Erosional Hazards on the Point Grey Cliffs:

Strategies for Classifying Risk & Priority Areas Using ArcGIS

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GEOB 308 - Quaternary and Applied Geomorphology

Capstone Assignment: Geomorphic Process in the Fraser Lowlands

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Table of Contents:

1. Abstract

This study undertakes a qualitative assessment of slope stability of the Point Grey Cliffs through an evaluation of literature and field site visits. Data is analyzed to produce a map of relative instability risk for our selected sites. Vegetation, D50 and slope angle appeared to be significant components of instability, and areas with low vegetation, high slope angle and certain D50 values were found to underlie high-risk slopes. The final map that we created holds important implications for future development considerations in terms of storm water routing and further land development.

2. Introduction

The University of British Columbia (UBC) Point Grey Campus is located on the traditional, ancestral, unceded and occupied territory of the xʷməθkʷəy̓əm (Musqueam) people (Musqueam, 1976). The campus sits atop the Point Grey Cliffs, the western edge of a 763-hectare peninsula, west of Vancouver (Aecom, 2013). The Point Grey Cliffs are made up of various glacio-fluvial and glacio-marine deposits that have been heavily influenced Pleistocene glacial processes in the Fraser Lowlands (Clauge and Ward, 2011).

The most predominant stratigraphic layers on the Point Grey Cliffs are the Quadra sands, a deposit from distal outwash apron from the last glacial advance during the Wisconsin Glaciation in the late Pleistocene (Clague, 1976). The sedimentary characteristics of the sands make them extremely vulnerable to erosional processes due to precipitation, and wave cutting action from the ocean below (Clague and Ward, 2011; Post, 1975). The stability of the Point Grey Cliffs on the north-west side of campus is of particular interest because these lands support valuable property such as the Museum of Anthropology (MOA), Norman Mackenzie House, and the UBC Anthropology and Sociology Building (ANSO). The erosional hazard that the slopes pose to UBC will put constraints on future land-use and development plans. In this paper, we will discuss how erosional hazards may be better understood through risk classification of particular slopes, and we will use this criterion to synthesize a potential decision-making model for UBC's future land-use and development plans.

Our main focus is to look at erosional hazards in predominantly high-risk areas. Therefore, we chose a study area that is concentrated on cliffs located on the north-west corner of the UBC campus, which support significant infrastructure. Sites 1 through 4 were chosen based on erosional activity observed *in situ*; sites 1-3 each represent an individual slope with a recent erosional failure associated with it, and site 4 is used as a control slope due to its lack of recent failure and adjacency to slope 1 (fig. 1).

2.1 Erosional Hazards in Context

The UBC Point Grey campus is underlain by a ~1-3 meter thick basal lodgement till, commonly referred to as the Vashon glacial drift, which was deposited during the last advance of the cordilleran ice sheet (~17-11 ka BP). Below the Vashon till is a thick sequence of cross-stratified sand and gravel, known as the quadra sands, with horizontally laminated clay/silt/peat interbeds that separate the quadra sands into two distinct sections; referred to as Q1 (above) and Q2 (below). These units were the result of glacio-fluvial depositional processes during the Pleistocene glacial and interglacial periods (Clauge and Ward, 2011). These units are exposed in certain sections of the Point Grey cliffs where recent erosional activity has taken place. Sedimentary characteristics of these units are described in detail with litho-stratigraphic profiles (figures 7,8,9).

Low cohesion of sand and gravel, combined with low-permeability of the underlying clay deposits, creates a potential failure plane when over-saturation occurs in the upper quadra sand layer. This can cause lateral flow of water underneath Q1, which we observed as water seepage out of the clay interbeds. Poor drainage mechanisms put the areas above and below these slopes at risk due to the unconsolidated nature of the quadra sands. The main mechanism of cliff erosion is precipitation and wave action erosion, with an average erosion rate of 30 cm per year (Pool, 1975). However, mechanisms are erosion are likely changing due to varying land use, sea level rise and precipitation regime changes.

3. Methods

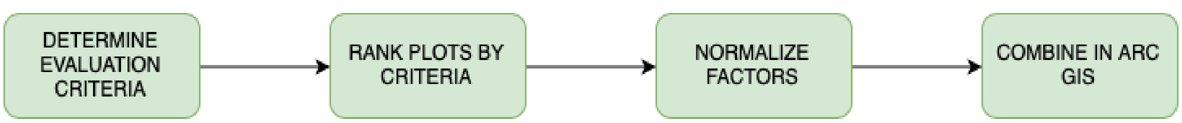

Fig. 2. Methods for creating a risk classification scheme for the Point Grey Cliffs.

3.1 Determining Evaluation Criteria

Evaluation criteria was based upon the infinite slope model which assumes homogeneity (identical conditions along vertical sections) within the Q1 deposit (Griffiths et al., 2011). This model was simplified to a generic factor of safety equation (Eq. 1). Difficulties in quantifying these parameters forced us to generalize our evaluation criteria to a relative ranking system (table 7). From the infinite slope model, we derived vegetation, sediment budget, D50, cohesion, slope angle, aquifer saturation, human traffic and depth of Q1 layer as our evaluation criteria.

$$FS = \frac{Resisting\ Forces}{Driving\ Forces} \rightarrow FS = \frac{C + (\sigma - \mu)\ tan\ (\phi)}{\tau}$$

{c = cohesion of sediment materials + cohesion from vegetation, σ = normal stress, μ = pore pressure, $tan\ (\phi)$ = soil friction, τ = shear stress}

Equation 1. Simplified factor of safety equation used to assess risk at sites 1 - 4 (Eaton, 2018). This was used as a general model and provided the foundation for our risk classification outputs.

3.2 Ranking Plots by Criteria & Normalizing Values

(Vegetation): The presence of living vegetation, in particular large trees with deep roots, increase slope stability (Watson, et al., 1999). We focused mostly on quantifying the impact of canopy species (trees), rather than understorey species. This decision was made because we were unable to find sufficient literature distinguishing the cohesion abilities of various understorey species that we surveyed. We combined our recorded site data with previously-recorded vegetation data on the Point Grey Cliffs from the UBC Living Breakwaters Project. We examined the role of vegetation quantitatively through empirical data from both our own site visits, as well as data from the Living Breakwaters Study to calculate the cohesive abilities of the trees. Qualitatively, we assigned 'points' based off of observed stability criteria (Table 1,3). Relevant data included tree locations, tree species, diameter at breast height (DBH), depth of Q1, the presence of cliff face vegetation, and the presence of slumped trees (Table 2), (Fig. 3).

(Sediment Budgets): Using data from Rens Harteveld's unpublished thesis on the coastal hazards of the Point Grey Cliffs (fig. 4), we were able to overlay his sediment budget analysis with our GPS plot locations, in order to determine where the cliffs were undergoing coastal erosion at the highest levels (Table 4).

(D_{50}): The 50th percentile sediment size (D_{50}) on a beach can act to reduce wave energy, and thus coastal undercutting (Sunamura & Horikawa, 1971). We measured the D_{50} at our four locations and used these as a contributor to slope stability (Table 5).

(Cohesion): Observations made on our site surveys concluded that the Q1 deposits along our study area were comprised of the same material. Qualitative measurements of cohesion did not differ significantly, so each site was weighted equally.

(Slope): Our methods for classifying slope involved gathering UBC Light Detection and ranging (LiDAR) data from UBC Geodata (UBC, 2019), and creating a Digital Elevation Model (DEM) raster from which we could classify individual pixels based on slope angle (0 - 90^{o}, with higher angles denoting higher risk). Values were then normalized from 0-1 (Fig. 5).

(Human Traffic): At each site, we ranked human traffic about the base of the cliff (on the beach) as low, medium or high; represented by corresponding values of 1, 2 or 3. We based our rankings off of observations and local knowledge of the area. Areas of the cliff that are inaccessible on foot at the base were given a low ranking (Table 6).

(Aquifer Saturation & Comparative Level of Oxidation): Aquifer saturation, comparative level of oxidation were also noted and used in our GIS analysis. Aquifer saturation and oxidation levels were weighted from 1-3, with one being the most stable and three being the least. Relative saturation and oxidation levels were determined from observable aquifer leakage and color change due to oxidation at the upper aquifer, since it poses the highest risk of erosion due to its position above an impermeable silt layer (UBC, 2017).

(*Depth of the Q1 Layer):* From the factor of safety equation, we know that the depth of a layer, contributes to the shear stress (Eaton, 2018). The depth of the first layer of quadra sands varied within our plots, from 6 - 30 meters. We ranked the deepest Q1 layers as the most dangerous, and then normalized them from 0 - 1.

3.3 Combine in ArcGIS

First, we traced polygons (not precisely) of our cliffs. This allowed us to assign our calculated ranking values to the cliff. For each criterion (vegetation, D_{50}, hydrological factors, etc.), a shapefile layer of the transects was used, and each transect was assigned a value, based on the normalized values in the tables above. We used the Weighted Sum tool to finally combine all factors together and determine which cliffs were at the highest risk. Each was weighted evenly in this evaluation, because the Factor of Safety equation shows linear relationships between all factors (Table 7).

4. Results

GIS analysis yielded risk classification of slopes showing red values at highest risk slopes, while green are relatively lower risk (Table 7). This created raster datasets for the traced transects with cell values indicated by the sum column (Table 7). Results of the risk classification show red values as the highest risk slopes, while green are relatively lower risk (fig. 6). Variation within the transects occurred because the DEM resolution for slope data was 10 x 10 meters, which needed to be simplified from 0.3 x 0.45 meter LiDAR data. All of the other criteria we calculated resulted in just one value for the entire slope. It is evident that the risk associated with each slope decreases with distance from the edge of the cliff. In general, slopes with dense vegetation cover, a greater D50 value, and a lower slope angle have the least amount of risk associated (e.g. sites 2 and 4). These were the most important factors in classifying risk for a given slope and had a noticeable difference on whether or not the slope was experiencing erosional processes.

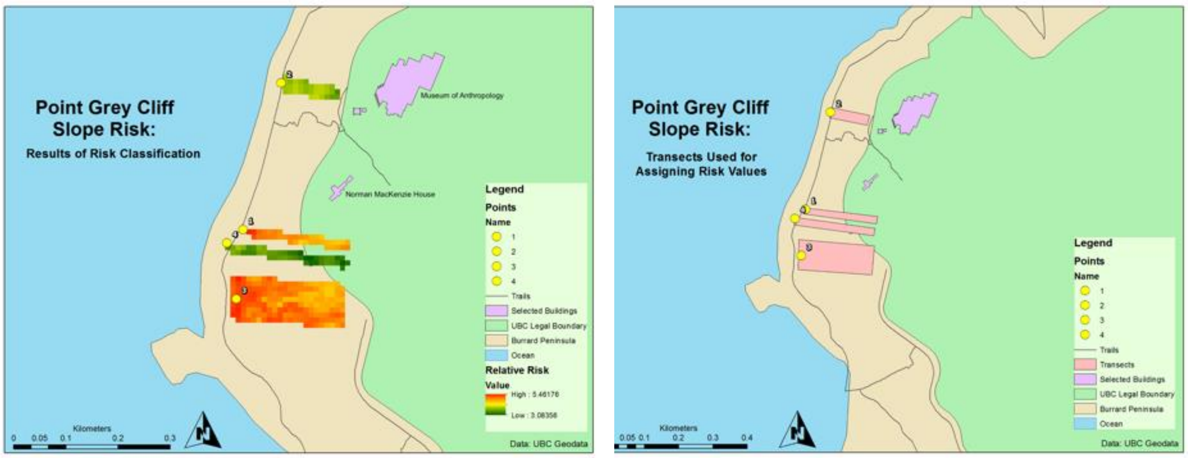

Fig. 6. Point Grey Cliff Risk Classification of Slope: Normalized slope angle from UBC LiDAR (left), transects used for sites 1 – 4 (right).

5. Discussion

5.1 Implications for Development

The implications of our analysis are principally concerned with land use and storm water management. Our analysis yielded results consistent with the constraints on development that UBC has already enacted (UBC, 2017). The UBC land use plan indicates that "there are significant constraints on development" in the north area of campus due to its "relation to the cliffs" (UBC, 2015). In fact, recent development near the cliffs has been almost exclusively "green edges" which preserve the "integrity of Pacific Spirit Regional Park" through the addition of areas of natural vegetation (UBC, 2015). The addition of natural areas enhances the slope stability of the cliffs by increasing vegetation and decreasing unnatural shear stress and loading of the slope.

Moreover, our analysis validates the efficacy of methods UBC has pursued to decrease erosional hazards through direct and indirect methods. Directly, UBC has increased vegetation of hazardous slopes in order to increase root cohesion and slope stability (UBC, 2017). Indirectly, UBC diverts storm water through a variety of methods, including a spiral drain near MOA to drain water from the upper to the lower aquifer, the prevention of infiltration within 300 meters of the cliffs and the installations of berms near MOA (UBC, 2017). Together, these methods reduce the risk of an overland flow flood event that could wash out the cliffs (UBC, 2017). By designating specific areas with the most prominent risk of slope instability, the map created in this analysis could aid future development assessments in terms of land use and storm water management.

5.2 Potential Sources of Error

Potential sources of error in our analysis would likely have occurred due to a lack of data, the qualitative nature of our analysis and future climatic changes that increase uncertainty. Primarily, our data was of considerably low resolution for the analysis conducted which could cause overgeneralization of certain variables. Conducting more detailed field studies of smaller areas would have assisted to make our data more detailed, but logistical restraints prevented us from collecting this data, namely hazards of causing erosion. Additionally, including the assets of the infrastructure above the cliffs would provide an interesting economic aspect of the analysis, but we did not have the data available to synthesize this into our analysis. Moreover, our analysis was inherently qualitative rather than quantitative due to data restrictions which allows for potential error due to lack of precise data. We valued all identified variables as having the same weight, which is not necessarily representative of the cliffs in general, as each site will differ in some regards to the next. Our site visits indicate that the D50 variable is likely more significant than previously thought; since site 4 is intact, while site 1 is visibly eroding and the only ostensible factor that changed is D50. Finally, future climatic change will increase uncertainty in our analysis. As sea levels rise, precipitation increases and varies in timing of intensity and temperatures increase certain variables may become more vulnerable to slope instability. For example, increased precipitation or magnitude of large events could incur instability in the upper aquifer.

5.3 Future Studies

Future studies could utilize better resolution data and increase the number of sample sites in order to develop a data set with increased resolution. This data set would allow for more in-depth analysis and could help develop a more nuanced model to map the entire area for erosional hazards. This could include sites located further south along the cliffs, as well as areas east of UBC campus. We expect to see erosional activity continue and therefore new sites will need to be examined. Data not publicly accessible or logistically possible to collect including size of sediment in coastal erosion and monetary value of infrastructure near the Point Grey Cliffs could contribute important details to a future model (Sunamura & Horikawa, 1971). Moreover, it would be interesting to explore a comparative analysis of erosional hazards relating to the quadra sands in different areas with similar geological properties. This would serve to validate our efforts and guide other institutions and organizations in putting constraints on land-use and development. A comparative analysis would also initiate the potential of bolstering the slope stability model we created for Point Grey Cliffs, making it more applicable to a wider array of locations.

6. Conclusion

Quaternary deposits from the Pleistocene glaciation pose significant constraints on land-use and development, and therefore their physical properties need to be understood in order to make informed decisions. Instability of the quadra sands necessitates actions be taken by UBC to modify and constrain land-use and development strategies, in order to preserve the integrity infrastructure, and mitigate risk to the public.

While the hazard map created does not provide a fully comprehensive view of the Point Grey Cliffs, it acts as a foundation for more nuanced analysis of erosional hazards by providing a model that can be built upon. From our model, we conclude that areas with high slope angle, low levels of vegetation and a lower D50 value are at significant risk of erosion, while areas with low slope angle, dense vegetation cover and a high D50 value are at a lower risk of erosion.

7. Appendix

Fig. 1. Overview of study area. Image retrieved from Goggle Earth on April 2, 2019.

TREE	ROOT DEPTH	COHESIVE PROPERTY	SOURCE
DOUGLAS FIR	0.70 - 1.35 m	High	Eis, 1973; Schmidt et al., 2001
WESTERN HEMLOCK	0.70 - 1.35 m	High	Eis, 1973; Schmidt et al., 2001
RED ALDER	unknown	Med	Schmidt et al., 2001
WESTERN RED CEDAR	0.70 - 1.35 m	unknown	Eis, 1973
BIG LEAF MAPLE	unknown	High	Schmidt et al., 2001
BLACK COTTONWOOD	Up to 3.2 m	unknown	Tufekcioglu et al., 1998
MORINDA SPRUCE*	unknown	unknown	

SWEET CHERRY*	unknown	unknown	
ENGLISH HOLLY	Low	Low	Peterken & Lloyd, 1976

Table 1. Cohesive properties of canopy trees present on our Point Grey cliff transects. *We were unable to find very much data on these, however, these trees are rare in our plots anyways, so we did not include them in our calculation of density.

Plot	Significant Cliff Face Vegetation	Living Slumped Trees	Roots Deep Enough to Penetrate to Q1?	Summed Values	Normalized Values	Relative Danger Rating
	(yes = +1)	(yes = +1)	(yes = +1)			
1	No	yes	Yes	2	0.5	
2	No	yes	no	1	1	High
3	No	no	yes	1	1	
4	Yes	yes	Yes	3	0	Low

Table 2. Cliff face vegetation and slumped trees, as well as tree species surrounding the site was collected.

Plot	Density of Med & High Stability Trees -- Entire Slope	Density of Med & High Stability Trees – Slope Base [trees/m^2]	Normalized Values for Arc GIS Model	Relative Danger
	[trees/m^2]			
plot 1	0.029	0.013	0	Low
Plot 2	0.073	0.027	1	High
plot 3	0.029	0.013	0	
plot 4	0.029	0.013	0	

Table 3. Density of trees associated with medium to high stability over the slope base and entire slope, as well as their normalized values for our GIS model and relative danger.

PLOT	SEDIMENT BUDGET [M^3/ YR]	NORMALIZED VALUES	RELATIVE DANGER
1	-25 262	0	low
2	-25 262	0	

3	-80 065		1	
4	-80 065	1		high

Table 4. Sediment budgets for sites 1-4 calculated by R. Harteveld n.d.

PLOT	D_{50}	NORMALIZED	RELATIVE DANGER
1	0.5	1	High
2	100		
3	0.5		
4	241	0	Low

Table 5. D_{50} at our four locations, and used these as a stability contributor.

PLOT	HUMAN TRAFFIC	HUMAN TRAFFIC	NORMALIZED VALUE	RELATIVE DANGER
1	Medium	2	0	Low
2	High	3	1	High
3	Medium	2	0	
4	Medium	2	0	

Table 6. Human traffic at the base of the cliffs.

Fig. 3: Plot locations lined up in relation to the Living Breakwaters Vegetation transects. Data from transect 2 was used to evaluate vegetation for plot 2. Data from transect 1 was used to evaluate vegetation for plots 1, 3, and 4.

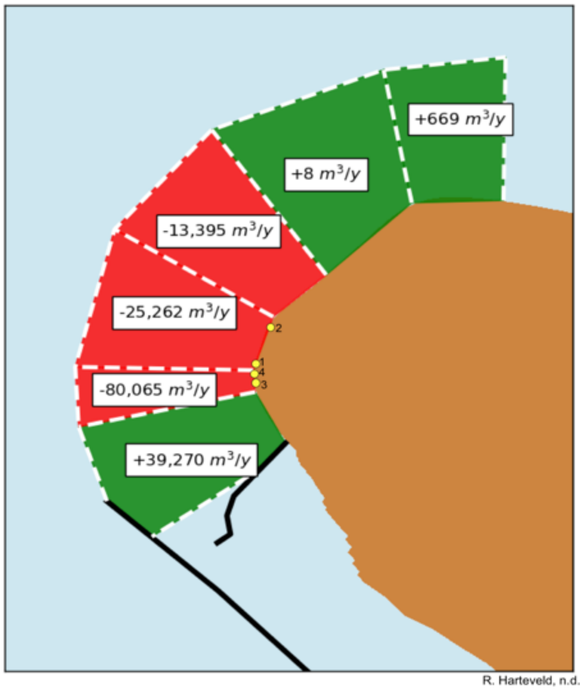

Fig.4. (left): Sediment budgets calculated by R. Harteveld, with our research plot locations depicted in as yellow points.

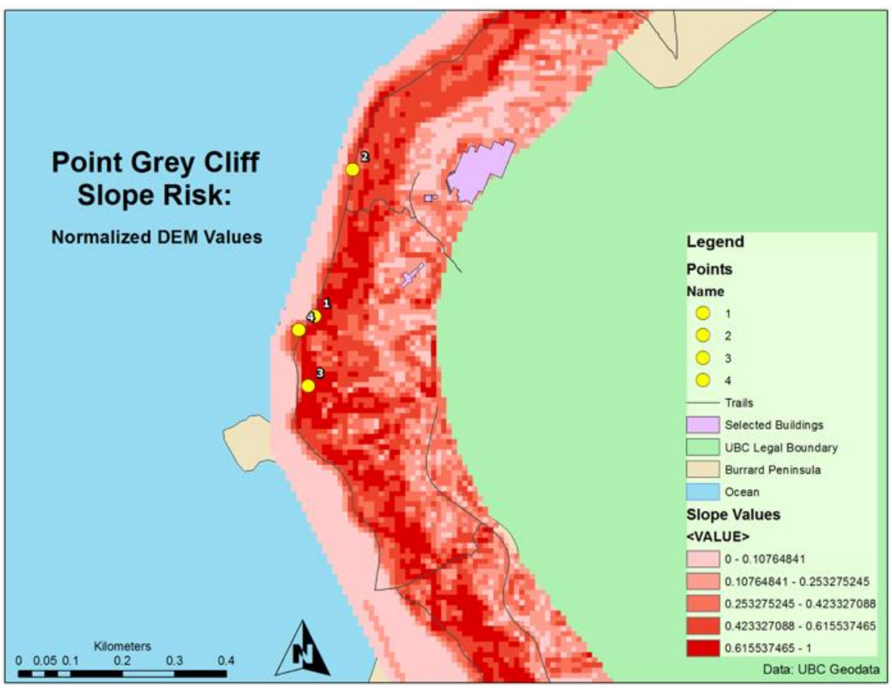

Fig. 5. Risk classification based on slope angle of our study area. Slope values are normalized 0-1 from a 0-90° classification of a 10 x 10 meter resolution DEM derived from UBC LiDAR data.

NORMALIZED VALUES OF EVALUATION CRITERION										
PLOT	**D50**	**Aquifer Saturation**	**Comparative Level of Oxidation**	**Sediment Budget**	**Depth of Q1 Layer**	**Cohesion of Sediment Materials**	**Tree Density**	**Human Traffic**	**Slope %**	**Sum (resultant pixel values)**
1	1	1	1	0	1	1	0	0	0-1	5-6
2	0.59	0	0	0	0.63	1	1	1	0-1	4.22-5.22
3	1	0.5	0.5	1	0	1	0	0	0-1	4-5
4	0	1	1	1	0	1	0	0	0-1	4-5

Table 7. Values that were summed using equal weight to determine final cell values of our slopes. Results that are high show higher erosion risk. Resultant values that are low show relatively lower erosion risk.

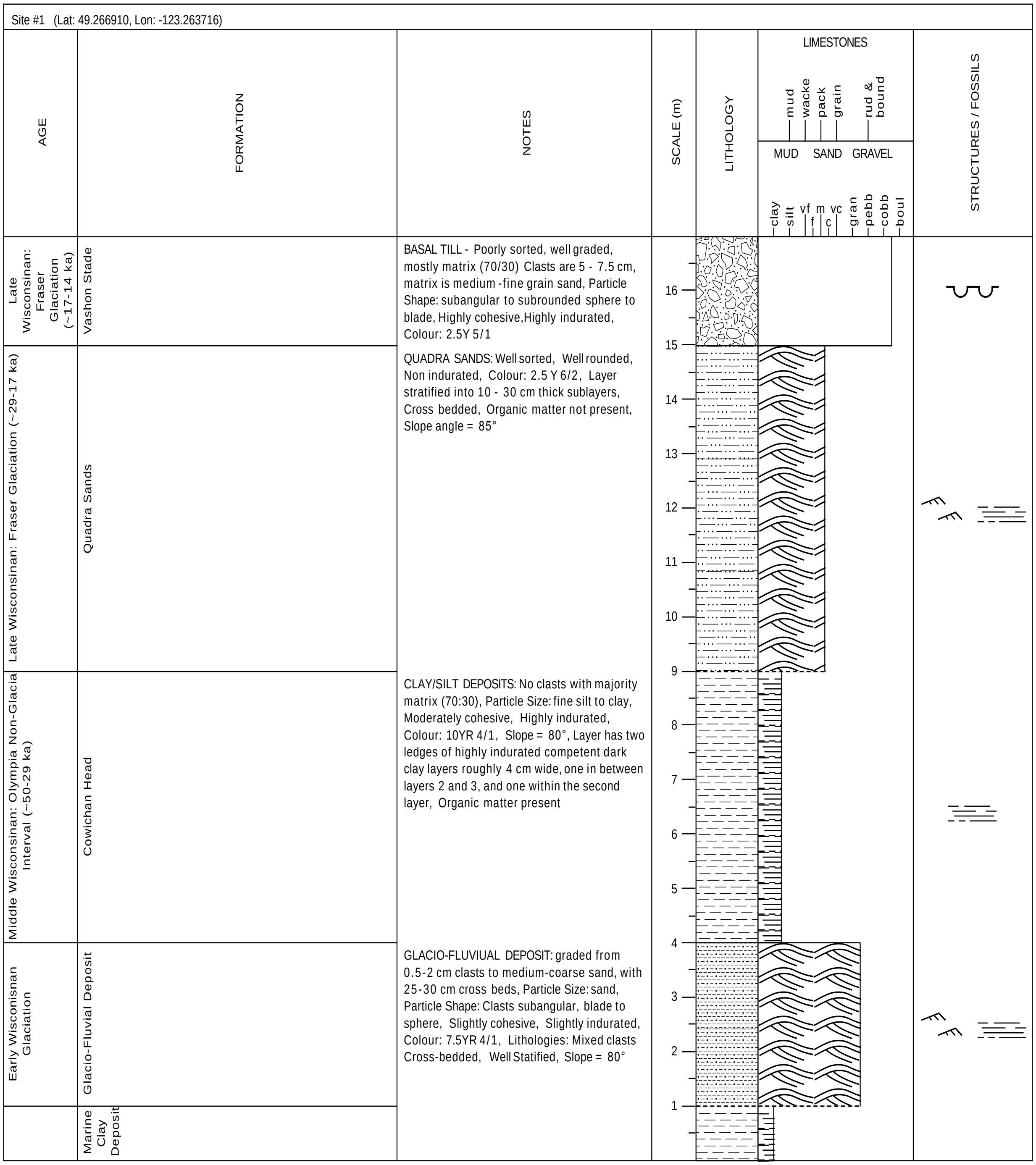

Fig. 7. Litho-stratigraphic profile of site 1. Data was collected *in situ* and later referenced in relevant literature.

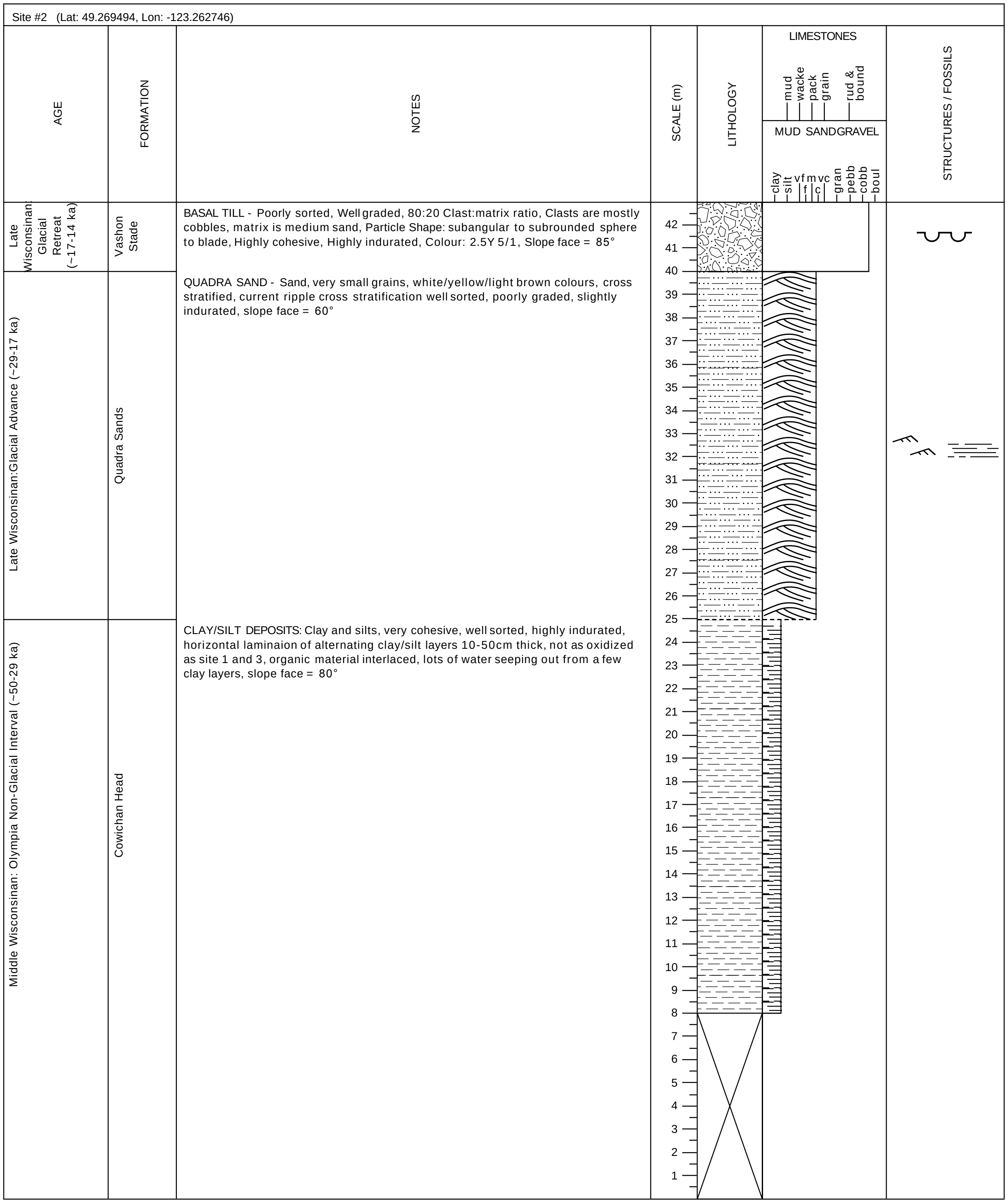

Fig. 8. Litho-stratigraphic profile of site 2. Data was collected *in situ* and later referenced in relevant literature.

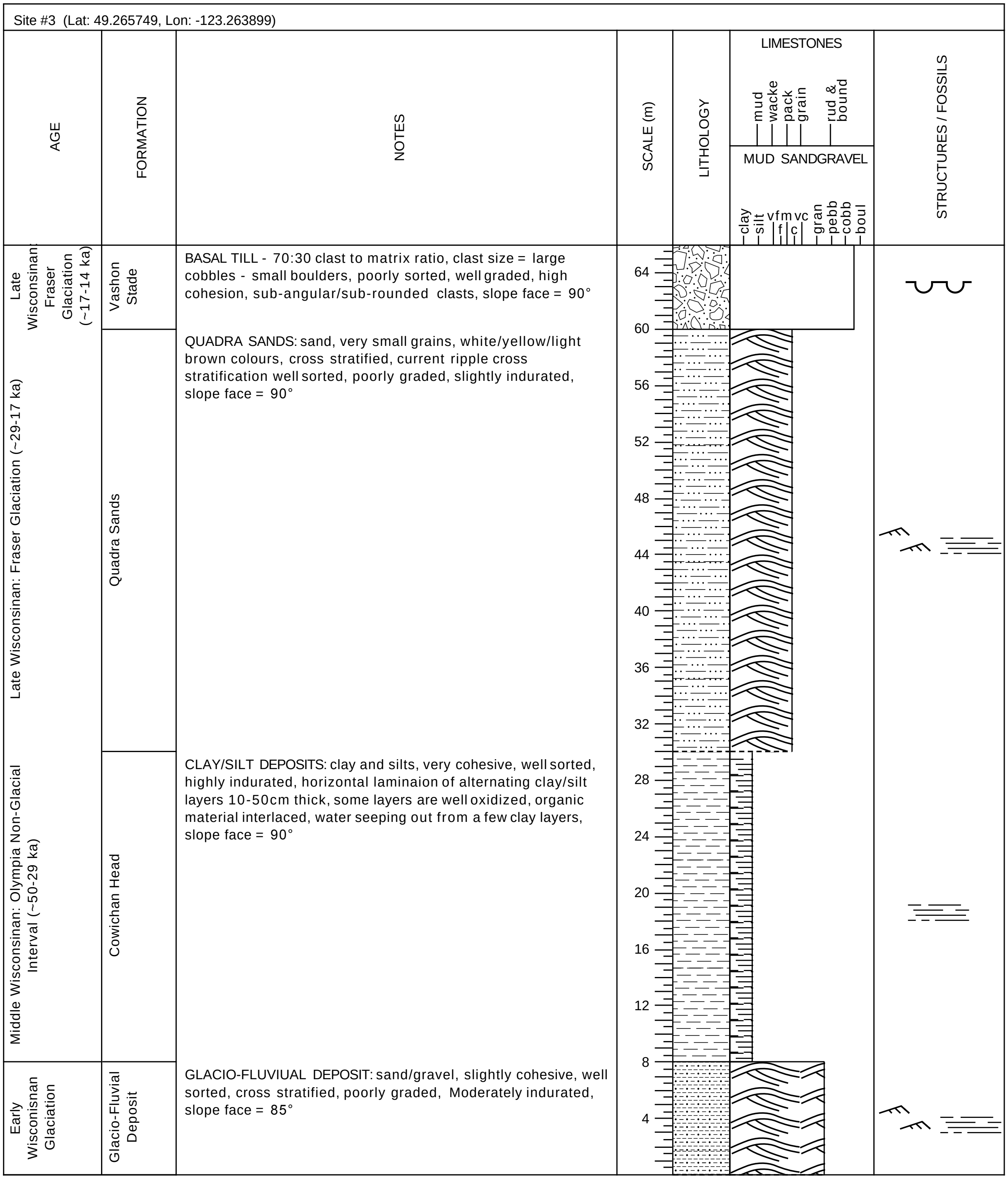

Fig. 9. Litho-stratigraphic profile of site 3. Data was collected *in situ* and later referenced in relevant literature.

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