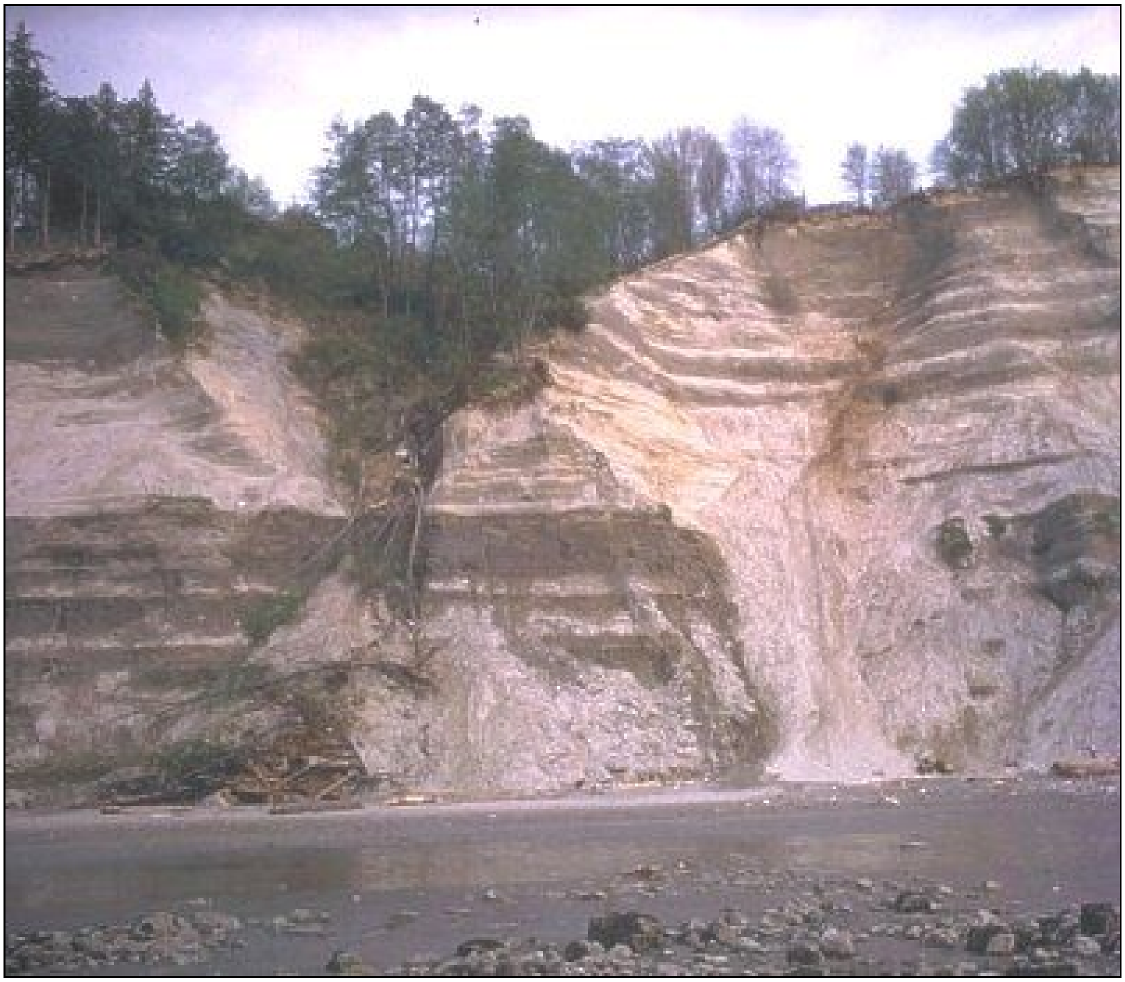
Stability of the UBC Point Grey Cliffs and the Effects of Vegetation on Slope Stability



Retrieved from https://web.viu.ca/earle/geol312/point-grey-erosion.htm

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Outline

Abstract

The recession and failure of the Point Grey Cliffs are of great concern to the local community because the cliffs not only support the University but also serve as a recreation area for the public. The results of our study assert that the unconsolidated nature of the sands, in combination with the ongoing erosion caused by wave action and precipitation, make the Point Grey Cliffs unstable and prone to failure. However, due to the stabilizing effects of vegetation, we believe that the erosion of cliffs do not pose an immediate threat to the university and will remain stable with current erosion rates (given that there are no large events such as an earthquake or a volcanic eruption). As such, we encourage the practice of using vegetation to stabilize cliff faces. The results of our findings are summarized in a proposed Terrain Stability Map that predicts areas where landslides may occur along the cliffs between Trail 3 and 4.

1. Introduction

Deposited by the Cordilleran Ice Sheet during the Fraser Glaciation, the Point Grey Peninsula on which the University of British Columbia (UBC) is situated, is made up of a lithostratigraphic unit called the *Quadra Sand*. The unconsolidated nature of the sands make them vulnerable to erosion[1] and has contributed in part to several mass wasting events along the Point Grey Cliffs. The stability of the the Point Grey Cliffs between Trail 3 and Trail 4 of the Pacific Spirit Park is of particular interest because these lands support the Museum of Anthropology (MOA), the UBC Anthropology and Sociology Building (ANSO), and the Cecil Green Park House. Slope failure along these cliffs would put the users of these buildings and anyone below at great risk. This study discusses three key factors that affect the stability of the cliffs that support this area (see Figure 1): low shear strength[2] of the Quadra Sands, the effects of coastal erosion, and the effects of heavy precipitation; and the effectiveness of using of vegetation as a way to increase slope stability and its effect on soil cohesion and slope stability. The results of our findings are used to create a Terrain Stability Map (see Appendix A) that predicts areas where landslides may occur along the cliffs between Trail 3 and 4. Finally, our findings are used as a backdrop to discuss the constraints on development.

[1] Erosion is defined as the transport of material away from its source (Stephenson, 2016).
[2] Shear strength is defined as the internal resistance of a body to shear stress (Stephenson, 2016).

Figure 1. Study area. Screenshot taken from Google Earth

2. Method

A combination of field data and research was used to determine the stability of the Point Grey Cliffs. Data regarding the slope angle, depth, vertical scale, and sedimentary makeup of the cliffs were collected from the study area (see Figure 1) using a trowel, tape measure, brunton, and a Munsell Chart. Various UBC Community Planning documents and scientific journals were also reviewed to determine key factors that affect the stability of the cliffs.

A basic vegetation survey was conducted to note the dominant tree species and low-lying vegetation in the study area. Areas that posed a threat to the stability of the cliffs, such as the density and age of vegetation, presence of dead vegetation, exposed sand faces, and steep slope angles, were also noted. These threats were determined through a review of related studies. These studies include journal articles related to the effect of vegetation on slope stability and a technical hazard report of Halfmoon Bay, which is geologically similar to the Point Grey Cliffs.

A contour map of the study area was created using 2010 elevation data obtained from GeoGratis. This data was accessed through Google Earth.

3. Results

3.1 Factors that contribute to the instability of the Point Grey Cliffs

Overridden and compacted by historical glacial advances, the Quadra Sands are found throughout the Lower Mainland of British Columbia. The sands are known to be cohesive and compact and thus, stable and appropriate for land development. However according to a *Hazard, Risk, and Vulnerability Analysis* conducted by EmergeX Planning Inc. for the Greater Vancouver Regional District, the Point Grey Cliffs are not stable, despite being made up of the Quadra Sands (2005). This is due to the unconsolidated nature of the sands in combination with the ongoing erosion caused by wave action and precipitation. The following subsections discuss these slope destabilizing factors in detail.

3.1.1 Sedimentary Deposits

Using field data collected from the study area, a stratigraphic profile of the Point Grey Cliffs was created (see Appendix A). Referring to Appendix A, Strata 3 is made up of approximately 21 meters of (impermeable) fine silts and sands; Strata 2 of approximately 45 meters of permeable sands known as the Quadra Sands; and Strata 1 consists of a complex of permeable diamicton overlain by approximately 3 meters of soil[3]. This stratigraphic profile directly relates to the instability of cliffs. According to a drainage strategy report of the UBC South Campus prepared by Aplin & Martin Consultants Ltd and Holland Barrs Planning Group, the presence of an aquitard and the observed seepage that occurs between Strata 2 and 3, indicate that the impermeability of the silts and sands in Strata 3 has resulted in subsurface water flow at the interface. Such an interface promotes sliding and dislodgement of material, thus contributing to slope instability. Based on these observations and supporting literature (GVRD Parks - West Area, 1991; Pottinger Gaherty Environmental Consultants Ltd., 2004; & Armstrong, Roots & Staargaard, 1990), it is concluded that the sedimentary make-up of the Point Grey Cliffs contribute to their instability.

3.1.2 Effect of coastal erosion

Facing the Strait of Georgia, the exposed cliff faces of the Point Grey Cliffs are subject to the effects of coastal erosion[4]. The base of the Point Grey Cliffs are estimated to be losing approximately 7.5 cm worth of material annually from the repeated impact of wave energy (University of British Columbia, 2004). As the base of the cliffs lose mass over time, the slope of the cliffs become progressively steeper and more prone to failure. According to the Greater Vancouver Regional District (GVRD), slopes with angles greater than 27.5° are are likely to fail (2005). With measured slope angles of more than 60° (see Appendix A), the chances of failure along the Point Grey Cliffs are extremely high and pose a large risk to anyone below sites of failure.

[3] This paper assumes that the stratigraphic profile detailed in Appendix A is uniform and extends horizontally throughout the study area.
[4] Coastal erosion refers to the gradual, permanent retreat of a shoreline as a result of wave and wind action removing or abrading material against the shoreline (Stephenson, 2016).

3.1.3 Effect of heavy rain events

Vancouver receives more than 200mm of precipitation a month on average (EmergeX Planning Inc., 2005). Excessive amounts of rainwater can decrease the shear strength of the Quadra Sands and increases the chance of slope failure. This is because the impermeable layer of silts and sands in Strata 3 of the Quadra Sands (see Appendix A) act as a barrier and prevents rainwater from dissipating into the sands below. As a result, the sands in Strata 2 become saturated with water. The increase in pore water pressure sets grains apart and reduces the shear strength of the material, thus promoting mass wasting events.

Heavy rain events also contribute to the instability of the slopes via stormwater runoff. The construction of the MOA, the UBC Anthropology and Sociology Building, and the Cecil Green Park House has resulted in a larger area of impermeable surfaces. Since there are less natural surfaces for rainwater to dissipate, the rainwater concentrates and runs off as a water surge (Aplin Martin Consultants Ltd. & Holland Barrs Planning Group, 2005). Such surges travel at high velocities and can potentially destabilize materials that support the slopes. In 1935 for example, stormwater runoff carved out a large gully in the cliffs behind Green College (UBC/Pacific Spirit Park Cliff Erosion Management Planning, 2000). Stormwater runoff also destroyed property by Coach House during storms in 1994 and 1997 (2000).

3.2 Vegetation as a method to increase the stability of the Point Grey Cliffs

Our vegetation survey found that red alders, douglas firs, and bigleaf maples are the dominant tree species on the Point Grey Cliffs. A dense understory of young douglas fir, sitka spruce, western redcedar was also observed. These observations are supported by other vegetation surveys done of the area (GVRD Parks - West Area, 1991 & Douglas, Meidinger & Pojar, 2002). The forested cliffs is one of the many efforts have been made by UBC, the government, and the Vancouver Parks Board to decrease the rates of erosion, and the chance of slope failure (UBC/Pacific Spirit Park Cliff Erosion Management Planning, 2000). Based on an extensive review of literature, we found that vegetation is an effective way to increase slope stability. The following subsections go into detail about the effect of tree roots, roots of small vegetation, and Red alders and dead vegetation on slope stability.

3.2.1 Effect of tree roots on slope stability

Various studies (Kokutse et al., 2016; Li et al., 2016; and Matsushi et al.) show the positive effects of tree roots on slope stability. Tree roots increase soil cohesion and the shear strength of the soil by binding loose materials together (Li et al., 2016). The increase in the shear strength of the soil that overlays a slope results in an increase in the shear strength of the slope itself (Li et al., 2016). This is particularly true during a rainfall event. As discussed in section 3.1.3, precipitation decreases soil cohesion and shear strength of a slope. However, in a study conducted by Li et al., plant roots were shown to decrease the destabilizing effects of precipitation. The study showed that the factor of safety of a vegetated slope after a rainfall event was higher than that of an unvegetated slope (2016) and that the six root structures considered in study (eg. roots with a wide lateral extent, plants with a strong tap root, roots that interact with other roots etc.) all had a stabilizing effect on the slope.

3.2.2 Effect of small vegetation roots on slope stability

Small vegetation such as bushes, grass and shrubs can substantially improve slope stability and prevent downward soil erosion. One method is through lowering pore water pressure due to grasses and shrubs with thin roots having a higher resistance to tensile stresses compared to thicker roots (Gyssels et al, 2005). Like thick tree roots, plant roots provide cohesion, and roots that are interlocked with soil (root-permeated soils) are known to be much stronger at withstanding mass movement compared to barren roots that do not have these interlocking soil. Small vegetation also provides similar mechanical soil reinforcement like the artificial geogrids/geotextiles to increase soil shear strength in the topsoil, which is more effective than early thick tree roots (Waldron, 1977). Furthermore, the study by Burylo, Hudek, Rey (2011) states that fibrous root systems that contain a mixture of "woody coarse roots and many fine and strong roots" commonly found in shrubs and herbaceous species are the most effective for soil reinforcement. This mechanism can be used to stabilize barren, shallow soil layers for restoration: herbaceous species recolonize the substrate quickly, allowing the less effective tree seedlings to grow large enough to stabilize upper layers of soil (Burylo, Hudek, Rey, 2011).

3.2.3 Effect of Red alders and dead vegetation on slope stability

Based on our vegetation survey and those conducted by others, Red alder (*Alnus rubra*) was found to be a dominant tree species in the study area. Red alders are fast growing trees that can establish an extensive fibrous root system within 3 to 5 years (USDA NRCS, 2006). As discussed above, such a root system help to stabilize slopes by increasing soil cohesion. Other benefits of Red alders include: a dense canopy cover that works to decrease the erosional effects of precipitation and wind, and the production of thick nitrogen-rich layers of litter. The latter helps to support the growth of other species such as douglas-fir which too, can help stabilize slopes.

However, it must be noted that Red alders have a relatively short life span of 60 years. If other vegetation fail to establish after the death of a community of Red alders (or after the death of any other vegetation), the soil that supports the community will likely erode. According to Reubens et al, tree roots decay to approximately 30 per cent of their original structure 12 years after the death of a tree (2007). This leaves behind cavities for water to permeate which ultimately leads to soil erosion as pore water pressure increases and soil cohesion decreases (Reuben et al., 2007). In order avoid the chances of soil erosion and to maintain slope stability, we urge authorities to replace dead Red alders (and dead vegetation) with species that have a longer life span such as douglas-firs.

4. Discussion of Results

4.1 Terrain Stability Map

As discussed in sections 3.1 and 3.2, factors affecting slope stability of the Point Grey Cliffs include: the sedimentary make up of the Quadra Sands, slope angle (as a result of the effects of coastal erosion), precipitation; and the presence of large and small vegetation root systems, and dead vegetation. Considering these factors we propose the Terrain Stability Map in Appendix C to predict areas where landslides may occur along the cliffs between Trail 3 and Trail 4. Each polygon in the map delineates an area of stable/unstable cliff and is labeled with a terrain stability class. The terrain stability classes are ranked from I to V and indicate the likelihood of slope failure (with I being the least likely and V being the most likely) based on the each factor of stability discussed in Section 3 of this paper. Table 1 summarized the rankings and the associated stability factors of each class. Our observations of slope angle are complemented by a contour map, which shows the gently sloping areas beneath the North Campus, along with the steep upper reaches of the cliffs progressing into gradually decreasing slope angles at the cliff bottoms. It is also worth noting that exposed sand faces were interpreted as a sites of historic landslides. Areas with this feature are were classified as Class IV or Class V because the exposed sand are more vulnerable to the erosional effects of precipitation (as opposed to cliff faces shielded by vegetation and soil).

As shown in the Terrain Stability map, the area Supporting the MOA, UBC Anthropology and Sociology Building and Cecil Green Park House is given a terrain stability class of I and II. The cliff edge of the area is supported by dense, mature trees, has a thick undergrowth, and no exposed sand faces. For these reasons, we believe that the stabilizing effects of vegetation is enough to prevent slope failure along these cliffs and this section of the cliffs do not pose an immediate threat to the university.

Terrain Stability Class	**Interpretation**
I	No significant stability problems exist. - Low or no slope angle (<27.5°)
II (see Figure 2)	Low likelihood of slope failure. - Moderate slope angle (<27.5°) - Mature forest - Dense undergrowth
III (see Figure 3)	Minor stability problems with moderate likelihood of slope failure. - Moderate to steep slope angle (27.5° - 60°) - Less dense forest or populated by young trees - Less dense undergrowth - Presence of dead vegetation
IV (see Figure 4)	Larger stability problems with a moderate likelihood of slope failure. - Steep slope angle (>60°) - Sparse forest of young trees - Sparse undergrowth - Presence of dead vegetation - Exposed sand faces
V	High likelihood of slope failure. - Steep slope angle (>60°) - Little to no trees - Little to no undergrowth - Presence of dead vegetation - Exposed sand faces

Table 1. Terrain stability classification.

Figure 2. Example of Terrain Stability Class 2 (Liu, B. *Terrain stability class 2.* 2 December 2016).

Figure 3. Example of Terrain Stability Class 3 (Liu, B. *Terrain stability class 3.* 2 December 2016).

Figure 4. Example of Terrain Stability Class 4 (Liu, B. *Terrain stability class 4.* 2 December 2016*)*.

4.2 Constraints on Use of Cliffs

While we believe that the land supporting the university is quite stable, we do recognize that the factors we discussed in section 3.1 constrain the use of the cliffs. Here we present some of these constraints.

Erosion of the cliffs leads to retreat of the top bank, which has been perceived as a threat to the MOA, UBC Anthropology and Sociology Building, and the Cecil Green Park House. The added weight of these structures increases the shear stress acting on the Quadra Sands and decreases slope stability. The Museum, despite the guarantee from geotechnical engineers that it does not contribute to cliff erosion, may add an unsafe weight load to the cliff tops, prompting collapse (UBC/Pacific Spirit Park Cliff Erosion Management Planning, 2000). This theory has resulted in the restricted use of the Museum's pond, which is filled only for special occasions. Lawn and garden maintenance has also contributed to surface water flow over the cliff top edge, significantly increasing erosion rates over small areas. Awareness of the cliff's susceptibility to erosion and failure has been manifested in their usage and controls over nearby development.

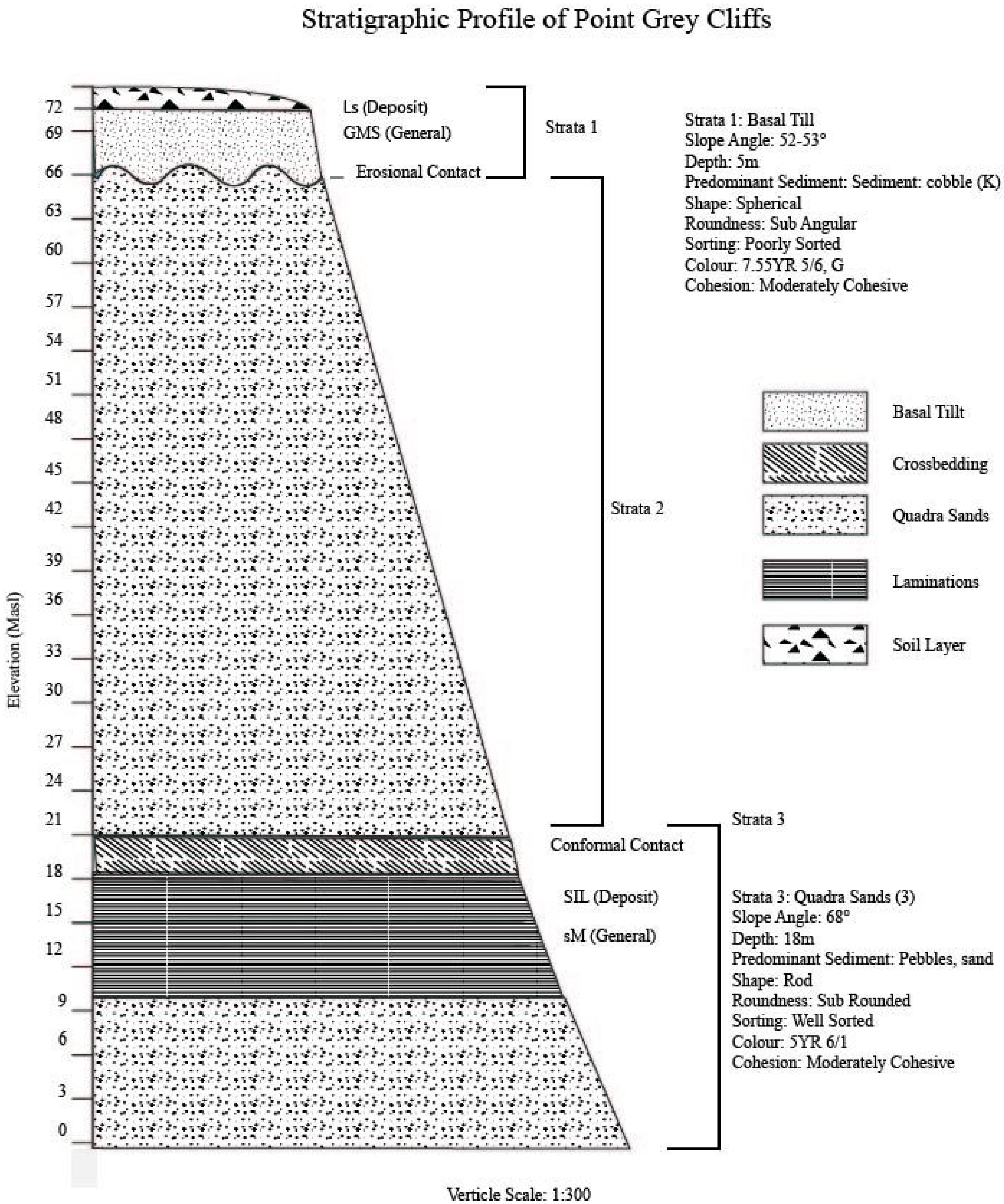
The fragility of the Point Grey Cliffs has resulted in restricted development in the North Campus and controlled pedestrian use near along the cliffs near the Museum of Anthropology, Cecil Green, and Coach House area. An assessment was conducted in 2003 to evaluate the technical ramifications the Cliffs' instability would have on future development. This information was incorporated into the *Comprehensive Hydrogeological and Cliff Erosion Assessment of Point Grey* by Sandwell, Piteau Associates and Trow Engineering. The report recommended a setback of 30 degrees from the horizontal, projected back from the toe-of-slope to the top-of-bank for new buildings in the North Campus Neighbourhood (University of British Columbia, 2004). Since the toe of the slope is not a permanent reference point, an Interim No-Build Zone was established to impose an additional setback from the cliff-edge to allow for monitoring of slope and top-of-bank stability (2004). This would help prevent additional weight being added to the cliff top.

Cliff erosion mitigation has been incorporated into UBC community planning via the *Land Use Plan.* According to the UBC/Point Grey Campus Land Use Plan, there are “significant constraints on development [in academic area north of NW Marine Drive] because of its relation to the cliffs” (p.14, 2015). The purpose of these regulations is to minimize the potential impact on the surrounding park lands and ensure the safety of the UBC facilities. These regulations are manifested in part by the area surrounding Green College and Cecil Green Park House included into a Green Edge, a zone designated to provide a sense of a community in a forest setting, while promoting protection of the integrity of Pacific Spirit Regional Park (2015). This buffer zone features green landscaping, trails, and fences to provide safety and prevent accelerated erosion. There are restrictions on maximum height and maximum site coverage for sites within the North Campus as well: the Museum of Anthropology may use up to 50% of its site area and expansions can be no higher than three stories (University of British Columbia, 2004). The threat of the receding slopes and the recognized erosive effects of developing too close to the cliffs has been deeply integrated into community planning at UBC.

5. Conclusion

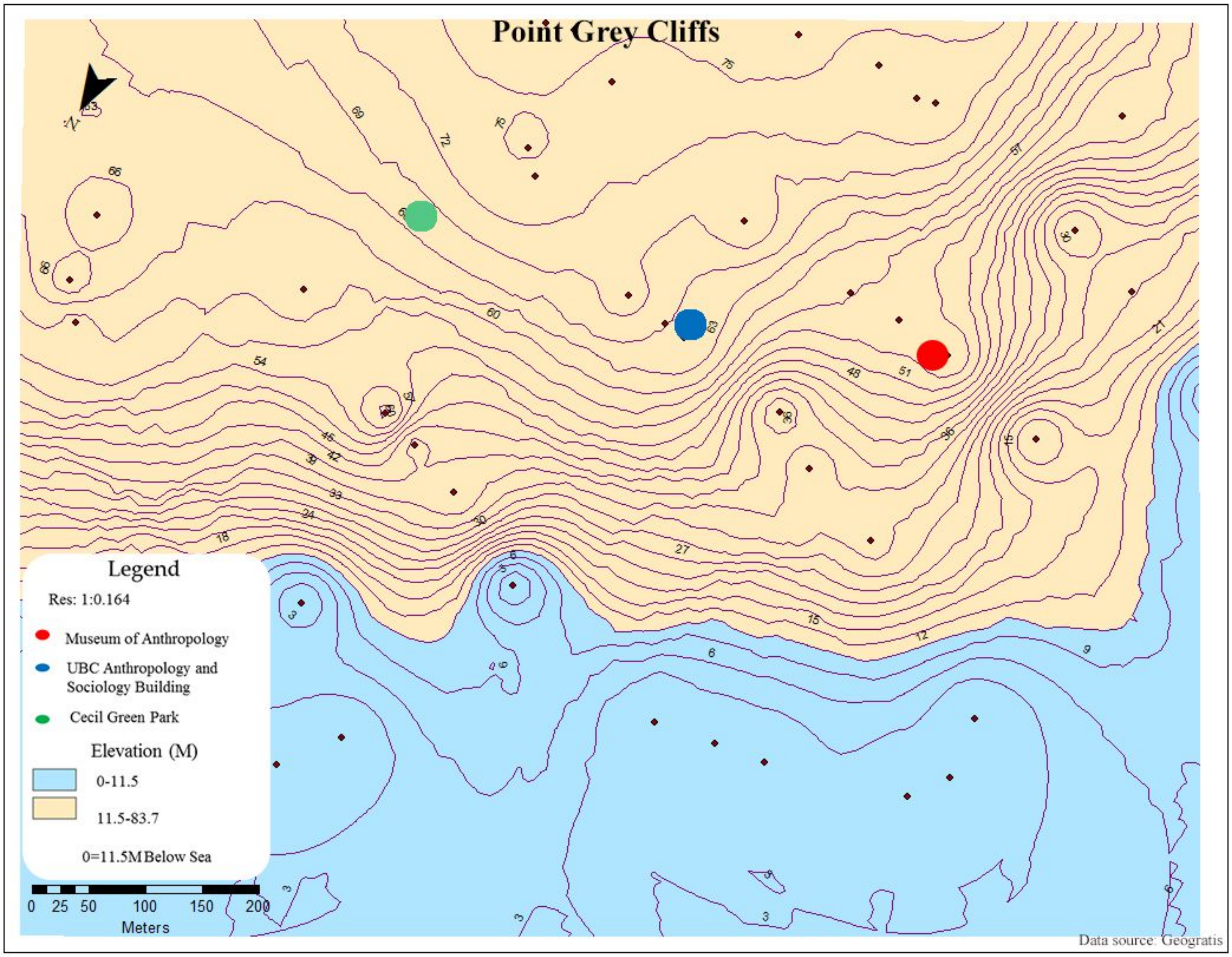
The Point Grey Cliffs are predicted to recede by 7.5 meters in the next 100 years (University of British Columbia, 2004). We recognize that the cliffs are inherently unstable and there are main constraints of the uses of the land, but given the various measures taken to combat the effects of erosion, we believe that the cliffs that support the MOA, the UBC Anthropology and Sociology Building (ANSO), and the Cecil Green Park House are not under major threat of failure from erosion alone. The destabilizing effects of heavy rainfall are negated by the roots of vegetation that cover the cliff faces, providing a stabilizing effect on the soil and preventing slope failure. Additionally, current regulations on areas adjacent to the cliff ensure future developments are not threatened by erosion and collapse. We do, however, advocate for the continuation of the revegetation practice, including the use of red alders and the removal of dead vegetation to ensure that coastal erosion remains low and to prevent saturation of the Quadra Sands during heavy rain events.

Appendix A



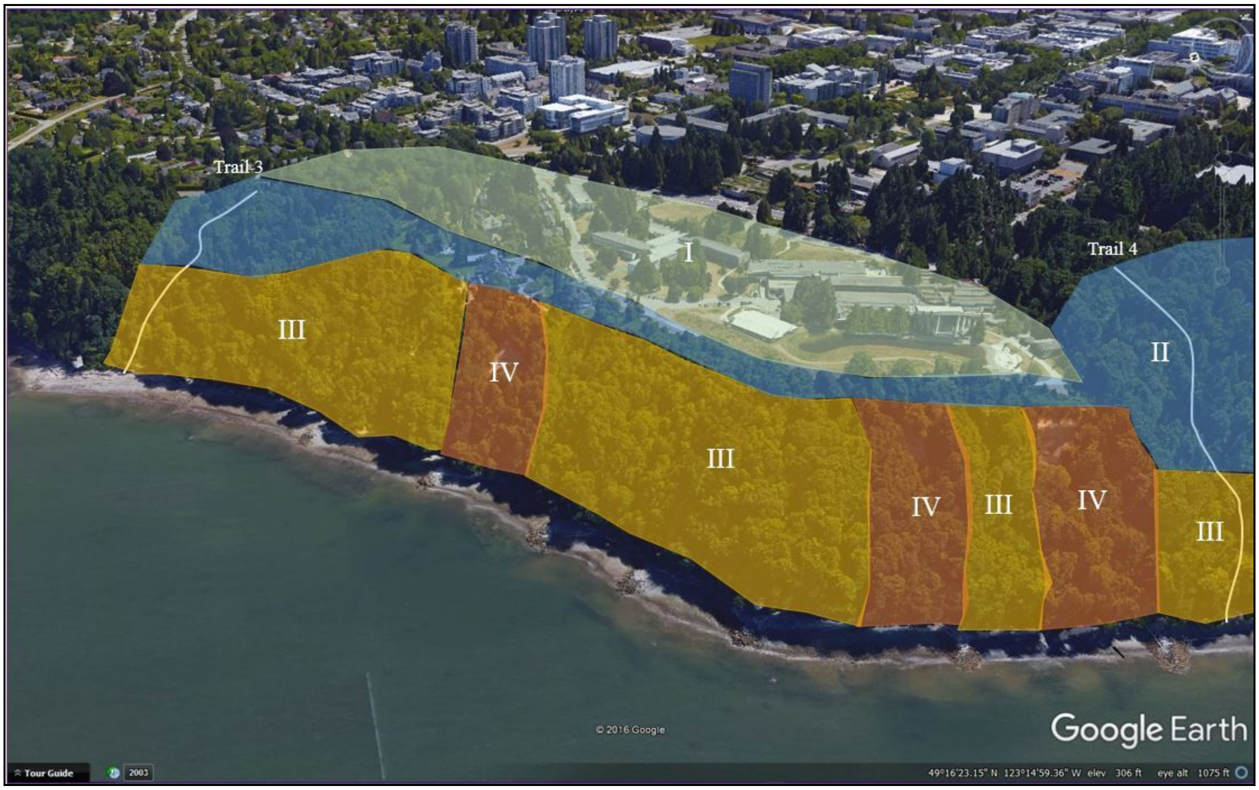
Stratigraphic Profile of Point Grey Cliffs
72
69
66
63
60
57
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
0
Elevation (Masl)
Ls (Deposit)
GMS (General)
Erosional Contact
Strata 1
Strata 2
Conformal Contact
SIL (Deposit)
sM (General)
Strata 3
Strata 1: Basal Till
Slope Angle: 52-53°
Depth: 5m
Predominant Sediment: Sediment: cobble (K)
Shape: Spherical
Roundness: Sub Angular
Sorting: Poorly Sorted
Colour: 7.55YR 5/6, G
Cohesion: Moderately Cohesive
Basal Tillt
Crossbedding
Quadra Sands
Laminations
Soil Layer
Strata 3: Quadra Sands (3)
Slope Angle: 68°
Depth: 18m
Predominant Sediment: Pebbles, sand
Shape: Rod
Roundness: Sub Rounded
Sorting: Well Sorted
Colour: 5YR 6/1
Cohesion: Moderately Cohesive
Verticle Scale: 1:300

Appendix B


Point Grey Cliffs
Legend
Res: 1:0.164
Museum of Anthropology
UBC Anthropology and Sociology Building
Cecil Green Park
Elevation (M)
0-11.5
11.5-83.7
0=11.5M Below Sea
0 25 50 100 150 200
Meters
Data source: Geogratis

Appendix C

Terrain Stability Map - Point Grey Cliffs between Trail 3 and Trail 4



Terrain Stability Class	**Interpretation**
I	No significant stability problems exist.
II	Low likelihood of slope failure.
III	Minor stability problems with moderate likelihood of slope failure.
IV	Larger stability problems with a moderate likelihood of slope failure.
V	High likelihood of slope failure.

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