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Memorandum:
Cape Cove Landslide
Findings from Field Visit
February 10 and March 10, 2000

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March 20, 2000

MEMORANDUM

TO: Glen R. Thommen
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FROM: George R. Priest, Ph.D., CEG (Registration No. E1020)

SUBJECT: Cape Cove Landslide, findings from field visit on February 10 and March 10, 2000

The following is a summary of my findings from the field examinations of February 10 and March 10, 2000 of the Cape Cove landslide, located on Highway 101 about 13 miles south of Yachats (Figures 1and 2). The slope above the highway failed repeatedly during December, 1999 through February, 2000 keeping the road closed through much of this time. The road is still closed most of the time for ongoing repairs. Observations are of slopes along Highway 101 and the ridge above both east and north of the landslide, within the landslide scar, and sea cliffs below and within about 200 feet north of the landslide. Access to the slide plane on March 10, 2000 and examination of drill core allowed a much more accurate analysis of the Cape Cove area than was possible in the previous (February 10) field examination. The previous (February 14, 2000) memorandum is herein replaced by this report.

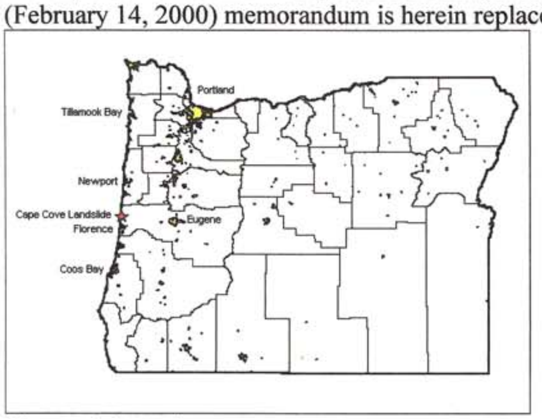

Figure 1. Location map

Figure 2. Cape Cove landslide scar above Highway 101, February 10, 2000.

SUMMARY AND CONCLUSIONS

The cause of the main slide was failure of a thin veneer of colluvium resting on a west-facing slope cut at about 36-37° in Yachats Basalt. Pore water pressure was apparently high enough in a zone about 15-20 feet above the Highway to weaken the oversteepened slope enough for failure. The steep highway cut and unusual rainfall combined to cause the failure.

Highway 101 is also vulnerable to bedrock slope failures above the highway. The Yachats Basalt is inclined at about 26° to the west (strike of N22°E), so the 36-37° slope is much steeper than the strata. The upper part of the Yachats Basalt consists of lava flows with interbedded weak paleosols and volcanic breccias that crop out 160 feet above the highway and form the top of the ridge. The lower part consists of hard basalt. This weak upper part could thus cause translational block slides. It may be useful to do a geotechnical analysis of the stability of this unit under various degrees of water saturation and pore pressure.

Colluvium above and below the highway is highly vulnerable to slope failure. The colluvim consists of firm, well graded clay- to boulder-size debris with low but variable permeability. Highway 101 is built mostly on a thick colluvial apron mantling the lower slopes. The colluvium is currently failing in a small active landslide below the highway adjacent to the north side of the Cape Cove landslide scar. The highway immediately above this small landslide has subsided gradually over the last few decades. The entire sea cliff below the highway has slopes of 53-78°, much higher than any reasonable angle of repose, so slope failure could occur at any time. The highway cuts north of the landslide scar have experienced slope failures in this material during and after highway construction, so future failures are probable there. The thin mantle of colluvial cover on rock slopes immediately above and south of the main landslide scar could be vulnerable to the same type of slope failure as the current slide. Highway 101 in the northern half of the slide scar to the tunnel lies on a thick colluvial apron that could also be vulnerable to slope failure.

Monitoring and detailed geotechnical analysis of all of these slopes should be considered.
Draining water from the colluvium and underlying bedrock and buttressing it will increase slope stability. Buttressing is a challenge because loading slopes undercut by wave action could cause them to fail, so light, strong buttresses or reinforcing of the slopes by piles and rock bolts is preferable.

On a smaller scale, large boulders in the colluvium may roll down the slope. One particularly dangerous boulder lies near the northeast headwall of the main slide. A large tree is perched atop this boulder and there is evidence of rocking motion at the base. The tree and boulder should be removed.

Keeping Highway 101 at Cape Cove open poses a major geotechnical challenge that will continue into the future. It may be worth doing a cost-benefit analysis of remediation versus rerouting of the road.

STRATIGRAPHY

The stratigraphic sequence in the area is summarized in Table 1; Figures 3 and 4 show a detailed geologic map and cross section of the slide area. Also shown is a small active landslide immediately north of the main landslide scar. Depiction of geology in areas adjacent to the detailed topographic map of the slide was not possible because no base map of sufficient accuracy was available. The available US Geological Survey 1:24,000-scale quadrangle is in significant disagreement with topographic contours and the road location shown on the detailed base map of Figure 3.

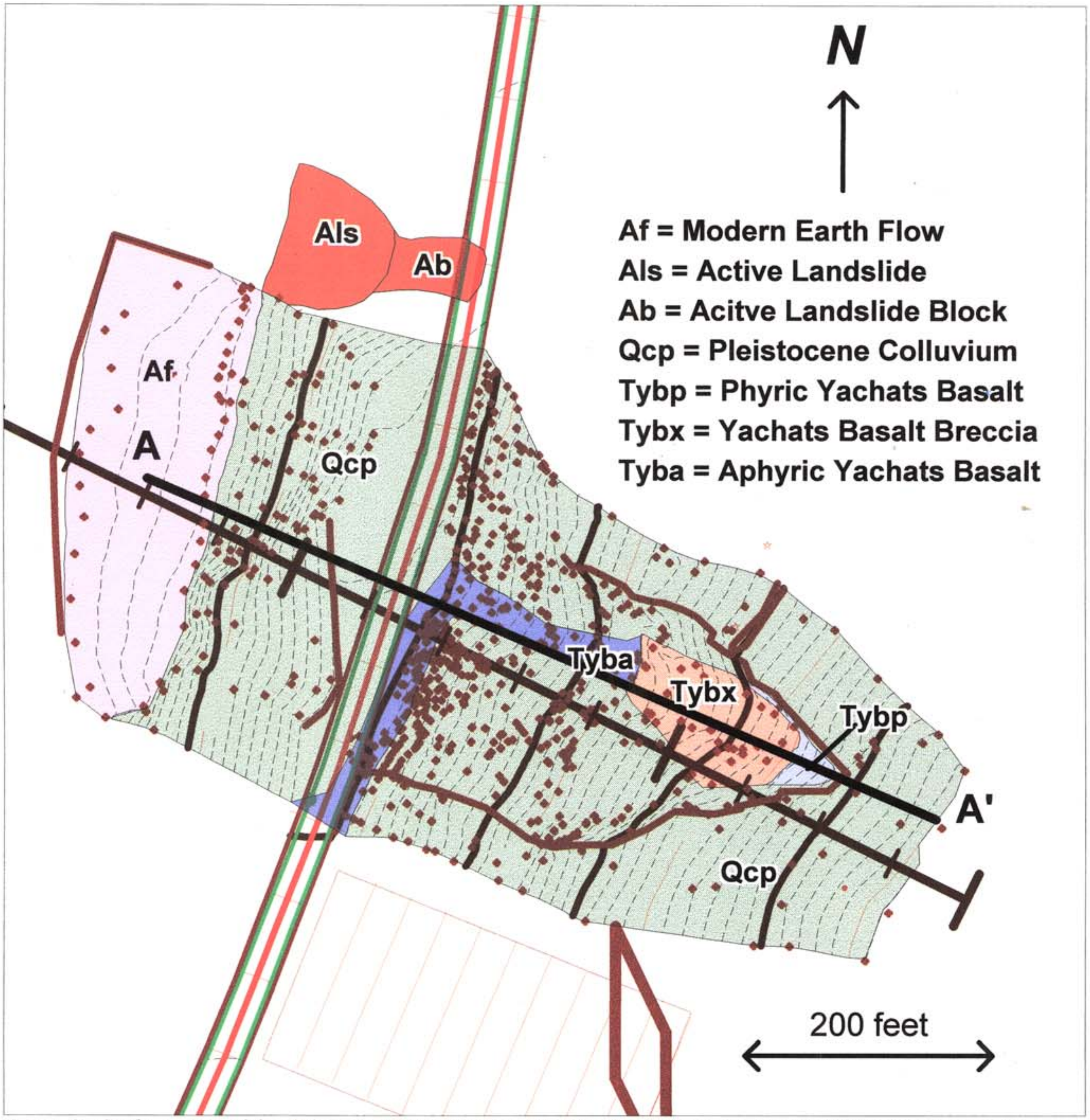

Figure 3. Geologic map of the slide area with slide scar outlined in heavy brown lines plus 9.8 foot (3 m) contours. Other lines are Highway 101 and engineering notations. Depiction of geology in adjacent areas was not possible because no base map of sufficient accuracy was available. The available US Geological Survay 1:24,000-scale quadrangle is in significant disagreement with topographic contours and road location shown on this base map.

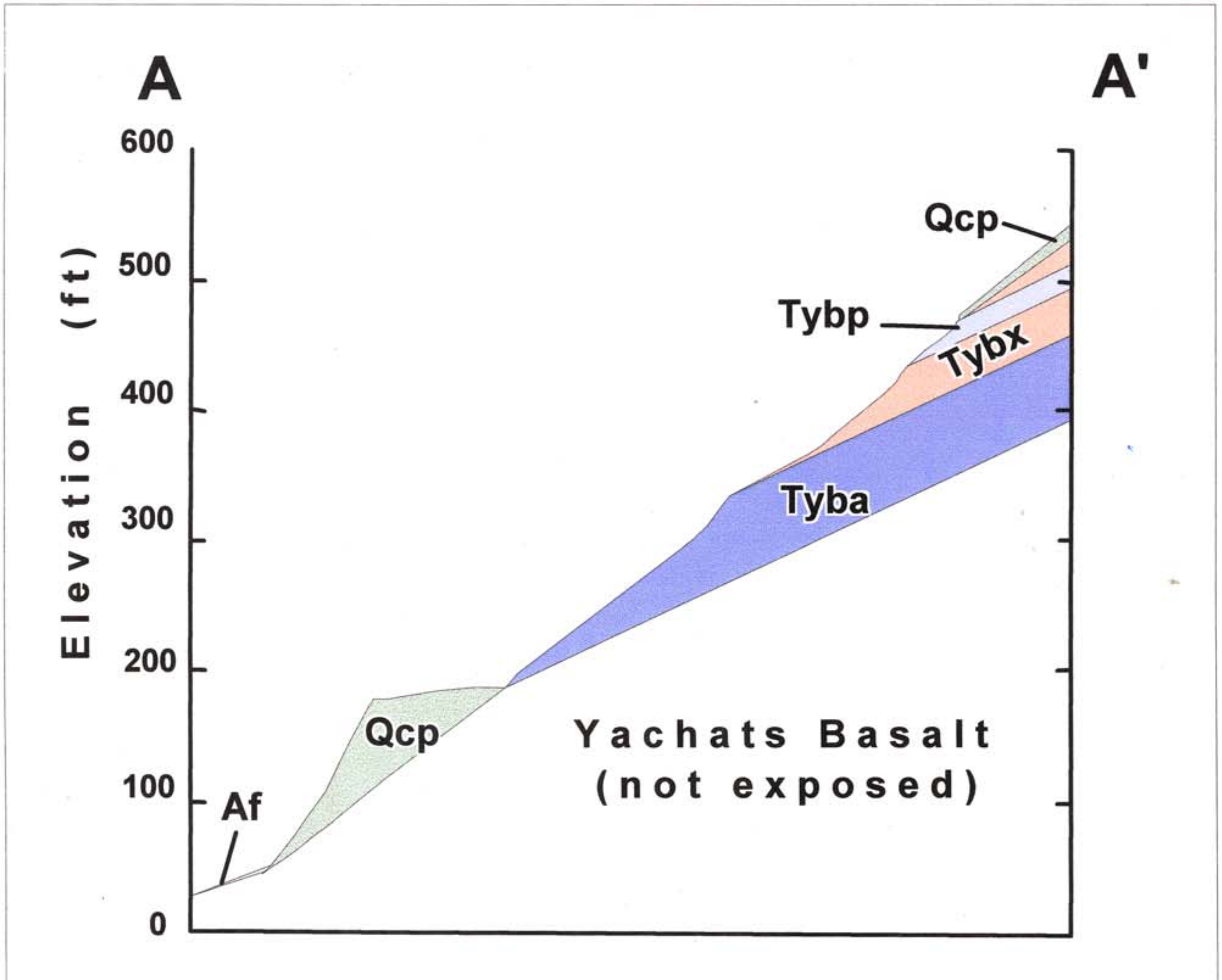

Figure 4. Cross section A-A' across the Cape Cove landslide scar. Note the thick apron of Pleistocene colluvium on the lower slope. Af is the fan of loose slide debris that poured onto the beach from the slide scar.

Table 1. Stratigraphy of the Cape Cove slide.

Unit	Description
Active earth flow (Af)	Modern earthen slide debris that cascaded onto the beach in December, 1999, forming a low sloping, water-saturated mound near sea level.
Active complex landslide (Als)	Landslide composed of blocks and slide debris with evidence very recent and ongoing movement (e.g. ground cracks, etc.).
Active slide block (Ab)	Block slide with translational or rotational movement and with evidence of very recent and ongoing movement (e.g. ground cracks, etc.).
Holocene colluvium and modern soils (not shown on geologic map)	Thin veneer of poorly indurated silty soil with or without angular basalt clasts from a few inches to several feet; poorly sorted (well graded) overall; thin (few feet) unit mantling most slopes in the area; evidence of mass movement from soil creep is rare, mainly confined to road cuts and few small, discontinuous areas on the natural slopes; very weak unit; appears fairly permeable. Essentially always underlain by unit Qcp.
Pleistocene colluvium (Qcp)	Moderately indurated soil with angular basalt clasts; some clast-supported layers, especially near base; poorly sorted (well graded); cobble- to pebble-sizes are most common clast size (Figure 5); may contain entrained logs and other woody debris. Has buried soils with rooted tree stumps at the base. Mantles most slopes in the area. Appears to thicken (tens of feet) on lower slopes relative to upper slopes (absent to a few feet thick); holds up near vertical slopes in many areas (Figure 6); evidence of mass movement from soil creep is rare, mainly confined to road cuts and few small, discontinuous areas on the natural slopes; highly variable permeability; abundant fines may limit permeability in most layers.
Upper Yachats Basalt (Tybp, Tybx)	Highly phyric lava flows (Figure 7), paleosols (Figure 8), and volcanic breccia (Figure 9) underlying the ridge above about 335 feet elevation (~160 feet above the highway); breccia and interbedded paleosols are mapped as unit Tybx; solid lava is unit Tybp; Unit Tybx forms moderate slopes; unit Tybp forms steeper slopes. Interbedded paleosols are soft, weak and nearly impermeable. One prominent paleosol occurs at the head of the main landslide scar underlying a solid lava flow (Figure 8). This paleosol and overlying lava appears to correlate with a similar exposure at the about the same elevation in the creek north of the main landslide. Lava and lava fragments have distinctive large (up to 1.2 cm) plagioclase crystals; fractures and vesicles generally filled with white zeolite; palagonitic breccia occurs in uppermost part near top of the ridge and can be found locally in the lower part unit.[1]
Lower Yachats Basalt, (Tyba)	Cliff forming hard aphyric basalt; (Figure 10); moderately fractured but strong unit capable of holding up near vertical cliffs.[1]

[1] See MacLeod and Snavely (1973), Snavely and MacLeod (1974), and Snavely and others (1980) for descriptions of the Yachats Basalt. The basalt is mainly subaerial basalt and basaltic andesite with a submarine palagonite breccia in the uppermost part. The aphyric lower part appears in hand specimen to be basalt. Macroscopic examination of the highly phyric rocks in the upper part indicate highly calcic (dark colored) plagioclase probably indicative of a basaltic andesite composition. Pyroclastic breccias are also highly phyric and are interbedded with red cindery material. These breccias could also be basaltic andesite, although more silicic compositions are possible. Petrographic and chemical analysis would be necessary to make a dertermination. Distinction between the phyric upper seqence and aphyric lower sequence is critical to the three point reconstruction of sequence dip from outcrops and drill core.

Figure 5. Pleistocene colluvium in sea cliff below Highway 101 on north side of Cape Cove slide scar.

Figure 6. Steep slope composed of Pleistocene colluvium below Highway 101 at Cape Cove slide scar. Note apron of loose slide debris (unit Af on geologic map) that cascaded onto the beach on lower right.

Figure 7. Highly phyric lava flow of upper Yachats Basalt at the head of the slide scar.

Figure 8. Soft clay-rich wet paleosol immediately below the phyric basalt flow of Figure 7 at head of slide scar. Mapped as part of the brecciated upper Yachats Basalt (Tybx). Colluvium from this red paleosol coats the slope below in red colors. This distinctive unit crops out in the small creek to the north and may be a major zone of weakness for translational block slides.

Figure 9. Pyroclastic breccia in upper part of the Yachats Basalt near contact with lower Yachats Basalt.

Figure 10. Lower Yachats basalt. This is a hard aphyric (lacking in large crystals) basalt flow. This outcrop is in the Cape Cove slide scar above Highway 101.

STRUCTURE

Regional bedrock structure is from a published geologic map (Schlicker and others, 1974) and indicates that rocks here, as elsewhere on the Oregon coast are inclined to the west. Tertiary sedimentary rock units generally strike northwest and dip 27° southwest in the nearest measured point at Devils Elbow about 1 mile north of the landslide. The strike (trend) of the failed slope is about N22E, with an inclination of 36-38° west northwest, so it is at an angle to the regional strike. This could mean that the slope cuts across dipping rock units, getting deeper in the section toward the north and west, or that the local strike and dip could be different from the regional attitude. Field observations in the slide plane indicate that the failed slope is steeper than the westward dip of the lava flow sequence. Estimated strike and dip in outcrop of the contact between the paleosol and overying phyric Yachats Basalt were N17-22°E strike with 12-32°W dip. Factoring in the drill hole data, the best strike and dip is N23°E; 26°W. This attitude was determined from a three point problem constrained by the elevation of the upper contact of the lower Yachats Basalt (unit Tyba) in two drill holes and in outcrop.

SLOPE STABILITY

The geologic history of mass wasting (soil creep and landslides) is critical to understanding the potential for slope failure. The colluvial mantle was probably developed thousands or tens of thousands of years ago when the climate was much wetter than at present. The moderate induration of most of this material and lack of large scale tilting of old growth trees supports the hypothesis that it has for the most part undergone only limited movement in the last few hundred years. Active landslides do occur but only where the slope has been severely undercut by either road construction or wave action. An important conclusion is that cursory examination of these slopes would have indicated that they were fairly stable before road construction.

Examination of the interior of the current landslide sheds some light on how slope failure has occurred prior to construction of the highway. The cliff of hard basalt at the head of the landslide scar is fully intact (even polygonal cooling fractures are closed) and lies on a distinctive red paleosol that has been recognized in an outcrop at a similar elevation in the small creek north of the landslide. Below this outcrop the basalt and underlying paleosol become increasingly disturbed by slow translational sliding until at about 90 feet down slope the basalt and underlying paleosol are fully fragmented. . The paleosol persists as a more or less continuous colluvial layer at the base of the colluvium for at least another 150-200 feet down slope from the partially disaggregated basalt. Tree stumps of recently cut old growth trees down slope and immediately north of the intact basalt show tree ring patterns indicative of very slight (almost imperceptible) tilting by slow soil creep in the last few hundred years. These relationships are consistent with slow creep of colluvium and slow translational sliding as the dominant mass wasting processes. Mass wasting has been exceptionally slow in the last few hundred years but may have been faster in the geologic past, as evidenced by the thick apron of moderately indurated debris at the base of the ridge.

Persistence of the red paleosol as a colluvial layer at the base of the colluvium and abundance of clay and silt in the overlying colluvium has important geotechnical implications. This clay-rich material is of low permeability, so it could prevent free drainage of ground water from the fracture-dominated aquifers in the lower Yachats Basalt. The extreme weakness of the basal red paleosol colluvium combined with the potential increase in pressure head behind colluvial mantle probably contributed to the December, 1999 slope failure. Indeed, considerable ground water was encountered by horizontal drains penetrating the fractured lower Yachats Basalt at the central toe of the slide (Figure 11). Removal of buttressing colluvium by the highway cut was the other contributing factor.

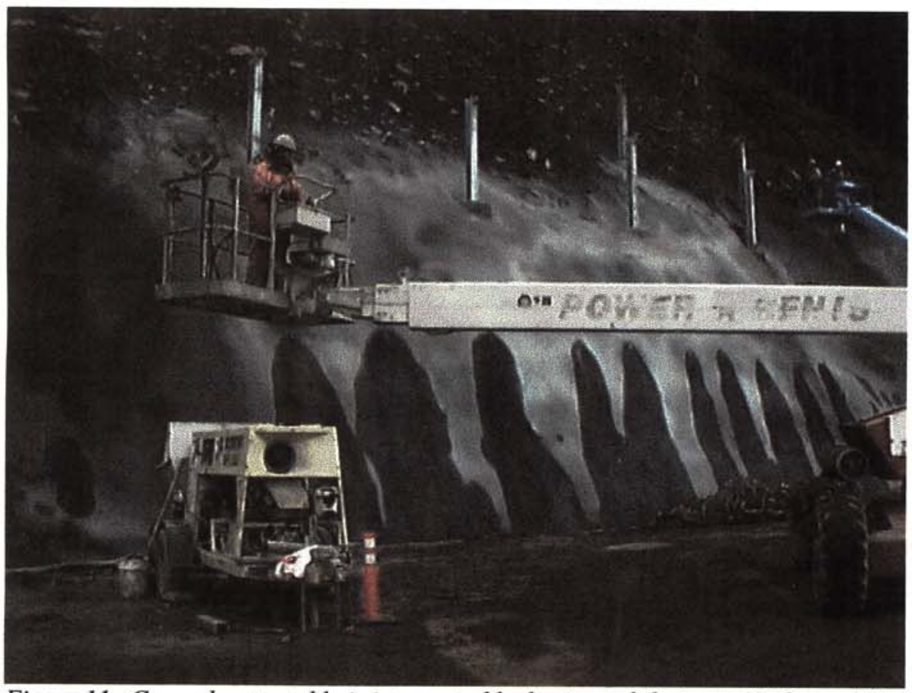

Figure 11. Ground water table is intersected by horizontal drains in Highway 101 road cut near the center of the Cape Cove slide scar. Lower slope has been coated with shotcrete and reinforced in this March 10 photograph. This cut is in the lower Yachats Basalt with a thin residual layer of Pleistocene colluvium cropping out above the wall. This thin layer is left over from the slusher operation and thickens to south (treed area in upper right corner) where it could be vulnerable to slope failures like the present one.

In fact all of the slopes disturbed by wave erosion or highway construction are probably very close to a factor of safety of 1.0. Undisturbed slopes above the highway cuts are 19-25°, so this is the likely stable angle of repose probably developed in large part during earlier geologic times when even wetter climate conditions prevailed. Slopes on the order of 53-78° occur from the beach to about 150 feet of elevation (about 40 feet below Highway 101). Slopes of about 40-50° occur from this point upward to the road where fill material and slide debris has been dumped over the side of the highway (Figures 4 and 12). As is apparent in Figures 6 and 12, natural slopes created by wave erosion approximate 55-78° even where underlain by Pleistocene colluvium. Road cuts above Highway 101 are generally 1:1 slopes (45°) with locally steeper spots near the headwalls of recent slide failures.

Of particular concern are sea cliffs and highway cuts in the northern half of the slide scar and points north to within about 100 feet of the tunnel. This area is underlain by a very thick colluvial mantle that is vulnerable to failure of both the road cut and sea cliff. There is a small (~110 feet wide, north to south) landslide below the highway on the north side of the slide scar (Figure 3). This landslide has caused gradual subsidence of Highway 101. Similar active landslides are apparent on the aerial photos along the sea cliff to the north. Active sliding has occurred on the Highway 101 cuts north of the slide scar during and after road construction (Glen Thommen, 2000, personal communication based on historical documents and photographs).

A thin, potentially unstable colluvial mantle covers all bedrock slopes above and south of the landslide. This colluvium could produce slope failures exactly like the present one. Outcrops at the head of the creek north of the landslide indicate that the colluvial-bedrock contact is a zone of water accumulation, being the source of the creek. If water accumulates at this contact above and south of the landslide, then the slope could be destabilized and fail. The landslide itself has essentially cut the toe out of the continuous colluvial mantle above the landslide, so this is probably an unstable slope.

Figure 12. Leveled slope cut in Pleistocene colluvium with fill material and slide debris dumped over the edge of the bluff.

All slopes above the highway also cut across the weak units of the upper Yachats Basalt, so translational block failures could be triggered by removal of buttressing colluvium or by unusual increases in water pore pressure. Isolated outcrops of upper Yachats Basalt exposed in the vicinity of two forest roads above the highway immediately north of the slide scar may be such translational blocks.

Large boulders can roll off of the steep slopes above the highway. One especially dangerous boulder lies near the northeast headwall of the landslide (35 feet N10E of survey marker SP-4). This 10 foot wide boulder is surmounted by a tree that is probably on the order of 200 feet high and 4.7 feet in diameter. The boulder has spaces beneath it that could be from rocking back and forth as the tree sways in the wind.

RECOMMENDATIONS

1. Further analysis of the slope stability is necessary to form firm conclusions. This would be greatly aided by detailed topographic mapping of the entire slope, so accurate geologic mapping could be done. Installation of piezometers and inclinometers would aid in understanding how fluctuations in water pore pressures relate to slope movements. Measurements of the engineering properties of the soil and rock units, particularly pore water pressures, could then be used to do quantitative stability analysis of slopes above and below Highway 101. Topographic mapping might be done by either field surveying or aerial photography. An advantage to aerial photography is production of orthophotographs that could be used in concert with stereo photos for highly effective geologic field mapping. Priority should be given to analysis and monitoring of steep road cuts and sea cliffs in the northern half of the slide scar to within about 100 feet of the tunnel.
2. The big fir tree and boulder near survey marker SP-4 should be removed.
3. Reasonable efforts should be made to lower groundwater tables and relieve pore water pressures where ever possible. The thin colluvial mantle above and south of the landslide scar may be particularly vulnerable to slope failure from ground water accumulation at the bedrock-colluvium contact. The thicker colluvial cover north of and below the landslide scar would also benefit from dewatering. Drainage of water from the bedrock-colluvial contact and fractured bedrock will probably be the most effective technique, since this will tap into zones of higher permeability than the colluvium itself. Nevertheless, local aquifers that might be encountered in the colluvium could also pose a danger and should be drained.
4. Efforts to buttress the slopes will be ineffective if, in the process, excessive load is added to already unstable slopes down slope of the toe of the buttress. This is a problem, since the most stable footing for a buttress is the active beach nearly two hundred feet below the road. Placement of a beach buttress would be expensive and would pose important policy questions about placement of buttress materials on the public beach. The other logical toe for a buttress is the highway, but loading the highway could cause failure down slope. If buttressing is pursued on the highway without down slope buttressing, then it should be as light and strong as possible, perhaps balanced by removal of rock and soil. Buttressing of the sea cliff below the road may also benefit from light, strong engineering structures, if a beach revetment is to be avoided.
5. In view of the slope stability problems in this area, it may be useful to do a cost-benefit analysis of alternative highway routes versus probable costs of continual remediation of slope failures on the existing highway.

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