2 FACTORS AFFECTING SHORELINE STABILITY

Factors affecting shoreline stability occur across a broad range of spatial and temporal scales (Figure 2.1). They involve a complex combination of interactions between geologic, oceanographic, and, to a lesser extent, biologic processes.

2.1 LONG TERM, REGIONAL CONTROLS

Deposition and tectonic deformation that has occurred along the Cascadia subduction zone over the last sixty million years has shaped the morphology of the Pacific Northwest coast. In this regard, a body of recent evidence indicates that a cycle of tectonic activity occurs along the convergent plate boundary that fronts the Pacific Northwest coast. During one part of the tectonic cycle, an extended period of gradual aseismic uplift of the coastal margin occurs in response to the accumulation of strain within the subduction zone. Gradual variations in mean water level, and hence shoreline position, accompany this part of the tectonic cycle. In contrast, the other part of the tectonic cycle is characterized by a major seismic event which occurs as the strain that has accumulated within the subduction zone is suddenly and dramatically released. Rapid variations in mean water level due to subsidence of the margin are associated with this part of the tectonic cycle. Superimposed upon these tectonically-induced variations in shoreline position are variations in global eustatic sea level due to the alternating growth and melting of glaciers. These repeated marine transgressions and regressions have also shaped regional coastal morphology.

One result of these processes operating over time scales of hundreds to thousands of years is that basalts deposited some 15 to 45 million years ago are today resistant headlands, prominent morphologic features along the Oregon coast. For the most part, the prominence of these features is such that over time scales of tens to hundreds of years they restrict longshore transport and thereby define discrete segments of shoreline. Viewing the Oregon coast in terms of headland-bounded segments of shoreline, or littoral cells, is a concept that is useful for both scientific and management purposes (Figure 2.2).

Another result of these processes is that sands and muds deposited some 2 to 40 million years ago, carried upward by tectonic activity, and eroded by waves of ancient seas, today form a series of marine terraces that back much of the Oregon coast. Because this uplift and erosion is differentially distributed along the coast, bluff-backed shorelines along some segments of the Oregon coast stand in marked contrast to dune-backed shorelines found elsewhere along the Oregon coast.

As much as 45% of the Oregon coast consists of dune-backed shorelines. The littoral cell that extends from Heceta Head on the north to Cape Arago on the south, for example, contains the Coos Bay dune sheet. This approximately 150 mile long coastal dune accumulation is the largest in the United States.
Other littoral cells characterized by dune-backed shorelines include the southern portion of the littoral cell that contains the Columbia River and Clatsop Plains, the Rockaway Littoral Cell, and the Nestucca Littoral Cell, on the north Oregon coast, as well as the littoral cells south of Cape Arago, south of Coquille Point, and in the vicinity of Gold Beach on the south Oregon coast.

Bluff-backed shorelines also makeup large segments of the Oregon coast. Much of the central Oregon coast, from Cascade Head on the north to Cape Perpetua on the south consists of bluff-backed shoreline for example. Similarly, portions of the south coast, north of Coquille Point and north of Blacklock Point for example, can also be characterized as bluff-backed shoreline. As will be seen further below, the distinction between segments of shoreline where a sandy beach and dune are the major morphologic elements, and those where a sandy beach and bluff are the major morphologic elements, is another a concept that is useful for both scientific and management purposes.

It was noted above that uplift and erosion is differentially distributed along the Oregon coast. In this regard, along coast differences in rates of aseismic uplift of the coastal margin approach, and in some cases slightly out pace, current rates of global eustatic sea level rise. Specifically, these net changes in mean water level, or relative sea level rise, are such that along northern and southern portions of the Oregon coast the mean water level is estimated to be decreasing at a rate that is currently on the order of 4 to 8 inches per century. In contrast, along the central Oregon coast the mean water level is estimated to be increasing at a rate that is currently on the order of 4 to 8 inches per century.

Observations have been made which point towards a first order correspondence between rates of relative sea level rise and shoreline stability. Along bluff-backed shorelines of the the south coast, the presence of talus at the toe of the slope and of heavy vegetation along the bluff face suggests that processes of wave attack have been relatively inactive since the occurrence of the last catastrophic subduction zone earthquake some 350 years ago: Along bluff-backed shorelines of the central Oregon coast, the absence of talus and at the toe of the slope and of vegetation on the bluff face suggests that processes of wave attack continue to be active.

However, when net rates of change of mean water level along the Oregon coast are compared with those observed elsewhere, the extent to which relative sea level rise is a factor affecting shoreline stability within Oregon coast littoral cells is relatively limited. Rates of relative sea level rise along the Atlantic and Gulf coast, for example, are estimated to be on the order of 2-6 times as high as those observed along the Oregon coast. This is because along the Atlantic and Gulf coasts, unlike the Oregon coast, rising global sea levels are coupled with a continuously subsiding coastal margin, and as a result, an ever increasing mean water level. Still, consideration of the extent to which relative sea level rise may be a factor affecting shoreline stability within individual Oregon coast littoral cells is warranted, particularly if rates of relative sea level rise increase as envisioned under scenarios of global warming in response to the greenhouse effect.

In addition to tectonically and eustatically-induced variations in mean water level, sand supply also represents a first order control on shoreline stability within Oregon coast littoral cells. In this regard, the sediment budget concept is relevant (Figure 2.4). This concept involves viewing a given segment of shoreline in terms of the positive or negative transfers of sediment that occur within it. The resultant balance of the sediment budget is determined by comparing the volume of sediment gained from sources (positive transfers) to the volume lost to sinks (negative transfers). A negative balance means that more sand is leaving than is arriving and, that as a result, that segment of shoreline is eroding. Conversely, a positive balance means that more sand is arriving than is leaving so that the segment of shoreline is accreting.

Whether intentionally or unintentionally, most HATs modify the sediment budget along a segment of shoreline in some manner (Figure 2.5). Beach nourishment, for example, results in augmentation of the sediment budget. By blocking contributions of sediment to the shoreline, seawalls may result in diminution of the sediment budget. Thus, efforts to alleviate hazards along one segment of shoreline
have the potential to impact other segments of shoreline. Because of the compartmentalized nature of the Oregon coast, where transfers of sediment are limited principally to exchanges within individual littoral cells, sediment budget considerations are particularly relevant in this regard.

Along the Oregon coast, potential sources of sand include rivers, bluffs, dunes, and the inner shelf. Potential sinks include, bays, dunes, offshore, dredging, and mining. Detailed sediment budgets of Oregon coast littoral cells are generally lacking. However, it is know that combinations of sources and sinks, as well as absolute budget balances, differ markedly between Oregon coast littoral cells. For example, in the littoral cell that extends from Yaquina Head south to Cape Perpetua, rivers, bluffs, and the inner shelf are likely sand sources. Here active sand volumes per meter of shoreline are estimated at 627 cubic meters. In contrast, active sand volumes per meter of shoreline are estimated at 77 cubic meters in the adjacent Beverly Beach Littoral Cell, where potential sand sources are limited to bluffs and the inner shelf.

2.2 SHORT TERM, LOCAL CONTROLS

Up to this point in the discussion of factors affecting shoreline stability, the focus has been on processes that operate over relatively large temporal and spatial scales. From the standpoint of chronic hazard alleviation, these processes are for the most part manifest as long term trends whose effects are permanent/irreversible (Figure 2.1). Superimposed on these long term regional controls, are processes that operate over relatively small temporal and spatial scales. It is these short term local controls, whose effects are both permanent/irreversible and temporary/reversible, that are the focus of the remainder of the discussion.

2.2.1 DUNE-BACKED SHORELINES AND PROCESSES OF WAVE ATTACK

Along dune-backed shorelines processes of wave attack are the primary control on shoreline stability (Figure 2.1). From the standpoint of ocean flooding it is primarily the magnitude of an extreme runup event that is of particular interest. In this regard, tides, storm surges, barometric pressure effects, temperature effects, and baroclinic currents all affect mean water level. Superimposed upon these longer term elevations in mean water level are short-term variations associated with the passage of waves. Extreme water surface elevations achieved during storms, and expressed at the shoreline as wave runup, result from the simultaneous occurrence of individual maxima within this range of forcing events.

The magnitude of wave runup is influenced not only by water levels and wave heights, but also by beach morphology. On wide, gently-sloping, dissipative beaches runup is weak because much of the incoming wave energy is expended in breaking before it reaches the shoreline (Figure 2.6a). On narrow, steeply-sloping, reflective beaches runup is strong because incoming waves break right at the shoreline with little prior loss of energy (Figure 2.6b).

Note affinities to storm/winter and swell/summer profiles in center of figure (from Komar, 1976).

From the standpoint of wave erosion it is not only the magnitude of runup but its frequency of occurrence that is of interest. In this regard, flooding and erosion along the Oregon coast are confined mainly to the stormy winter months. During this season, regional atmospheric circulation is dominated by the Aleutian Low, a series of low pressure centers that move over the coast at intervals of several days to a week or two and bring heavy rains, high velocity south to southwesterly winds, and high waves. Breaking wave heights of 25-30 feet are not uncommon during winter storms. The shoreline system responds to such high winter waves by transferring sand offshore and storing it in subaqueous bars (Figure 2.6 a). As a result of this erosion, the profile takes on a more concave form (i.e. it becomes more dissipative).

In the summer, the regional atmospheric circulation is dominated by the North Pacific High which brings fair weather, moderate velocity north-north westerly winds, and low waves. During this season, the shoreline system responds to the low waves by transferring sand onshore and storing it in the subaerial beach and dune (Figure 2.6 b). As a result of this accretion, the profile takes on a more convex form (i.e. it becomes more reflective). Profile changes in response to seasonal variations in wave height can be dramatic (Figure 2.7). Such seasonal beach cycles are a characteristic feature of Oregon coast littoral cell dynamics.

During winter storms, rip currents are an important element of nearshore circulation in Oregon coast littoral cells. Rip currents are wave-generated, seaward-flowing currents that develop as part of a larger pattern of horizontal cell circulation (Figure 2.8). In the process of eroding crescent-shaped embayments and moving sand offshore, they act as the locus of storm wave attack. A major episode of erosion that occurred at Siletz Spit in 1972-73 has been clearly associated with rip currents. Similarly, rip currents are likely to have contributed to erosion that occurred at Nedonna Beach in 1977-78 and at Netarts Spit since 1982-83. Erosion in the lee of rip currents can be dramatic, reaching inland as much as 150 feet. However, such erosion tends to be limited in longshore extent, generally affecting only several hundred feet of shoreline.

Besides rip currents, longshore currents are also an important element of nearshore circulation in Oregon coast littoral cells. Generated by waves approaching at an angle to the shore, longshore currents flow parallel to the shoreline (Figure 2.9). Thus, unlike rip currents whose effects on shoreline stability tend to be relatively local, longshore currents affect shoreline stability across the entire length of the littoral cell. Because winds and waves tend to arrive from the southwest during the winter and from the northwest during the summer, Oregon coast littoral cells generally exhibit a seasonal reversal in the direction of longshore as well as cross-shore transport (i.e.net transport is offshore and to north in winter, net transport is onshore and to the south during the summer). The tendency for bay spits to be oriented both to the north and south, and for deposition on opposite sides of harbor jetties to be relatively symmetrical, suggests that in general there is a long term balance between northerly versus southerly sand transport in Oregon coast littoral cells.

Although the concept of long term zero net longshore transport may apply to most Oregon coast littoral cells, it is clear that it does not apply to all Oregon coast littoral cells. A case in point is the littoral cell that encompasses the Columbia River cell, where there is a net northerly direction of longshore sediment transport. Also, the concept of zero net longshore transport does not apply to short term shoreline change. In this regard, significant short term variation in shoreline position has been associated with the 1982-83 El Nino event. During this event, due to the southward displacement of winter storm tracks, waves approached the coast from a more southwesterly direction than normal. An increased frequency of large storms, and in turn more frequent high waves also occurred during this event. Wave heights in the Coquille-Newport area exceeded the average wave height by 2 standard deviations on 22 days for example. Finally, anomalously high values of mean sea level, values as much as 2 feet above the average, were also reported during this event.

In many Oregon coast littoral cells the response to these conditions appears to have been a short-term net displacement of sand from the southern to the northern ends of littoral cells (Figure 2.10). More precisely, the southern ends of littoral cells experienced major erosion during and in the years immediately following an El Nino. At the northern ends of littoral cells, accretion occurred in conjunction with and over the years following an El Nino. Such is the case in the Cannon Beach Cell where, at Arch Cape, located on the southern end of the cell, erosion that occurred in association with the 1982-83 El Nino resulted in the loss of a home to the sea. In contrast, dwellings in Cannon Beach, located at the northern end of the cell, have been experiencing accretion verging on inundation since the 1982-83 El Nino. Similarly, in Neskowin, at the southern end of the Nestucca Cell, erosion occurred in association with the 1982-83 El Nino: Sand accretion in Pacific City, at the northern end of the Nestucca Cell, has resulted in the loss of a home to sand inundation (Figure 2.11). Similar patterns of shoreline change were observed in along portions of the central Oregon coast, near Newport. Alsea Spit and Netarts Spit are also specific locations on the Oregon coast where erosion problems have been attributed to the northward displacement of sand during the 1982-83 El Nino event. Thus, interannual variations in the direction of longshore transport should be viewed as a particularly important factor affecting shoreline stability within Oregon coast littoral cells, although specific effects in any given littoral cell are expected to vary.

Before considering factors affecting the stability of bluff-backed shorelines, the significant role wind-driven sediment transport plays in controlling shoreline stability along some segments of dune-backed shoreline should not be overlooked. As noted above in the context of the 1982-83 El Nino event, excessive accumulation of wind blown sand is a concern along northern portions of several north Oregon coast littoral cells. Excessive accumulation of wind blown sand has also been observed locally within other littoral cells along the Oregon coast (e.g. Bayshore, north of Waldport). Like wave-driven sediment transport, Oregon coast littoral cells generally exhibit a seasonal reversal in the direction of wind-driven sediment transport, with south-southwesterly winds dominating in the summer and north-northwesterly in the summer. Although it has been suggested that along the north coast south-southwesterly winds are the effective winds and along the south coast north-northwesterly winds are the effective winds, the relative dominance of south-southwesterly versus north-northwesterly in individual littoral cells is not well understood.

2.2.2 BLUFF-BACKED SHORELINES AND PROCESSES OF MASS WASTING

Along bluff-backed shorelines processes of wave attack and processes of mass wasting both control shoreline stability (Figure 2.1). Mass wasting includes gradual weathering processes that result in long term trends of bluff recession, such as direct wind and rain impact, as well as episodic landsliding or slumping. The term landsliding is generally applied to translational mass movements, or motions that occur along a more or less planar surface. The term slumping is generally applied to rotational mass movements, or motions that occur about an axis. As most mass movements posses both translational and rotational components of motion however, the terms landsliding or slumping are taken here to represent a broad range of gravity-driven rock, soil, or sediment mass movements (Figure 2.12).

Along bluff-backed shorelines, shoreline stability is pretty much synonymous with slope stability. In this regard, a number of factors affect slope stability, basically by acting to increase driving forces and/or reduce resisting forces (Table 2.1). Bluff material composition is a primary control on slope stability. Hard headland-forming basalts for example, while not immune to mass wasting, do not readily give way. In contrast, soft bluff-forming sandstones and mudstone are highly susceptible to mass wasting. Prolonged winter rains saturate these porous bluff materials, both loading the the slope and lowering cohesive strength, to further decrease slope stability. The geometry and structure of bluff materials also affects slope stability (e.g. bedding and fractures constitute lines of weakness). Further, and together with differences in the permeability of layers, they can control surface as well as subsurface drainage. The slope of bedding may also be relevant in this regard.

With reference to the Oregon coast, much of the shoreline along the central coast consists of seaward-dipping relatively impermeable Tertiary mudstones overlain by permeable Tertiary sand and siltstones. These units are in turn overlain unconformably by Pleistocene marine terrace sands. This sequence of rock units is known to be prone to deep-seated landsliding/slumping, particularly along the segment of shoreline between Yaquina Head and Otter Rock. Where bluffs consists entirely of Plesitocene terrace sands, small, shallow, surficial sloughing rather than than large, deep-seated massive landslides are the primary concern. This distinction between deep-seated slides and shallow surficial sloughs, and a corresponding distinction between long term trends and short term events

By removing sediment from the base of bluffs and by cutting into the bluffs themselves, processes of wave attack may also affect slope stability. The extent to which the beach fronting the bluff acts as a buffer is important in this regard. For example, in the actively eroding Beverly Beach cell, where

sand volumes are low and as a result the fronting beach is narrow, it has been observed that wave runup reaches the toe of the bluff more frequently than it does in adjacent cells. Similarly, in the Lincoln City cell it has been observed that wave runup reaches the toe of the bluff more frequently at the southern end of the cell, along Gleneden Beach where the beach is coarser-grained, steeper-sloping, and narrower(i.e. more reflective), than it does at the northern end of the cell along Road's End Beach, where the beach is finer-grained, gentler, and wider (i.e. more dissipative). Correspondingly, bluff recession has been shown to occur at a higher rate at Gleneden Beach than it does at Road's End.

With respect to actual rates of bluff recession in response to mass wasting and wave attack, high long term rates have been observed along some segments of shoreline. In the vicinity of the Jump Off Joe (Newport) for example, long term rates of bluff recession are as high as 5 feet per year. Along much of the bluff-backed shoreline of the Oregon coast however, long term rates of bluff recession are typically less than 1 foot per year. Still, owing to its spatial variability and episodic nature, together with the permanence of its effects, mass wasting should be viewed as a particularly important factor affecting shoreline stability within Oregon coast littoral cells.

2.2.3 HUMAN ACTIVITIES

Human activities affect the stability of both dune-backed and bluff-backed shorelines (Figure 2.1). At longer time and larger space scales jetty construction and maintenance dredging are factors that can affect shoreline stability (Figure 2.13a). This is particularly true along dune-backed shorelines. The Columbia River and Tillamook Bay jetties, for example, have both been shown to have had a significant impact on patterns of erosion and accretion observed within their respective littoral cells. With respect to maintenance dredging, it has been estimated that one million cubic meters of sand is dredged from Yaquina Bay annually. The entire Newport Cell is estimated to have about 11 million cubic meters of sand. Thus, each year roughly 10 % of the littoral cell sand volume is placed offshore. How much of this sand gets back onshore is unknown.

Cumulative effects of shoreline hardening and the planting of European Beachgrass can also be considered in this context. The latter of these two activities has had a particularly marked affect on the morphology of the Oregon coast. Prior to the introduction of European Beachgrass, generally open unvegetated sand along the shoreline was associated with the presence of large expanses of active dunes that extended considerable distances inland in some areas. With the spread of European Beach grass, the vegetated foredunes that today characterize much of the shoreline of the Oregon coast formed as major portions of these active dune areas were stabilized.

There are a variety of human activities that can affect shoreline stability over shorter time and smaller space scales. Examples of activities typically associated with residential and commercial development include grading and excavation, surface and subsurface drainage alterations, vegetation removal, and vegetative as well as structural shoreline stabilization (Figure 2.13b, 2.13c). With the exception of the latter two, these activities tend to be a particular concern along bluff-backed shorelines where they affect slope stability. With respect to the latter two activities, Nedonna Beach, Manzanita, Pacific City, and Bayshore, are examples of localities where vegetative stabilization has had an effect on shoreline stability; Pacific City and Bayshore are also examples where structural stabilization has had an effect on shoreline stability. Human activities typically associated with recreational use and that are particularly relevant along dune-backed shorelines include pedestrian and vehicular traffic. These activities may result in the loss of fragile vegetation cover (e.g. Coos Bay Dune Sheet.). Human activities associated with recreational use and that are particularly relevant along bluff-backed shorelines include not only pedestrian and vehicular traffic, but also graffiti carving. For example, along Gleneden Beach naturally occurring bluff recession is likely to have been accelerated by graffiti carving.

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