthermore, the January 1939 storm is now thought to be equivalent to a 1% (annual probability) storm or 100-year event (P. D. Komar, personal communication, 2006). In contrast, estimates of the MPED for the Cove Beach area (Table 5) are generally lower (average = 102 ft [31 m] wide); the lower values are entirely a function of the site's higher beach-berm junction elevations.

Bluff Erosion Hazard Zones

Some of the widest bluff erosion hazard zones occur on cliffs composed of interbedded sandstone and mudstone and bluffs compromised by active or potentially active landslides (Table 6). The widest high-hazard zone (400 ft) associated with an active landslides occur south of Ecola Point above Crescent Beach in Ecola State Park (Plate B-4, Appendix B). High-erosion hazard is mapped in the Silver Point area where the width of the high-hazard zone reaches 300 ft above the Silver Point landslide. A 330-ft-wide high-hazard zone is mapped along steep sea cliffs composed of Smuggler Cove formation sedimentary rock northeast of Cape Falcon (Plate B-8, Appendix B). Other areas characterized by wide high-hazard zones include bluffs north of Arch Cape beach, bluffs above Arcadia Beach, and along the towering (>100 ft high) sea cliffs of Tillamook Head.

The narrowest erosion hazard zones are mapped along bluffs composed of basalt and resistant sedimentary rock (Table 6). These bluffs are unlikely to experience future retreat of more than 20 ft in the next 60 years because the rock lithology is less susceptible to erosion and weathering and the bluffs have reached the slope of repose.

Table 6. Minimum, mean, and maximum lateral distances of bluff top retreat forecast for bluffs of various composition and height.

Bluff Material	Bluff Height (ft)	High-Hazard Zone (ft)	Moderate-Hazard Zone (ft)	Low-Hazard Zone (ft)
Basalt subject to rock falls and topples	<100	20–35	45–175	70–325
Basalt subject to rock falls and topples	≥100	20–360	48–390	76–415
Resistant sedimentary rock	<100	35–60	60–85	85–110
Resistant sedimentary rock	≥100	20–50	50–75	75–105
Interbedded sandstone, mudstone	<60	20–60	45–285	70–540
Interbedded sandstone, mudstone	>60	20–330	50–360	75–385
Quaternary deposits	<150	30–150	65–220	100–290
Active and potentially active landslides	variable	20–400	48–555	76–710

These distances define the landward limit of the high-, moderate-, and low-hazard zones, measured from the bluff edge, predicted over a time interval of 60 to 100 years and include the lateral distance of the projected angle of repose for talus of the bluff material. The distances for the low-hazard zone also incorporate estimates of the maximum block failure width.

Bluff Erosion and Landslides

The following sections summarize field observations of bluff erosion processes operating along the southern Clatsop County coast. The discussion includes brief descriptions of the coastal geology along six reaches of the coastline. This summary also highlights conspicuous landslides that impact coastal bluffs, including the historically active landslides at Ecola State Park, the Hemlock Street S-Curves in Cannon Beach, and Silver Point (Figure 1).

Seaside and Tillamook Head

Much of the City of Seaside is built on a 2.3-mi-long spit composed of basalt cobbles (Plate A-1, Appendix A) that originated as rocky debris produced by landslides on Tillamook Head. The cobble berm has formed as a result of ocean waves transporting resistant landslide rubble toward the east and north. A remarkable historical example of this process occurred in July 1987 when a large landslide on the north flank of Tillamook Head produced a debris field of basalt boulders (Plate A-2, Appendix A). Over the ensuing months, the debris from the landslide was distributed along the beach, eventually building a smaller, secondary cobble berm outboard of the main cobble beach in the vicinity of the cove at the south end of Seaside (Figure 7). Eventually, the secondary berm migrated onto the main beach, causing the cobble berm to prograde seaward. Examples of other prehistoric and potentially active landslides in this area are ubiquitous (Figure 8) and attest to the importance of this process in supplying sediment to Oregon beaches.

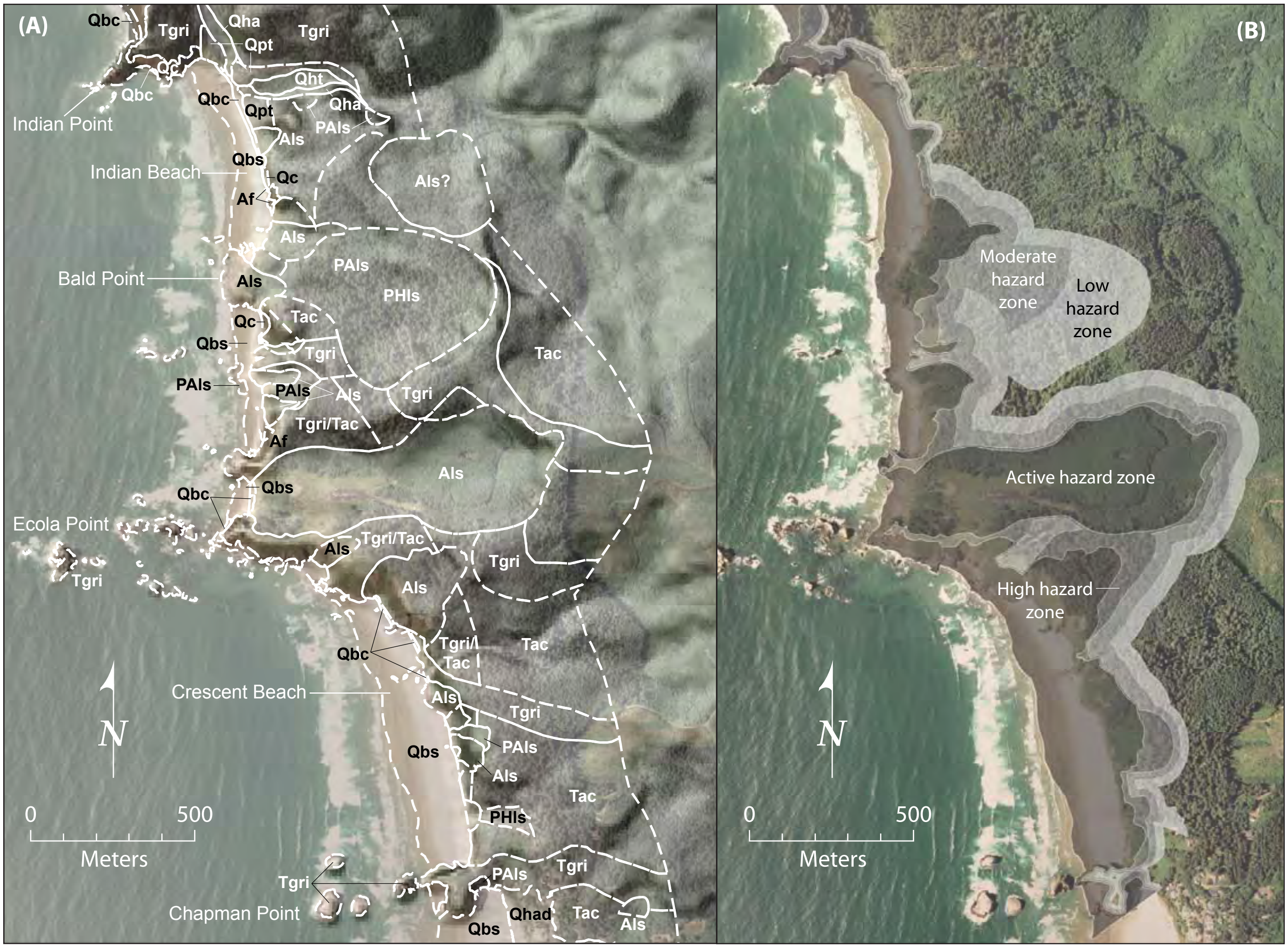
Tillamook Head (Plate A-3, Appendix A), as mapped by Niem and Niem (1985), consists of intrusive Grande Ronde basalt that abuts resistant Smuggler Cove formation mudstone that underlies the north flank of the headland (Figure 9). Large complex slides, involving both translation and rock avalanche mechanisms, appear to be the dominant mode of failure along the northern flank of Tillamook Head where slopes are underlain by Smuggler Cove mudstone. On the other hand, south of the mudstone-basalt contact,

Figure 7. Oblique aerial photo (view to southeast) of a migrating cobble-boulder berm that developed at the cove, at Seaside's southern shoreline, from the 1987 landslide on Tillamook Head. Within one month the berm connected to the north-south beach at the upper left corner of the photo. Larger winter surf pushed the rubble onto the original east-west shoreline (foreground in lower right of photo), killing all intertidal sea life. Waves then moved the cobbles and boulders westward with negligible progradation of the east-west shoreline and onto the north-south beach where the material formed a series of coalescing berms that shifted the shoreline 300 ft westward. The rocky material continues to advance slowly northward along the beach, driven by winter surf. Photo courtesy of Paul D. See.

Figure 8. Panorama of the toe of an active landslide on the northwestern side of Tillamook Head. Reddish-brown basalt (Tgri) overlies white and gray mudstone (Tsc), which sharply overlies dark gray breccia. The landslide failure plane is inferred to correspond to the contact between mudstone and breccia.

sea cliffs over 1,000 ft high and mantled by basalt colluvium appear to be maintained near the slope of repose, sculpted by chronic rockfall, sloughing and local large block slides. West-dipping platy jointing observed in the basalt (Figure 9) facilitates this failure mechanism. We speculate that the apparently more extensive landslides along the northern part of the headland may be the result of narrow basalt dikes that reduce the strength and competency of the Smuggler Cove mudstone and thereby lower the resisting forces and reduce the slope failure threshold.

Figure 9. Geologic contact between white, tuffaceous mudstone of the Smuggler Cove formation (Tsc) (left) and strongly jointed, west-dipping Grande Ronde Basalt (Niem and Niem, 1985), northwest flank of Tillamook Head.



Explanation

Geologic Map Units

Af	Active debris flow (historical)
Als	Active landslide complex (historical)
Qbc	Latest Holocene beach gravel
Qbs	Latest Holocene beach sand
Qhad	Latest Holocene dune sand
PAls	Potentially active landslide complex
PAf	Potentially active debris flow
Qha	Holocene alluvium, undifferentiated
Qht	Holocene stream terrace deposits
Qc	Late Pleistocene to Holocene colluvium
PHls	Late Pleistocene to Holocene landslide complex
Qpt	Late Pleistocene coastal terrace deposits
Tgri	Middle Miocene Grande Ronde Basalt
Tgri/Tac	Middle to lower Miocene Astoria Formation intruded by basalt
Tac	Middle to lower Miocene Astoria Formation, Cannon Beach member

Erosion Hazard Zones

- Active hazard zone
- High hazard zone
- Moderate hazard zone
- Low hazard zone

Figure 10. Ecola State Park maps of (A) coastal geology and (B) erosion hazard zones, including the area of the 1961 Ecola State Park landslide.

Ecola State Park

In addition to the Ecola State Park landslide (Figure 2), many active landslides are accelerating the rate of bluff erosion along the park's shoreline (Figure 10). Schlicker and others (1961) attributed prevalent landslides at Ecola State Park to "oversteepening of unstable rocks in the sea cliffs by wave erosion." Elevated ground water levels from winter storms likely increased pore fluid pressures, decreased the effective rock strength, and added weight that overburdened the slope, which also probably contributed to movement of the February 1961 slide. Local geology may also have had exacerbating effects.

The park's geology is characterized by intrusive basalt dikes that form vertical sea cliffs and prominent headlands, such as Indian Point, Ecola Point, and Chapman Point, separated by less competent Astoria Formation sedimentary rocks that are extremely susceptible to gravity-driven slope failure (Plate A-4, Appendix A). Schlicker and others (1961, p. 87) described the sedimentary rocks in the park as "thin-bedded, fine- to medium-grained sandstones and silty shales that grade upward into massive fine-grained clayey siltstones." Niem and Niem (1985) assigned these rocks to the Cannon Beach member of the Astoria Formation and mapped the entire park area as a zone of soft sediment deformation due to intrusion of volcanic rocks. Frenchman Springs Member basalt dikes and sills, distinguished from Grande Ronde basalt by distinctive feldspar phenocrysts, pervasively invaded and contorted the unconsolidated sediment, as evidenced by rock exposures that exhibit complex folding and small-scale faulting (Figure 11). Frenchman Springs lavas are fairly abundant along the southern part of Tillamook Head, but they are subordinate to the Grand Ronde sills and dikes. Rock outcrops at Ecola Point show Frenchman Springs basalt flows that have pushed aside the plastic younger sediments of the Astoria Formation. Schlicker and others (1961) postulated that deformation caused by volcanic intrusions may weaken the sedimentary rock and make them more slide prone.

Evidence of other active and prehistoric landslides, in addition to the 1961 slide, are well expressed in the coastal landscape throughout Ecola State Park. Bald Point, for example, consists of rocky rubble deposited by a landslide that overran Indian Beach (Figure 10). Rock outcrops along

Figure 11. Folded strata in Astoria Formation sedimentary rock along the southern margin of landslide near Bald Point, south of Indian Beach, Ecola State Park.

the toe of the landslide show southwest oriented striations that may indicate the direction of transport during the landslide (Figure 12). Aerial photographs from 1939 reveal the expression of a prehistoric landslide headscarp with dimensions similar in scale to the 1961 landslide (Figure 2) (Schlicker and others, 1961). Bluffs backing Crescent Beach also exhibit arcuate scarps indicative of active landslide terrain (Figure 13). Evidence of activity includes buckling and displacement of the park entrance road as well as recent wave erosion scarps in the toes of landslides that expose beach deposits and drift logs buried by slide debris (Figure 14).

Cannon Beach

Most of the City of Cannon Beach and the community of Tolovana Park are developed on gently sloping, relatively flat, late Pleistocene coastal terrace deposits (Plate A-5, Appendix A). Terrace sediments include well-cemented fluvial (?) gravels (Figure 15), massive beach sand, and poorly bedded mud with fossil shell from estuarine environments

Figure 12. Slip indicators (linear striations parallel to pencil) on a possible landslide failure plane exposed along the beach directly north of the Bald Point, Ecola State Park, indicate a southwest slip direction.

(Figure 16). In many areas, low bluffs of the coastal terrace presently are protected from storm wave erosion by a ramp of dune sand. However, winter storm waves periodically reach elevations sufficient to erode the dunes and wear away bluff deposits; a severe storm in 1939 motivated owners of the Ecola Inn to construct a sea wall (Figure 17). Other shore protection structures require continued maintenance to contend with persistent effects of wave erosion (Figure 18).

Slopes on upland hills composed of Cannon Beach member sedimentary rocks near Silver Point, at Tolovana Hill, and north of the city are susceptible to slumping, debris flows, and large landslides (Ross, 1977). Ross (1977) attributed slumping in the Astoria Formation and terrace deposits in the south end to backwearing by storm wave erosion that removed lateral support to the slopes. Other factors influencing slope stability in these areas include seasonal ground water fluctuations, cut-and-fill developments, road grading methods, storm water control, culvert maintenance, and excessive irrigation used for landscaping (Ross, 1977). Slopes underlain by basalt dikes and sills that invade Cannon Beach member sedimentary rocks make areas in the northern and southern parts of Cannon Beach prone to landsliding — much like the terrain that typifies Ecola State Park. Local slumps mapped by Ross (1977) north of the city appear to be related to failures in road fills and an abandoned basalt quarry.

Hummocky topography, landslide headscarps, vertical displacements of Hemlock Street, and cracking and settlement observed at multiple properties illustrate the impacts of landsliding on the west side of Tolovana Hill (Figure 19). The S-Curves landslide is a smaller (2.3 acres) complex of slumps and block rotational landslides on the southwestern flank of the hill. The slide involves Cannon Beach member mudstone, although chaotic debris flow deposits that overlie the sedimentary bedrock (Figure 20) suggest a long history of landsliding in the area. Motivated by chronic slope movement that has caused damage to Hemlock Street and adjacent properties and houses for decades (Ross [1977] noted up to 3 ft of vertical displacement in the road in 1977), the City of Cannon Beach hired engineering consultants to study the area and propose a solution to stabilize the landslide (White and Rondema, 2003). From our inspection of the repaired road surface, which showed no evidence of displacement, a system of subsurface drains designed to lower groundwater level and dewater the slide mass appears to have temporarily stabilized the landslide, at least by the date of this report. (Figure 21).

Figure 13. View looking south toward Chapman Point. Cannon Beach and Haystack Rock are visible in the distance. Coastal Bluffs in Ecola State Park (foreground), north of Chapman Point, are susceptible to mass movement and in many places are underlain by active landslides.

Figure 14. Wave erosion scarp exposes landslide debris that overrides beach cobbles and drift logs along Crescent Beach in Ecola State Park.

Figure 15. Cemented gravel deposit exposed at base of low bluff near Haystack Rock in Cannon Beach. Well-rounded beach or fluvial gravel includes mudstone and basalt clasts and forms late Pleistocene coastal terraces (Qpt).

Figure 16. Low bluffs in the southern part of the Tolovana Park community consist of hard, medium- to fine-grained grey sand, overlain by brown sandy mud with shell fragments. From the presence of shells and the texture and massive structure of the sand in these late Pleistocene coastal terrace deposits (Qpt) suggest transgression from a beach to an estuarine depositional environment.

Figure 17. Forty-eight-percent of the shoreline of Cannon Beach is armored with sea walls or riprap to mitigate coastal erosion. This seawall was built after a severe winter storm in January 1939.

Figure 18. Example of a seawall in Cannon Beach that has been undermined by wave erosion.

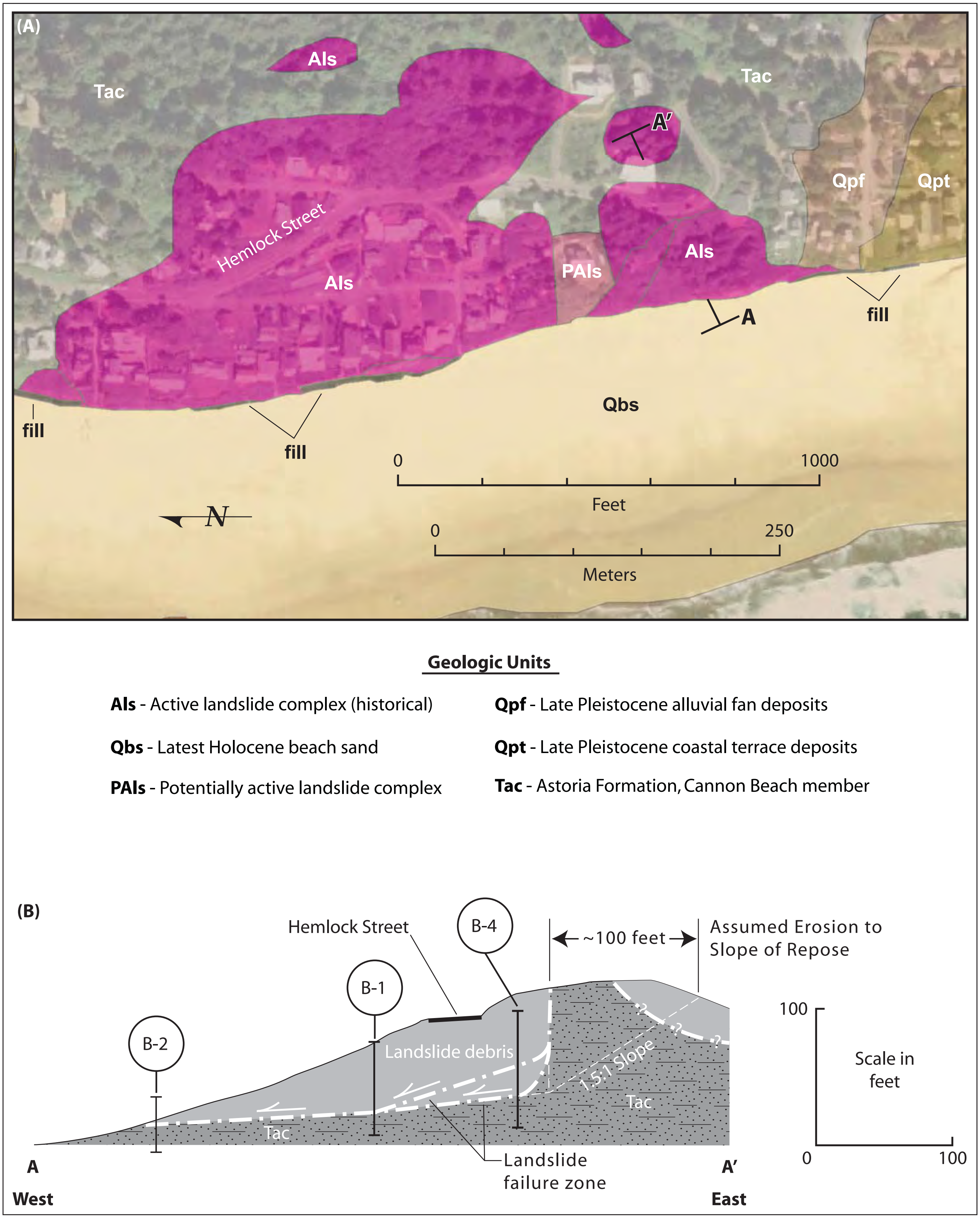


Figure 19. Geologic map and cross section of S-Curves Landslide, Cannon Beach.

Figure 20. Road cut along Hemlock Street at the top of the S-Curves landslide. The deposit consists of angular basaltic rubble in a matrix of orange-brown sandy silt.

Figure 21. Horizontal drains exposed at the toe of the S-Curves landslide consist of 150- to 300-ft-long, 1.5-in slotted PVC pipe. The drains carry away ground water for the purpose of lowering the water table and potentially stabilizing the S-Curves landslide in Cannon Beach (Horning, 2004).

Silver Point to Hug Point State Park

Chronically unstable slopes characterize bluffs between Silver Point and Hug Point State Park (Plate A-6, Appendix A). Along the northern part of this stretch of coastline, several active landslides have occurred in interbedded sandstone and mudstone of the lower Cannon Beach member of the Astoria Formation (Tac1, Figure 22). On the morning of February 4, 1974, the Silver Point landslide moved the Oregon Coast Highway 80 ft downslope toward the ocean and formed a 35-ft-high diagonal scarp across the roadway (Figures 3 and 23). Humbug Point, a small headland underlain by resistant Grande Ronde basalt, marks the southern extent of landslide-related features evident on aerial photographs.

Pleistocene coastal terrace deposits underlie much of the Arcadia Beach area that extends from Humbug Point to Hug Point. Terrace deposits typically consist of weakly bedded silt to sandy silt interrupted by gravel channels (Figure 24) or interbedded with peaty layers and roots or stumps in growth position (Figure 25). Houses in the southern part of the community are threatened by active landsliding encroaching toward the east.

To the north and south of Hug Point State Park, bluffs expose Angora Peak sandstone. Large, resistant blocks of sandstone and basalt on the beach below bluffs involved in active and prehistoric landsliding may reflect the remnants of rockfall that has since been eroded by ocean waves (Figure 26). At Hug Point, steep 90- to 120-ft-high bluffs of contorted Angora Peak sandstone are capped with thin (10- to 15-ft thick) mantles of sandy coastal terrace deposits. Paleovalleys incised into the sandstone bedrock are filled with alluvial fan deposits graded to a lower base level, possibly during a Pleistocene sea level lowstand (Figure 27). Bluffs backing an isolated pocket beach south of Austin Point expose steep (up to 45 degrees) seaward-dipping slopes in sandstone particularly susceptible to rock fall and slumping (Figure 28).

In the months following the 1974 Silver Point landslide, L. R. Squier, Inc. (1974) completed a subsurface investigation that focused on the landslide history, geotechnical conditions of the site, and probable cause of the slope failure. The following paragraphs summarize the unpublished report by L. R. Squier, Inc. (1974) filed with the Oregon Department of Transportation.

Cracks in Highway 101 repaired prior to 1974 and evidence of topographic scarps in 1967 aerial photographs of the area of the Silver Point landslide suggest chronic slope movement may have weakened the ground, thereby making the area susceptible to catastrophic failure. For example, displacements along a diagonal crack across the highway (Figure 3) required periodic resurfacing to maintain the elevation of the roadway over the seven years prior to 1974. Movement at the crack normally occurred during the wet

Figure 22. West dipping, interbedded mudstone and sandstone of the lower Cannon Beach member (Tac1), Astoria Formation at Silver Point. Note the lenticular sandstone bed in the middle section.

winter season. Review of 1967 stereo-paired photographs identified an older landslide scarp upslope of and aligned with the diagonal crack in the highway. In the winter of 1972-1973, a minor crack in the roadway developed about 280 ft south of the diagonal crack.

Increases in the rate and magnitude of movement on both the diagonal crack and the minor crack across the highway initiated in December 1973 and continued into January 1974. A short period of relative stability in late January was followed by renewed movement on February 2, two days before the landslide, when a 14-in displacement developed on the diagonal crack with movement that continued to accelerate over the day. On February 3, audible sounds of tree roots breaking and growth of a major scarp uphill of the highway indicated slow failure was underway. By the evening of February 3, vertical displacements across the diagonal crack and upheaval of the roadway south of the minor crack led to traffic closure on the highway. Residents reported shaking and rumbling similar to an earthquake on the morning of February 4, the presumed time of greatest landslide movement. Two coalescing tongues of the landslide flowed onto the beach, forming a toe about 900 ft wide (Figure 3). Measured from the upper scarp to its toe, the landslide's length extended approximately 1,200 ft.

L. R. Squier, Inc. (1974) concluded that the Silver Point landslide was triggered by the combination of high rainfall in the winter of 1973-1974 and unstable slopes highly susceptible to landsliding due to progressive deterioration of the underlying slope materials with time. In the geologic context of the northern Oregon coast, the event was not unexpected as noted in studies prior to 1974 that emphasized that Silver Point and the surrounding area are particularly prone to landslide hazards (North and Byrne, 1965; Schlicker and others, 1961; Schlicker and others, 1972). Rainfall data from Seaside, Oregon, obtained by L. R. Squier, Inc. (1974) show unusually high precipitation well above average annual rainfall occurred in November 1973 and above average rainfall continued through March 1974. The report attributes the primary cause of slope failure to above average precipitation in the months leading up to the landslide. Finally, L. R. Squier, Inc. (1974) labeled the landslide as a natural event and concluded that highway construction, maintenance, or other activities did not contribute to or cause the Silver Point landslide.

Arch Cape

The community of Arch Cape occupies a broad coastal terrace with few active landslides impacting relatively low (<30 ft high) bluffs (Plate A-7, Appendix A). The entire shoreline is naturally armored by a cobble beach periodically covered with sand during summer months. Late Pleistocene coastal terrace deposits that underlie Arch Cape typically consist of well-cemented, rounded river gravels deposited by ancestral Arch Cape Creek (Figure 29). Inset into the coastal terrace are late Holocene stream terrace deposits formed by Austin (Figure 30), Shark, and Arch Cape Creeks. Although no prominent landslides were identified along Arch Cape beach, shallow, superficial slumps appear to degrade the bluffs locally. Along the north flank of Arch Cape, however, active complex landslides and rock falls have formed a colluvial apron that abuts the southern edge of the Arch Cape Creek floodplain (Plate A-7, Appendix A).

Arch Cape to Cape Falcon

Cove Beach borders a crescent-shaped recess in the coast between Arch Cape and Cape Falcon. The small beach community of Falcon Cove that overlooks Cove Beach faces the most severe erosion and landslide hazards among coastal communities in southern Clatsop County. More than 65 percent of coastal bluffs backing Cove Beach show evidence of active or prehistoric mass movement (Plate A-8, Appendix A).

The coastal terrace and landslide-related landforms inset into bluffs at Cove Beach illustrate the result of long-term erosion processes operating over hundreds of millennia. Resistant bedrock, including Smuggler Cove formation, Cape Falcon conglomerate, and Grande Ronde basalt, forms the headlands of Arch Cape and Cape Falcon (Niem and Niem, 1985) (Appendix A). At Arch Cape, block inclusions of Angora Peak sandstone, exposed in sea cliffs towering over 300 ft high, are enveloped in basalt. South of Cove Beach, a 200-ft-wide sliver of well-consolidated Cape Falcon volcanic conglomerate armors steep, 150-ft-high sea cliffs. However, between these resistant promontories, Niem and Niem (1985) mapped Smuggler Cove formation mudstone invaded by basaltic sills and dikes. Like the north flank of Tillamook Head, deep-seated landslides and persistent active slumping characterize the Cove Beach area. Therefore, the higher occurrence of ancient and active landslides in terrain underlain by Smuggler Cove mudstone implies a higher susceptibility to slope failure.

(A)

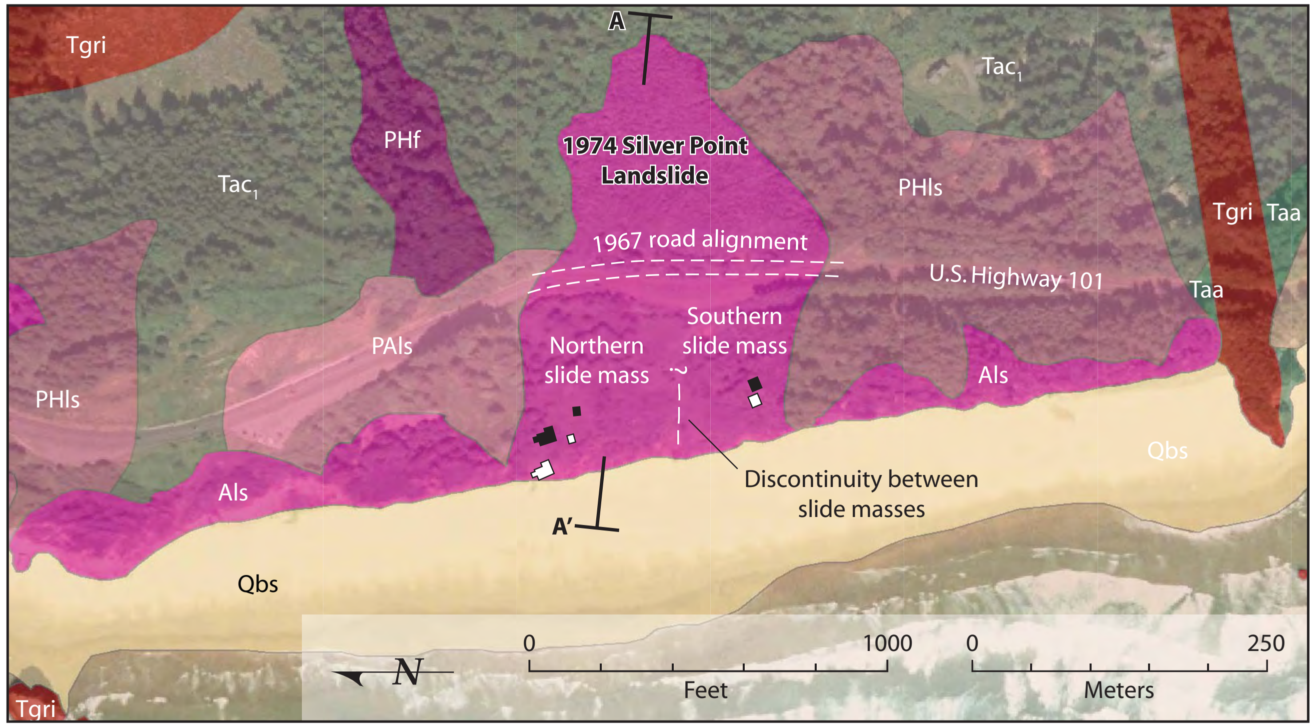


Figure 23. (A) Geologic map of Silver Point showing the location of the 1974 Silver Point landslide. (B) Simplified geologic cross section (A - A') of the 1974 Silver Point landslide (modified from L. R. Squier, Inc., 1974).

Geologic Units

Als - Active landslide complex (historical)

Qbs - Latest Holocene beach sand

PAls - Potentially active landslide complex

PHf - Late Pleistocene to Holocene debris flow

PHls - Late Pleistocene to Holocene complex landslide

Tac$_1$ - Astoria Formation, Angora Peak sandstone

Taa - Astoria Formation, Angora Peak sandstone

Tgri - Middle Miocene, Grande Ronde basalt

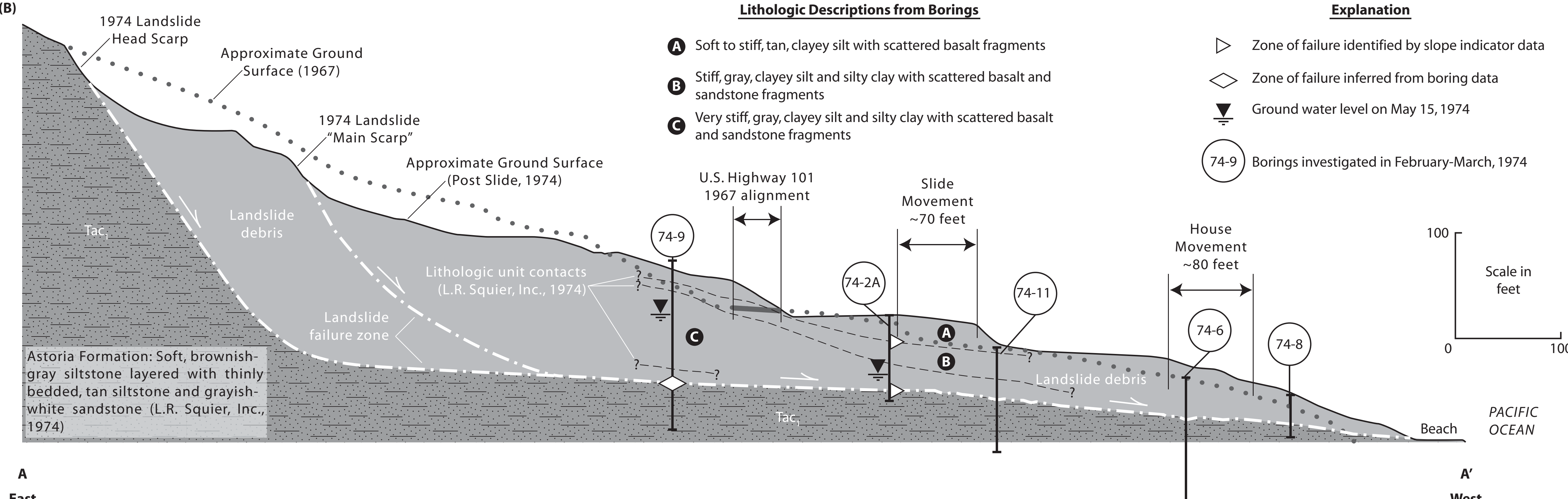
Explanation

House location 1967

Post-1974 landslide house location

A' Geologic cross section A-A' (L.R. Squier, Inc., 1974)

(B)



Lithologic Descriptions from Borings

A Soft to stiff, tan, clayey silt with scattered basalt fragments

B Stiff, gray, clayey silt and silty clay with scattered basalt and sandstone fragments

C Very stiff, gray, clayey silt and silty clay with scattered basalt and sandstone fragments

Explanation

Zone of failure identified by slope indicator data

Zone of failure inferred from boring data

Ground water level on May 15, 1974

74-9 Borings investigated in February-March, 1974

Figure 24. Bluff exposures south of Humbug Point at Redrock Creek reveal an eroded contact between late Pleistocene coastal terrace deposits and the overlying gravel-rich landslide deposit with chaotic clast orientations. The sharp lower contact, marked by the rock hammer, may be an ancient landslide failure plane.

Figure 25. Between Humbug Point and Hug Point, late Pleistocene coastal terrace deposits consist of massive to weakly bedded silt with interbeds of peat and large woody debris. In some cases the wood appears to include buried stumps rooted in growth position.

Figure 26. Large, deep-seated landslides north of Hug Point involve gray, weakly-bedded silts mapped elsewhere as late Pleistocene coastal terrace deposits. Vertically bedded slabs of sandstone blocks (middle right) and anomalous blocks of basalt, located on the beach, may be the resistant remains of prehistoric landslide deposits eroded by ocean waves.

Figure 27. Late Pleistocene debris flow deposits fill a paleovalley incised into Angora Peak sandstone north of Hug Point. Overlying coastal terraces deposits consist of sand with lenses of pebble gravel.

Figure 28. A syncline deforms Angora Peak sandstone forming a small pocket beach south of Austin Point and north of Arch Cape beach. The north limb of the syncline dips 45 degrees to the southwest, making the slopes above prone to dip slope block sliding.

Figure 29. Wood pilings form a rudimentary sea wall (middle distance) along Arch Cape. Bluffs 20 to 30 ft high in late Pleistocene coastal terrace deposits expose dense, cemented gravels (above sea wall).

Figure 30. At the north end of Arch Cape, late Holocene stream terrace deposits of Austin Creek consist of largely massive, yellowish brown silt with minor lenses of coarse sand to gravel. The Austin Creek terrace is inset into late Pleistocene coastal terrace that underlies the Arch Cape area.

Evidence for prehistoric landslides in the Cove Beach area includes hummocky landforms and exposures of landslide deposits in coastal bluffs. Because landforms related to ancient landslides were delineated by interpreting aerial photographs (Table 1) and 1:24,000-scale U.S. Geological Survey topographic maps, the exact dimensions of mapped prehistoric landslides remain uncertain. Exposed along the northern part of Cove Beach, bluffs composed of poorly sorted debris flow fan deposits mantled by colluvium (Qc/PHf) suggest the construction of debris aprons by ancient rock fall on the southern flank of Arch Cape (Figure 31). South and west of the rocky debris flow deposits, a prominent cobble berm impounds a small lagoon that occupies a reentrant in the cove (Figure 32). The origin of this reentrant is unknown. However, eroded bluffs south of the cobble berm expose contorted mudstone beds we mapped as a prehistoric block landslide (PHb, Plate A-8, Appendix A) that suggests the reentrant may be a landslide-related feature. We speculate that westward translation of the landslide block may have formed the grabenlike feature now occupied by the lagoon.

Bluffs backing the central and southern parts of Cove Beach also show indications of prehistoric movement. Cove Beach road traverses the north margin of a large hummocky mound we map as a prehistoric rock avalanche deposit (PHf). In addition to its geomorphic expression, additional evidence for this landslide includes possible sag ponds near the headwall along Highway 101 and exposures of large sandstone blocks chaotically mixed in a matrix of sand and silt (Figure 33) that overlie late Pleistocene coastal terrace deposits. The age of these probable ancient rock avalanche deposits is unknown. However, development of a thick soil A-horizon in deposits overlying the landslide debris is similar to A-horizon characteristics in late Pleistocene coastal terrace deposits exposed in adjacent bluffs, suggesting a similar age. Along Oswald West State Park Road in the southern part of Cove Beach, benched topography is interpreted to reflect several deep-seated landslides localized along the contact between basalt and Smuggler Cove mudstone mapped by Niem and Niem (1985). The topographic expression of the largest prehistoric slide has been confirmed by the presence of a large arcuate heads-

Figure 31. At the north end of Cove Beach, 20- to 30-ft-high bluffs cut into debris fan deposits expose debris flow channels rich in coarse, angular basalt clasts.

Figure 32. A broad cobble berm impounds a small lagoon near the north end of Cove Beach. Arch Cape can be seen in the distance.

Figure 33. Chronic erosion and land sliding along Cove Beach has required many homeowners to modify or move houses away from retreating sea cliffs. Large, jointed sandstone blocks surrounded by sand and silt are inferred to reflect late Pleistocene rock avalanche deposits.

carp resolved in preliminary bare-earth lidar imagery developed from data acquired in 2009 by the Oregon Lidar Consortium (I. P. Madin, personal communication, 2009). Active landslides at the base of these bluffs warn of possible reactivation of the older landslides (Plate A-8, Appendix A).

Active landslides are eroding coastal bluffs in the Cove Beach area at rapid rates. The scalloped bluff edge above the central part of Cove Beach reflects active slumping that has formed arcuate headwall amphitheatres with maximum widths of 125 to 300 ft (Figure 33). Toward the south, shallow slumps and soil sloughs impact the entire length of the bluff (Figure 34). However, at the southern end of Cove Beach, wave erosion has exposed bluffs composed entirely of prehistoric landslide deposits (Figure 35). Exposure of a landslide failure plane in the toe of this ancient landslide (Figure 36) and active debris flow aprons shedding off the bluff (Figure 37) suggest recent renewed movement or impending reactivation of prehistoric landslides destabilized by wave erosion at the base of the bluff.

Figure 34. House undermined by bluff collapse due to wave erosion, southern part of Cove Beach.

Figure 35. Angular basalt clasts in sandy silt matrix form a chaotic landslide deposit (left) at the south end of Cove Beach. The deposit overlies late Pleistocene beach cobbles and sand (right). Along the failure plane at the base of landslide deposits is a 10- to 15-cm-thick, dark gray, fat clay gouge layer. Back-tilted bedding in the beach deposits indicates the entire bluff has moved in the past.

Figure 36. A 10- to 15-cm-thick, dark gray, fat clay gouge layer has developed along the landslide failure plane at the south end of Cove Beach.

Figure 37. Debris flow deposit and debris chute at the south end of Cove Beach. This rock avalanche occurs along the northern margin of resistant Cape Falcon conglomerate (dark gray rock on right) that forms near vertical, 130 to 180-foot-high sea cliffs.

SUMMARY

This report describes the methods and results used to develop a GIS database that defines coastal erosion hazard zones for both dune- and bluff-backed shorelines in southern Clatsop County. The methodology follows approaches used by Allan and Priest (2001a, 2001b) and Priest and Allan (2004) to evaluate coastal erosion hazards for the Clatsop Plains, Tillamook County, and northern Lincoln County, respectively, with some modifications. The database included with this report, when combined with the results of Allan and Priest (2001a) for northern Clatsop County, is intended to be used by County and local land-use planners to promote safer and more sustainable development in the dynamic coastal environment.

The active-hazard zone for southern Clatsop County encompasses areas of coastal bluffs and dunes undergoing active erosion (Appendix B), whether by extreme wave erosion, near-shore sediment transport, gradual erosion, or mass-wasting processes. On dune-backed shorelines, the active-hazard zone reflects the zone of historical beach variability and dune and backshore areas where shore processes regularly modify and reshape ephemeral landforms. On bluff-backed shorelines the active hazard zone includes the beach, bluff toe, and escarpment, all seaward of the top edge of the bluff. The active hazard zone was mapped from field observations, 2005 digital orthophotographs, and by analysis of 1998 and 2002 lidar data.

Erosion hazard zones for bluff-backed shorelines (Appendix B) have been derived from evaluations that incorporate coastal geologic mapping (Appendix A), observed slopes of repose for talus of bluff materials, estimates of historical bluff erosion rates, and empirical estimates of maximum landslide block widths (Table 3). The hazard zones are defined by three scenarios that have decreasing relative likelihood over the next 60 to 100 years.

- *High-Hazard Zone* – Depicts width of bluff retreat caused by gradual or episodic erosion over a period of 60 years based on the mean erosion rate estimated from historical data. This scenario also assumes the bluff slope reaches and maintains an empirically determined angle of repose for talus of the bluff material. Widths of the high-hazard zone range from 20 to 400 ft, depending on local bluff geology.
- *Moderate-Hazard Zone* – Represents the intermediate hazard zone with a boundary defined as the average between the high- and low-hazard zone boundaries. The purpose of this zone is to depict possible erosion scenarios more extreme but less likely than scenarios encompassed by the high-hazard zone that may include combined processes of landslides, subaerial weathering, and episodic bluff erosion over a period of 60 to 100 years. Widths of the moderate-hazard zone range from 25 to 155 ft, depending on local bluff geology.
- *Low-Hazard Zone* – Encompasses the most severe scenario for bluff retreat over a period of 60 to 100 years including maximum estimated landslide block width, bluff retreat to an ideal slope of repose, and bluff erosion at a rate equal to the mean historical erosion rate plus one standard deviation from the mean, and error from measurement uncertainty. Lateral distances to the landward boundary of the low-hazard zone range from 25 to 155 ft, depending on local bluff geology.

Variations in the broad ranges of shoreline retreat predicted for dune-backed beaches (Appendix B) reflect uncertainty in the geometric model used to evaluate shoreline response to extreme storm-wave erosion. The MPEDs used to delineate dune erosion hazard zones vary significantly between the four dune-backed sections of shore and ranged from 102 to 280 ft (31 to 85 m) for the high-hazard zone, 145 to 474 ft (44 to 145 m) for the moderate hazard zone, and 158 to 600 ft (48 to 183 m) for the low-hazard zone. The high-hazard zone encompasses the extent of erosion possible during a single extreme storm with historical precedent. Although less probable, the wider erosion hazard zones predicted by the moderate- and low-hazard scenarios are warranted because they encompass possible shoreline retreat caused by processes in addition to extreme storm waves, including migrating rip-current embayments, long-term transport of sand by longshore drift, onshore and offshore processes, and regional coastal subsidence caused by great Cascadia subduction zone earthquakes (Allan and Priest, 2001).

The high-, moderate-, and low-hazard zones may be viewed as potential areas of future expansion of the active hazard zone (Appendix B). Riprap placed along nearly 50 percent of the shoreline fronting Cannon Beach will likely require ongoing monitoring and maintenance to mitigate future expansion of the active hazard zone, particularly if sea level rise begins to accelerate over the next century. Areas underlain by active or potentially active landslides may experience mass movement, particularly during winter storms characterized by high rainfall. Areas of particular concern regarding any existing or new development include active landslides within Ecola State Park; the area west of Tolovana Hill, including the S-Curves landslide in Cannon Beach; landslides at Silver Point; areas at the southern end of Arcadia Beach north of Hug Point; and the entire Falcon Cove community. Site-specific investigations of geologic hazards should be required in these areas before building permits are issued.

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APPENDIX A. COASTAL SHORELAND GEOLOGY AND LANDSLIDE MAPS FOR SOUTHERN CLATSOP COUNTY

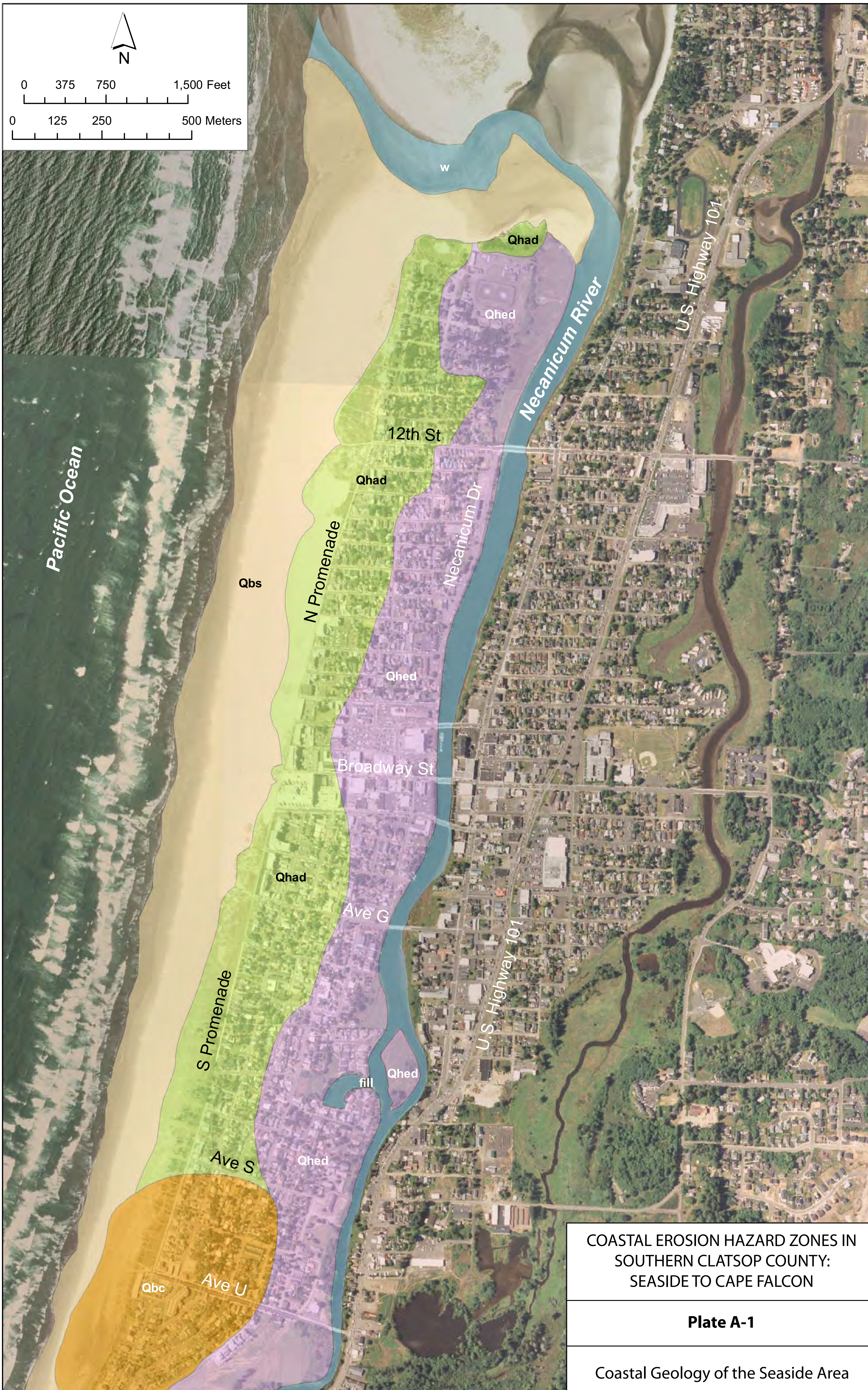
Appendix A contains a description of geologic units for the maps in Appendix A and 1:9,600-scale printable maps of coastal geology and landslides for the southern Clatsop County coast (Seaside to Cape Falcon). The map image page dimensions are 11 inches wide by 17 inches tall.

APPENDIX B. MAPS OF EROSION HAZARD ZONES FOR SOUTHERN CLATSOP COUNTY

Appendix B contains 1:9,600-scale printable maps of erosion hazard zones for southern Clatsop County (Seaside to Cape Falcon). The map image page dimensions are 11 inches wide by 17 inches tall.

Table A-1. Descriptions of Geologic Units Used in Appendix A Maps

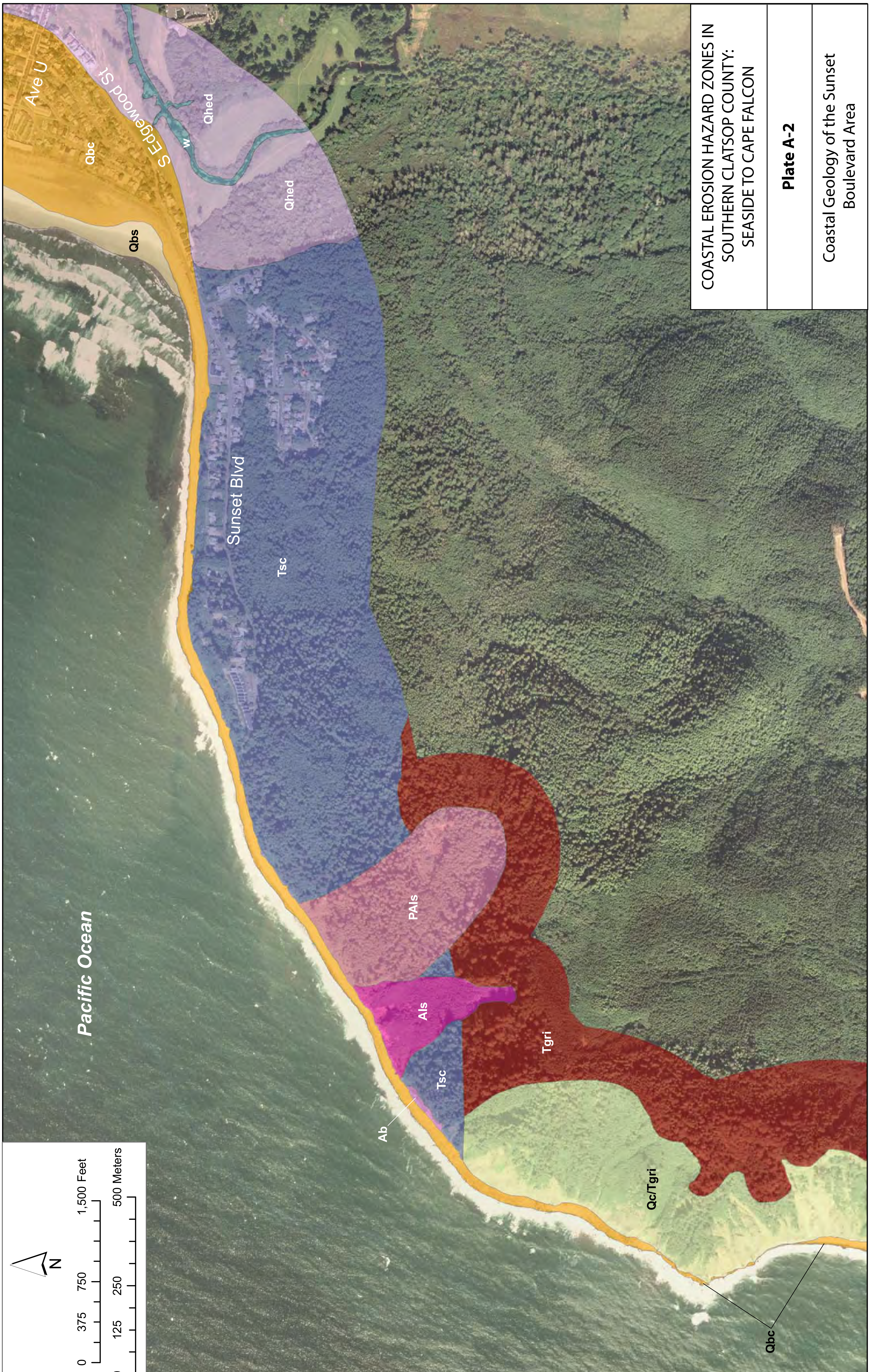
Map Symbol	Description of Geologic Units
fill	**Artificial fill (historical).** Material deposited by humans including highway, road and railroad embankments, riprap, and other shore protection structures. Fill may consist of engineered or non-engineered material.
w	**Water.** Small bodies of water including lakes, streams, and small reservoirs. The Pacific Ocean is not included in this map unit.
Ab	**Active slide block or slump (historical).** Block of rock or consolidated sediment that is actively moving down slope by translation or rotation (slumping) or both and showing evidence of historical movement.
Af	**Active soil or rock flow deposits (historical).** Flow of soil or rock that is currently or recently active.
Als	**Active complex landslide (historical).** Complex landslide (small slide blocks with variable types of translational and rotational movement plus highly disaggregated slide debris) showing evidence of historical movement.
Qbc	**Latest Holocene beach gravel.** Local deposits of well-rounded gravel, including pebbles, cobbles, and boulders typically found near the junctions of beach and dune or bluff. Gravel lithology reflects local bedrock types including basalt, siltstone, and sandstone.
Qbs	**Latest Holocene beach sand.** Well-sorted deposits consisting of fine to medium sand with some fine gravel. Along some beaches, sand may form a thin veneer (<5 ft thick) over shallow bedrock erosion surface. This unit also may include low, ephemeral transverse dune sheets and foredunes formed by seasonal winds.
Qhad	**Latest Holocene active dune sand.** Fine-grained, well-sorted sand deposited by eolian processes in historical time.
PAls	**Potentially active complex landslide deposits.** Latest Holocene to late Pleistocene landslide deposits without evidence of historical movement. However, based on relative lack of dissection of deposits, unknown stability of the slide, and inconclusive geomorphic characteristics interpreted from aerial photographs, Holocene movement cannot be precluded.
PAf	**Potentially active soil or rock flow deposits.** Flow of soil or rock that is currently stable but probably had recurrent down slope movement in the last 150 years.
Qha	**Holocene alluvial deposits, undifferentiated.** Unconsolidated sand, silt, and gravel deposited in alluvial fan, stream terrace, or basin environments where separate types of deposits could not be differentiated. Where mapped, the deposits usually fill shallow valleys along small- to medium-sized streams. The relatively smooth, undissected form of the valley floors suggests that the deposits are relatively young, likely Holocene in age, and have not been subject to post-depositional modification and erosion.
Qhd	**Holocene stabilized dune sand.** Fine-grained, well-sorted eolian sand stabilized by vegetation. These semi-consolidated and weakly cemented deposits were differentiated from younger active dunes on the basis of soil development, vegetation, geomorphic expression, and interpretations of lidar and detailed coastal topographic data.
Qhed	**Holocene estuarine delta deposits.** Deltaic deposits that form at the mouths of coastal streams where tidal currents mix saline water from the ocean with freshwater from streams. Estuarine delta deposits may consist of a variety of materials including silt and clay deposited by tidal and fluvial processes and interbedded organic-rich layers composed of peat or woody debris. Near the mouths of the larger streams and rivers where tidal processes dominate, deposits may consist predominantly of fine- to medium-grained sand locally interbedded with lenses of fluvial gravel.
Qhb	**Late Pleistocene to Holocene basin deposits.** Unconsolidated, fine-grained sediment, primarily silt and clay, deposited in small coastal basins, deflation plains, and interdunal swales. The basins are identified by vegetation, topographic position, surface morphology, and soil type and often contain seasonal wetlands or small lakes impounded by coastal dunes. These deposits may interfinger locally with dune sand, alluvial deposits, and lacustrine sediment.
Qht	**Holocene stream terrace deposits.** Unconsolidated to moderately consolidated and moderately to well-sorted sand, silt, and gravel deposited by streams in point bar and overbank environments. Low, relatively smooth, and undissected terraces are inset into Pleistocene coastal terrace deposits (Qpt) along Arch Cape and Arcadia.
PHb	**Late Pleistocene to Holocene block landslide.** Block of rock that has moved down slope in prehistoric times but is currently stable.
PHf	**Late Pleistocene to Holocene soil or rock flow deposits.** Flow of soil or rock down slope in prehistoric times that is currently stable.
PHls	**Late Pleistocene to Holocene complex landslide deposits.** Landslide deposits that formed in the late Pleistocene to Holocene that lack geomorphic evidence for historical movement.
Qc	**Late Pleistocene to Holocene colluvium.** Unconsolidated to moderately consolidated, poorly sorted gravel, sand, and silt including breccia and small blocks or slumps along coastal bluffs and often mantling shallow bedrock (e.g., Qc/Tgri). In some cases, colluvium may bury or be associated with potential landslide deposits, including Af, Als, and PHf.
Qhb	**Late Pleistocene to Holocene basin deposits.** Unconsolidated, fine-grained sediment, primarily silt and clay, deposited in small coastal basins, deflation plains and inter-dunal swales. The basins are identified by vegetation, topographic position, surface morphology, and soil type and often contain seasonal wetlands or small lakes impounded by coastal dunes. These deposits may interfinger locally with dune sand, alluvial deposits and lacustrine sediment.
Qpf	**Late Pleistocene alluvial fan deposits.** Moderately to poorly sorted, poorly bedded sand, silt, and gravel deposits that form broad, fan-shaped surfaces that emanate from stream valleys and small gullies along the western flank of basalt hills of the western Coast Range near Yachats. Late Pleistocene alluvial fan deposits include material carried down steep mountain valleys by debris flows that debauched out across relatively flat coastal terraces. The late Pleistocene age interpreted for these deposits is based on moderately consolidated deposits, moderate dissection evident in the fan surfaces, deeper soil development relative to Holocene alluvial deposits, and outcrops that show fan deposits directly overlying and in some cases interfingering with late Pleistocene coastal terrace deposits (Qpt).
Qpt	**Late Pleistocene coastal terrace deposits.** Unconsolidated to moderately consolidated gravel, beach, and dune sand; locally contains minor consolidated clay-rich paleosol, colluvium, debris flows, and alluvial sand, silt, and gravel deposited in channel and point bar environments.
Tfsi	**Middle Miocene, Frenchman Springs Member basalt** (from Niem and Niem, 1985). Invasive flows of the Columbia River Basalt Group of Beeson (1979) that include columnar-jointed dikes, sills and peperite complexes with distinct labradorite phenocrysts. Forms the Cannon Beach landmark Haystack Rock and invades Astoria Formation sedimentary rock at Ecola Point.
Tgrp	**Middle Miocene, Grande Ronde Basalt pillow palagonite complexes** (from Niem and Niem, 1985). Basalt complexes consisting of altered basaltic glass, pillow breccias, and submarine pillow lavas. For an expanded description, see Niem and Niem (1985).
Tgri	**Middle Miocene, Intrusive Grande Ronde Basalt** (from Niem and Niem, 1985). Includes invasive sills (15 to 650 ft thick), dikes, and irregular masses of basalt correlated with the Grande Ronde Basalt on the basis of field relationships, age, geochemistry, and other characteristics. For an expanded description, see Niem and Niem (1985).
Tcf	**Middle Miocene, Cape Falcon conglomerate** (from Niem and Niem, 1985). Consists of very poorly sorted, hard volcanic conglomerate containing angular to rounded cobbles and boulders of basalt, basaltic andesite, dacite, and blocks of fossiliferous Anora Peak sandstone of the Astoria Formation (Taa). For an expanded description, see Niem and Niem (1985).
Tac	**Middle to lower Miocene, Astoria Formation, Cannon Beach member** (from Niem and Niem, 1985). Includes well-bedded, laminated to massive micaceous mudstone. The lower part of the Cannon Beach member (**Tac_1**) includes thin-bedded feldspathic sandstone and mudstone; the cross-laminated to laminated sandstone is fine grained, micaceous and carbonaceous, graded and contains sedimentary structures consistent with deposition by turbidite processes (e.g., load cases and convolute bedding). For an expanded description, see Niem and Niem (1985).
Taa	**Middle to lower Miocene, Astoria Formation, Angora Peak member** (from Niem and Niem, 1985). Includes laminated to massive, fine-grained arkosic sandstone and, less commonly, cross-bedded coarse-grained volcanic sandstone. For an expanded description, see Niem and Niem (1985).
Tsc	**Lower Miocene to upper Eocene, Smuggler Cove formation** (informal) (from Niem and Niem, 1985). Includes thick-bedded, tuffaceous claystone and siltstone with interbeds of volcanic sandstone, tuffs, clastic dikes, and glauconitic sandstone. For an expanded description, see Niem and Niem (1985).



COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate A-1

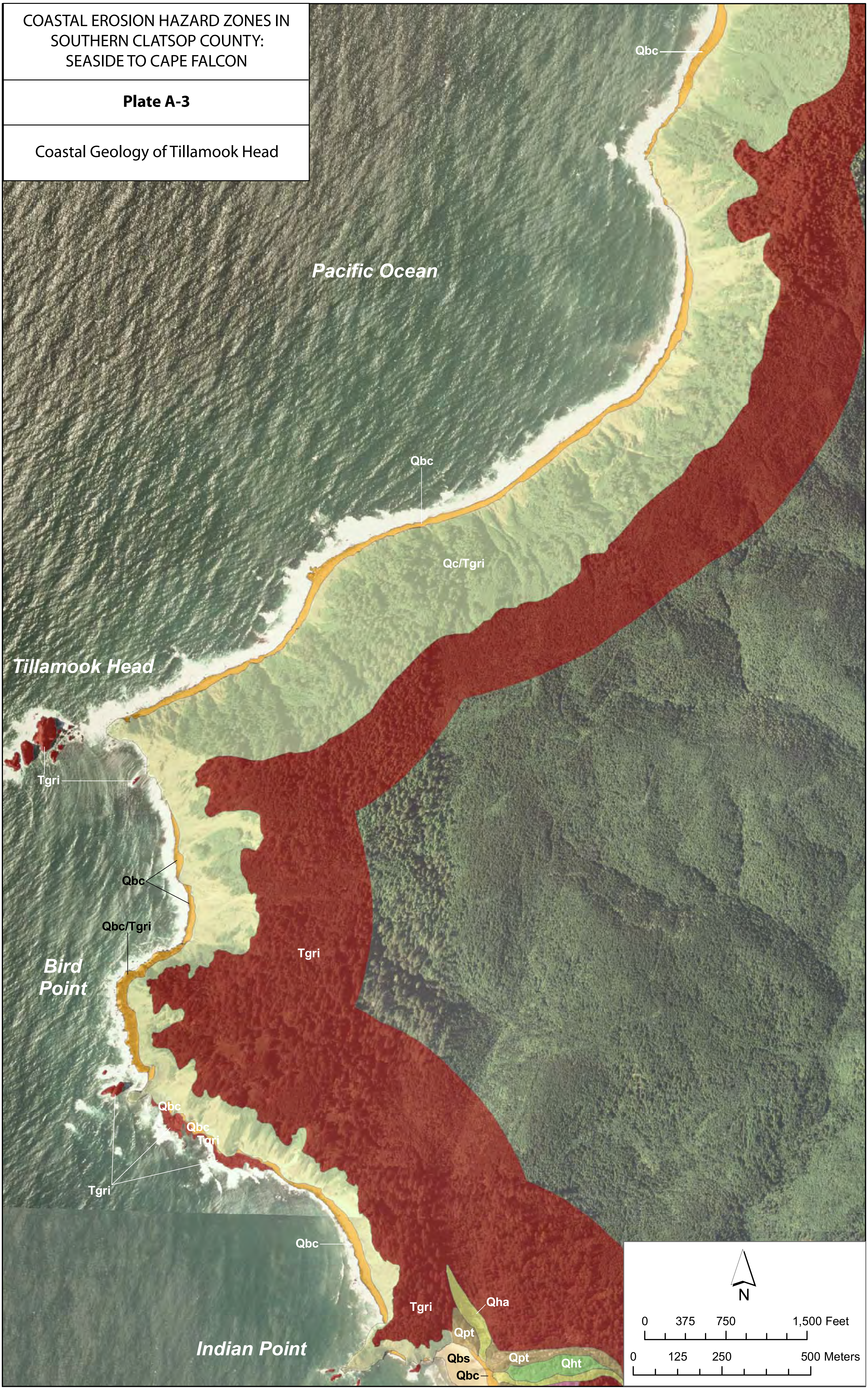
Coastal Geology of the Seaside Area

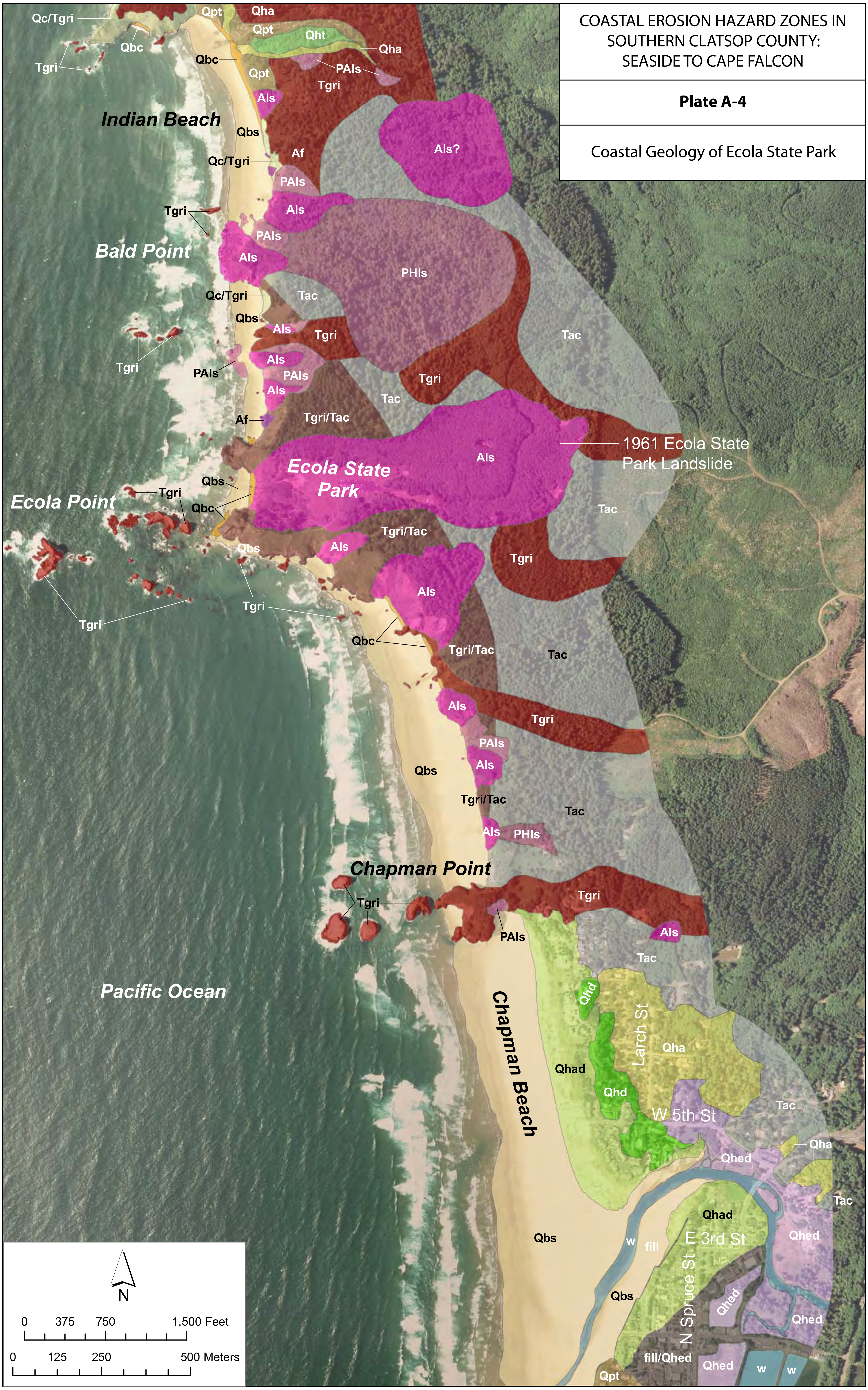

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON
Plate A-2
Coastal Geology of the Sunset Boulevard Area
Ave U
S Edgewood St
Qbc
Qhed
w
Qhed
Qbs
Sunset Blvd
Tsc
PAls
Als
Tsc
Tgri
Ab
Qc/Tgri
Qbc
Pacific Ocean
N
0 375 750 1,500 Feet
0 125 250 500 Meters

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate A-3

Coastal Geology of Tillamook Head




COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON
Plate A-4
Coastal Geology of Ecola State Park
Indian Beach
Bald Point
Ecola Point
Ecola State Park
1961 Ecola State Park Landslide
Chapman Point
Chapman Beach
Pacific Ocean
Larch St
W 5th St
E 3rd St
N Spruce St
Qc/Tgri
Qbc
Tgri
Qpt
Qha
Qht
PAls
Als
Als?
Qbs
Af
PHls
Tac
Tgri/Tac
Qhd
Qhad
Qhed
fill
fill/Qhed
w
N
0 375 750 1,500 Feet
0 125 250 500 Meters

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

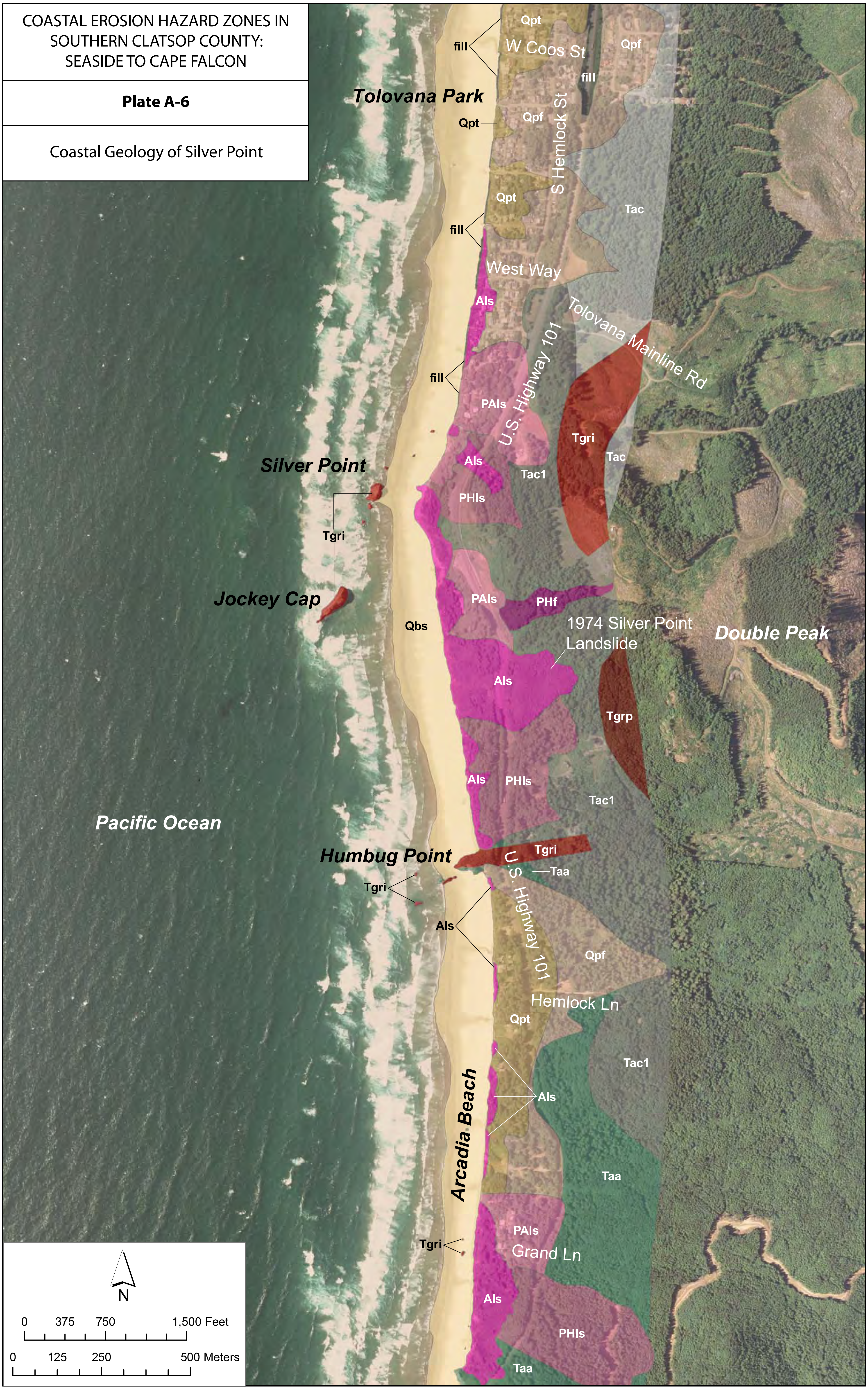
Plate A-5

Coastal Geology of Cannon Beach

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate A-6

Coastal Geology of Silver Point



COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

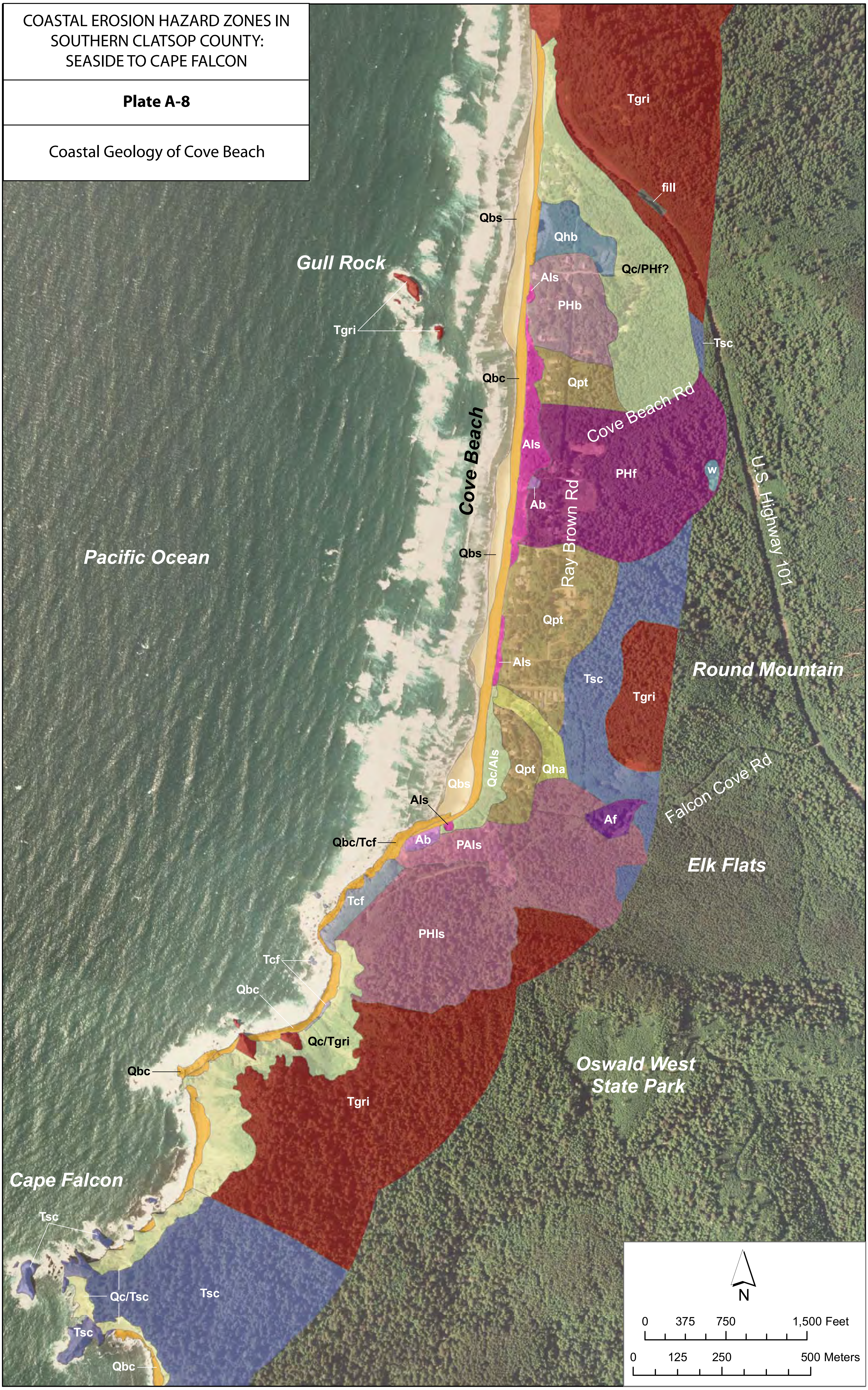
Plate A-7

Coastal Geology of the Arch Cape Area

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate A-8

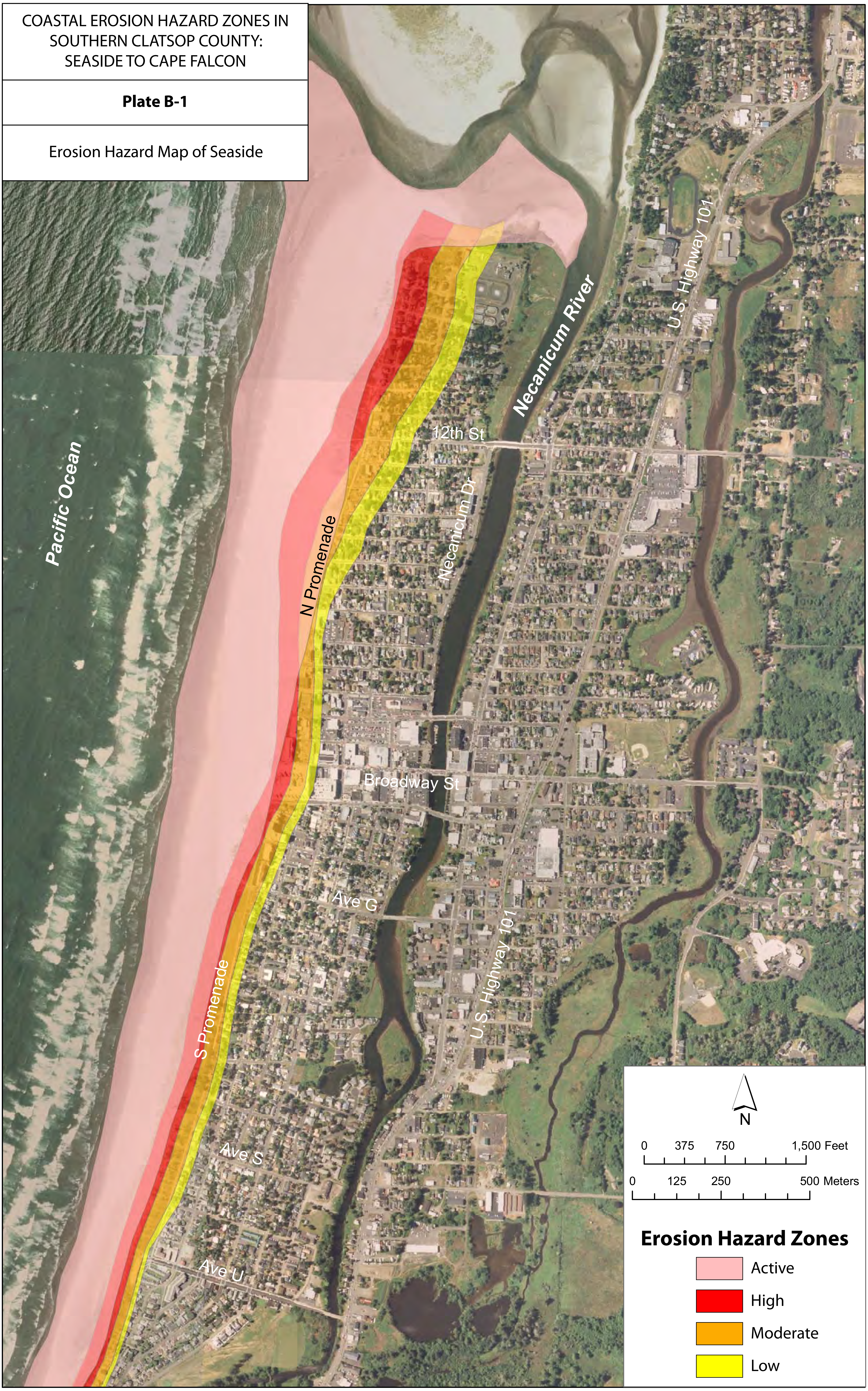
Coastal Geology of Cove Beach



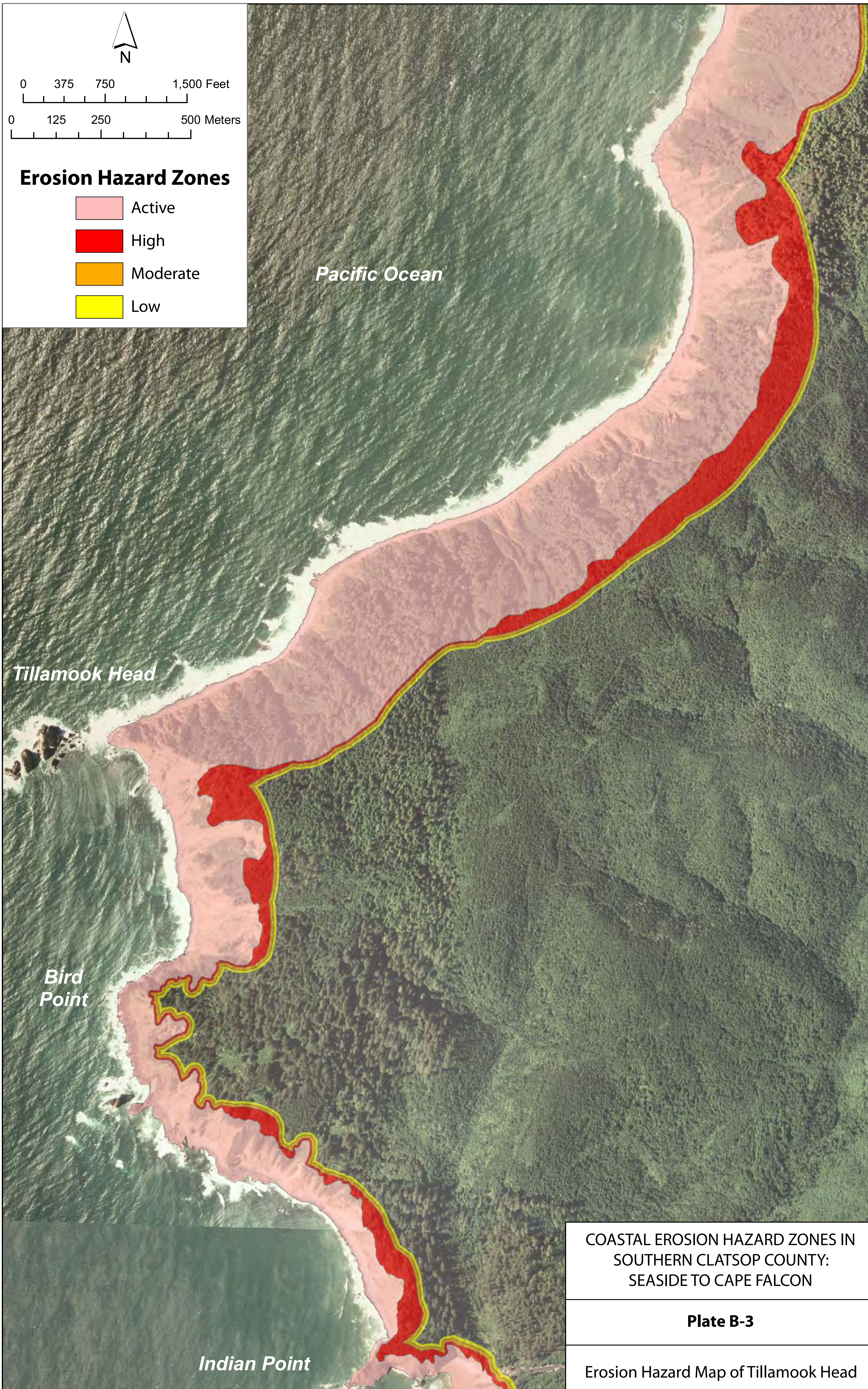
COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate B-1

Erosion Hazard Map of Seaside



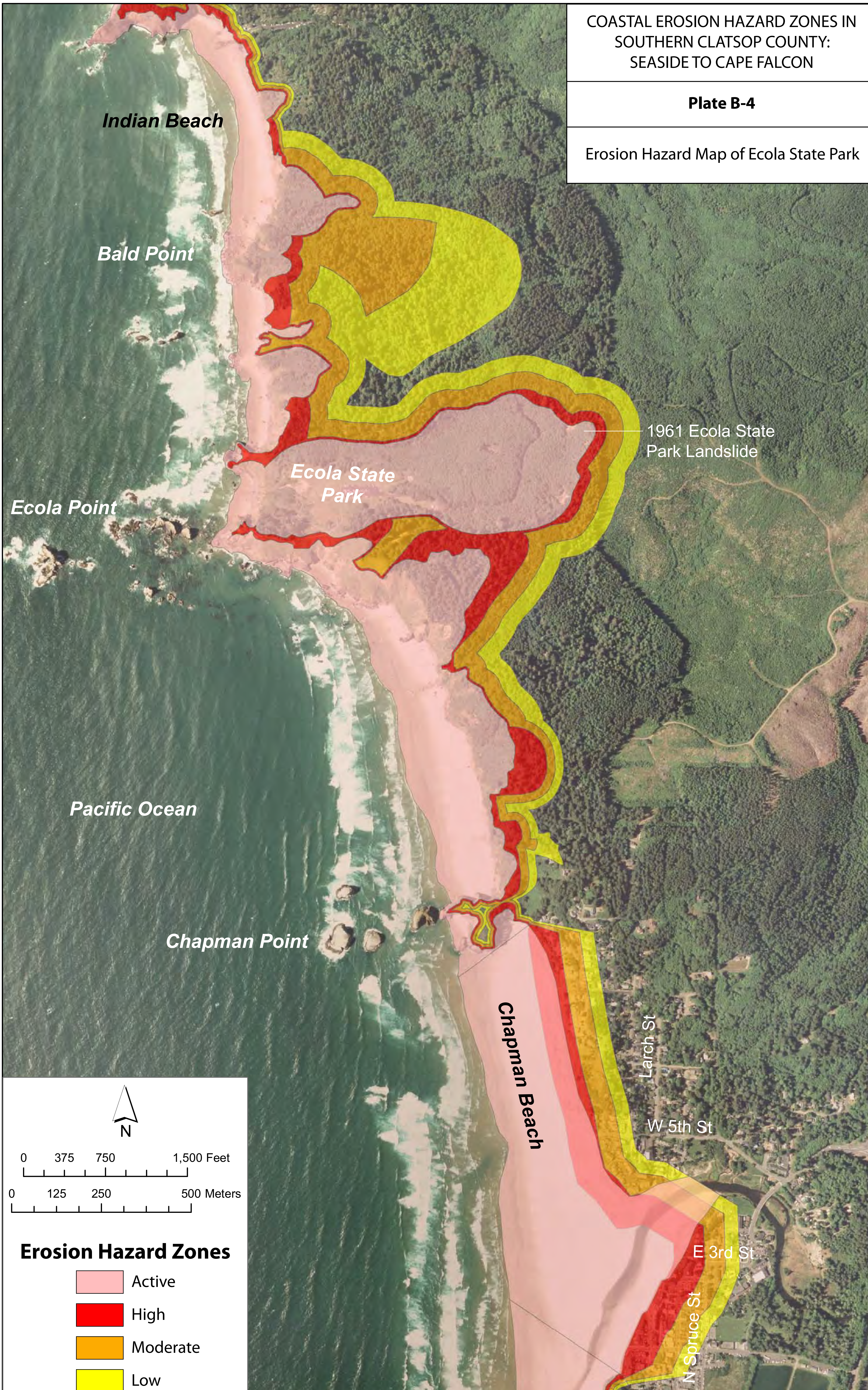

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON
Plate B-2
Erosion Hazard Map of the Sunset Boulevard Area
Ave U
S Edgewood St
Sunset Blvd
Pacific Ocean
N
0 375 750 1,500 Feet
0 125 250 500 Meters
Erosion Hazard Zones
Active
High
Moderate
Low

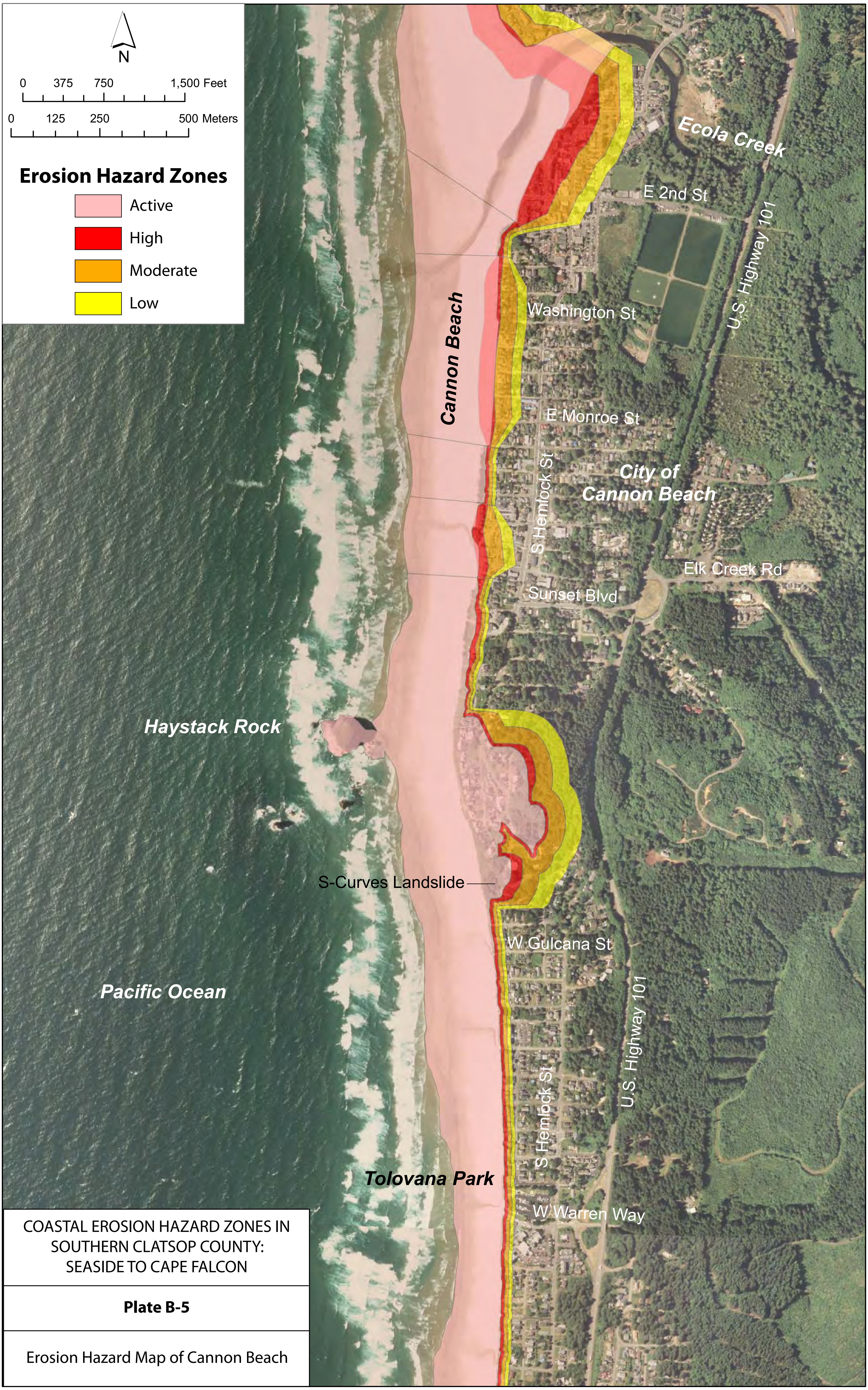


COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate B-3

Erosion Hazard Map of Tillamook Head

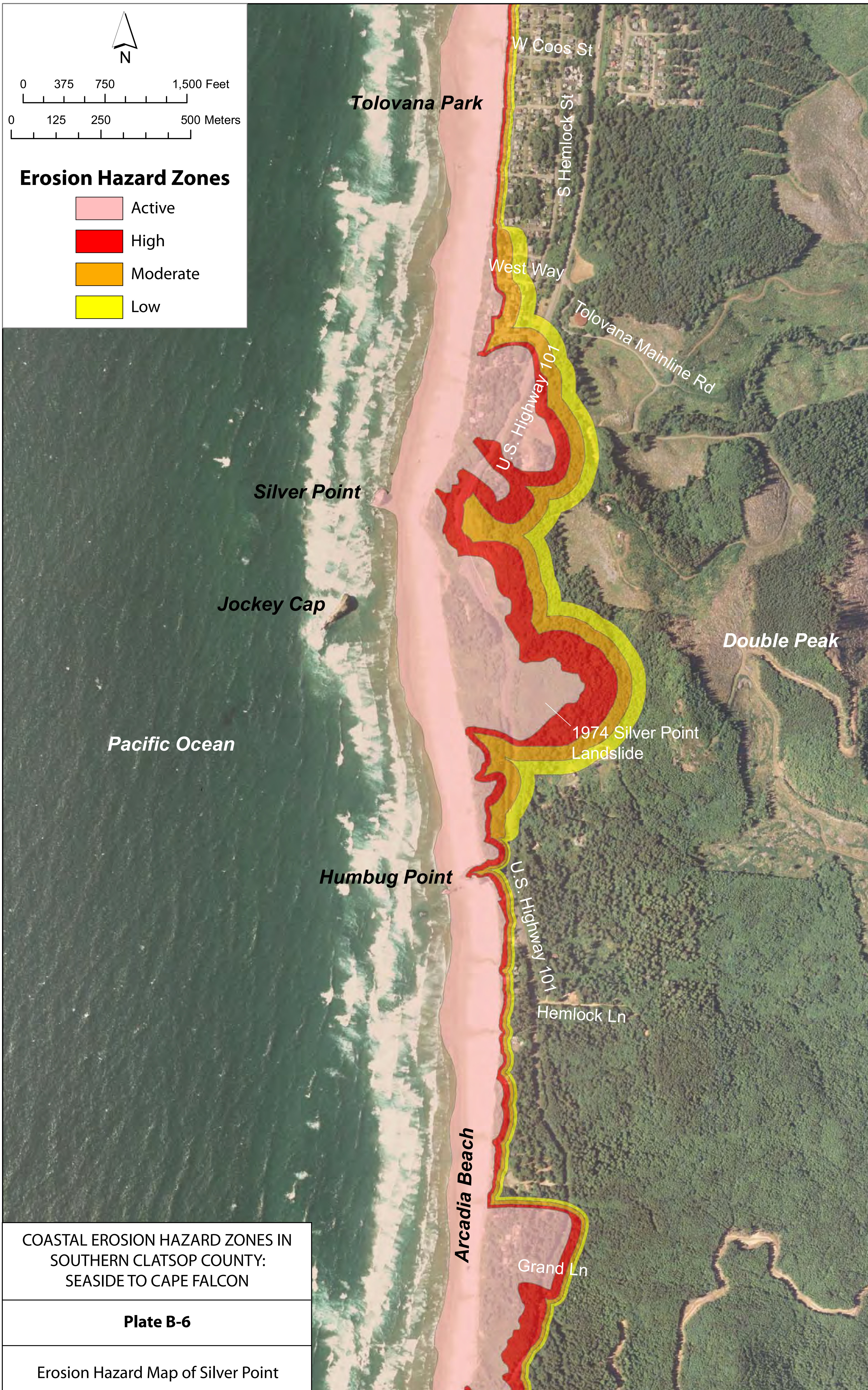

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON
Plate B-4
Erosion Hazard Map of Ecola State Park
Indian Beach
Bald Point
1961 Ecola State Park Landslide
Ecola State Park
Ecola Point
Pacific Ocean
Chapman Point
Chapman Beach
Larch St
W 5th St
E 3rd St
N Spruce St
N
0 375 750 1,500 Feet
0 125 250 500 Meters
Erosion Hazard Zones
Active
High
Moderate
Low



COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate B-5

Erosion Hazard Map of Cannon Beach



COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

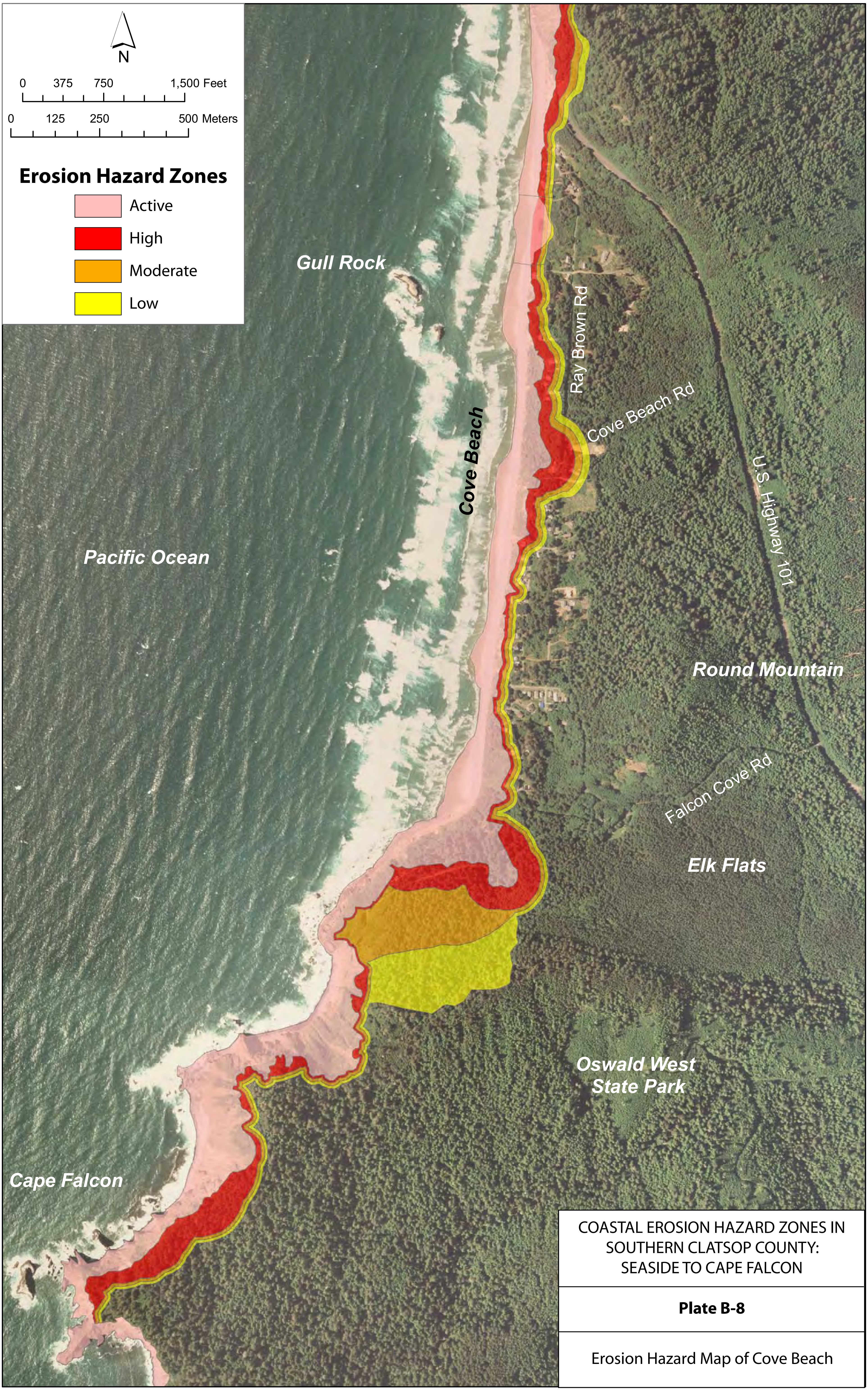
Plate B-6

Erosion Hazard Map of Silver Point

COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate B-7

Erosion Hazard Map of the Arch Cape Area



COASTAL EROSION HAZARD ZONES IN SOUTHERN CLATSOP COUNTY: SEASIDE TO CAPE FALCON

Plate B-8

Erosion Hazard Map of Cove Beach