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Reconnaissance Geologic Evaluation for Building Suitability of a Portion of the Moolack Beach Landslide, Lincoln County, Oregon

By

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May 9, 2003

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EXECUTIVE SUMMARY

Oregon Parks and Recreation Department (OPRD) requested on April 24, 2003 that the Oregon Department of Geology and Mineral Industries (DOGAMI) do a site reconnaissance and geologic evaluation for building suitability on a property at Moolack Beach in Lincoln County. The information is for appraisal purposes. This report summarizes the result of a one-day field reconnaissance of the area. The report is not a detailed geotechnical analysis.

The subject property is unsuitable for construction. It is located within one of the largest active landslides in Lincoln County; such slides can seriously damage any structure or utilities where fissures and scarps cause ground breakage. The landslide is riddled with fissures and ground cracks, so virtually all sites could have some ground deformation. Stopping or drastically slowing slide movement would be necessary before the site would be safe for construction. Remediation (dewatering, buttressing, etc.) of the slide movement would be difficult and expensive given its large size.

The northern ~40 percent of the study area is composed of landslide blocks that are less broken up than the rest of the area. This portion of the study area is less likely to cause damage to structures. Although it is not recommended, it may be possible to use some of this area for some kind of temporary use like a campground. Installing any type of utility service on this active landslide would be a major engineering challenge, given the ongoing ground deformation.

A portion of the area falls in the FEMA 100-year ocean flooding zone. The area is also vulnerable to catastrophic flooding from tsunamis generated by infrequent but potentially devastating Cascadia subduction zone earthquakes.

Additional detailed, site-specific geotechnical analysis needs to be done in order to more accurately depict site conditions. Such work is recommended, if any type of development is contemplated.

INTRODUCTION

Oregon Parks and Recreation Department (OPRD) requested on April 24, 2003 that the Oregon Department of Geology and Mineral Industries (DOGAMI) do a site reconnaissance and geologic evaluation for building suitability on a property at Moolack Beach for appraisal purposes. The property is identified on the Lincoln County Assessor’s Map #10-11-17CD, tax lot 100, and #10-11-17CA, tax lot 600 (Figures 1 and 2). The area is 1190 feet long and ~300 feet wide. This report summarizes findings from rapid reconnaissance-level field work on April 29, 2003.

This work should be considered preliminary and no substitute for a detailed, site-specific geotechnical investigation. Geologic mapping suffered from insufficient topographic map data, so all features are located very approximately (± 30 feet horizontal); only the grossest geologic features could be mapped within the time and resources available.

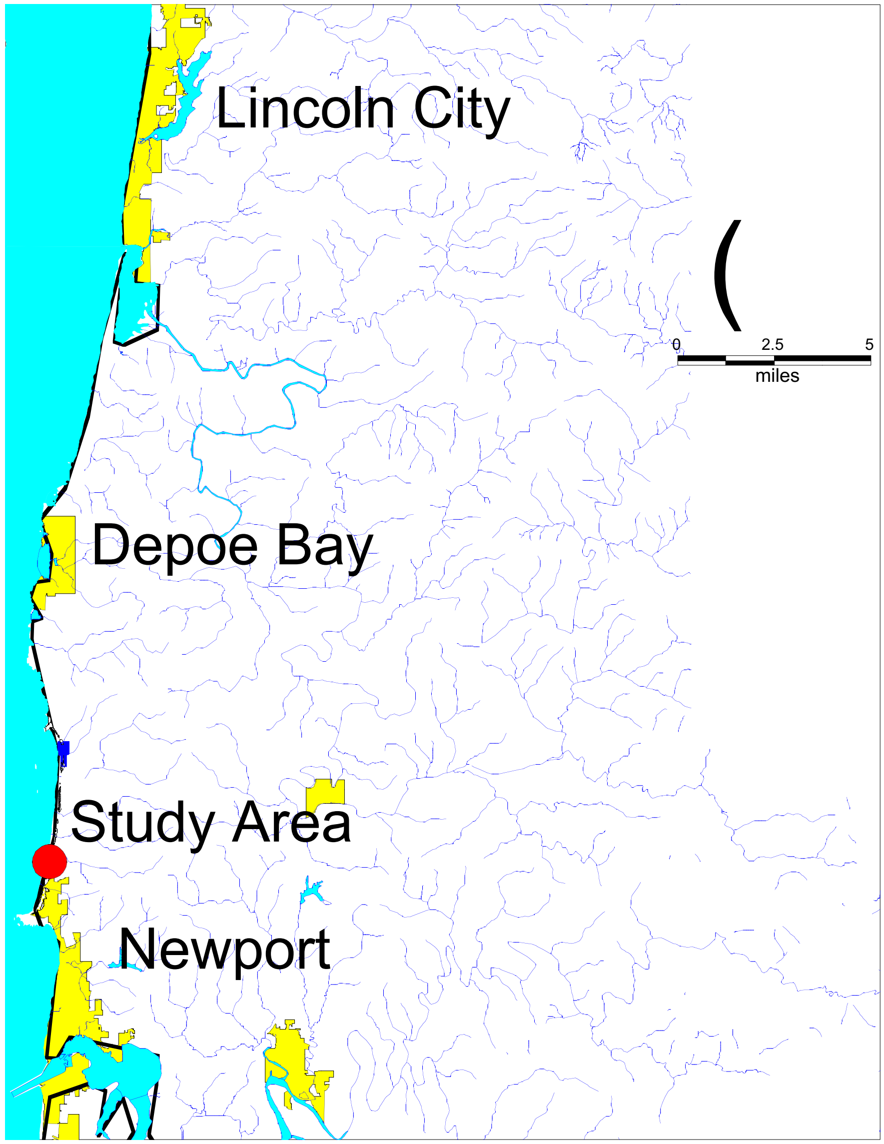

Figure 1. Location of the study area in Lincoln County, Oregon.

Figure 2. Study area on 1993 orthophotographic base map. Red numbers are tax lot numbers. Head symbols show location of photographs used in the report and are labeled with appropriate figure numbers.

GEOGRAPHIC AND GEOLOGIC SETTING

The property lies within one of the largest active landslides in Lincoln County (Figure 3). The slide is offsetting Highway 101 downward and westward on an annual basis, necessitating continual repairs. The slide has been named the Moolack Beach Landslide by the Oregon Department of Transportation (ODOT) and was previously mapped by Priest (1997). The slide is in westward-inclined sedimentary rock of the Astoria Formation. Capping Quaternary marine terrace sand deposits ride passively on the landslide blocks.

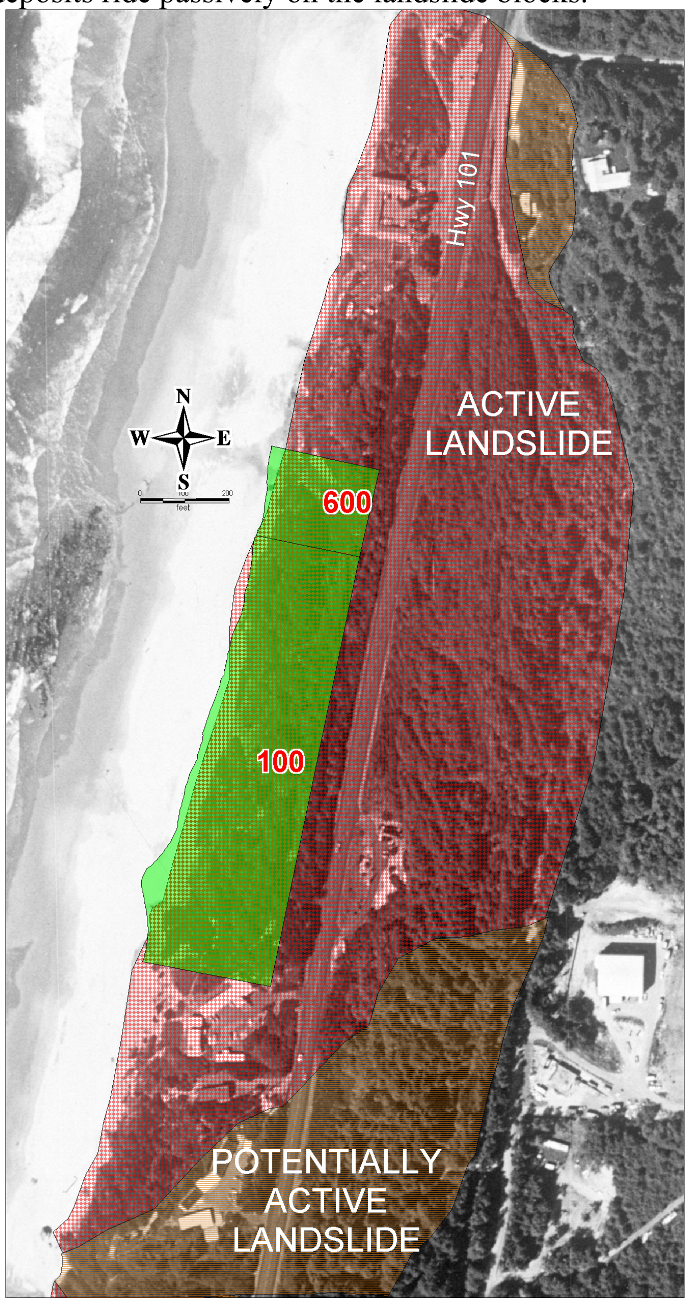

Figure 3. Study area is shown in green and lies in the active Moolack Beach Landslide. Mapped landslide boundaries are modified from Priest (1997).

The landslide is eroded back from the toe by wave erosion, forming a sea cliff composed of fractured Astoria Formation and overlying marine terrace sand (Figure 4). Mathiot (1973) obtained an erosion rate of –0.49 ft/year by monitoring bluff toe change during a 250-day (September 1972 to May 1973) period using a semi-permanent survey marker. This measurement was done on the Moolack Beach Landslide 410 feet north of the study area. Priest and Allan (2002) concluded that overall erosion rate for this general area (Beverly Beach littoral cell) is on the order of –0.5 ft/yr with a conservative rate of –0.8 ft/yr, but these estimates have high uncertainties.

Figure 4. Eroded landslide forms a sea cliff. Toe of the slide is probably west of the photo (left) in or near the surf zone. Astoria Formation forms wave cut terrace in foreground and is partially covered with beach sand and gravel. Sea cliff is composed of Astoria Formation siltstone (dark gray to dark orange unit) in the lower 6-9 feet overlain by 10-30 feet of Quaternary marine terrace sand (light-colored unit).

Most of the study area is forested and has rolling topography typical of active landslide terrain (Figure 5). The coastal bluff near the toe of the landslide is about 40-52 feet high (Figure 4) over most of the length of study area, rising to an elevation of 68 feet at the south edge of the area. Elevations are somewhat higher east of the coastal bluff, but in several places there are small closed basins formed by down-dropped blocks within the landslide (Figure 6). These basins trap meteoric water.

The highly fractured nature of the landslide material probably promotes infiltration of water. Fractures are probably closely spaced in these basins, based on observations in exposures of in analogous landslides.

Figure 5. Looking north along an entry road into the property; note the landslide scarp on the right and down-dropped block (small basin) in the left background. Property is heavily forested.

Figure 6. Small down-dropped block in the slide here forms a closed basin that traps surface runoff water.

One small creek runs underground through the northern edge of the property and was flowing at the time of the field work. This creek emerges at the sea cliff from a 1.6-foot diameter concrete pipe (Figure 7). The eastward extent of this pipe is not known. The flowing water appears to cause enhanced erosion of the sea cliff at this point. Evidence is the reentrant in the cliff and broken pieces of the pipe lying about in the reentrant. The fill material above the pipe is also eroding more rapidly than surrounding material, probably in response to runoff. This subaerial erosion has created a small dry gulch extending east-southeast of sea cliff for about 60 feet (Figure 7).

Figure 7. Looking east at reentrant in sea cliff where a small creek emerges from a 1.6-ft diameter concrete pipe buried in a trench excavated in Quaternary marine terrace sand (tan unit on right) and buried by fill (dark unit). Pipe is located 70 feet south of the north property boundary and appears to run east-southeast. Note the dry gulch just visible on the left where surface runoff has eroded the fill..

Groundwater in this region generally flows more easily in the permeable marine terrace sand than the relatively impermeable siltstone of the Astoria Formation. Movement of oxygenated ground water at the terrace sand-siltstone contact (Pleistocene wave cut platform) has probably caused the siltstone to have a rust-colored stain (Figure 8); alternatively, the stain could be from Pleistocene weathering (i.e. a paleosol), but this would be unlikely on a wave cut platform. Ground water can also flow in fractures. Mass movement has locally caused heavy fracturing of rock in the landslide mass, so groundwater flow may be heavily influenced by fractures. Swanson (1974) observed two springs issuing from the base of the sea cliff in the southern half of the study area (see his Figure 1). Swanson also noted that some creeks in the main landslide mass east of the study area disappear into the fracture system.

Figure 8. Heavy iron oxide stain in Astoria Formation siltstone (dark orange material forming a low slope) at the contact with the overlying Quaternary marine terrace sand (lighter colored unit forming steep slope). Note the near horizontal bedding in the terrace sand. The Astoria Formation is dipping west at about 15 degrees at this locality (south central part of the study area); Pleistocene wave cut platform appears to dip ~7º east, the likely dip of the marine terrace sequence as a whole.

GEOLOGY

Geologic units and descriptions are summarized in Table 1. Distribution of units is given on the geologic map of Figure 9. Figure 10 shows geologic and topographic complexity in the southwest part of the study area. Mapping and descriptions are based on a one-day field reconnaissance and previous work in the general area.

Slides in the area generally form in seaward-dipping weak siltstone or mudstone units in the Astoria Formation, as coastal erosion cuts sea cliffs into these weak layers. These same geological conditions pertain in the study area. Seaward-dipping fine-grained silty sandstone, siltstone, and mudstone of the Astoria crop out along the sea cliff and in the modern wave-cut platform. Intensity of landslide deformation increases from north to south in the study area becoming most intense at the southwest corner. In this southwest corner landslide scarps are too numerous and closely spaced to map separately. Some of the complexity of the transition between this area and the more intact, lower elevation block to the north is illustrated in Figure 10.

Table 1. Description of geologic units.

Unit	Description
Surficial soil	Dark gray sandy loam (weathered marine terrace sand); thickness not measured but probably from a few inches to a foot or two; moderately graded; permeable.
Beach sand	Tan quartzo-feldspathic medium grained, poorly graded unconsolidated sand; probably about 2-3 feet thick in north part of area; thin to absent from beach platform in southern half of the study area; highly permeable.
Beach cobbles	Dark gray rounded cobbles of local bedrock in berms a few feet thick at the base of sea cliff mainly at north end of area; partly may be partly alluvial at mouth of small creek at north end of the study area; poorly graded; highly permeable
Colluvium	Tan-colored loose sand from shallow mass movement of weathered marine terrace sand; exact thickness unknown, but 14 feet of unit is exposed in sea cliff at south end of the study area; poorly graded; permeable. Only shown on the geologic map where unit is ~10 feet or more thick at south end of the study area.
Quaternary marine terrace sand	Tan-colored moderately consolidated medium grained quartzo-feldspathic sand with horizontal bedding in lower 25 feet; bedding in upper 5 feet is either absent or at high angles typical of dunes; poorly graded; permeable to groundwater unless paleosols (gray layers) are present. No gray layers observed in sea cliff but some clay-rich fragments seen in disturbed soil in a few places on top of the bluff could be pieces of gray layer.
Tertiary Astoria Formation	Dark gray to light gray rock composed of siltstone and moderately graded (moderately sorted) fine grained silty sandstone; forms 50-foot exposure in sea cliff at south end of study area; forms lower 6-9 feet of sea cliff in most of the study area; moderately graded; low permeability except in fractures.

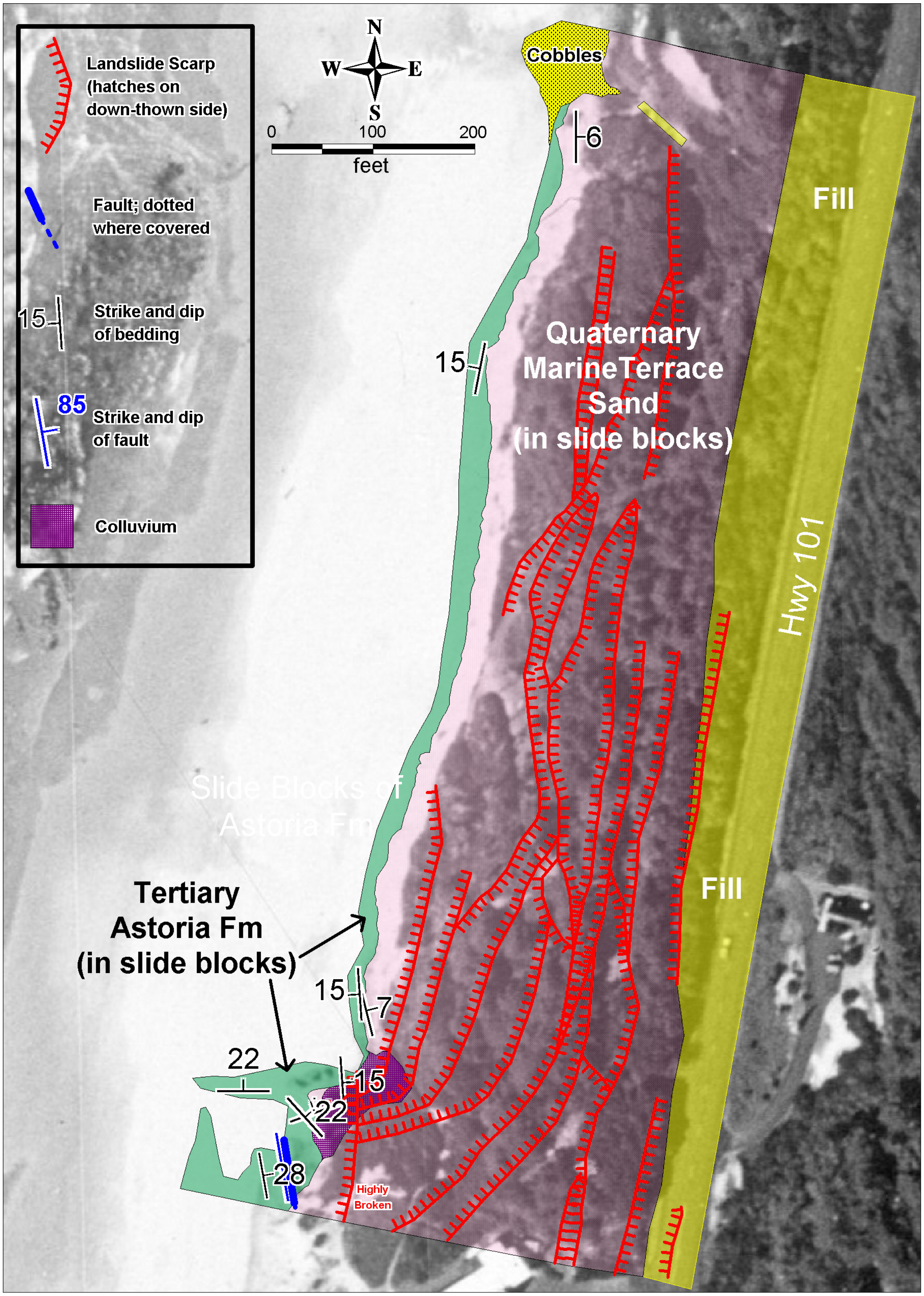

Figure 9. Geologic map of the study area. Uncolored area west of colored areas is chiefly beach sand and minor gravel. Areas surrounded by inward pointing hatches are down-thrown slide blocks in fissures; areas surrounded by outward pointing hatches are uplifted blocks relative to surrounding areas.

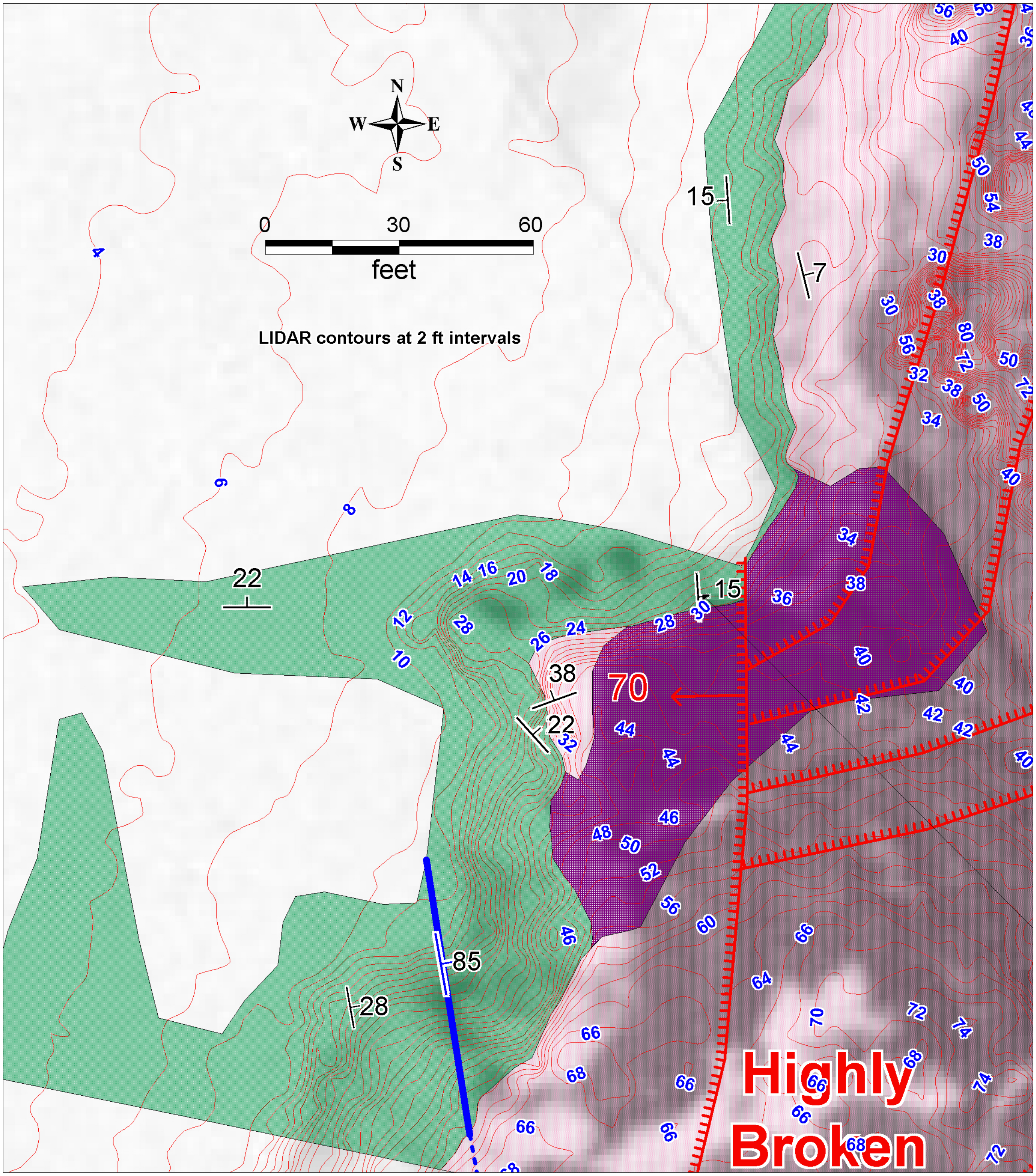

Figure 10. Close up of southwest part of the geologic map with topographic contours (thin red lines with blue elevation labels) derived from a 1998 LIDAR survey by USGS and NOAA. A black and white 1993 orhtophotograph is the base map. LIDAR is most accurate in areas free of vegetation (white patches on the base map). Red arrow and number on scarp show amount and direction of dip. See Figure 9 map legend for explanation of other symbols. Note changes in dip of the Astoria Formation (blue green) across slide block and fault boundaries.

Exposures on the sea cliff reveal the complexity of the interplay between landslide and tectonic deformation. In the northern slide block pre-landslide dip of the Astoria is estimated to be at 21-22º west based on the 6-7º east dip of the formerly flat Quaternary marine terrace and 15º west dip of the underlying Astoria (Figures 9 and 10). Preexisting tectonic structure and modern landslide deformation in the southwestern corner of the study area cause the Astoria exposed at the sea cliff to dip 22º north to 28º east northeast (Figures 10 and 11). The overlying Quaternary marine terrace sand there is tilted 38º to the north-northwest, while Astoria formation directly underlying the steeply dipping marine terrace sand dips 22º northeast. The sharp northward flexure of the marine terrace sand in the southwestern part of the area brings the lower contact from an elevation of ~58 feet at the south edge of the study area to ~22-24 feet over a north-south distance of only 120 feet (Figure 10). This flexure is most likely due to landslide deformation.

Sea cliff exposures of the Quaternary marine terrace sand provide a convenient way of estimating overall vertical displacement at the western margin of the study area. The landslide causes the lower Quaternary marine terrace sand contact to be displaced from original elevations of ~80-95 feet to elevations of 20-22 feet at the sea cliff along most of the length of the study area; hence vertical displacement is 58-75 feet. The top of the terrace deposits is relatively flat, although there is some topography from former dunes, so the top surface can also be used as a marker to estimate vertical displacement. Elevation at the top of the headscarp of the landslide is ~120 feet, whereas the top of the terrace sand in the north slide block is at about 50 feet of elevation, where not deeply eroded; this gives 70 feet of vertical displacement. Vertical displacement decreases to 22-37 feet in the southwestern edge of the study area where the marine terrace contact lies at an elevation of ~58 feet (Figure 10).

Figure 11. Looking north northeast at southwest part of the study area. Linear outcrop in foreground is Astoria Formation sandstone dipping 28º east. Linear outcrop at left center is Astoria Formation sandstone dipping 22º north. Light tan unit in upper right is Quaternary marine terrace sand dipping 38º northwest and lying on Astoria Formation (dark red brown) dipping 22º northeast. The main north block of the slide is in the background upper left.

No subsurface information was available at the site, but one inclinometer hole was drilled February 24, 1972 by ODOT. Exact location of the borehole was not available at the time of this report, but it was described as being drilled on the east edge of Highway 101 in the vicinity of the old kite shop (Figure 2; Bernie Kleutsch, personal communication, 2003); this would place it ~130 feet east of the study area at an elevation of ~74 feet. Data from this hole indicates that it encountered ~15 feet of Quaternary marine terrace sand underlain by 67 feet of Astoria formation siltstone. The inclinometer pinched off July 3, 1974 from a slide plane at a depth of 55 feet. Swanson (1974) inferred that the slide plane is controlled to some extent by the ~11-14º west dips of the Astoria, but drew a cross section with an average slide plane dip on the order of 4º west, when corrected for vertical exaggeration on his cross section figure. Although not stated, Swanson (1974) also apparently assumed that the slide toe was at the base of the sea cliff, an assumption that may not be correct. He curved his slide plane to slightly lower angle to achieve intersection with the bluff toe. Slide deformation well out into the beach platform favors a depth to the main slide plane that is below beach level (<6-12 feet elevation). Extending a 4º dip from the elevation of the slide plane on the east side of Highway 101 (19 feet elevation from the ODOT borehole data) would place the slide at ~-8 feet elevation at the sea cliff. Presumably the slide curves upward at some point west of the sea cliff to intersect the surface.

Total horizontal displacement on the landslide can be estimated from the vertical displacement, if slide plane geometry is known. Deviations of the Highway 101 centerline reveal an ~8 feet west displacement, but the landslide has been moving much longer than the ~50-60-year age of the highway. The minor back rotation (6-7º) of the main north slide block and development of numerous down-dropped blocks within the slide favor a dominant translational motion with slight curvature of the slide plane near the toe to account for the rotation. If slide dip is similar to the 4º west dip inferred by Swanson (1974) and the slide is mostly translational down this dip, then, based on vertical displacement of the lower contact of the marine terrace sand, total horizontal offset at the sea cliff is ~ 800-1,100 feet in the northern 85 percent of the area and ~300-500 feet in the southern 15 percent. Since slide geometry is not known, these estimates are highly speculative.

EARTHQUAKE HAZARDS

The site is on an active landslide that would probably experience dramatically accelerated movement during a major earthquake. It is well known that in the Oregon coast lies above the Cascadia subduction zone fault. Earthquakes of up to magnitude 9 are possible on this major fault but are rare events (Atwater and others, 1995). The last one of this magnitude occurred in 1700 (Satake and others, 1996). Thirteen similar events have occurred in the last 7627±150 calendar years before present, so recurrence is ~ 600 years (Goldfinger and others, 2002). Peak ground acceleration from all seismic sources with a 2 percent probability of exceedance in 50 years is on the order of 67 percent of the acceleration due to gravity (US Geological Survey, 2002, from web site http://geohazards.cr.usgs.gov/eq/html/data2002.html).

Liquefaction is probable in water saturated beach and colluvial sand. Liquefaction is possible in the marine terrace sands, if saturated with ground water.

Lateral spreading will likely occur toward all free faces, including road cuts and the sea cliff. Shallow sloughing failures are likely on all steep slopes in the event of a large earthquake.

There is no evidence of surface fault ruptures. The one mapped fault does not appear to cut the Quaternary marine terrace deposits, so it is not active.

FLOODING

The 100-year coastal flood zone with wave action velocity (V-zone) taken from digital files of the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) and projected onto a 1993 orthophotograph is shown in Figure 12. No V-zone elevation is listed on the published FIRM for this area, but a V-zone elevation of 31 feet is listed 1 mile south of the study area. LIDAR data from 1998 show that the coastal sea cliff reaches elevations of ~40-50 feet over much of the study area, so the digitally projected V-zone inundation line in Figure 12 may be too far inland for most of the study area. Inaccurate digitizing of the original published line may be the cause.

No 500-year coastal flood zone is listed on the FIRM, but the area is known to be vulnerable to flooding from tsunamis generated by Cascadia subduction zone earthquakes. Periodicity of these flooding events is the same as the previously discussed recurrence of Cascadia earthquakes (i.e. 13 events over 7627±150 calendar years before present). Digital projection of the Senate Bill 379 tsunami inundation boundary for this area (Priest and Baptista, 2000) is also shown on Figure 12 and generally falls just below the 40-foot contour on published USGS topographic quadrangles. Oregon Senate Bill 379 limits construction of critical and essential facilities like schools and hospitals in the official tsunami inundation zone. Interestingly, the SB 379 boundary is generally seaward of the V-zone digitized from the FIRM maps (Figure 12). It should be noted that the detailed tsunami inundation analysis for Yaquina Bay (Priest and others, 1997) has a worst case tsunami inundation boundary close to 50 feet elevation at the open coast. This elevation is generally assumed in evacuation planning at the open coast for the City of Newport.

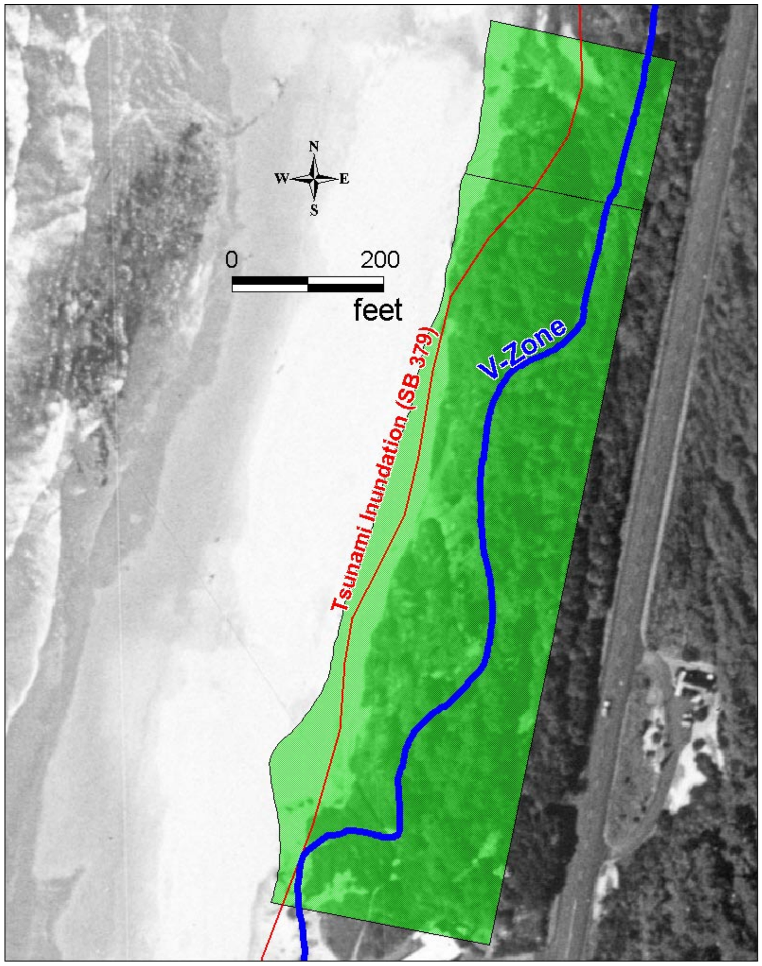

Figure 12. Flood hazard boundaries. V-zone = ocean velocity zone (flooding from waves); SB 379 = Oregon Senate Bill 379.

In summary, the area is partially in the published FIRM V-zone, but it is not known with precision how much of the area is in the zone. The FIRM boundary shown in Figure 12 may extend too far inland, possibly because of a digitizing error. The study area is also subject to flooding from rare but catastrophic Cascadia subduction zone tsunamis.

SUITABILITY FOR CONSTRUCTION

The study area is on an active landslide; such slides are unsuitable for construction, unless movement is stopped through geotechnical remediation. The slide can seriously damage any permanent structure where fissures and scarps cause ground breakage. The landslide is riddled with fissures and ground cracks too numerous to show at the scale of the geologic map, so virtually all sites could have some ground deformation.

Remediation (dewatering, buttressing, etc.) of the slide would likely be difficult and expensive given its large size. Remediation within the property boundaries might be insufficient, since the slide is much larger than the study area.

Slide movement is probably sufficiently slow that temporary structures such as mobile homes or use of the area as camp sites may be possible on some intact slide blocks. The northern ~40 percent of the study area has the most intact slide blocks, but even these areas have numerous fractures and slide scarps too small to map in this reconnaissance study. Even these temporary uses are not recommended, since damage would still be possible, especially if such sites are serviced by utility and sewer/septic lines. Any utilities crossing the slide would have to be built to withstand large amounts of deformation. In particular, sewage, if disposed on site in septic systems, may possibly leak out onto the beach through joints and shears before it is rendered safe by natural soil filtration and oxygenation. This problem could be exacerbated should septic lines and tanks be ruptured by ground movement. Injection of septic water into the subsurface throughout the year may increase water pore pressure within the slide mass, causing acceleration of movement. Surface and subsurface drainage systems in general should aim to carry as much water offsite as possible.

Again, it is not recommended, but if any grading is done, care should be taken to avoid depressions within the slide (graben and colluvial-filled fissures) and slide scarps. Grading and filling of these active structures should also be avoided. Such modification will obscure the structures, making any site development decisions more difficult. Adding fill to depressions within the landslide may add driving force to the slide.

FURTHER WORK

Further work is only justified, if there is some intent to make use of this site for some form of development (e.g. campground). Such use is not recommended, but, if undertaken, a detailed topographic and geologic map of the area needs to be produced. Elevation contours on a ~2-foot interval and geologic mapping at an appropriate scale would be needed to provide accurate locations of slide scarps and other features. Soil properties would also need to be evaluated for permeability, suitability for septic systems, and for use in compacted fill.

Likewise, the dry gulch that is developing over the buried creek on the northern margin of the study area (Figure 7) would need to be studied to determine why and how this erosion is occurring and how to stop it. Remediation of the apparent rapid erosion of the sea cliff in front of the buried creek would also need to be evaluated.

If remediation of landslide movement is contemplated, drilling of several inclinometer and piezometer holes in east-west transects across the landslide would be needed. Monitoring movement and water pressure changes in these boreholes over at least one wet season will provide the data needed to define slide geometry and driving forces. Remediation options such as dewatering of the slide could then be evaluated.

The FEMA V-zone needs to be more accurately plotted to see how much of the area falls in the zone. Likewise, more accurate coastal erosion rates need to be calculated by monitoring erosion and analyzing bluff change on rectified historical aerial photography.

SUMMARY AND RECOMMENDATIONS

OPRD requested that DOGAMI do a site reconnaissance and geologic evaluation of this property for building suitability in order to do an appraisal. One day of field observations and preexisting data are summarized here.

The property is on one of the largest active landslides in Lincoln County. The slide continually offsets Highway 101 downward and westward, prompting ODOT to give it a formal name, the Moolack Beach Landslide. The Moolack Beach Landslide is a translational slide penetrating deep into the mudstone, siltstone and sandstone of the Tertiary Astoria Formation. The seaward inclination of the Astoria promotes slide failure down the bedding plane dip, as waves erode the coastal bluff. The property is entirely underlain by up to 30 feet of poorly consolidated Quaternary marine terrace sand, which rides passively on the slide blocks of Astoria formation. The landslide is considerably larger than the property, extending 1000 feet north, 600 feet south, 500-600 feet east, and an unknown distance west of property boundaries. Coastal erosion, proceeding at about 0.5-0.8 ft/yr has eroded back the coastal bluff from the slide toe, which is somewhere out in the surf zone. The main slide plane is 55 feet below ground surface ~130 feet east of the property (ODOT borehole data). The contact between the Quaternary marine terrace sand and the Astoria is a Pleistocene wave cut platform that lies about 22-24 feet elevation over the northern ~85 percent of the property. Internal landslide deformation causes the contact to rise abruptly to 58 feet of elevation in the southwestern part of the area. Based on the elevation of this contact at the sea cliff, total vertical offset on the Moolack Beach Landslide is 58-75 feet in the northern 85 percent of the area and 22-37 feet in the southwestern 15 percent of the area. Assuming a slide-plane dip is ~4º west, total horizontal offset at the longitude of the sea cliff is ~ 800-1,100 feet in the northern 85 percent of the area and ~300-500 feet in the southern 15 percent. Since slide plane geometry is not known, the inferred horizontal offset is highly speculative and is only an order of magnitude estimate.

The subject property is unsuitable for construction because it is on an active landslide. Such slides can seriously damage any structure or utilities where fissures and scarps cause ground breakage. The landslide is riddled with fissures and ground cracks, so virtually all sites could have some ground deformation. Stopping or drastically slowing slide movement would be necessary before the site would be safe for construction. Remediation (dewatering, buttressing, etc.) of the slide movement would be difficult and expensive given its large size.

The northern ~40 percent of the study area is composed of landslide blocks that are less broken up than the rest of the area. This portion of the study area is less likely to cause damage to structures. Although it is not recommended, it may be possible to use some of this area for some kind of temporary use like a campground. Installing any type of utility service would be a major engineering challenge, given the ongoing ground deformation.

A portion of the area falls in the FEMA 100-year ocean flooding zone. The area is also vulnerable to catastrophic flooding from tsunamis generated by infrequent but potentially devastating Cascadia subduction zone earthquakes.

Additional detailed, site-specific geotechnical analysis needs to be done in order to more accurately depict site conditions. The 100-year ocean flooding zone (V-zone) should be more accurately located than could be done in this study. Likewise, more accurate coastal erosion rates need to be calculated by monitoring erosion and analyzing bluff change on rectified historical aerial photography. Such work is recommended, if any type of development is contemplated.

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