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LANDSLIDE AND EROSION HAZARDS OF THE DEPOE BAY AREA, LINCOLN COUNTY, OREGON

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NOTICE

The Oregon Department of Geology and Mineral Industries produced this paper at the request of the Depoe Bay City Commissioners to meet an immediate need. The report and, especially the accompanying maps, will be produced in final form at a later time. This report has not been edited by the staff of the Oregon Department of Geology and Mineral Industries.

CONTENTS

FIGURES

LANDSLIDE AND EROSION HAZARDS OF THE DEPOE BAY AREA, LINCOLN COUNTY, OREGON

NON-TECHNICAL SUMMARY

INTRODUCTION

This report and the accompanying three maps were produced by the Oregon Department of Geology and Mineral Industries (DOGAMI) at the request of the City of Depoe Bay. The report chiefly outlines chronic hazards of mass movement (unstable slopes) and sea cliff erosion identified during 1991-1993 investigations supported by the Federal Emergency Management Administration (FEMA) and the Department of Land Conservation and Development (DLCD) under the auspices of the National Oceanographic and Atmospheric Administration (NOAA). These investigations focused on the 31-mile stretch of coast from Cascade Head on the north to Seal Rock on the south.

An overview of catastrophic earthquake hazards is also included, but these hazards are not mapped. The techniques for mapping earthquake hazard areas are being developed for an ongoing pilot study of the Siletz Bay area (from the D River to the Gleneden Beach Wayside).

This is a preliminary report encompassing the city limits of Depoe Bay and adjacent lands. The final reports will cover chronic hazards of the entire 31-mile study area and catastrophic hazards of the Siletz Bay area. All should be available by the end of 1994.

SUMMARY OF GEOLOGIC HAZARDS

The chronic hazards of mass movement (rock toppling, landslides, slumps, and soil or rock flows) and sea cliff erosion for the Depoe Bay area are summarized on three 1" = 400' photographic base maps (see Figure 1 for map locations). Hazard areas and points where shoreline erosion is estimated are located within about 40 feet of the actual location, so the maps are for generalized planning; not site specific analysis. Detailed explanation of the geologic processes at work in the area, mapping methodology, interpretation of the map symbols, and use of the data by planners is covered in the geotechnical report below. The geotechnical report is provided for those wishing a more detailed explanation of the geologic hazards and use of the hazard information. Particular attention should be paid to the sections entitled "Advice to Users." These sections offer detailed advice about the use and misuse of the maps.

Large scale mass movements appear to be prehistoric (older than about 150 years) and may be related to prehistoric earthquakes. Prehistoric mass movement has affected several steep hillsides of siltstone and mudstone that surround Depoe Bay, but none occur in areas that are presently developed. Care must be taken not to cause reactivation of these potentially unstable areas by development. For example, cutting the toe (lower end) out of a landslide or injecting

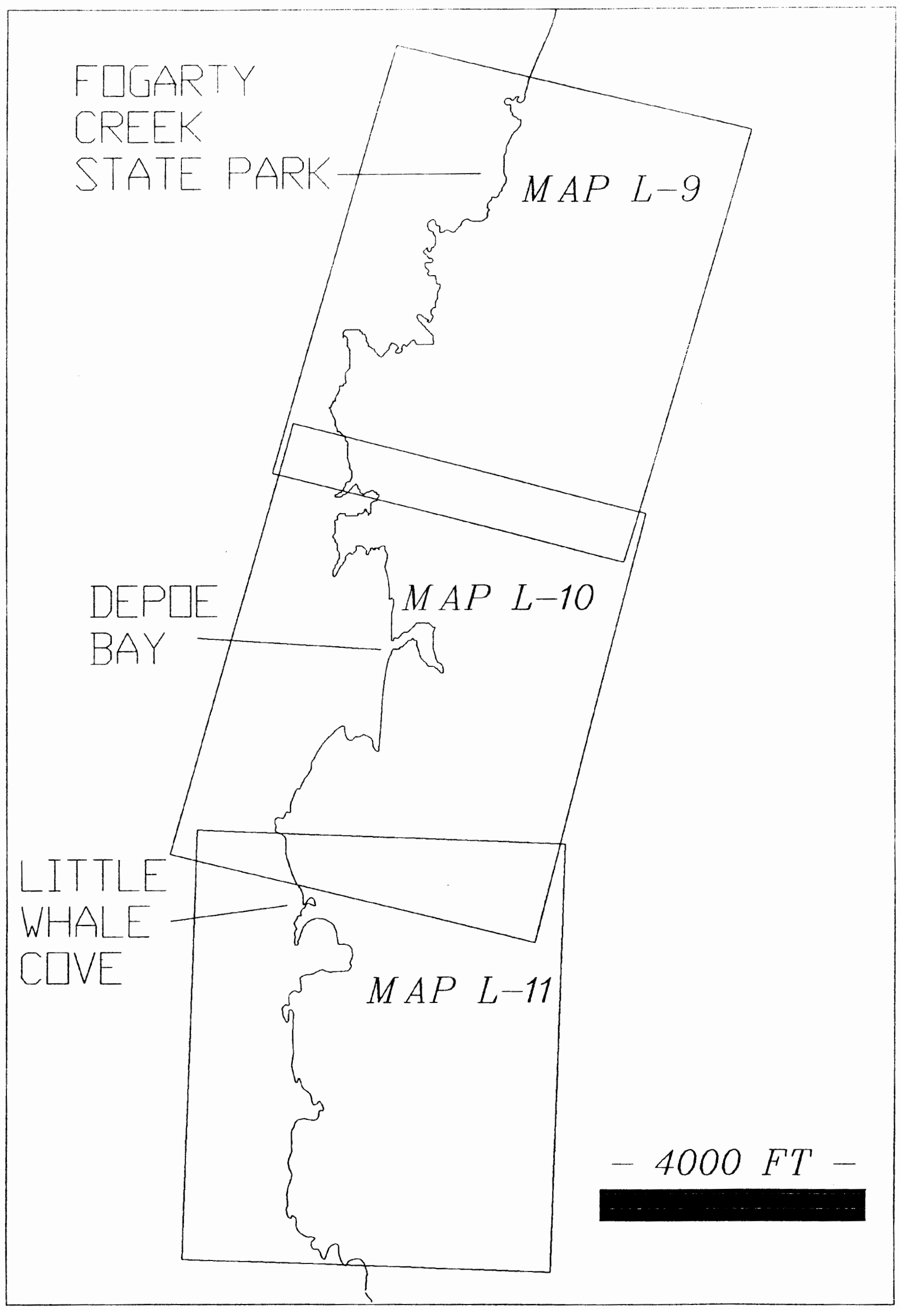

Figure 1. Index to location of the hazard maps.

waste water into it should be avoided or mitigated during development.

There is a small scale toppling hazard at Fogarty Creek State Park on the south end of the beach. Rocks several feet in diameter can topple seaward off the cliff where a fault shatters the rock. This hazard is shown because the potential falling rocks are so large and the landing place is a high use public beach. Clearly rocks can topple off of any of the sea cliffs, especially during freeze-thaw cycles.

Error in measurement of sea cliff erosion rates essentially equalled the rates, so exact rates cannot be specified. However, it is clear that most erosion rates are on the order of 0.2 ft/yr or less and probably approach zero at the hard rock basaltic headlands and the steep basaltic shoreline immediately in front of downtown Depoe Bay. Advice on use of the erosion rate data is given in the geotechnical report in the section entitled "Hazard Map Explanation and Methodology".

The area is at risk from great (M8-9) earthquakes on the giant offshore fault known as the Cascadia subduction zone (Figure 2). Areas subject to tsunami (tidal wave) inundation, amplification of ground shaking, liquefaction (formation of quick sand or quick clay during shaking), and earthquake-induced landsliding should be mapped for land use and emergency planning. Note that historically earthquakes are more likely to cause new landslides than to reactivate old ones, so the map of previous mass movements presented here is not a proxy for a map of earthquake-induced landslide hazards.

ABBREVIATED EXPLANATION OF MAP SYMBOLS

Tick marks shown along the shoreline are places where erosion rates were estimated. The rates are either listed directly on the map or compiled in Appendix 1. The negative sign on each rate indicates shoreline positional change toward land (erosion). See the geotechnical report below for a full explanation of the methodology and technical use of the data.

PHls refers to a typical complex landslide that is currently stable but probably formed in prehistoric times.

PHb refers to block of rock that has moved down slope in prehistoric times but is currently stable.

PHf refers to a flow of soil and rock downslope in prehistoric times that is currently stable.

Enclosed wavy lines are fault zones where erosion rates may be somewhat higher than normal because the rock is shattered.

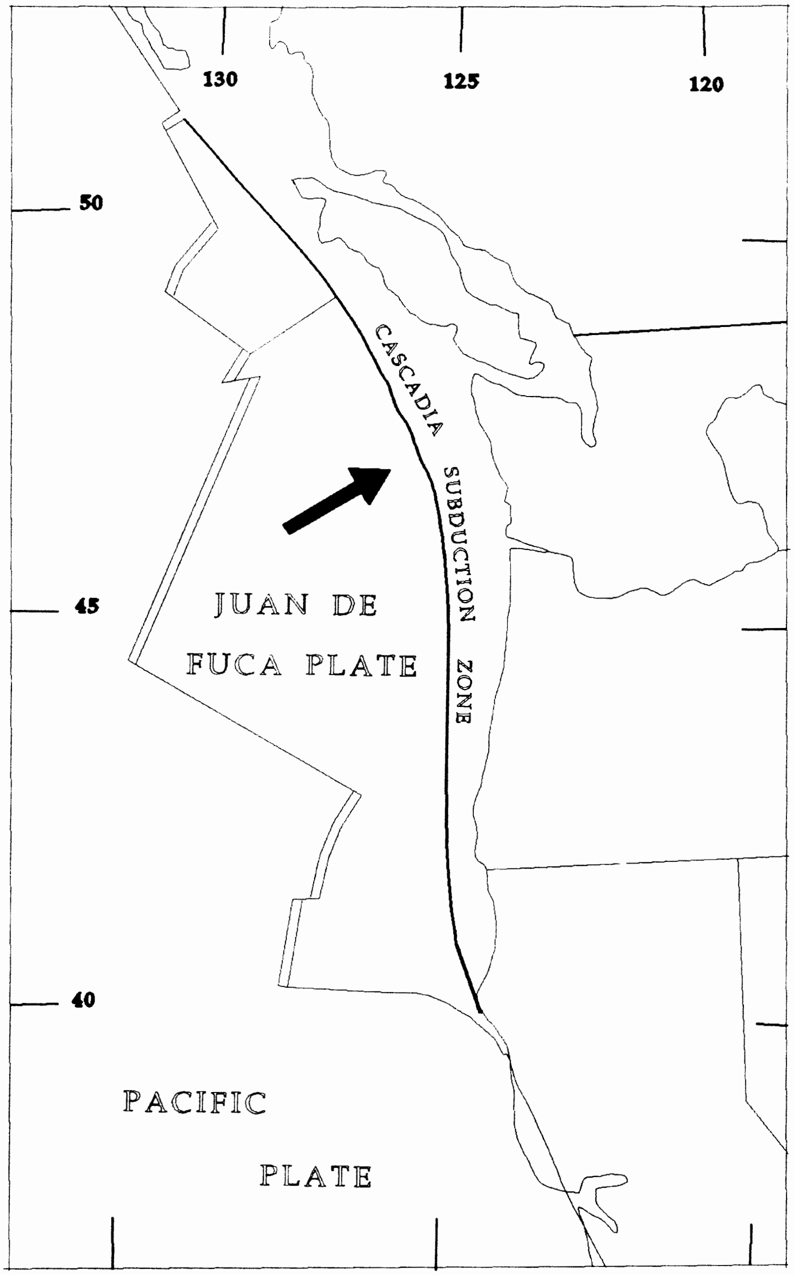

Figure 2. Plate tectonic map of the Pacific Northwest. Juan de Fuca Plate plunges beneath North America at the Cascadia Subduction Zone, one of the largest active faults in North America. Large arrow indicates direction of convergence of the Juan de Fuca Plate with North America.

The area subject to a toppling hazard at Fogarty Creek State Park (Map number L-9) is labeled on the map and shown as a mosaic of irregular lines.

GEOTECHNICAL REPORT AND DETAILED ADVICE TO USERS

INTRODUCTION

This geotechnical report summarizes the geologic setting and resulting hazards that affect the Depoe Bay area. The text is intended for the technical and non-technical reader who is interested in a detailed discussion of the hazards and the use of the three hazard maps.

ROCK UNITS AND GEOLOGIC HISTORY

Most of the sea cliffs on the open coast in the Depoe Bay area are composed of two hard volcanic rock formations (Depoe Bay Basalt and overlying Cape Foulweather Basalt) with well consolidated sandstones (sandstone of Whale Cove) sandwiched in between (Figure 3). The highly fractured siltstone and sandstone of the Astoria Formation underlies these rocks and forms the base of the cliffs behind the inner bay and the most of the hills on the east side of town. All of these rocks were deposited millions of years ago when the area was covered by the sea.

The basalt flows traveled down the ancestral Columbia River all the way from the Oregon-Idaho border, the product of giant flood basalt eruptions 14 to 16 million years ago (Beeson and others, 1979). The cold sea water chilled much of the molten lava, causing it to fracture into small fragments which were quickly cemented together by weathering (Snavely and others, 1973).

The rocks were uplifted during the last several million years only to be repeatedly beveled by incursions of the sea during interglacial times in the last 1.6 million years. About 80,000 years ago one of these high sea stands cut a platform near the top of the present sea cliffs (based on correlation to a marine terrace of the same approximate elevation described by Ticknor (1993) at Otter Rock). The 80,000 year platform is capped by 10-30' of barely consolidated sandstone derived from the former beach sands (marine terrace deposits). Much of downtown Depoe Bay sits atop the sands on this wave cut platform.

FAULTS AND EARTHQUAKE HAZARDS

<u>Cascadia Subduction Zone</u>
About 100 miles offshore there is a giant highly active fault that forms the boundary between the oceanic crustal plate and the North American continental plate (Figure 2). This fault is termed the

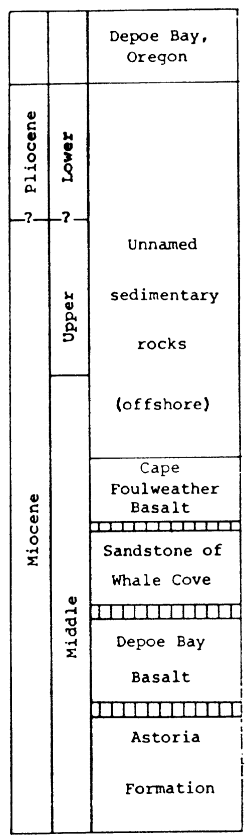

Figure 3. Rock units of the Depoe Bay area (taken from Shavely and others, 1973)

Cascadia subduction zone, and, like all subduction zones, it is the surface along which the two plates are pushed inexorably together, sticking and slipping at intervals of hundreds of years. Each slip may cause earthquakes as large as magnitude 8-9. The last great earthquake was probably about 300 years ago, and scientists agree that another could happen at any time. Probabilities are in the range of 10-20 per cent chance in the next 50 years (Adams, 1990; Peterson and others, 1991). A great earthquake would cause severe shaking lasting a minute or more and large tsunamis (tidal waves, seismic sea waves) which would impact low lying areas. Most loss of life in historic subduction zone earthquakes world wide is from the tsunamis.

Local Faults

Depoe Bay, Little Whale Cove, and Whale Cove owe their existence to north trending faults which cut the older rocks, juxtaposing hard Cape Foulweather Basalt on the noses of the headlands against the more easily eroded sandstone of Whale Cove that forms the landward part of each headland. This zone of faults will be referred to as the Depoe Bay fault zone. The faults dip 16-65^{o}west with rakes in the fault planes of 42 to 80^{o}from horizontal. The trend and general location of the faults exposed in sea cliffs at Little Whale Cove, Depoe Bay and Pirate Cove are consistent with a zone of closely related faults or a single fault with local irregularities in the fault surface. The fault system does not cut the overlying marine terrace deposits and is probably not presently active. The sea has gouged out caves in the fault zone which will some day become sea arches and seaways between offshore sea stacks of the volcanic rock. Where the sea has entirely removed the armor of Cape Foulweather Basalt, it quickly eroded through the sandstone of Whale Cove to the harder Depoe Bay Basalt. This basalt protects downtown Depoe Bay from wave erosion.

Other faults are chiefly located offshore and are related to forces at the Cascadia subduction zone that compress and rotate large blocks of the earth's crust in a clockwise direction (Goldfinger and others, 1992; 1992a; 1993; Wells and Heller, 1988). The faults bounding these blocks trend nearly perpendicular to the shoreline (west northwest trending left lateral faults of Goldfinger and others, 1990; 1992; 1992a) and, in general, penetrate further landward than shore-parallel structures related to compression at the subduction zone. Faults at a high angle to the shoreline offset the 80,000 year marine terrace deposits downward about 18 feet on the north side of Fogarty Creek and down another 15 feet on the north side of Fishing Rock. It may be that these faults are somehow related to the offshore faults. Since many of the offshore faults may be active (Goldfinger and others, 1990), these local faults may be as well. If so, they pose a duel threat of earthquake shaking and direct offset of the surface. For example, the fault that probably follows Fogarty Creek could conceivably cause offsets in the highway bridge there. The fault at Fishing Rock could affect local houses and roads, including Highway 101. Detailed mapping and age determination of these faults is recommended. This may be accomplished by a combination of geological and geophysical investigations.

Since the focus of this report is on chronic erosion and mass wasting hazards, faults are shown on the hazard maps only where they create a hazard from erosion or from toppling and rock fall. Hence fault zones are shown only where they are relatively large and exposed in the sea cliffs.

Advice to Users

Mapping of earthquake hazards is beyond the scope of the investigation. Adequate protection of the public through land use and emergency planning will require mapping of potential tsunami inundation and areas prone to amplification of ground shaking, liquefaction (formation of quick sand or quick clay during shaking), earthquake-induced landsliding, and surface fault offset. Siting of critical facilities such as emergency shelters, hospitals, schools, and fire stations in areas most prone to damage from earthquakes and tsunamis should be avoided. Emergency evacuation and response routes should be planned in the same way.

SEA CLIFF EROSION RATES

There is no erosion rate data for the shattered rocks of the Depoe Bay fault zone or other small faults in the sea cliffs, but the rates are likely to be higher than for adjacent, unbroken rocks. Collapse of the underlying sea caves poses an additional hazard to homes on these faults.

Erosion rates for the volcanic rocks and the sandstone of Whale Cove are of the same magnitude as the measurement error (0.06-0.16 ft/year). Presumably the sandstones would erode somewhat more rapidly if not protected by the adjacent volcanic rocks, perhaps on the order of the rates measured in the Agate Beach area to the south (-0.25 ± 0.36 ft/year).

The soft marine terrace deposits atop the wave cut platform are protected from wave erosion by the underlying hard rocks. Once these soft rocks erode back to a stable slope angle from the underlying rocks they will not erode significantly faster than the hard rocks, unless there is a surface stream present. Measurement of stream bank erosion rates is beyond the scope of this study.

MASS MOVEMENT (Landslides and other rock and soil movement)

Introduction

The nomenclature for mass movements is modified slightly from Sidle and others (1985). The chief modification is use of the term "slide block" to refer to any large block of rock that has moved down slope by rotational (backward tilting) or translational (straight down slope) sliding.

Rock Falls and Topples

All of the sea cliffs in the area have some degree of hazard from rocks falling, especially during and immediately after freezing conditions. In some areas such as Fogarty Creek State Park, large blocks of rock can topple outward from the sea cliff onto high use public beaches. Rock fall and toppling hazards are not mapped unless there is clear evidence of imminent toppling of large blocks of sea cliff onto high use beaches. In general such toppling hazards are restricted to cliffs intercepted by faults.

Bedrock Slides and Flows

Where slopes are steep the siltstones of the Astoria Formation can slide as slide blocks (rotational rock slumps or translational rock slides) that can transform down slope into jumbles of broken rock (rock flows). The sliding can occur on bedding or along the fractures, so it is very difficult to predict which slopes will fail. It is safe to say that existing slides and flows are places where more movement is likely, especially if there is evidence that movement has occurred within the last several years (i.e. bowed trees, cracked pavement, etc.). In general all of the bedrock landslides and flows in this area are in the surrounding hills of the Coast Range and appear to be prehistoric, possibly related to great earthquakes.

Soil Flows and Creep

Soil moves down slope constantly in a process termed creep. When soil is mobilized by water into thick slurries or masses that flow down slope, these features are termed earth flows, if fine grained, and debris flows, if coarse grained. Unlike bedrock landslides, slumps, and rock flows, many of these earth flows and debris flows are shallow failures that terminate at the base of the soil column. Where soil is thick, however, these flows can entrain nearly as much material as bedrock landslides. Soil creep is active throughout the area. Mapping areas of creep or distinguishing large scale soil flows from rock flows is beyond the scope of this study. Large scale rock flows, soil flows, and debris flows are combined into one unit on the hazard maps.

Lateral Spreads

Some topographically high areas can spread slowly down even gentle slopes, if there is a weak layer of rock or soil beneath. This process is most common when soil is liquefied (shaken into a quick sand or quick clay condition) during earthquakes. Mapping areas vulnerable to lateral spreads is beyond the scope of this study.

Complex Mass Movements

Rock slumps can break up down slope into debris flows or mixtures of flows and slumps. These complex mass movements are typical of large landslides. Many of the prehistoric landslides in the area are complex mass movements of this kind.

HAZARD MAP EXPLANATION AND METHODOLOGY

Base Maps and Aerial Photography

The base maps accompanying this report are non-rectified 1993 photos at the 1" = 400' scale. Non-rectified photos are not adjusted for scale distortions inherent in aerial photography, so **data plotted on these maps cannot be directly transferred to geographic information systems**. Positional data was collected during the 1993 aerial photography that will allow rectification, but there is insufficient support to allow rectification of the photos at this time. The digital positional data and images can be obtained upon request.

Shoreline Erosion Rates

Explanation of Map Symbols: The shoreline change rates are shown as negative when the change is toward land (erosion) and positive when toward the ocean (accretion). In the Depoe Bay area all historic shoreline change is from erosion. Appendix I lists estimated erosion rates in feet per year for the points on the shoreline intercepted by the short lines (transects) drawn on the maps. **State Plane coordinates of the shoreline-transect intersection points are referenced to the 1927 North American Datum (NAD). Note that these coordinates will be adjusted to the NAD 1983, when final publication occurs**. Each line has a label such as "C400" that refers to the corresponding label in the database of Appendix I. Where transects, because of the geometry of the shoreline, miss important rock type changes for which there is nearby erosion rate data, the estimated erosion rate is shown directly on the map, delimited by a line subparallel to the shore with tick marks at each end.

Methodology: Erosion and accretion rates were estimated in this area by comparing modern and historical house-to-bluff distances. The modern distance was measured with a tape in the field. The historical distance was taken from 1967 vertical air photos of the Oregon Department of Transportation, estimating photo scale at each point from field measurement between objects persisting since 1967. This technique effectively corrects for radial and other photographic distortions on the 1967 photos.

Rates of erosion and accretion were determined by dividing the amount of positional change of the shoreline or bluff by the amount of time separating the observations, generally 26 years. The positional change was measured along a line (transect) perpendicular to an arbitrary base line drawn roughly parallel to the coast. Transects are located approximately every 150 ft along the coast. Any transect is within about plus or minus 40 ft. of its actual location. This locational error reflects the scale of the base maps and the fact that the base map photos are not rectified.

If an individual house-to-bluff measurement site fell within 40 ft of a transect, that transect was assigned the erosion rate. If it fell between two transects, both were assigned the erosion rate. This technique honors the individual house-to-bluff data points but preserves the focus of the database which is for generalized planning rather than site specific analysis.

Where there was no way to measure house-to-bluff rates, the rate was estimated, if possible, by taking the average (mean) of house-to-bluff rates from geologically similar areas in Lincoln County. These rates are subject to great uncertainty which is reflected, in part, by relatively large plus and minus errors listed with the rates.

As previously explained, the geometry of the shoreline causes the transects to miss important rock type changes in some areas, so rates in these areas are shown directly on the map. The rates shown are estimated from house-to-bluff measurements in the same geological setting. Again, the positional accuracy of the drawn boundaries of these rates is plus or minus 40 ft.

Erosion Rate Errors: The error listed next to each erosion or accretion rate reflects the absolute measurement errors caused by photographic scales and field measurement problems, as well as the scatter of the data in multiple trials. In statistical terms the listed rate is one standard deviation from the mean (average), so, assuming a normal probability distribution of possible values (bell-shaped curve), there is about a 68 per cent chance that the actual rate lies between one extreme or the other of the error range. Expanding the range to two standard deviations (twice the listed plus or minus error) raises the chance to 95 per cent. If the distribution is not normal, there is still at least a 75 per cent chance that the actual rate is within two standard deviations of the mean (Chebyshev's theorem). For example, a rate of -0.10 0.05 ft/yr has a 75 per cent chance of being between 0.00 ft/yr and -0.20 ft/yr, regardless of the shape of the frequency distribution of possible values.

No erosion rates are estimated for areas armored by shoreline protection structures (SPS) such as sea walls or rip rap, since these devices change the natural erosion rate to near zero until they are themselves eroded away. The likelihood of SPS being eroded away varies dramatically depending on the type, quality of installation, and coastal setting. Judgements about appropriate erosion rates in areas with SPS should be made in consultation with appropriate experts in engineering and coastal geology. SPS are, in general, lacking in the Depoe Bay area.

For a more detailed explanation of the methodology and sources of error in the database of shoreline change rates see Priest and others (1993). Note also that some of the rates listed here differ from those of Priest and others (1993). The rates listed here should be used, since they reflect more refined mapping and locational data.

Advice to Users: The house-to-bluff erosion rate data base for this area is very sparse, so most of the erosion rates are estimated by averaging data from geologically similar areas. These rates and the individual house-to-bluff rates are only crude estimates of the order of magnitude of the actual erosion rates. **<u>The rate data presented here are for generalized planning only and must be augmented by detailed geotechnical studies for specific sites</u>**.

Use of the mean erosion rate or the mean plus one or two standard deviations are possible choices for generalized planning (e.g. setbacks), depending on the amount of caution thought appropriate. Use of mean erosion rates minus one or more standard deviations is not recommended for planning purposes, since this would have a high probability of underestimating the hazard.

<u>Mass Movement</u>

Explanation of Map Symbols: Areas subject to slides and flows were separated into three age categories:

PH (prehistoric): Currently stable but probably unstable in prehistoric times (>150 years before present), possibly during great (M8-9) earthquakes. If the probabilities of movement are approximately the same as those for great earthquakes, then there is approximately a 10-20 per cent chance of movement in the next 50 years (Adams, 1990; Peterson and others, 1991). However, if disturbed by works of man, these areas could become unstable. Most of these areas are large-scale (hundreds of feet) slide blocks and landslides with no evidence of recent movement. Most are extensively eroded within and at the contacts of the disturbed ground.

PA (potentially active): Currently stable (few if any bowed trees and little evidence of current slope movement), but probably with recurrent movement in the last 150 years. Disturbance of these features by works of man could reactivate them. Unlike the prehistoric slides, these features are generally not extensively eroded and have well preserved landslide topography. Many show no evidence of movement since 1939 or 1967 aerial photography but are probably more likely to have movements than the prehistoric slide areas. Exact probabilities of movement are not known but are probably greater than the probability for prehistoric slides (10-20 per cent in the next 50 years). Mass movements of this age were not found in this study.

A (active): Currently unstable with evidence such as bowed trees, cracked pavement, and broken modern soil indicative of ongoing movement. Mass movements of this age were not found in the Depoe Bay area.

Subscripts are added to the above labels to indicate the nature of the mass movement:

f (flow): indicates a highly broken up mass of soil or rock that was deposited by a debris flow, earth flow, or rock flow.

b (slide block): indicates that a <u>block</u> of rock has slipped down slope, rotating backward as a slump or slipping straight down slope as a rock slide.

ls (complex landslide): indicates an area with a complex mixture of flows and blocks typical of most large landslides.

?: indicates uncertainty about the age or type of the mass movement. Uncertainty generally arises from ambiguous evidence as interpreted from air photos and field reconnaissance. Because of the reconnaissance nature of the hazard study, some inland areas with difficult access were mapped only by interpretation of air photos. Many of these areas are queried.

Methodology and Errors: Geological mapping in the field and on 1993 vertical air photos was undertaken to define the boundaries of areas of mass movement. Boundaries are within about plus or minus 40 feet of their actual location. This error is inherent in the scale of the base maps and uncertainties in the field mapping.

Note that only large-scale features were mapped. For example, areas with small-scale (5-40 feet wide) sloughing of cliffs are not mapped.

Advice to Users: <u>Areas of mass movement shown on the maps are located from reconnaissance level mapping; such mapping should not be used as a substitute for site-specific geotechnical mapping</u>. Each mapped mass movement area should be examined by a qualified professional before development occurs to determine the actual extent of the hazard.

Lack of a mapped large-scale mass movement on steep slopes does not indicate that there cannot be a mass movement there. It is possible to miss mass movements when utilizing reconnaissance mapping techniques. According to Keefer (1984, p. 406) in a study of 40 earthquakes world wide, "Few earthquake-induced landslides reactivate older landslides; most are in materials that have not previously failed." Hence many slopes without mapped landslides could pose a threat in the event of an earthquake. According to Sidle and others (1985), even without earthquakes, many soil laden slopes over 25° are subject to rapid mass movement. They found that the lower limits for initiation of slumps is 7 to 18°; those for earth flows are 4 to 20°. Dragovich and others (1993) found that "a slope gradient of 50 per cent (26.6°) or better delimits the onset of significant shallow landsliding on slopes prone to failure." They also note that deep-seated failures occur at lower slope gradients than shallow failures.

As a practical guide, it is recommended that **<u>any slope greater than about 25 per cent (14°) be examined by a qualified professional before development</u>. <u>This detailed examination is especially essential in siltstones of the Astoria Formation</u>**. See Schlicker and others (1973) for maps of the Astoria Formation and slopes greater than 25 per cent.

For **all categories of mass movement**, actions should be avoided that further destabilize the slope. Planning should therefore take into account development effects. For example, excavation of a steep slope or cutting the toe out of a stable landslide could cause slope failure. Similar failures can be caused by injecting waste water into an existing landslide or into a steep slope.

Mass movements can cause a severe flooding hazard where they block streams. This can be followed by renewed mass movement when the temporary lake spills over, cutting through the blockage (toe) of the displaced soil or rock mass and catastrophically flooding downstream. Evaluation of this hazard scenario may be advisable for unstable slopes poised above significant streams.

ACKNOWLEDGEMENTS

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APPENDIX 1

EROSION RATE DATABASE FOR THE DEPOE BAY AREA

APPENDIX I
EROSION RATE DATABASE FOR THE DEPOE BAY AREA

TRANSECT	RATE	ERROR	SPS?	SOURCE OF RATE
#c201	−0.09	0.16	N	MEAN BASALT RATE
#c202	−0.09	0.16	N	MEAN BASALT RATE
#c203	−0.09	0.16	N	MEAN BASALT RATE
#c204	−0.09	0.16	N	MEAN BASALT RATE
#c205	−0.09	0.16	N	MEAN BASALT RATE
#c206	−0.09	0.16	N	MEAN BASALT RATE
#c207	−0.09	0.16	N	MEAN BASALT RATE
#c208	−0.09	0.16	N	MEAN BASALT RATE
#c209	−0.09	0.16	N	MEAN BASALT RATE
#c210	−0.09	0.16	N	MEAN BASALT RATE
#c211	0.00	0.07	N	C219−220 VALUE
#c212	0.00	0.07	N	C219−220 VALUE
#c213	0.00	0.07	N	C219−220 VALUE
#c214	0.00	0.07	N	C219−220 VALUE
#c215	0.00	0.07	N	C219−220 VALUE
#c216	0.00	0.07	N	C219−220 VALUE
#c217	0.00	0.07	N	C219−220 VALUE
#c218	0.00	0.07	N	C219−220 VALUE
#c219	0.00	0.07	N	NO. 159−1, 67−93, INGMAR
#c220	0.00	0.07	N	NO. 159−1, 67−93, INGMAR
#c221	0.00	0.07	N	C219−220 VALUE
#c222	0.00	0.07	N	C219−220 VALUE
#c223	0.00	0.07	N	C219−220 VALUE
#c224	−0.09	0.16	N	MEAN BASALT RATE
#c225	−0.09	0.16	N	MEAN BASALT RATE
#c226	−0.09	0.16	N	MEAN BASALT RATE
#c227	−0.09	0.16	N	MEAN BASALT RATE
#c228	−0.09	0.16	N	MEAN BASALT RATE
#c229	−0.09	0.16	N	MEAN BASALT RATE
#c230	−0.09	0.16	N	MEAN BASALT RATE
#c231	−0.09	0.16	N	MEAN BASALT RATE
#c232	−0.09	0.16	N	MEAN BASALT RATE
#c233	−0.09	0.16	N	MEAN BASALT RATE
#c234	−0.09	0.16	N	MEAN BASALT RATE
#c235	−0.09	0.16	N	MEAN BASALT RATE
#c236	−0.09	0.16	N	MEAN BASALT RATE
#c237	−0.09	0.16	N	MEAN BASALT RATE
#c238	−0.09	0.16	N	MEAN BASALT RATE
#c239	−0.09	0.16	N	MEAN BASALT RATE
#c240	−0.09	0.16	N	MEAN BASALT RATE
#c241	−0.09	0.16	N	MEAN BASALT RATE
#c242	−0.09	0.16	N	MEAN BASALT RATE
#c243	−0.09	0.16	N	MEAN BASALT RATE
#c244	−0.09	0.16	N	MEAN BASALT RATE
#c245	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c246	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c247	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c248	−0.09	0.16	N	MEAN BASALT RATE
#c249	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS

TRANSECT	RATE	ERROR	SPS?	SOURCE OF RATE
#c250	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c251	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c252	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c253	−0.08	0.08	N	MEAN BASALT−ARMORED POCKET BEACH SS
#c254	−0.09	0.16	N	MEAN BASALT RATE
#c255	−0.09	0.16	N	MEAN BASALT RATE
#c256	−0.09	0.16	N	MEAN BASALT RATE
#c257	−0.09	0.16	N	MEAN BASALT RATE
#c258	−0.09	0.16	N	MEAN BASALT RATE
#c259	−0.09	0.16	N	MEAN BASALT RATE
#c260	−0.09	0.16	N	MEAN BASALT RATE
#c261	−0.09	0.16	N	MEAN BASALT RATE
#c262	−0.09	0.16	N	MEAN BASALT RATE
#c263	−0.09	0.16	N	MEAN BASALT RATE
#c264	−0.09	0.16	N	MEAN BASALT RATE
#c265	−0.09	0.16	N	MEAN BASALT RATE
#c266	−0.09	0.16	N	MEAN BASALT RATE
#c267	−0.09	0.16	N	MEAN BASALT RATE
#c268	−0.09	0.16	N	MEAN BASALT RATE
#c269	−0.09	0.16	N	MEAN BASALT RATE
#c270	−0.09	0.16	N	MEAN BASALT RATE
#c271	−0.09	0.16	N	MEAN BASALT RATE
#c272	−0.09	0.16	N	MEAN BASALT RATE
#c273	−0.09	0.16	N	MEAN BASALT RATE
#c274	−0.09	0.16	N	MEAN BASALT RATE
#c275	−0.09	0.16	N	MEAN BASALT RATE
#c276	−0.09	0.16	N	MEAN BASALT RATE
#c277	−0.09	0.16	N	MEAN BASALT RATE
#c278	−0.09	0.16	N	MEAN BASALT RATE
#c279	−0.09	0.16	N	MEAN BASALT RATE
#c280	−0.09	0.16	N	MEAN BASALT RATE
#c281	−0.20	0.14	N	NO. 165−6, 67−93, INGMAR
#c282	−0.06	0.12	N	NO. 165−7, 67−93, INGMAR
#c283	−0.08	0.08	N	NO. 165−8, 67−93, INGMAR
#c284	0.00	0.11	N	NO. 165−9, 67−93, INGMAR
#c285	0.00	0.11	N	NO. 165−9, 67−93, INGMAR
#c286	0.00	0.11	N	NO. 165−9, 67−93, INGMAR
#c287	−0.09	0.16	N	MEAN BASALT RATE
#c288	−0.09	0.16	N	MEAN BASALT RATE
#c289	−0.09	0.16	N	MEAN BASALT RATE
#c290	−0.09	0.16	N	MEAN BASALT RATE
#c291	−0.09	0.16	N	MEAN BASALT RATE
#c292	−0.09	0.16	N	MEAN BASALT RATE
#c293	−0.09	0.16	N	MEAN BASALT RATE
#c294	−0.07	0.10	N	MEAN OF C313 AND C314
#c295	−0.07	0.10	N	MEAN OF C313 AND C314
#c296	−0.09	0.16	N	MEAN BASALT RATE
#c297	−0.09	0.16	N	MEAN BASALT RATE
#c298	0.00	0.12	N	NO. 165−11, 67−93, INGMAR
#c299	0.00	0.12	N	NO. 165−11, 67−93, INGMAR
#c300	0.00	0.14	N	NO. 165−12, 67−93, INGMAR

TRANSECT	RATE	ERROR	SPS?	SOURCE OF RATE
#c301	−0.09	0.16	N	MEAN BASALT RATE
#c302	−0.09	0.16	N	MEAN BASALT RATE
#c303	−0.09	0.16	N	MEAN BASALT RATE
#c304	−0.09	0.16	N	MEAN BASALT RATE
#c305	−0.09	0.16	N	MEAN BASALT RATE
#c306	−0.09	0.16	N	MEAN BASALT RATE
#c307	−0.09	0.16	N	MEAN BASALT RATE
#c308	−0.09	0.16	N	MEAN BASALT RATE
#c309	−0.09	0.16	N	MEAN BASALT RATE
#c310	−0.09	0.16	N	MEAN BASALT RATE
#c311	−0.09	0.16	N	MEAN BASALT RATE
#c312	−0.09	0.16	N	MEAN BASALT RATE
#c313	−0.07	0.10	N	NO. 222−2, 67−93, INGMAR
#c314	−0.07	0.10	N	NO. 180216600, 67−92, GOOD
#c315	−0.09	0.16	N	MEAN BASALT RATE
#c316	−0.09	0.16	N	MEAN BASALT RATE
#c317	−0.09	0.16	N	MEAN BASALT RATE
#c318	−0.09	0.16	N	MEAN BASALT RATE
#c319	−0.09	0.16	N	MEAN BASALT RATE
#c320	−0.09	0.16	N	MEAN BASALT RATE
#c321	−0.09	0.16	N	MEAN BASALT RATE
#c322	−0.09	0.16	N	MEAN BASALT RATE
#c323	−0.09	0.16	N	MEAN BASALT RATE
#c324	−0.09	0.16	N	MEAN BASALT RATE
#c325	−0.03	0.06	N	NO. 165−16, 67−93, INGMAR
#c326	−0.03	0.06	N	NO. 165−16, 67−93, INGMAR
#c327	−0.09	0.16	N	MEAN BASALT RATE
#c328	−0.09	0.16	N	MEAN BASALT RATE
#c329	−0.09	0.16	N	MEAN BASALT RATE
#c330	−0.09	0.16	N	MEAN BASALT RATE
#c331	−0.09	0.16	N	MEAN BASALT RATE
#c332	−0.09	0.16	N	MEAN BASALT RATE
#c333	−0.09	0.16	N	MEAN BASALT RATE
#c334	−0.09	0.16	N	MEAN BASALT RATE
#c335	−0.09	0.16	N	MEAN BASALT RATE
#c336	−0.09	0.16	N	MEAN BASALT RATE
#c337	−0.09	0.16	N	MEAN BASALT RATE
#c338	−0.09	0.16	N	MEAN BASALT RATE
#c339	−0.09	0.16	N	MEAN BASALT RATE
#c340	−0.09	0.16	N	MEAN BASALT RATE
#c341	−0.09	0.16	N	MEAN BASALT RATE
#c342	−0.09	0.16	N	MEAN BASALT RATE
#c343	−0.09	0.16	N	MEAN BASALT RATE
#c344	−0.09	0.16	N	MEAN BASALT RATE
#c345	−0.09	0.16	N	MEAN BASALT RATE
#c346	−0.09	0.16	N	MEAN BASALT RATE
#c347	−0.09	0.16	N	MEAN BASALT RATE
#c348	−0.09	0.16	N	MEAN BASALT RATE
#c349	−0.09	0.16	N	MEAN BASALT RATE
#c350	−0.09	0.16	N	MEAN BASALT RATE

TRANSECT	RATE	ERROR	SPS?	SOURCE OF RATE
#c351	−0.09	0.16	N	MEAN BASALT RATE
#c352	−0.09	0.16	N	MEAN BASALT RATE
#c353	−0.09	0.16	N	MEAN BASALT RATE
#c354	−0.09	0.16	N	MEAN BASALT RATE
#c355	−0.09	0.16	N	MEAN BASALT RATE
#c356	−0.09	0.16	N	MEAN BASALT RATE
#c357	−0.09	0.16	N	MEAN BASALT RATE
#c358	−0.09	0.16	N	MEAN BASALT RATE
#c359	−0.09	0.16	N	MEAN BASALT RATE
#c360	−0.09	0.16	N	MEAN BASALT RATE
#c361	−0.09	0.16	N	MEAN BASALT RATE
#c362	−0.09	0.16	N	MEAN BASALT RATE
#c363	−0.09	0.16	N	MEAN BASALT RATE
#c364	−0.09	0.16	N	MEAN BASALT RATE
#c365	−0.09	0.16	N	MEAN BASALT RATE
#c366	−0.09	0.16	N	MEAN BASALT RATE
#c367	−0.09	0.16	N	MEAN BASALT RATE
#c368	−0.09	0.16	N	MEAN BASALT RATE
#c369	−0.09	0.16	N	MEAN BASALT RATE
#c370	−0.09	0.16	N	MEAN BASALT RATE
#c371	−0.09	0.16	N	MEAN BASALT RATE
#c372	−0.09	0.16	N	MEAN BASALT RATE
#c373	−0.09	0.16	N	MEAN BASALT RATE
#c374	−0.09	0.16	N	MEAN BASALT RATE
#c375	−0.09	0.16	N	MEAN BASALT RATE
#c376	−0.09	0.16	N	MEAN BASALT RATE
#c377	−0.09	0.16	N	MEAN BASALT RATE
#c378	−0.09	0.16	N	MEAN BASALT RATE
#c379	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c380	−0.17	0.09	N	NO. 221−2, 67−93, INGMAR
#c381	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c382	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c383	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c384	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c385	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c386	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c387	−0.17	0.09	N	BASALT−GUARDED SS POCKET BEACH; RATE FROM C380
#c388	−0.09	0.16	N	MEAN BASALT RATE
#c389	0.00	0.08	N	NO. 167A−3, 67−93, INGMAR
#c390	−0.02	0.08	N	N0. 167A−5, 67−93, INGMAR
#c391	−0.56	0.14	N	NO. 167A−6, 67−93, INGMAR
#c392	−0.09	0.16	N	MEAN BASALT RATE
#c393	−0.09	0.16	N	MEAN BASALT RATE
#c394	−0.09	0.16	N	MEAN BASALT RATE
#c395	−0.09	0.16	N	MEAN BASALT RATE
#c396	−0.09	0.16	N	MEAN BASALT RATE
#c397	−0.09	0.16	N	MEAN BASALT RATE
#c398	−0.09	0.16	N	MEAN BASALT RATE
#c399	−0.09	0.16	N	MEAN BASALT RATE
#c400	−0.09	0.16	N	MEAN BASALT RATE

TRANSECT	RATE	ERROR	SPS?	SOURCE OF RATE
#c401	−0.09	0.16	N	MEAN BASALT RATE
#c402	−0.09	0.16	N	MEAN BASALT RATE
#c403	−0.09	0.16	N	MEAN BASALT RATE
#c404	−0.09	0.16	N	MEAN BASALT RATE
#c405	−0.09	0.16	N	MEAN BASALT RATE
#c406	−0.09	0.16	N	MEAN BASALT RATE
#c407	−0.09	0.16	N	MEAN BASALT RATE
#c408	−0.09	0.16	N	MEAN BASALT RATE
#c409	−0.09	0.16	N	MEAN BASALT RATE
#c410	−0.09	0.16	N	MEAN BASALT RATE
#c411	−0.09	0.16	N	MEAN BASALT RATE
#c412	−0.09	0.16	N	MEAN BASALT RATE
#c413	−0.09	0.16	N	MEAN BASALT RATE
#c414	−0.09	0.16	N	MEAN BASALT RATE
#c415	−0.09	0.16	N	MEAN BASALT RATE
#c416	−0.09	0.16	N	MEAN BASALT RATE
#c417	−0.09	0.16	N	MEAN BASALT RATE
#c418	−0.09	0.16	N	MEAN BASALT RATE
#c419	−0.09	0.16	N	MEAN BASALT RATE
#c420	−0.09	0.16	N	MEAN BASALT RATE
#c421	−0.09	0.16	N	MEAN BASALT RATE
#c422	−0.09	0.16	N	MEAN BASALT RATE
#c423	−0.09	0.16	N	MEAN BASALT RATE
#c424	−0.09	0.16	N	MEAN BASALT RATE
#c425	−0.09	0.16	N	MEAN BASALT RATE
#c426	−0.09	0.16	N	MEAN BASALT RATE
#c427	−0.09	0.16	N	MEAN BASALT RATE
#c428	−0.09	0.16	N	MEAN BASALT RATE
#c429	−0.09	0.16	N	MEAN BASALT RATE
#c430	−0.09	0.16	N	MEAN BASALT RATE
#c431	−0.09	0.16	N	MEAN BASALT RATE
#c432	−0.09	0.16	N	MEAN BASALT RATE
#c433	−0.09	0.16	N	MEAN BASALT RATE
#c434	−0.09	0.16	N	MEAN BASALT RATE
#c435	−0.09	0.16	N	MEAN BASALT RATE
#c436	−0.09	0.16	N	MEAN BASALT RATE
#c437	−0.09	0.16	N	MEAN BASALT RATE
#c438	−0.09	0.16	N	MEAN BASALT RATE
#c439	−0.09	0.16	N	MEAN BASALT RATE
#c440	−0.09	0.16	N	MEAN BASALT RATE
#c441	−0.09	0.16	N	MEAN BASALT RATE
#c442	−0.09	0.16	N	MEAN BASALT RATE
#c443	−0.09	0.16	N	MEAN BASALT RATE
#c444	−0.09	0.16	N	MEAN BASALT RATE

EXPLANATION OF COLUMN HEADINGS AND ABBREVIATIONS

TRANSECT: Number of the transect where the rate is measured.

RATE: Erosion rate in ft./yr (minus = recession of shoreline)

ERROR: Plus or minus error of the rate @ one standard deviation.

SPS?: Is there a shoreline protection device? Yes or No.

SOURCE OF RATE: Indicates how the rate was found.

MEAN OF BASALT RATE: Mean rate for basalt, Cascade Head to Seal Rock.

MEAN BASALT–ARMORED POCKET BEACH SS: Mean of rates from this geologic setting, Cascade Head to Seal Rock.

BASALT–GUARDED SS POCKET BEACH; FROM C380: Analogous to rate at transect C380.

C219–220 VALUE: Assigned erosion rate of transects c219 and c220.

NO. 159–1, 67–93, INGMAR: Field number, measured from 1967 to 1993 by Ingmar Saul.

No. 180216600, 67–92, GOOD: Field number, measured from 1967 to 1992 by Andra C. Ansevin, Scott Allen and Christine Valentine

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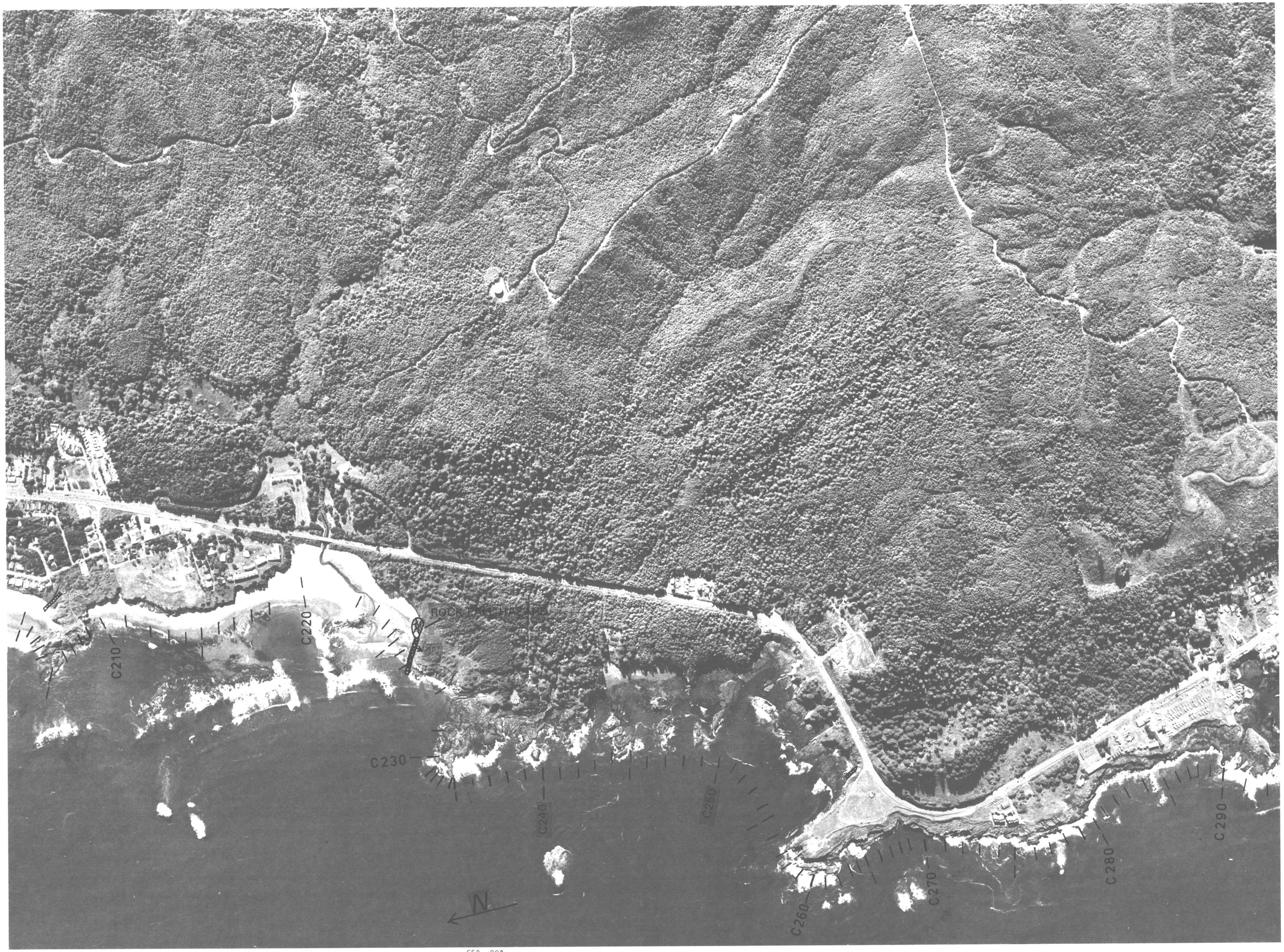

Scale = 1:4800

65° 80°
Fault zone in sea cliff (arrow = dip; diamond arrow = rake)

Boundary of active (A), potentially active (PA), or prehistoric (PH) complex landslide (ls), debris/earth flow (f), or slide/slump block (b)

— — C 210 Erosion rate transect (see database for rate)

-0.07 ± 0.10 Boundary of erosion rate (ft/yr; - = erosion; + = accretion)

Mapping by George R. Priest
Oregon Department of Geology and Mineral Industries
1992 and 1993
Publicly Released: 1994

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Oregon Department of Geology and Mineral Industries

Scale = 1:4800

65° 80°

Fault zone in sea cliff (arrow = dip; diamond arrow = rake)

Boundary of active (A), potentially active (PA), or prehistoric (PH) complex landslide (ls), debris/earth flow (f), or slide/slump block (b)

——C310 Erosion rate transect (see database for rate)

-0.07 ± 0.10 Boundary of erosion rate (ft/yr; - = erosion; + = accretion)

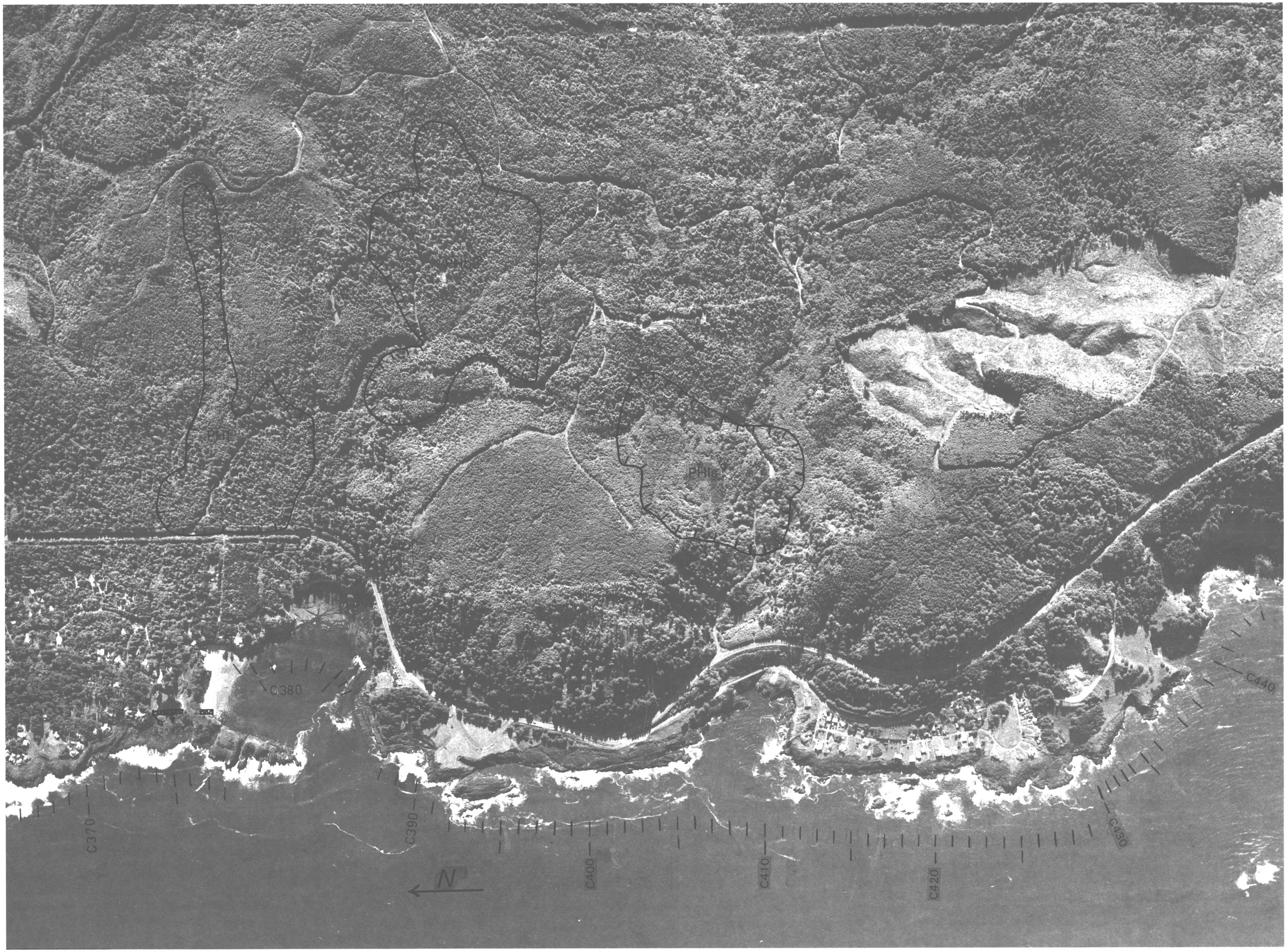
Mapping by George R. Priest

Oregon Department of Geology and Mineral Industries

1992 and 1993

Publicly Released: 1994

OPEN-FILE REPORT 0-94-3
Oregon Department of Geology and Mineral Industries



Scale = 1:4800

65° 80°
Fault zone in sea cliff (arrow = dip; diamond arrow = rake)

Boundary of active (A), potentially active (PA), or prehistoric (PH) complex landslide (ls), debris/earth flow (f), or slide/slump block (b)

— — C 410 Erosion rate transect (see database for rate)

-0.07 ± 0.10 Boundary of erosion rate (ft/yr; - = erosion; + = accretion)

Mapping by George R. Priest
Oregon Department of Geology and Mineral Industries
1992 and 1993
Publicly Released: 1994