State of Oregon
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Open-File Report

OFR-03-08

Review of Geologic Report for Surfrider Resort Proposal, Lincoln County, Oregon
OPRD Permit #BA-555-03

By

George R. Priest, Jonathan C. Allan, and Yumei Wang

Oregon Department of Geology and Mineral Industries

2003

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REVIEW OF GEOLOGIC REPORT FOR SURFRIDER RESORT PROPOSAL, LINCOLN COUNTY, OREGON OPRD PERMIT #BA-555-03

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Oregon Department of Geology and Mineral Industries

April 11, 2003

INTRODUCTION

On April 2, 2003 the Oregon Parks and Recreation Department (OPRD) requested assistance from the Coastal Field Office of the Oregon Department of Geology and Mineral Industries (DOGAMI) in the form of a technical review of a geologic report accompanying OPRD Permit #BA-555-03. The geologic report describes a proposal for the construction of a shoreline protection structure (SPS) immediately north of Fogarty Creek to decrease erosion of the sea cliff fronting the Surfrider resort. The specific request was that DOGAMI:

1. Examine the adequacy of the geotechnical report with respect to characterization of factors affecting slope stability plus wave, groundwater, and subaerial erosion.
2. Examine the adequacy of the report with respect to its review of alternatives to the proposed SPS.
3. Evaluate the adequacy of the report with respect to potential adverse impacts to adjoining unprotected bluff areas and the integrity of rock units to which the proposed shoreline protective structure will be connected.

GEOLOGIC SETTING: OBSERVATIONS FROM AN APRIL 4, 2003 SITE VISIT

The area in question is shown on Figure 1 and consists of a sea cliff composed of about 24 feet of dark gray Astoria Formation overlain by approximately 30 feet of Quaternary marine terrace sand. The Astoria is composed of pelecypod-bearing silty clayey fine grained sandstone with minor interbeds of medium grained sandstone. In hand speciman, most of the Astoria at this locality appears to be a mudstone but actually has a high enough fine sand content to be classified as sandstone, according to Dr. Alan Niem (personal communication, 2003). One thin (~ 1 foot wide) north-south trending vertical diatreme dike filled with fragments of Astoria Formation and devitrified basaltic glass cuts through the Astoria. The terrace sand is horizontally bedded coarse pebbly sand in the lower 10 feet and appears to be medium to coarse sand in the upper part. A dark Holocene soil caps the sequence. The contact between the Astoria Formation and the Quaternary deposits consists of a near horizontal surface. The Astoria is inclined seaward, striking N43ºE and dipping 21ºNW, and is characterized by significant jointing and zones of weakness. The local bluff trend is north-south with numerous reentrants on the cliff face.

The beach seaward of the bluff face consists of coarse sand and therefore is steep (slope (S) = 0.07 (1 on 14)) and reflective to intermediate in the classification of Wright and Short (1983). Such beaches are highly dynamic such that they respond rapidly to changes in the offshore wave energy. Furthermore, because of the steep nature of the beaches, wave runup is able to reach much higher elevations on the backshore, allowing the hydrostatic and hydrodynamic pressures generated by the wave swash to erode the rock surface. Hydrostatic pressures result from the mass of water and air impacting a surface, while the hydrodynamic pressures result from turbulence and the compression of entrained air against the rock. As a result, if a rock surface is characterized by a narrow fronting beach (i.e. has limited buffering potential), reentrants, extensive jointing and zones of weakness, the hydrostatic and hydrodynamic properties associated with wave swash can be further concentrated along the reentrants, where they may rapidly erode the Astoria (Figures 2 and 3).

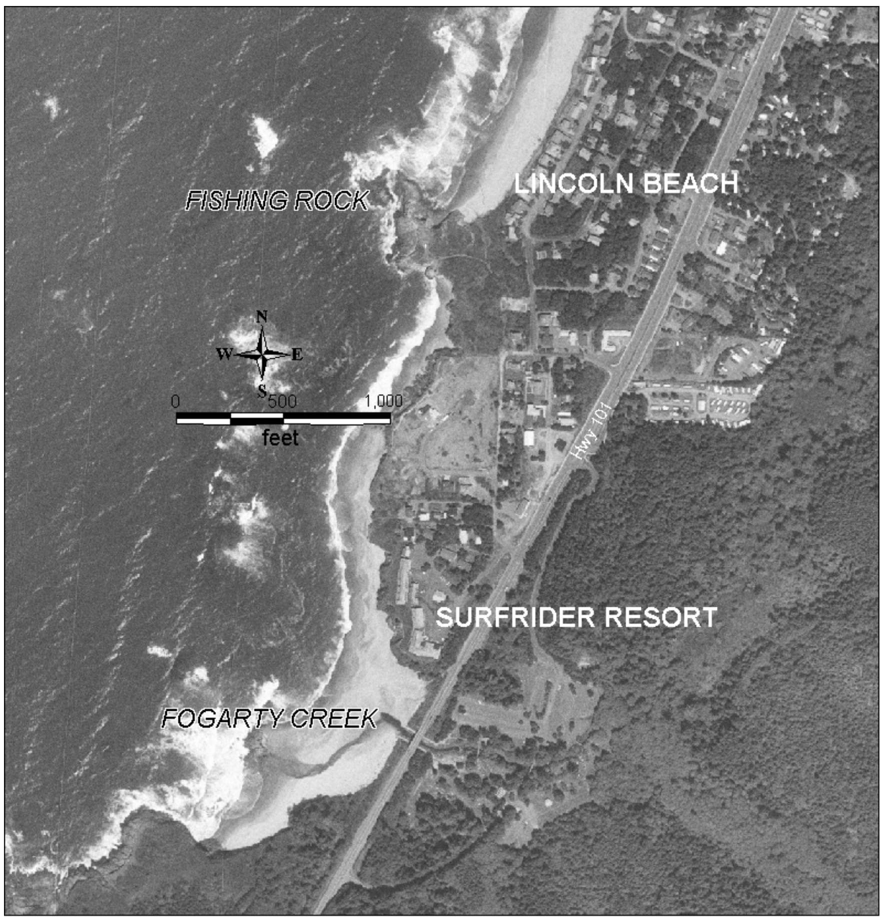

Figure 1 Location of Surfrider Resort. North-south trending portion of sea cliff is area of concern. Note the gap in offshore rocks immediately west of the resort that allow waves to break much closer to the beach.

Reentrants located along the bluff follow tectonic joint systems in the Astoria Formation that strike N50-65ºE and dip 82-85º NW. Erosion is also promoted by north-south to northwest trending joints and faults that cause the northeast to east-trending fissures to widen out north-south. Prominent joints and small faults are parallel to bedding and at N12ºW; 57ºW, N27ºW; 75ºW, N10ºW; 48ºE, N10ºE; 74ºE. Where bedding-parallel shearing has occurred, the upper block of Astoria is highly fractured at high angles along these northerly trends (Figure 4.). A prominent N35ºW-trending fault or sheared joint dips 65-73ºW (Figures 3-5). Erosion along this structure in combination with erosion along the other northeast and northwest-trending joints and small faults is in the process of creating sea stacks of the Astoria west of this feature. These future sea stacks are in a stronger part of the Astoria where joints are more widely spaced (Figure 6).

Figure 2 Looking east at reentrants in dark gray Astoria Formation; reentrants have reached to within 30 feet of the Surfrider Resort building at the top of the bluff. Orange to tan unit is overlying Quaternary Marine Terrace deposits. Steve Williams of OPRD is on the right; Jonathan Allan of DOGAMI is on the right.

One prominent joint does cut through the outer (western) part of the cliff face trending N27ºW and dipping 75ºW. This joint creates a separate block of Astoria Formation at the nose of the small promontories that project out from the bluff (Figure 6). This joint is a zone of weakness with respect to wave erosion.

As bedding-parallel shears are exposed in the eroding cliff face, blocks of Astoria and overlying marine terrace sand may slide on these bedding planes, particularly where the local bluff trend becomes sub-parallel to bedding strike. Significant flow of groundwater was observed coming from sheared bedding planes and cross cutting joints and shears. Water pressure may be high enough to initiate movement once the buttressing rock is eroded away.

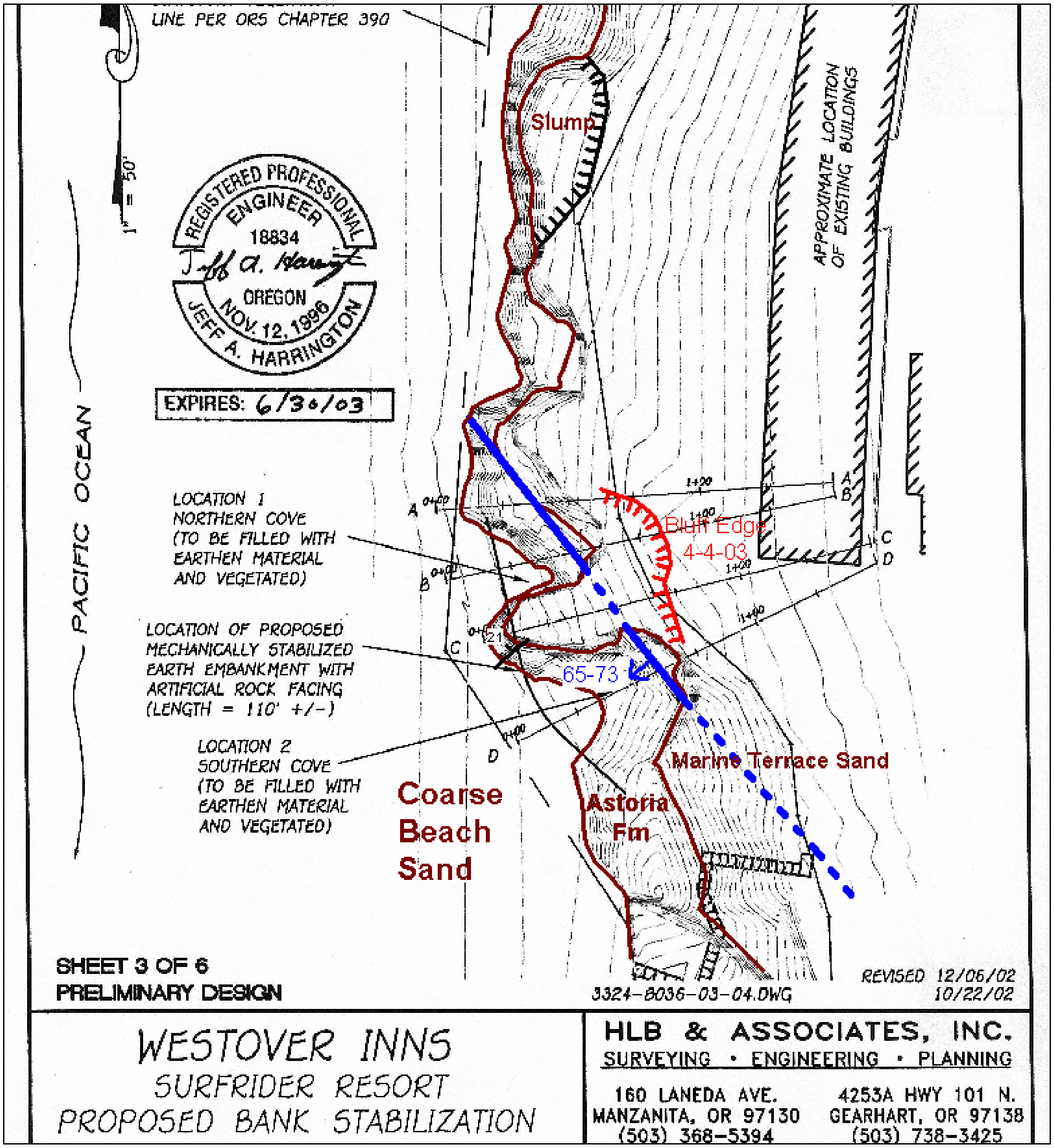

Figure 3 Geologic map with prominent fault or sheared joint system shown in blue with inclination of in degrees in direction of blue arrow. The structure is dashed where covered by Quaternary marine terrace sand. Geologic contacts are brown lines; geologic units are labeled with brown lettering. Strike and dip of a thin sandstone bed in the Astoria Formation (see Figure 6) is shown with strike and dip symbol. All black and white graphics (topographic map and illustration of engineering features) are from HLB & Associates, Inc. Note April 4, 2003 location of the bluff edge (shown in red hachures) compared to the bluff edge on the December of 2002 topographic map. The corner of the building is now only 30 feet from the sea cliff.

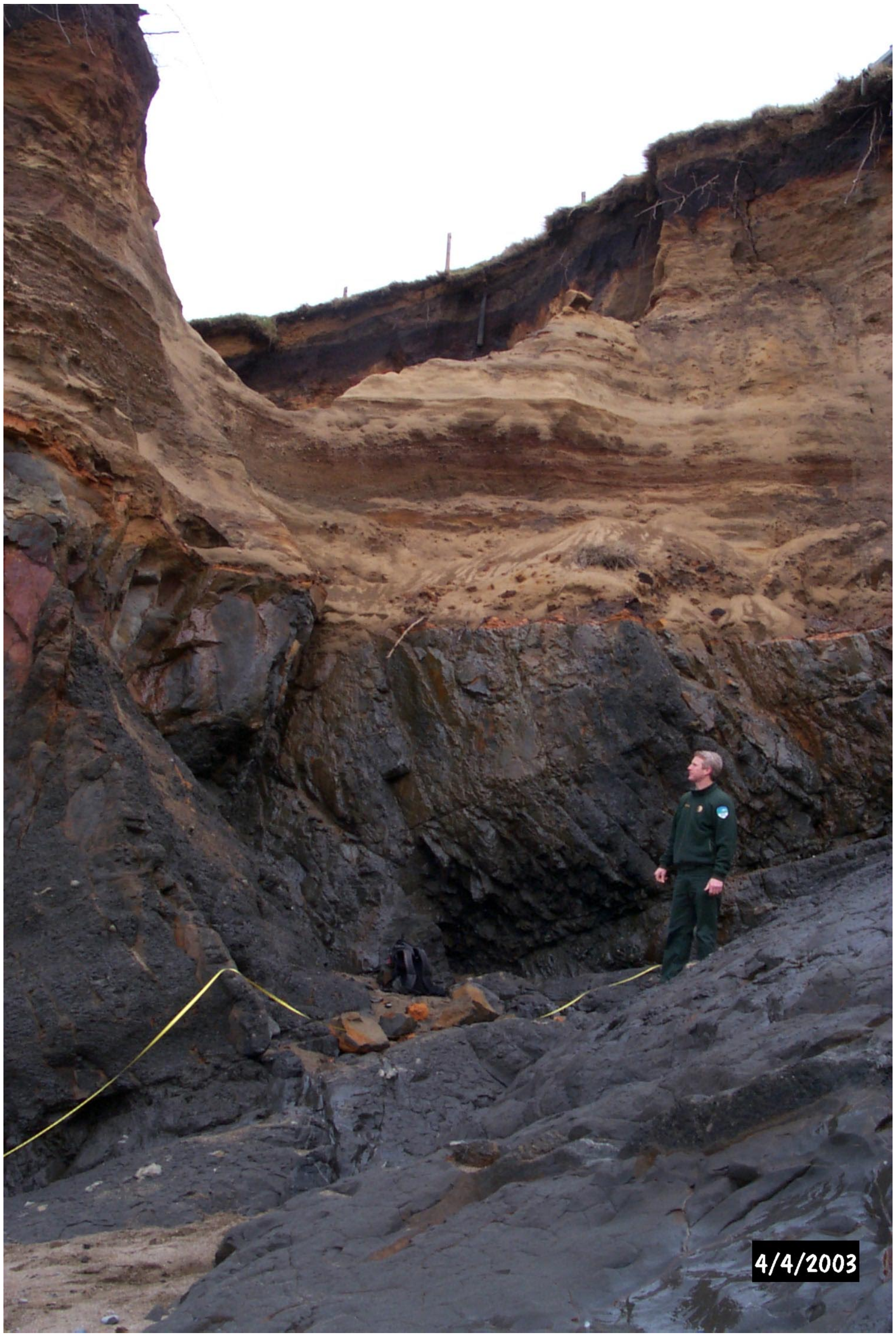

Figure 4 View looking northeast. Steve Williams is standing on prominent bedding plane shear in silty clayey fine-grained sandstone of the Astoria Formation. Shattered Astoria overlies the bedding plane shear in upper right part of picture. A northwest trending fault or sheared joint system terminates the shattered Astoria in the left center of the picture. Note how erosion in the shattered Astoria has nearly removed the septum of rock and terrace sand. Iron stain at horizontal contact of highly permeable marine terrace sand with the nearly impermeable Astoria is probably indicative of lateral groundwater movement along the contact. Similar stains on high angle fractures in the Astoria are probably indicative of vertical flow of oxygenated groundwater into the fracture system. Such flow was observed during the field visit. Note the dark Holocene soil exposed at top of bluff.

Figure 5 Close up view to northwest at the prominent N35W trending, west-dipping sheared joint or fault in Astoria Formation. Location is in left central part of the photograph of Figure 4. Trace of structure is shown in blue on Figure 3.

Figure 6 View to the north at northwest-trending joint in Astoria Formation at nose of small promontory. Note the northwest-dipping thin sandstone bed. This open fracture system is a significant zone of weakness for wave erosion.

What appeared to be a slump or translational slide was also identified at the north end of the site. It had a few feet of vertical offset. There was no time to do a detailed investigation of its cause, but a sketch of the approximate location is given in Figure 3.

Groundwater also moves freely through the poorly indurated Quaternary marine terrace deposits. Some spring water was observed weeping from the contact of these deposits with underlying Astoria. Heavy iron oxide stain on Astoria Formation at this contact may be evidence for lateral and vertical movement of oxygenated groundwater that changes reduced iron in the iron smectite clay to a higher oxidation state (Alan Niem, 2003, personal communication; Figure 4). The stain may also be from conversion of FeO carried in solution by groundwater to more oxidized, less soluble forms of iron. Another possibility is that this iron-stained zone is a paloesol, but this seems less likely since the contact is a wave-cut platform that would not have been amenable to soil-forming processes. Groundwater saturation of friable marine terrace deposits probably decreases their strength, making them more susceptible to failure from stress-release fracturing and cantilevered block falls (see Hampton, 2002 for explanation of the cantilevered block fall process). The cantilevered block fall process keeps the upper part of the sea cliff at a near vertical slope (Figure 4).

SEDIMENT SOURCES

Oregon's beaches have limited sand sources and simple sediment budgets. In a study of the beach-sand mineralogy along the coast, Clemens and Komar (1988) found that the sand was derived from three main sources, the Klamath Mountains in southern Oregon and northern California, the Coast Range mountains backing most of the coast, while sediments from the Columbia River are concentrated in the north along the Clatsop Plains and did not extend south of Tillamook Head. It was concluded, however, that those sources cannot supply sand to the littoral cells at present due to the numerous headlands that characterize the Oregon coast, the sand instead having reached the cells thousands of years ago, carried onshore by beach migration under the rising sea at the end of the Ice Age. As a result, there are only limited quantities of modern sand being added to the beaches, and this varies considerably from cell to cell.

Beach sediments that characterize the Fogarty Creek pocket beach are likely derived from three potential sources. These include; the marine terrace deposits that overly the Astoria Formation, alluvial sand from Fogarty Creek, and offshore sand brought into the system by littoral transport.

Erosion of the coastal bluffs, primarily those containing Pleistocene dune and beach sands, represents a major sand source for most of Oregon's beaches. At Fogarty Creek, an examination of the grain-sizes identified above the marine terrace indicates that they are similar in size to those that characterize the contemporary beach. This reinforces the view that the bluff is a major contributor of sand to the beach. However, historical erosion rate along the Fogarty Creek bluffs has been quite low. For example, Priest and others (1994) estimated that the bluffs have been eroding at a rate of ~0.1 foot/year. A comparison of the bluff on 1939 and 1993 air photos showed negligible changes in the geometry of the bluff line in the study area. Rapid erosion of 50-60 feet in the reentrants along the sea cliff during the last 6 years is therefore unprecedented in the previous 50 years or so.

Another possible sediment source is material provided by Fogarty Creek, which is likely to provide a mixture of sand, gravels and cobbles. We are, however, unsure how much sediment is derived from the Creek. Sediments may also be derived from littoral or along-shore transport. However, such movements will vary temporally and spatially in response to seasonal variations in the wave energy, climate events such as El Niños or decade to inter-decadal climate cycles associated with the Pacific Decadal Oscillation. All of these processes will result in significant variations in the volume of sand present on the beach, which will ultimately influence the ability of the beach to buffer the incident wave energy.

El Niños in particular, are likely to influence the volume of sand on the beach. Typically during an El Niño there is a southward displacement of the storm tracks so they mainly cross the coast of central California. As a result, storm waves reach the Oregon coast from a more southwesterly quadrant, creating an abnormally large northward transport of sand within its littoral cells. This creates "hot spot" erosion at the south ends of the cells, north of the bounding headlands, and also north of migrating inlets (Komar, 1986, 1998). The opposite response is found south of the headlands, where the northward displaced sand accumulates. A comparison of LIDAR topographic data (Light Detection and Ranging Data) measured by the U.S. Geological Survey in 1997 (pre- El Niño) and 1998 (post-El Niño), indicate that the average high water shoreline position eroded landward by some 70 ft immediately in front of the Surfrider resort, leaving only 60 ft of beach to buffer the waves. However, conditions during the 1998-99 La Niña winter were even more extreme, so that it is likely that the beach eroded landward still further. Certainly, our visit to the site on April 4, 2003 revealed that the beach in front of the resort was extremely narrow, offering very little protection to the bluffs.

Despite these various sediment sources it can be concluded that sediments derived from the adjacent bluffs and creek is likely to be small since there is little evidence of long-term shoreline progradation along the beach. For example, an examination of shoreline positions identified on the 1928 National Ocean Service topographic (T) sheet, 1994 USGS digital orthophotos, and 1997 and 1998 LIDAR shorelines indicate no long-term shoreline progradation or erosion. This finding is consistent with other observations of shoreline responses along the Oregon coast, whereby the beaches respond episodically to major storms (Allan and others, in review).

CAUSES OF EROSION

There are a variety of possible reasons for the dramatic changes that have occurred along the bluff that fronts the Surfrider resort. These include the following:

1. A dramatic increase in wave heights over the past several winters; the largest storm waves occurred during the 1997-98 El Niño and 1998-99 La Niña winters (Allan and Komar, 2002). These storms produced significant wave heights that reached 46 ft. Furthermore, these events were also characterized by increases in mean sea level due to the 1997-98 El Niño climate phenomena and as a result of storm surges along the coast; surges locally raised mean sea level by 1.6 to 3.3 ft;
2. Greater access of waves to the sea cliff as the buffering beach sand was removed;
3. Change of rock resistance to erosion in the interior of the sea cliff;
4. Channeling of wave energy into northeast-trending fissures in the Astoria;
5. Channeling of wave energy through offshore breaks in rock reefs (Figure 1); and,
6. Some combination of the above factors.

The first factor has been well documented by Komar and Allan (2000) and Allan and Komar (2001, 2002). Of particular importance, is that these studies demonstrate a dramatic increase in wave energy along the central Oregon coast since 1996, with the estimated 100-year wave now placed at ~ 50 ft. It is beyond the scope of this report to adequately evaluate factor 2. Nevertheless, it is apparent from the 1997 and 1998 LIDAR data and our site visit that the beach width is narrow and offers little protection from waves (Figure 1). Since fracturing and jointing increase in the interior of the bluff, factor 3 is likely to be quite significant. Factor 4 promotes hydraulic fracturing of the rock when waves are funneled into these fissures and trap air bubbles. Factor 5 may explain why this portion of the bluff has eroded more than similar areas north and south. Once Factor 5 allowed breaching of the relatively unfractured Astoria in the outer sea cliff, Factors 3 and 4 probably resulted in accelerated erosion. Hence it is likely that all of these factors have been significant in increasing the erosion rate in recent years.

REVIEW COMMENT #1. *Adequacy of the geotechnical report with respect to characterization of factors affecting slope stability plus wave, groundwater, and subaerial erosion.*

The report does a fair job of characterizing erosion rate and lithologic factors affecting wave and subaerial erosion. It also correctly describes the importance of groundwater at the marine terrace-Astoria contact. However, the report does not evaluate the importance to slope stability of groundwater pressure in the fracture system cutting the Astoria, particularly the sheared bedding planes. It is likely that the proposed buttress adequately remediates any potential translational failure on sheared, water-saturated bedding planes, but this was not specifically treated in the report. Ponding of groundwater in the SPS will likely be remediated by the proposed perforated pipes that will penetrate the SPS. Further reduction of water pressure could be achieved by horizontal drains in the bedrock itself, although this may not be necessary, given the likely buttressing effect of the SPS and adjoining rock promontories, none of which have had obvious translational failures.

The report indicates that runoff had been previously controlled by drainage without specifying how exactly this was done. During our site visit, it was apparent that there was considerable runoff occurring at a number of locations, particularly in the two main reentrants and also north and south of these areas. We therefore question the effectiveness of previous remediation of runoff and infiltration of runoff into the groundwater. Runoff of surface water and infiltration of groundwater both from local storm drains and from surrounding areas needs further explanation in the report.

Should the shotcrete wall fail, the mechanically stabilized fill behind the wall would probably not survive for very long under sustained winter wave attack. For this reason, the performance and construction of the wall should be explained in some detail. For example, it is not clear that the shotcrete would be reinforced with steel mesh or some other means. Detailing may be quite important with respect to wave erosion resistance. That said, the report does do a good job of explaining how the wall will be recessed into the bedrock at the bottom and sides of the structure. Erosion around the sides is probably mitigated by recessing the wall 5-10 feet inland; however, erosion along major joints like the one in Figure 6 could be a problem and should be treated in the report.

Regarding erosion around the sides of the SPS, the report does not address likely erosion along the extension of the N35ºW shear zone immediately north of the proposed north end of the SPS. This zone of weakness could provide early breaching to the side of the SPS, which may lead to destabilization of the structure.

No supporting data was offered to support the notion that the recessing the shotcrete wall 2 feet vertically into the Astoria would prevent undermining of the wall. Toe scour was supposed to be remediated by the dish shape of the wall, but, again, no supporting data was offered.

The report does an inadequate job of estimating potential storm wave impacts to the sea cliff and the proposed SPS. Wave run-up is arbitrarily estimated at 30 feet with the actual run-up to be deferred upon consultation with DOGAMI staff. Estimation of run-up is a complex scientific undertaking that is not likely to be addressed by a quick consultation with DOGAMI. Our initial qualitative analysis indicates that 30 feet is likely not high enough. For example, staff in the Coastal Field Office, during field work in the winter of 2002-2003, measured runup elevations on a steep cobble berm at Cape Lookout State Park (Tillamook County) reached and elevation of 30 feet. Thus one might expect to see much greater run-up on the beach and bluff at Fogarty Creek over the 50-year design life.

No estimate is given for the likely forces that may be imparted to the proposed SPS by waves and entrained ballistics such as logs, cobbles, or boulders. No quantitative estimate is given of the performance of a thin, brittle shotcrete wall under likely storm wave conditions. Indeed, such an estimate is not possible without some evaluation of wave parameters. No explanation was given why waves large enough to move large quarry rock would not also cause the shotcrete wall to fail. The report does conclude that the adjoining Astoria sea cliff may erode several feet during the 50-year life of the SPS, but does not explain why the brittle, thin shotcrete wall would fair better than the Astoria, especially during the early stage of erosion when waves would be funneled into the 5-10 foot reentrant occupied by the wall. It is our opinion, that the issue of wave runup and wave forces impacting on the proposed structure should be re-examined. Given the complex nature of the environment and the type of structure being proposed, it is our opinion that such analyses should be undertaken by a qualified coastal engineer. For these reasons we question whether the 50-year design life for the shotcrete wall is realistic. It may be that an aggressive program of maintenance would address these issues. The report does mention that maintenance will be necessary.

A rather steep slope is shown for the final grade in the upper part of the sea cliff. This part of the cliff is composed of friable marine terrace sand. The upper part of this slope is shown unsupported by fill. Such weak material may not be stable at the slope angle shown in the illustrations.

The proposed fill in the 2:1 slope above the mechnacially stabilized embankment is not mechanically stabilized. Some explanation is needed for lack of mechanical stabilization.

The report does not address the apparent slump feature noted in the north part of the study area north of the proposed SPS (Figure 3). Propagation of further slope failures of this kind may threaten the northern part of the resort in the future. If this is a translational failure, it may have implications for translational failures that could affect the SPS.

REVIEW COMMENT #2. *Adequacy of the report with respect to its review of alternatives to the proposed SPS.*

According to CERC (1984), the type of structure used for shore protection depends on the following criteria:

(1) Foundation conditions;
(2) Exposure to wave action;
(3) Availability of materials;

(4) Both initial costs and expected repair costs; and,
(5) Past performance records of structures used in the area.

Due to the magnitude and type of erosion that is occurring along the Surfrider bluff face and the extreme nature of the wave environment along this coast, the types of engineering options that may be utilized at the proposed site are limited and may include the following:

- No engineering solution, i.e. abandonment and let nature take its course;
- Abandon a portion of the building or relocate the building, i.e. setback from the bluff;
- Rip rap revetment;
- Construct a sea wall or bulkhead; and,
- Some form of mechanically stabilized embankment.

While there are other options that range from "soft" (e.g. beach renourishment, dynamic revetments) to "hard" engineering (e.g. offshore breakwater), none of these latter options will adequately address or stop the bluff face from eroding further. Thus, while each of these latter types of engineering solutions may reduce the amount of energy that impacts the toe and face of the bluff, they will not alleviate the ongoing recession of the Astoria Formation and the Quaternary sediments that will occur regardless in response to wave and subaerial processes (e.g. weathering). This is because the bluff slopes are near vertical in many places and will continue to erode landward until they establish some form of stable slope.

The report from HLB & Associates provides a number of alternatives to the proposed SPS, which range from a form of vegetated stabilization to the "do nothing" approach. The document does an adequate job of summarizing each of these options.

The report rightly acknowledges that a "hard" solution such as a rip rap revetment is likely to have a large footprint on the beach, will likely have a significant impact to the beach, and may affect people's ability to access the beach in front of the resort. A comment was made that large quarry rock used in a revetment could be moved about by waves and become a hazard. Accordingly, this option was disregarded by HLB & Associates. No supporting data for the potential for rock movement was given. We note that many rip rapped bluffs along the Oregon coast appear to persist for years without substantial alteration. We also wonder about the contention that rip rap would pose a danger to the public when moved about by waves. Would it be likely that someone would be below the revetment when waves capable of moving quarry stone were striking it? Would the waves themselves be just as hazardous as any rock that might move under these conditions?

The option of a sea wall or bulkhead was discounted on the grounds that such structures are unsightly, and may modify the flow of sand along the shoreline. However, it is worth noting that sea walls themselves don't interrupt longshore sediment transport, though they can cause enhanced toe scour to the fronting beach. It was unclear why a sea wall or bulkhead could not be "textured" with some kind of shotcrete covering or some other technique to disguise its appearance. It was also unclear why a seawall or bulkhead could not be used in combination with the proposed mechanically stabilized embankment to provide erosion protection and a buttress to the upland slope.

The mechanically stabilized embankment (faced with shotcrete) option was considered to be the best solution for the site since it essentially meshes both “hard” and “soft” forms of engineering. However, as indicated previously, we have reservations about the ability of the shotcrete to withstand the wave forces and erosion, although committed maintenance of the structure may remediate this problem.

The retreat option was discounted on the grounds that the structure is too large and that there is little room to maneuver. One option worth exploring is whether it is feasible to remove or move a portion of the threatened building.

REVIEW COMMENT #3. *Adequacy of the report with respect to potential adverse impacts to adjoining unprotected bluff areas and the integrity of rock units to which the proposed shoreline protective structure will be connected.*

Theoretically a hard SPS can cause enhanced erosion on sandy beaches for lateral distances north-south of up to 70 percent of the length of the SPS. This would be 154 feet north and south of the structure with most severe “end effect” erosion being adjacent to the end of the structure. It is unclear whether these observations hold for a bluffed, narrow beach like the one at this site. Setting the structure 5-10 feet back into the sea cliff should remediate these effects until the sea cliff is eroded back. In other words, the end effect, if there is one, is probably no worse than that already produced from the geometry of the current sea cliff.

The report concludes that there would be no significant loss of sand supply associated with the SPS, citing the low sand content of the bedrock (Astoria Formation). The fine grained nature of most of the Astoria in this area does indeed make it a poor beach sand source. The report does not quantitatively estimate the sand content of the overlying marine terrace deposits that would be removed from supplying the beach with sand for the next 50 years of erosion. While this amount of sand is not likely large in absolute terms, it may be significant in the context of this small pocket beach littoral cell. The report actually has no quantitative estimate of sand supply from any source. While such quantitative estimates are generally beyond the scope of a typical geotechnical report, the issues should probably be more extensively discussed.

The report also ignores any reference to long-term sea level rise. Along the central Oregon coast, sea level is rising at a rate of about 3 - 4 mm/yr based on the Newport tide gauge (Flick and others, 1999). Over 50 years, this equates to an increase in mean sea level by about 0.6 ft. Such an increase will cause the average shoreline position to recede landward by approximately 6 – 10 ft, and will enable waves to reach higher elevations. If the SPS is effective in stopping bluff retreat to accommodate this shoreline change, beach width will decrease in front of the structure, regardless of design factors like the dish shape of the wall. Ultimately the beach will be lost at all tidal stages, if the wall is maintained without beach nourishment into the indefinite future. A quantitative or semi-quantitative estimate of the life of the recreational beach in front of the structure would be useful information to provide to OPRD regulators.

REFERENCES CITED

Allan, J.C. and P.D. Komar, 2001, Wave climate change and coastal erosion in the US Pacific Northwest: Proceedings of the 4th Conference on Ocean Wave Measurement and Analysis, WAVES 2001, San Francisco, California, ASCE: 680-690.

Allan, J.C. and P.D. Komar, 2002, Extreme storms on the Pacific Northwest Coast during the 1997-98 El Niño and 1998-99 La Niña: Journal of Coastal Research, 18(1): 175-193.

Allan, J.C., P.D. Komar and G.R. Priest, in review, Shoreline variability on the high-energy Oregon coast and its usefulness in erosion-hazard assessments: Journal of Coastal Research, (SI).

CERC, 1984, Shore Protection Manual: Washington D.C., U.S. Government Printing Office, 2 Vols.

Clemens, K.E. and P.D. Komar, 1988, Oregon beach-sands compositions produced by the mixing of sediments under a transgressing sea: Journal of Sedimentary Petrology, 58(3): 519-529.

Hampton, M.A., 2002, Gravitational failure of sea cliffs in weakly lithified sediment: Environmental & Engineering Geoscience, v. 8, no. 3, p. 175-191.

Komar, P.D., 1986, The 1982-83 El Nino and erosion on the coast of Oregon: Shore and Beach, 54(2): 3-12.

Komar, P.D., 1998, The 1997-98 El Niño and erosion on the Oregon coast: Shore & Beach, 66(3): 33-41.

Komar, P.D. and J. Allan, 2000, Analyses of extreme waves and water levels on the Pacific Northwest coast: Oregon Dept. of Land Conservation and Development, Salem, Or: 24.

Priest, G.R., I. Saul and J. Diebenow, 1994, Explanation of chronic geologic hazard maps and erosion rate database, coastal Lincoln County, Oregon: Salmon River to Seal Rocks: Open-File-Report O-94-11, Oregon Department of Geology and Mineral Industries, Portland, Oregon: 45p.

Wright, L.D. and A.D. Short, 1983, Morphodynamics of beaches and surf zones in Australia: P. D. Komar, Handbook of coastal processes and erosion: CRC Press: 35-64.