

Sediment characteristics at the delta of Chuckanut Creek, Mud Bay, Bellingham,  
Washington

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A report prepared in partial fulfillment of  
the requirements for the degree of

Master of Science  
Earth and Space Sciences: Applied Geosciences

University of Washington

March, 2019

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MESSAGE Technical Report Number: 070

## Abstract

Mud Bay is south of Bellingham, WA, in the northern portion of Chuckanut Bay. It is predicted to be inundated by tsunamis generated by large Cascadia earthquakes. In this report, I describe shallow sediments in the bay and at the delta where Chuckanut Creek enters the bay. I also describe shoreline changes recorded by historic charts and photographs. In these records, I do not find evidence for tsunami deposits. However, my observations may have some bearing on the sediment budget in Mud Bay. I find that historical charts show the progradation of a subaerial delta at the mouth of Chuckanut Creek from 1898 to present. I used grab samples, gouge cores, and test pits to collect samples from the banks of Chuckanut Creek, the delta, and the bay itself. There are several sandy horizons in the delta, with sand compositions similar to the glacial deposits through which the creek is incising. One distinctive horizon is traced through some additional input from the local bedrock, Chuckanut Sandstone. None of the sand horizons contain marine fossils. Two gouge cores from southeast corner of the bay show fine sand at 1 m depth abruptly coarsening at 80 cm depth and fining up toward the surface. Residents of Chuckanut Village on the shores of Mud Bay report that the bay has shallowed in the past 50 years, and I discuss my observations in the context of possible anthropogenic influences on sediment supply and retention. A companion study finds sedimentation rates up to 1 cm/year, suggesting that if tsunami deposits are preserved in Mud Bay, they are deeper than the sediments I sampled.

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## Acknowledgements

I first wish to thank Mary Alice Benson for inviting me to join her in Mud Bay. Without her ideas and support and patience with my random idea texts this would have been more difficult.

I wish to thank all the people who came into the field to help me collect samples, my parents Kim and Tim Wratten, Elizabeth Davies, Carrie Garrison-Laney, and Mathew Gerrek.

I also wish to thank Jo and Denny Miller for their support in the field and invitations to use their bathroom and enjoy cups of tea after being in the bay.

Thank you to Wayne Gerner for his stories of growing up around Mud Bay.

A huge thank you to Juliet Crider and Brian Collins for talking through every step of this process with me, and all the prompts to write a better more coherent report.

Finally thank you to the QRC for being willing to fund my research if I had found some samples to test.

## 1. Purpose and Scope

Mud Bay is in the northern section of Chuckanut Bay just south of Bellingham in northwest Washington State (Fig. 1). A small community, Chuckanut Village, lives on the shores of the bay and on the cliffs overlooking the area. Chuckanut Creek enters the bay along the southeast edge.

Mud Bay is a shallow bay that opens to the south directly into Chuckanut Bay. It is protected from the Salish Sea by headlands to the West cutting Mud Bay off from Bellingham Bay. No previous tsunami work has been conducted in this location, but the estuarine setting is ideal for preserving tsunami deposits, and models predict some inundation in Mud Bay (Appendix B). Mud Bay has the potential to hold tsunami deposits but we could not find them with this project.

I went to Mud Bay to identify sandy horizons that are distinguishable as tsunami deposits. By describing the bay sediment in the Southeast corner of Mud Bay with gouge cores I hoped to find sand layers within the bay. I also sampled across Chuckanut Creek's delta with gouge cores and test pits, and investigated the structure of the delta by clearing the banks of Chuckanut Creek to collect grab samples. I didn't identify anything that could be described as a tsunami deposit but I present this report as a record of my observations.

## 2. Background

### 2.1 Geologic Setting

The Chuckanut Creek watershed sits on two main geologic units, the Eocene Chuckanut Formation and undifferentiated glacial drift (Fig. 2) (Easterbrook, 1976). Chuckanut Creek starts in the Padden member of the Chuckanut Formation, then flows into the Bellingham Bay member (Johnson, 1982). Chuckanut Creek has run under I-5 since its construction in the late 1960's, and downstream of this point the creek runs through glacial drift until it meets Mud Bay. At the bay Chuckanut Creek crosses Quaternary alluvium deposited by Chuckanut Creek and an unnamed seasonal creek.

The Chuckanut Formation is an Eocene sedimentary unit. It is composed of seven inter-fingered members, ranging from conglomerate, to siltstone, with much of the formation being an arkosic sandstone (Mustoe, 2002). These sandstones formed in a nonmarine environment as shown by the terrestrial fossils and pollen analyses (Johnson, 1984). Fine grained units include siltstone, mudstone, and very fine-grained sandstone with coal. Key minerals found in the Chuckanut sandstone are quartz, feldspar, and biotite, with minor amounts of muscovite (WA Department of Natural Resources, 2019). The Bellingham Bay member of the Chuckanut Formation forms the cliffs south of Chuckanut Bay and is formed of alternating coarse and fine-grained units that fine upwards (Johnson, 1984). These repetitive coarse and fine units are indicative of a fluvial system with cutbanks and meanders. Point counts of the Bellingham Bay member reveal that quartz and feldspar are the main constituents with a large percentage of mica (Table 1) (Johnson, 1982). The Padden member of the Chuckanut Formation forms the cliffs around Chuckanut Bay. It also

consists of alternating coarse and fine grained units (Johnson, 1982). The clasts are well rounded with a larger amount of lithic fragments than the Bellingham Bay member (Johnson, 1982). The mainland exposures of conglomerate and medium-coarse sandstone appear to have been deposited by a coarse-load meandering river (Johnson, 1982). Point counts of the Padden member show a similar percentage of quartz but less feldspar and mica (Table 1) (Johnson, 1982). Undifferentiated glacial drift is the other major map unit in the watershed. This glacial sediment is a diamict with lenses of moderately to well sorted gravel, sand, silt, and clay (Lapen, 2000). It was deposited during the Pleistocene Frasier Glaciation (Easterbrook, 1976). There are occasional dropstones and it is variably fossiliferous. The thickness of these sediments vary from a few meters to 90m. Chuckanut Creek has incised into the glacial drift along two-thirds of its length (Fig. 2).

The glaciers that produced this sediment also added a large load to the surrounding land, including Chuckanut Bay. As the glaciers have retreated the land is slowly rising, resulting in isostatic rebound, to regain equilibrium (Thorson, 1989). Currently the land is rising slightly faster than sea level rise and there is a net lift in the land relative to sea level of  $3 \pm 12$  cm/century (WA Coastal Resilience, 2018). There is an estimated 12-24cm rise in sea level by 2050 for Chuckanut Bay (WA Coastal Resilience, 2018). However due to isostatic rebound the land is still rising faster than sea level rise.

Tsunamis generated by a number of active faults in the area have the potential to affect sedimentation in Mud Bay. Many estuaries around the Salish Lowlands hold sand layers that are a record of local or coastal tsunamis (Garrison-Laney, 2017). Cascadia subduction-zone events from off of the Pacific coast present the greatest regional earthquake and tsunami hazard (Atwater et al., 2016), and tsunami models suggest that a Cascadia tsunami could plausibly reach Mud Bay (Garrison-Laney, pers. comm.). The Cascadia subduction-zone last ruptured in 1700 (Atwater, 1987) and is the most likely tsunami source that could leave a deposit in Mud Bay. The Southern Whidbey Island Fault and Devil's Mountain Fault could also cause tsunamis in this area (WA DNR, 2018). Recently identified faults crossing Bellingham Bay, such as the Sandy Point Fault and Birch Bay Fault (Kelsey et al., 2012) are also possible tsunami sources.

## 2.2 Geomorphology

Mud Bay is a very shallow area at the north end of Chuckanut Bay. As early as the late 19<sup>th</sup> century it was shallow, still accessible, but unusable for shipping (Gilbert, 1887). There is now a sharp change in depth from the shallow Mud Bay to the deeper, outer Chuckanut Bay at the train causeway (Fig. 1). Earlier studies of Mud Bay by students at Huxley College produced a geologic map (Farrow et al., 1989), which described large sections of the bay as pure mud and mud with sand, or silt with decaying wood.

Chuckanut Creek enters the northeast corner of the bay close to Woodstock Farm and is the main source of fresh water entering the bay (Fig. 1). It is a short 9.3km creek that carries water from the Chuckanut Hills. In the course of its travels it drops 370m (USGS, 1998), making its way

through the Bellingham Bay and Padden members of the Chuckanut Formation and undifferentiated glacial drift. Chuckanut Creek transitions from gravel bedded to sand bedded at the junction with the bay.

## 2.3 Human Settlement and Land Use

Chuckanut Bay has been settled for at least two thousand years, and likely longer (Campbell et al., 2010). Over that interval, and especially in the past 150 years, land use has changed dramatically, with potential to influence sedimentation in Chuckanut Creek and Mud Bay.

The Salish people of the Pacific Northwest have lived along the shores of Chuckanut Bay for the past millennium. These communities left shell deposits and artifacts dating from 800-500BC (Campbell et al., 2010). The most useful information to this project is the location of shell middens across Mud Bay. Shell middens are collections of shells left behind after harvesting shellfish, in essence garbage dumps. Shell middens are typically located at or just above sea level, providing a useful reference point for past shorelines. Published archaeological work in this area has been limited to shell midden identification on nearby Woodstock Farm (Campbell et al. 2010). Location 45WH758 (UWW-05-03) is closest to the site locations for this study. It is a shell midden in the intertidal zone, exposed in the cutbank along the shore. The site appears to be a primary cultural deposit, placed by humans and not redeposited by the creek, with lithic artifacts, woody debris, charcoal, and multiple types of shell fragments. The approximate calibrated radiocarbon age range is 600-1450AD (Campbell, 2010). Seven other sites on the shores of Mud Bay are reported by Campbell et al. Site 45WH54 is a pre-contact midden on a narrow terrace above the North shore of the bay and is also in the 1280-1420AD calibrated age range. Many of the other sites are on terraces higher up the banks, including two sites of petroglyph carvings in the Chuckanut Sandstone.

By 1887 farmers were working in the valleys east of the bay, and logging and mining had become the main industries in the area (Gilbert, 1887). To stay close to resources, Chuckanut Village was founded in the late 19<sup>th</sup> century for loggers to live outside of the cities of Bellingham and Fairhaven (Gilbert, 1887). In 1901 a train trestle was built across the mouth of Mud Bay. Originally built as a wooden train trestle open along much of its length (Campbell et al., 2010), it was replaced in the 1920's with a riprap causeway with short opening of 64m (Puget Sound Nearshore, 2012). Through the latter half of the 20<sup>th</sup> century, residential neighborhoods were developed on the northwest and northeast margins of the bay. Interstate 5 (I-5), a major four-lane roadway that is adjacent to Chuckanut Creek for much of the creek's length was constructed through the Chuckanut Hills in the late 1960's (Campbell, 2010).

## 3. Methods

### 3.1 Desk Review

To find changes within the shoreline of Mud Bay and Chuckanut Creeks channel I used ArcGIS to georeference aerial photos and historic charts. Using 2013 Lidar from the Washington State

lidar portal as a base map I georeferenced the maps and photos and added my testing locations. I used historic naval charts dating back to 1860, with charts from 1898, 1906, 1928, 1946, 1969, 1993, and 2011 to map the change in bay shape. Aerial photos from 1944, 1962, 1978, 1998, 2001, and 2018 were used to see how Chuckanut Creek's channel has changed. I also used Google Earth to measure the length of Chuckanut Creek, and to find the drop in elevation I used the 1998 topographic map (USGS, 1998).

### 3.2 Field Methods

In order to evaluate sediment characteristics, I sampled sediment from the riverbank at the mouth of Chuckanut Creek, from test pits and gouge cores on the delta, and gouge cores in the bay behind the causeway (Fig. 3; Table 2). I also measured a short transect to place observations in relative position.

To connect my observations, I conducted a 90m hand level transect near the head of the delta, from the tree line to the mud flats. Elevation was recorded using a hand level and stadia rod every meter, at creek banks, and measuring the wetted width. We also recorded changes in vegetation along the transect. Hand level error was plus or minus 5cm vertically, as gauged in the field. The transect starts at the tree line, crosses the creek at LW-5, and ends on the mud flats (Fig. 3).

To sample the layers of material from the bay I used a gouge core. At stations in the bay (MAB-3 and MAB-4), samples for  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  sediment accumulation analysis were collected every 2cm for the 1<sup>st</sup> 20cm, every 5cm for 20-70cm, and every 10cm for 70-100cm. This sampling was to capture the vertical  $^{210}\text{Pb}$  profile, reported separately by Benson (2019). Samples collected below 1m were taken every 10cm, inclusive of  $\pm 1$  vertical cm, for this study.

To collect material from the delta, I used a gouge core and dug test pits. The test pit sites (LW-15 and LW-16,) and gouge core sites (LW-11 and LW-12) were located along the transect on the delta (Fig. 3).

To see a fuller picture of the delta sediments I cleared the banks of Chuckanut Creek and collected grab samples. These stations were studied to get an impression of any laterally continuous layers and horizontal layering within the delta. Six sections were cleared along the banks: four along the right bank and two on the left bank. Riverbank station LW-5 was broken into 3 sections along a 9m part of the right bank. Samples were taken from the middle section of LW-5 (Fig. 3: Table 2). LW-13 had cleared sections on the left and right bank. LW-14 was furthest upstream on the left bank.

To compare samples to source material, grab samples were taken from the glacial sediments upstream and from the bed of Chuckanut Creek. The grab samples from Chuckanut Creek were of loose surface material, taken with a shovel (LW-5, LW-13, LW-14, LW-17). The samples from the riverbed were sand only, the gravel and cobbles were not sampled (Fig. 3: Table 2). The grab sample was taken from the glacial bank ~1m above the creek (LW-18) (Fig. 3: Table 2).

Samples from the gouge cores, test pits, and cleared banks on the delta were collected at regular intervals, 10cm, inclusive of  $\pm 1$  vertical cm, in order to document sediment size and composition changes. At some sites additional samples were taken from distinctive horizons not captured in the larger intervals (LW-5, LW-15, LW-16)(Table 2).

### 3.3 Laboratory Methods

Grain size and mineralogical tests were conducted on samples taken from the field. Grain size analysis was performed on all bay core samples, the samples from one test pit, and samples from two of the bank exposures. Other exposures appeared very similar in outcrop, so analyses were not repeated. Each sample was examined under a Unitron ZSB microscope, and selected samples were point counted for mineral assemblage data (Table 2). Point count samples were chosen from distinct layers visible in field exposure or samples that were distinct in the initial screening. Point counts were also used to identify coarse sand layers that were laterally extensive, and to compare mineral assemblages to source material. Distinct layers were not observed in bay cores in the field, but one sample from core MAB-3 and two from core MAB-4 were analyzed.

Particle size was measured using a laser diffraction particle size analyzer, a Fraunhofer .rf780d. The tests used a 60second sample period conducted three times, with a pump setting of 55, and no sonication. The sample info, size statistics, size listing, and average information was saved for each sample (Table 2).

Point counts provide a quantitative analysis of specific mineral assemblages within the sands of Mud Bay. I used an Olympus BX-41 microscope. Point counts were conducted to roughly 100 points, counting minerals, organics and unknown objects. Using this information bar charts were produced with organic material included, and just mineral content, and ternary diagrams.

## 4. Results

### 4.1 Channel/land use change from historic maps and air photos.

The shoreline near Chuckanut Creek has advanced 280m SW and 90m NW into the bay since 1898 (Fig. 4). In 1898 the channel had no obvious delta within the bay and the opening of Chuckanut Creek pointed upstream. By 1969 the delta had started to build, and the mouth of Chuckanut Creek had started to prograde into the bay. In 1993 the delta has grown out into the bay and it has continued to do so through 2013. This has left a large subaerial delta visible, with non-salt tolerant plants (grasses) growing on it. Approximating the delta as a quarter-cone, I use an intermediate value for shoreline progradation as the radius (185 m) and the thickness of delta sediments above tide flat deposits exposed in the riverbank ( $\sim 1$  m) as height of the cone, I estimate that on the order of  $9 \times 10^3 \text{ m}^3$  of sediment has accumulated within the Chuckanut Creek delta between 1898 and 2013.

The channel of Chuckanut Creek, across Mud Bay, has changed from early records, but appears stable in recent decades. When combining the aerial photos the main change to Chuckanut Creek

appears to be a shift from the channel hugging the south cliff, to moving north out into the bay by 1978 (Fig. 5).

Review of Lidar shows no sign of landslide headscarps or distinctive landslide deposits in the Chuckanut Creek watershed. Much of the watershed is based in bedrock that could slide as a block, instead of moving as a rotational landslide and leave a less visible scarp. Either no inventory covers the Chuckanut Creek watershed or no landslides have been recorded with the Washington State Landslide inventory.

#### 4.2 Field Observations

The glacial sediment observations at LW-18 showed a diamict of fine sand and silt, with gravel and cobbles. There is very little coarse sand and fine gravel. The cobbles are granite and metamorphic rocks. The bed of Chuckanut Creek at this location is cobbles and gravel with very little sand, even in the quiet backwater areas.

The riverbank samples upstream showed layers of sand and gravel. The base of the exposures are formed of coarse sand and gravel. This is the only layer of gravel seen on site, with individual grains up to 4cm diameter. Around the bands of gravel, yellow tan sand appeared in horizontal layers.

The riverbank samples at LW-5 exposed the deltaic depositional regime of Mud Bay (Fig. 6). Laterally extensive coarser sand layers outcrop at this location (56cm, 62cm, and 79cm). Finer sands surround these coarse layers. The bottom section from 79cm down was formed of thin layers of black and gray material (Fig. 7). The black layers were organic material and wood debris, the gray layers were fine silty sand. These formed the oldest visible sediments, and were sharply distinct from the next unit at the upper contact.

The test pits and cores on the delta demonstrated a few coarser sand bands. LW-12 at 45cm depth the sands transitioned from coarse below to finer. Test Pit LW-15 had coarse sand bands at 20 and 37cm depth. Test Pit LW-16 contained three bands of coarser sand, at 40cm, 45cm, and 47cm. Around these coarser layers fine sands were visible that under field observations appeared to have a similar composition.

The gouge core samples from the bay, revealed slight shifts in bay sediment size over time. Core MAB-3 was collected out in the middle of the bay near the right bank of the creek at low tide. The upper 1 m of the core appeared a homogenous gray fine sand and is the subject of detailed study in a separate report (Benson, 2019). MAB-4 was collected in the intertidal zone, from the left side of the creek. The upper 1 m of the core also appeared to fine upwards and is again the subject of a separate study (Benson, 2019). This core from 1m to 2.1m, also fined upwards but contained pieces of gravel at the bottom in a matrix of fine sands. No obvious layers appeared within these sediments as compared to the bank and transect sediments.

### 4.3 Grain Size Analysis

Grain sizes were analyzed on a total of 78 samples from 8 sites (Table 3). Overall the sediment size in the Chuckanut Creek delta and Mud Bay is dominantly fine to medium sand.

At the cleared banks of the creek are distinct layers of finer and coarser material. At LW-5, the coarsest sand bands form the layers that preferentially erode and can be traced into the bank but not upstream (37, 51, 60, 70, and 80cm depths).

Along the transect horizons of different grain sizes stand out. In test pit LW-16 the sands at 45 and 47cm were over 340 $\mu$ m in mean size making them distinctly coarser than the background material. Coarse layers were also visible in LW-12 at 40 and 80cm, with sands just under 300 $\mu$ m in mean size.

On the mud flats the grain sizes show fining upwards sequences with an abrupt change in size between sequences. At MAB-3, the transition is found at 80cm and at MAB-4 90cm. No distinct event horizon is visible in the sediment but a sharp rise in grain size to 540 $\mu$ m in MAB-4 and just under 300 $\mu$ m in MAB-3 (Fig. 8). After this jump in grain size the material appears to fine again to roughly the same size it was before the jump.

### 4.4 Mineralogical Analysis and Sediment Provenance

In order to determine the provenance of the sediments of Mud Bay, general mineralogical assessments were conducted. The overall mineralogical analysis showed large amounts of quartz, feldspar, mica, and hornblende in all samples (Appendix D). Other minerals that appeared in smaller amounts in the samples were hornblende, plagioclase, magnetite, garnet, and epidote.

To directly compare mineral assemblages between samples and potential source materials, point counts were conducted on all sand layers exposed in the river bank and targeted sand layers from test pits and gouge cores across the delta (Table 4). Point counts were also conducted on one sample below the grain size transition from MAB-3 (120cm) and above and below the transition from MAB-4 (46, 160cm). Point counts on all samples, revealed that sands were 30-60% quartz. Biotite and muscovite were also significant components of most samples. Other minerals that appear in most samples are plagioclase, hornblende, and epidote. Magnetite and zircon appear in a few samples. Many unknown grains were encountered, especially in the finer grained layers. No microfossils were observed in any of these samples, from the bay or the delta.

When point counting samples and comparing mineral assemblages, the Sandy Horizon (LW-5 at 51cm, LW-16 at 45cm, and LW-12 at 40cm) appears to be slightly different from the other samples, and contains over 60% quartz, 13-14% biotite, and 5-6% hornblende, when the organic material is removed (Fig. 9).

The point counted layers below and above the grain size transition in the shallow cores from Mud Bay show a slight difference in mineralogy (Fig. 10). The deeper samples from the bay at MAB-4 show mostly quartz with a larger amount of unknown minerals. The shallower core samples from the bay contain, epidote, magnetite, and zircon. The biggest difference between the

two samples is the shallower sample has a much higher percentage of muscovite and biotite. Both samples contain a large amount of wood.

To evaluate sediment source, I compare the point counted samples to published mineral assemblages for the Chuckanut Formation (Johnson, 1982) and the sample I collected from the glacial deposit just upstream from the delta. I used QFL diagrams to directly compare these sediments to Johnson's work on the Chuckanut Sandstone (Fig. 11). All point counted samples show limited feldspar, with a range in lithic percentages, but a large amount of quartz (Fig. 11). This is distinct from Chuckanut Formation which contains a higher percentage of feldspar. To highlight glacially-transported sediment, a Q GEM L diagram was used. This compared garnet, epidote, and magnetite, with quartz, and lithics (Fig. 11). These analyzed samples are similar to the glacial deposit at LW-18. To evaluate whether the concentration of organics has changed over the past 100 years I produced a QOL diagram comparing levels of organics with quartz and lithic fragments. When the organics are included comparing quartz, organic materials, and all other grains a large range is shown in the organics (Fig. 11). This range is not distinct with depth.

The Chuckanut Formation and glaciomarine drift appear to be the main sources for the sand found in the river bank and delta of Chuckanut Creek. The point counts show that the samples contain sub-rounded quartz and mica similar to that found in the Bellingham Bay member and Padden member of the Chuckanut Formation, but missing feldspar (Johnson, 1984) (Fig. 11). The garnet, epidote, and magnetite are diagnostic of a glacial source, and are also found in the sample taken from the glacial drift up the creek at LW-18. Absence of marine microfossils rules out a tsunami source for the sediment found in the sand layers.

## 5. Discussion

### 5.1 Mud Bay and Chuckanut Creek Delta Sediments

Sandy layers in the delta have a composition that closely matches the glacial sediment and Chuckanut Sandstone found upstream. One particular sandy horizon exposed in the riverbank and test pits has a composition that appears slightly different from the surrounding material with more Chuckanut Sandstone influence (Fig. 9). The bay sediments appear to have the same sediment sources as the delta, with the recent sediment containing more glacial minerals and micas. The bay sediments also display a sharp increase in sediment size and then a fining upwards sequence. None of these samples look like tsunami deposits; however some of these observations might have a bearing on the recent sedimentation history of Mud Bay.

Anecdotal reports from the residents of Chuckanut Village suggest that Mud Bay has shallowed over the past several decades. There are stories of water skiing in the bay in residents' youth (Wayne Gerner, pers. comm.); now, however, at low tide all but a river channel is exposed to the atmosphere, and at high tide less than 1m of water is present in the bay.

## 5.2 A Shallower Mud Bay

If Mud Bay is indeed shallower today than it was 50 years ago, we could attribute this change to either relative sea level change or sediment infilling in the bay. If sedimentation is responsible, then some of the historical land use changes may have influenced sediment flux into or out of the bay.

Land level changes due to glacial isostatic rebound and eustatic sea level change could contribute to shallowing of Mud Bay. Relative to sea level, Chuckanut Bay is rising  $3 \pm 12$  cm/century. The land has been rising out of the sea since the last glaciation and will continue to do so, however at such a slow rate that it cannot explain the shallowing observed in Mud Bay by residents of Chuckanut Village. The shell midden closest to this location, 45WH758 (UWW-05-03) is exposed at low tides in the channel of Chuckanut Creek. Though it is hypothesized that this deposit is low in comparison to the bay due to slumping in the side of the channel (Campbell, 2010), it helps to show the area has not changed elevation significantly since its initial deposition.

Historical logging and land clearing has been shown to increase sediment production elsewhere. Studies on five fans in Vermont show coarsening upward sequence in sediment associated with logging (Jennings et al., 2003). Sediment yields on these fans increased several hundred times over background levels following European settlement and land clearance. Although the Chuckanut Creek catchment is small, based on the five Vermont fans, it seems plausible that historical logging in the areas around Chuckanut Creek possibly added identifiable sediment into the system. If logging disturbed the hillslopes, we might expect to see evidence for landsliding on steep hillslopes in the watershed. If these disturbances delivered sediment to the bay, I would expect a sediment composition similar to the Chuckanut Formation.

There is no direct evidence for landslides in the Chuckanut Creek watershed. There are no visible scarps or debris, and no slides appear on Washington State inventories. It is unlikely that logging on the hills above Chuckanut Creek caused a sediment influx through increased landsliding. The bedrock itself will weather slowly due to mechanical and physical forces adding sediment to Chuckanut Creek slowly. There is not sufficient information to suggest land clearing increased sedimentation into Mud Bay.

The train trestle originally built in 1901 and replaced with a causeway in the 1920's is a possible source of decreased energy in Mud Bay and therefore increased sedimentation. The train causeway enclosed Mud Bay, cutting off much of the wind and wave influences. Studies on two river estuaries in Canada, the Avon and Petitcodiac Rivers, indicate that after causeway completion both rivers underwent rapid infilling (Proosdij et al., 2009). Both the Avon and Petitcodiac Rivers are much larger than Chuckanut Creek, and the causeways are across the rivers not across a bay. This case study suggests that it is possible that by restricting the outlet of Mud Bay and reducing wave energy, more sediment coming from Chuckanut Creek was deposited within the bay after causeway construction. If the causeway is limiting energy input

into the bay, we expect to observe increased sedimentation rates and finer sediments after construction.

The transition in grain size in the cores from the Southeast corner of Mud Bay does not point towards the causeway increasing sedimentation, but the fining upwards sequence afterwards could. Based on the sedimentation rate established by Benson, of 0.2cm-1.1cm/year, the abrupt coarsening and gradual fining of the bay sediment could be in the time window of causeway construction. We might expect the causeway to reduce bay energy, by limiting wave and wind energy inputs, and induce settlement of fine sands and silts. However the construction of the causeway by itself does not provide a mechanism for the abrupt coarsening seen approximately 80cm down. I observe a change in mineralogy in MAB-4 from below to above the coarsening event that may indicate some shift in sediment source, transportation, or deposition, as a higher percentage of glacial minerals is found in the more recent sediment.

Another plausible mechanism for the abrupt coarsening, from 130 $\mu$ m to 540 $\mu$ m at MAB-4, would be migration of Chuckanut Creek across the bay. The aerial photo record does not go far enough back to follow Chuckanut Creek since the construction of the trestle, but it has not flowed over MAB-3 or MAB-4 in the past 70 years.

A third possible human influence on sedimentation to the Bay is the construction of Interstate 5 (I-5) in the late 1960's. As far back as 1963 studies looked at how every step of highway construction could possibly add sediment to local streams (Bullard, 1963). Local residents describe a large influx of sediment entering the bay with its construction (Campbell, 2010), and Chuckanut Creek was described as "chocolate milk", during construction over a couple years (Wayne Gerner, pers. comm.). During construction a large section of the Chuckanut Sandstone was blasted to make way for the highway, some of that sediment could have been deposited on the delta of Chuckanut Creek, as Chuckanut Creek runs along I-5 for roughly 2/3 of the creeks length (Fig. 2). If only 1% of the estimated bedrock removed for the roadway made it to the bay as sand, we would see 2.5cm of sediment across the bay. Thus it is plausible that construction of I-5 may have contributed an observable pulse of sediment. Since the source of this sediment is Chuckanut sandstone, I might expect to see a discrete horizon of sandy material with mineralogy consistent with the Padden and Bellingham Bay members.

Point counts on all the sandy layers visible in the riverbank at LW-5 identified one horizon (51cm) that has a higher proportion of Chuckanut Sandstone to the other coarse sands. This Sandy Horizon is also identified in test pit LW-16 (45cm) and core LW-12 (40cm) across the delta (Fig. 9/12). It is possible that this particular horizon could be attributed to the disturbance of Chuckanut Sandstone during the construction of I-5. These observations by themselves do not provide a definitive link to construction of I-5; they could also plausibly be storm related or due to an unidentified landslide. Dating these sediments in some way would help to establish the time these sediments were deposited and possibly point towards a source.

### 5.3 The Delta of Chuckanut Creek

Evidence for the growth of the delta built by Chuckanut Creek in the past century comes directly from the aerial photos and navigational charts (Fig. 4), illustrating that the shoreline has migrated 100s of meters into the bay. The cleaned cut banks along Chuckanut Creek display six layers of medium-grained sand. These deposits are distinct and some can be traced for tens of meters across the delta, but they do not appear to extend upstream. The age of these horizons is not constrained, but at least some and possibly all could plausibly have been deposited in the past century, because the delta did not exist at its current position in 1898 (Fig. 4).

What is the origin of these sandy horizons? Possibilities include migration of Chuckanut Creek, tsunami deposits, winter storm-related deposits, or the anthropogenic influences discussed above: land clearing and construction of I-5. I rule out tsunami deposits, because the sands do not contain any marine fossils and also because the horizons are likely too young. The most recent tsunamic-genic earthquake was approximately 300 years ago (Atwater, 1987). It is possible that the sand layers simply record repeated migration of the channel of Chuckanut Creek across the position of the transect line. However, the channel migration map (Fig. 5) suggests migration across the transect line only once in the past 50 years. I consider it likely that these horizons are deposits related to high-flow events (storms) from Chuckanut Creek, contributing to the progradation of the delta. This would explain the glacial signature to most of the sand horizons.

Could any of these horizons be related to the release of sediment by land clearing or the construction of I-5? If so, we would expect the composition of the sands to include more Chuckanut Formation material, because this underlies the disturbed hillslopes and road cuts. The layer highlighted in figure 12 is a possible candidate. The Sandy Horizon is traceable from the bank to test pits and cores in the delta, it is at a similar elevation with consistent mineralogy (Figs. 9/12). It is coarser than the other sands and has a higher proportion of quartz and feldspar and lower proportion of magnetite common in the glacial deposits (Fig. 6, E). Without additional age constraints it is not possible to assign this horizon confidently to a particular event.

The sediment appears to build and cover the delta in pulses but the trestle applies a constant reduction in energy. The accumulation rates from the bay, 0.2-1.1cm a year (Benson, 2019) do not go deep enough to pick up a distinct change in accumulation rates.

#### 1.15.4 Future Projects

Two options are being proposed by the Puget Sound Nearshore Ecosystem Restoration Project to restore Mud Bay. The first is removing the causeway and replacing it with an open trestle, and the second is adding another opening to the causeway. Either option would allow a little more energy into Mud Bay to remove some of the accumulated sediment.

There are large gaps in our understanding of the sediment regime of Mud Bay Bellingham, WA. By setting up a sediment trap and stream gauge along Chuckanut Creek, it would be possible to measure the amount of sediment entering the bay. Measuring periodic transects across the bay or using terrestrial LiDAR would show where the bay is actively accumulating sediment and how

this changes over the seasons and years. Dating layers of interest would narrow down the source of these sediments, and possibly trace them back to an event, be it a storm, tsunami, or construction.

Future coring might reveal tsunami deposits. By using a vibracore out in Mud Bay it may be possible to sample 3m depths that could reach at least 300 years into the past, given the accumulation rates recorded by Benson. If tsunami deposits are preserved in the bay, this might locate them. Another area to test could be the marshy area behind the manmade berm along the northeast shore of Mud Bay.

## 6. Summary and Recommendations

From this study there is no evidence for tsunamis across the delta of Chuckanut Creek and the Southeast corner of Mud Bay.

This report does not provide any concrete evidence for shallowing of the bay, but does not refute anecdotal reports. If the bay is shallowing, increased sediment deposition behind the trestle is the more likely cause over isostatic rebound. The increased sediment accumulation is seen directly in the progradation of the delta at the mouth of Chuckanut Creek. The high accumulation rates calculated by Benson also point towards high sediment retention within the bay.

It is not possible to definitively point to one source for the high sediment accumulation. Land use changes around the bay and highway construction within the Chuckanut Creek watershed are events that may have increased sediment supply for short episodes in the past 150 years. Sandy horizons in the delta might record these events, but this study does not find definitive evidence linking the layers to particular anthropogenic events, nor does this work entirely refute those hypotheses. The events alone are not sufficient to fill the bay with sediment. It seems likely that the train causeway shifted the bay energy dynamics enough to retain sediment since its construction. Additional work, including more detailed examination of sediments from deeper in the bay are required to assess any change in sedimentation due to causeway construction.

The sediment entering Mud Bay, Bellingham is covering any tsunami deposits that may be within the bay. By coring deeper within these sediments we might be able to locate tsunami deposits and also identify if and when the depositional environment of Mud Bay has changed.

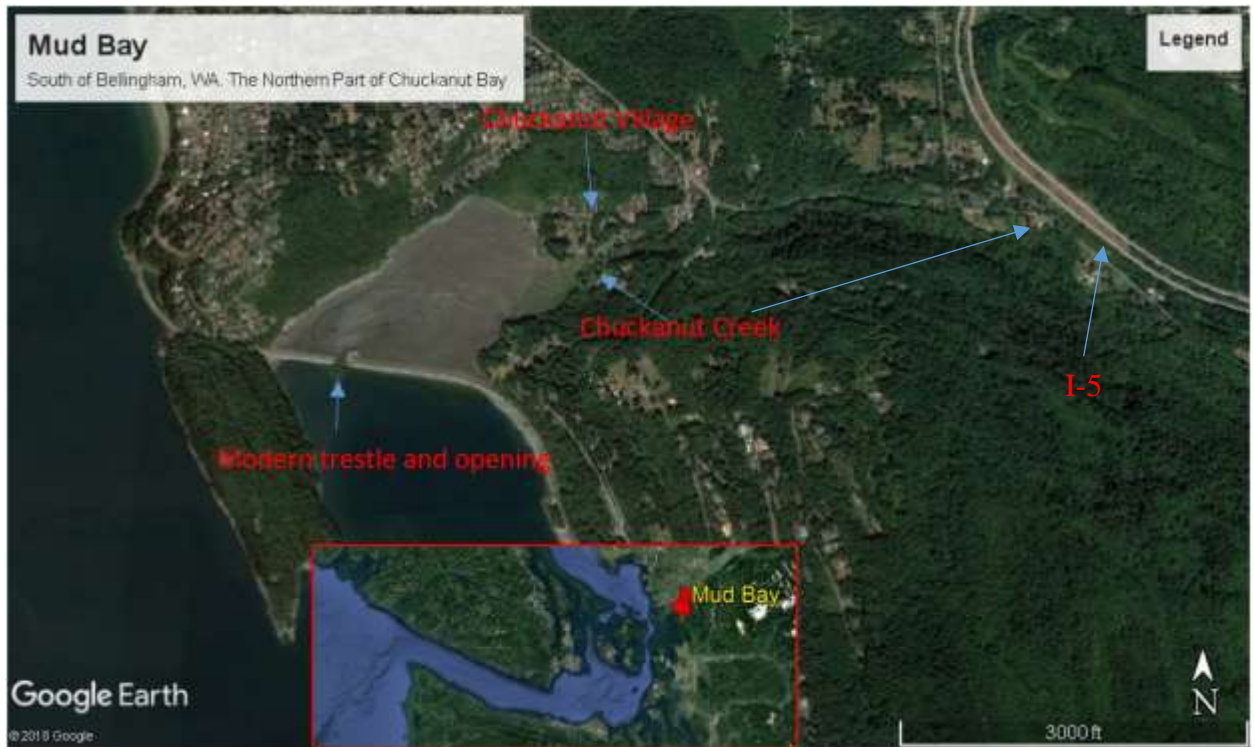
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*Figure 1.* Map of Mud Bay within Chuckanut Bay, Washington.

With location of train tracks, I-5, Chuckanut Village, and increased housing around Mud Bay (GoogleEarth, 2018)

### Geologic Map of Chuckanut Creek Watershed

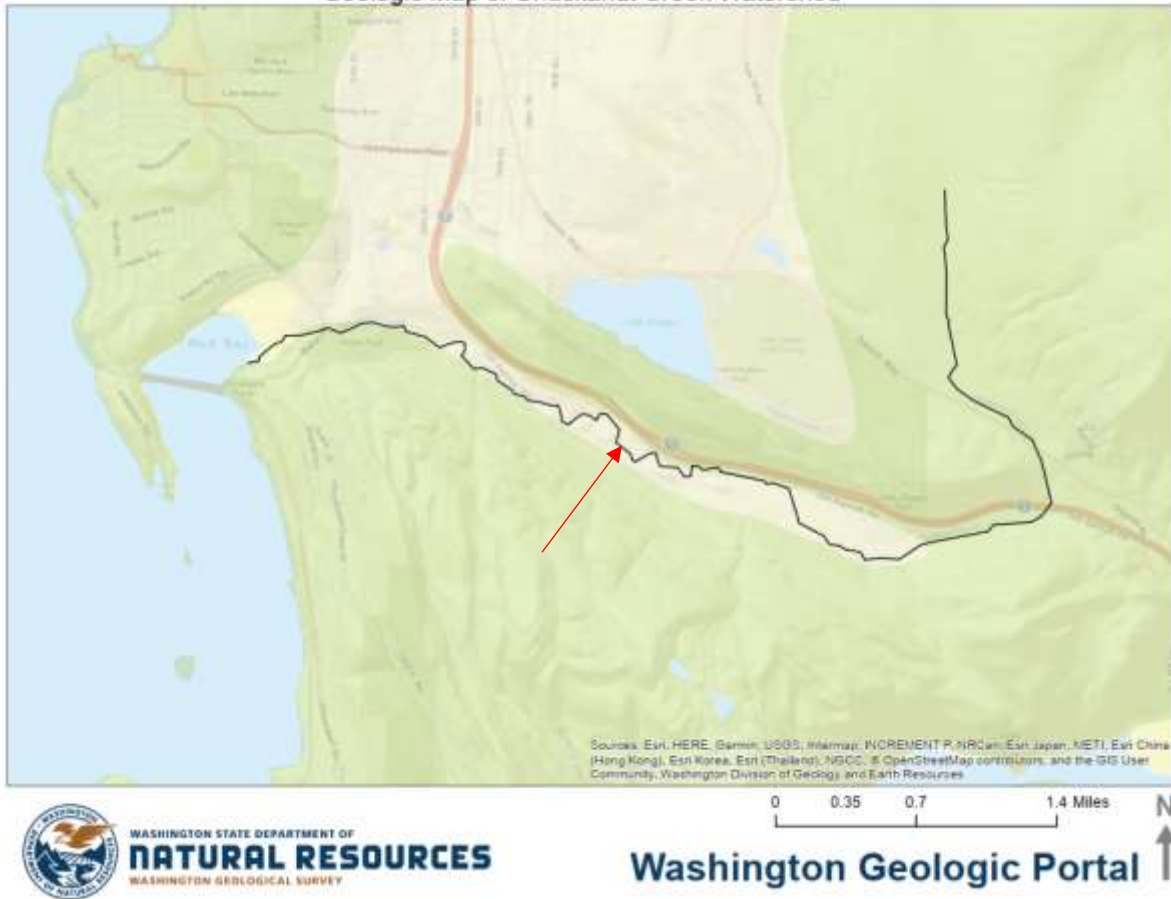


Figure 2. Geological Map of Chuckanut Creek Watershed

Focusing on Mud Bay, Bellingham. Red arrow points to Chuckanut Creek.

#### Geologic Units 100k

- Holocene artificial fill and modified land
- Quaternary alluvium
- Pleistocene continental glacial drift
- Tertiary sedimentary rocks and deposits
- Water

A.



B.



Figure 3. Site locations.

A. Broader map showing site locations from the bay out through the clay bank (LW-18-18) which is the furthest sample up the creek, MAB-3 and MAB-4 are gouge core locations, LW-17-18 is a river bed grab sample, and LW-18-18 is a bank grab sample. B. Sample locations along the hand-level transect. LW-5-18, LW-13-18, and LW-14-18 are cleaned banks, LW-11-18, and LW-12-18 are gouge core sites, and LW-15-18 and LW-16-18 are test pits.

## Chuckanut Bay Shape and Station Locations

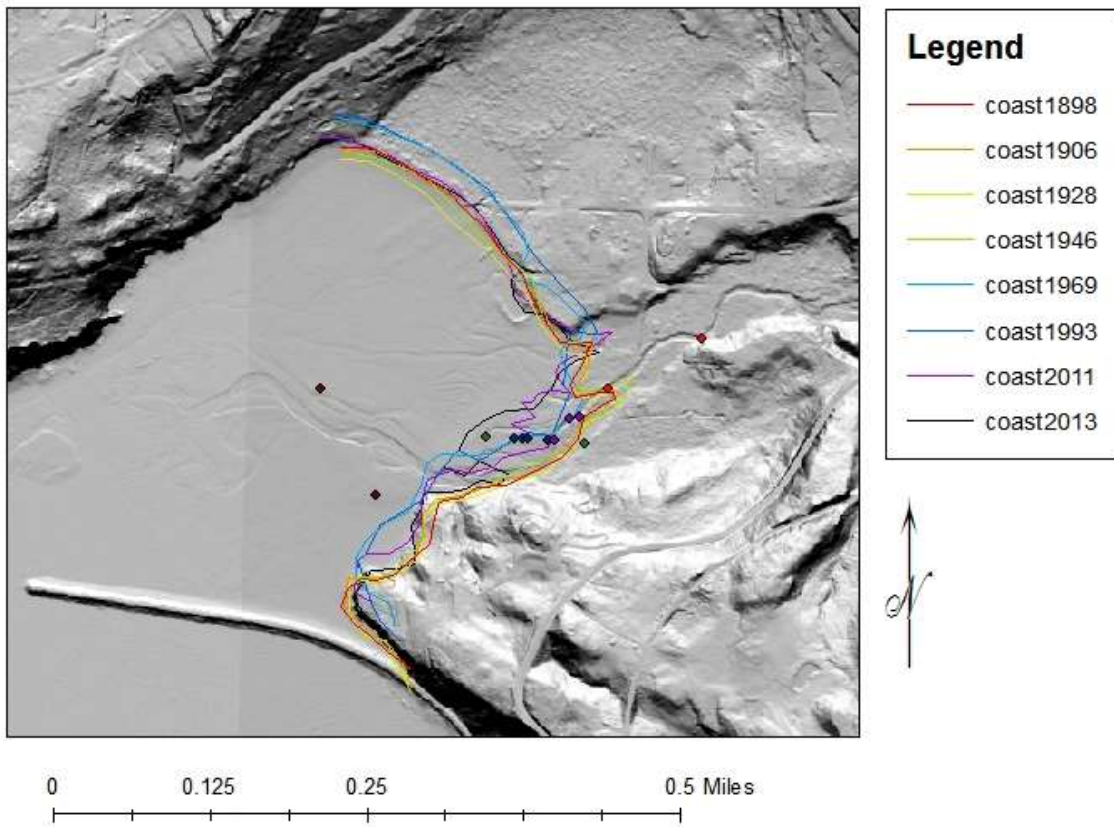


Figure 4. Chuckanut Creek Delta

The building of Chuckanut Creek delta from 1898 to present identified from navigational charts.

## Chuckanut Creek and Station Locations

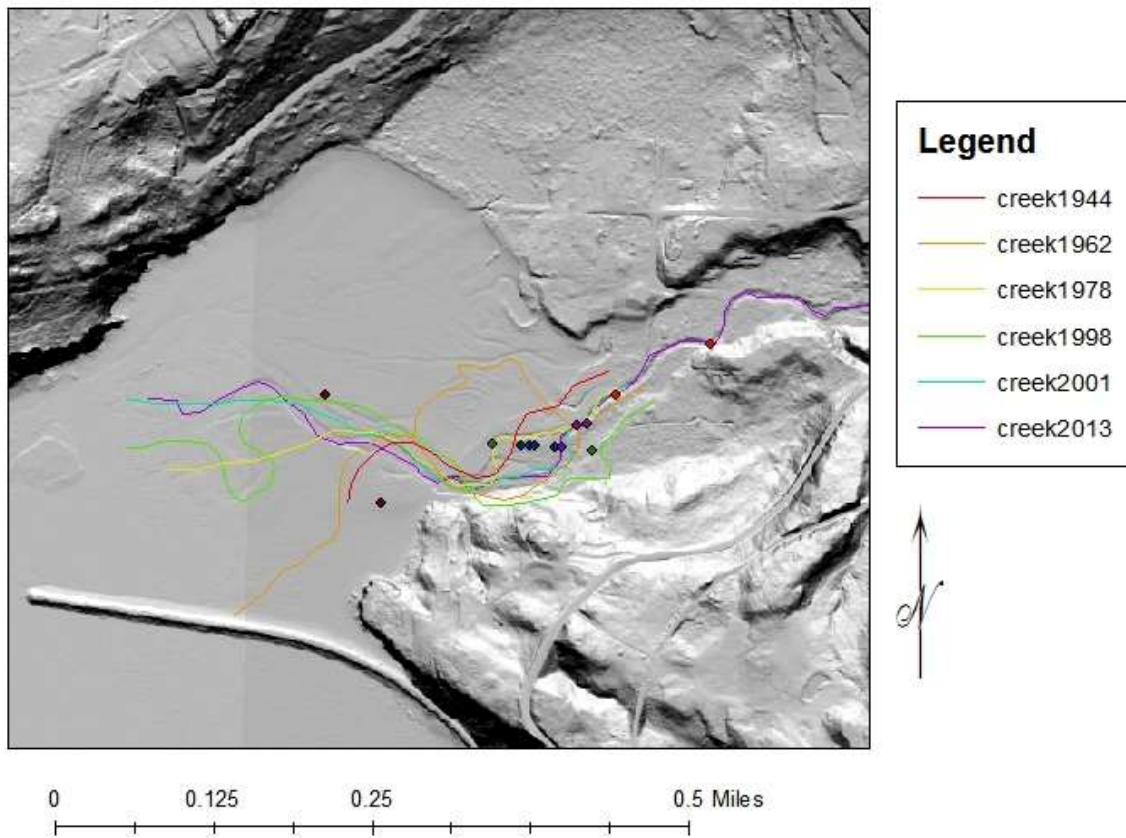


Figure 5. Map of the Chuckanut Creek Channel

Showing the placement of the channel from 1944 through 2013, and the locations of coring and sampling sites. Channel was placed using aerial photos.

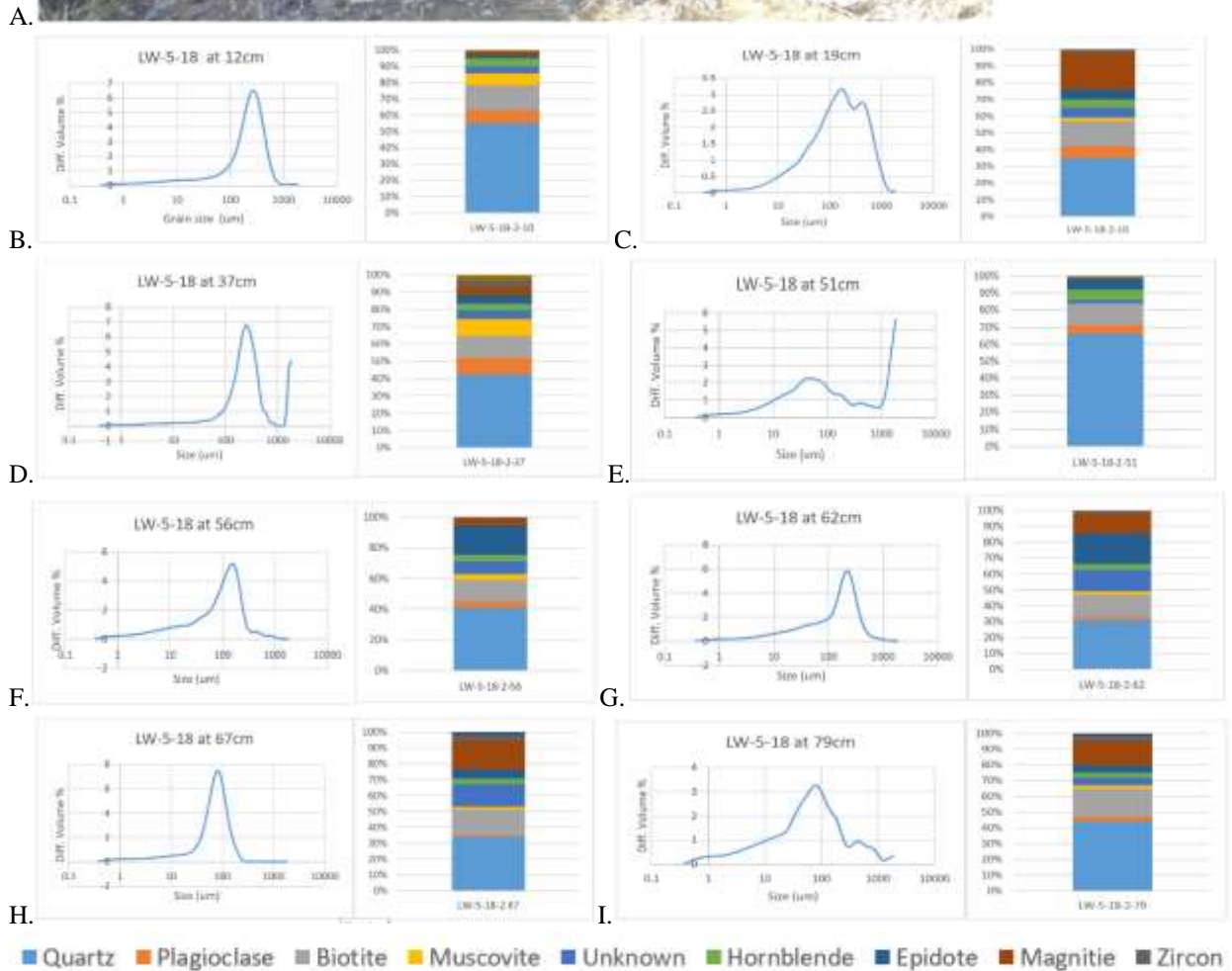
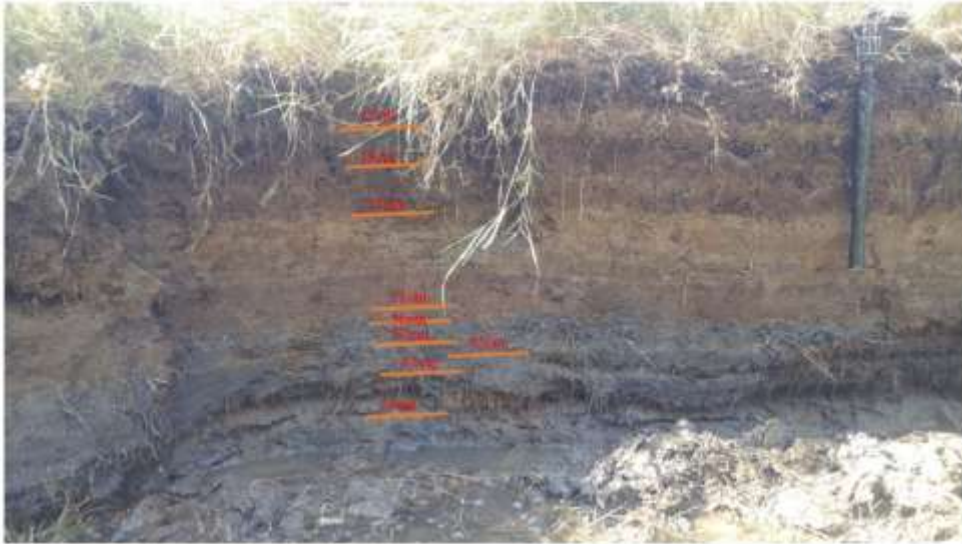


Figure 6. Composite picture of LW-5-18

With grain size analyses and mineral assemblages for specific layers. A cleared bank at LW-5-18 section 2. B.12cm deep. C. 19cm deep. D. 37cm deep. E. 51cm deep. F. 56cm deep. G. 62cm deep. H. 67cm deep. I. 79cm deep.



Figure 7. Alternating fine sand and organic layers

Thin layers found at LW-5-18 section 3 below 80cm depth.

A. LW-5-18. A wider shot showing the cohesion of the lower layers. Taken September 1<sup>st</sup>, 2018

B. LW-5-18. Layers of sand and plant material with shovel for scale. Looking down on the section. This is the resistant layer shown in the first photo from May. Taken 2<sup>nd</sup> September 2018.

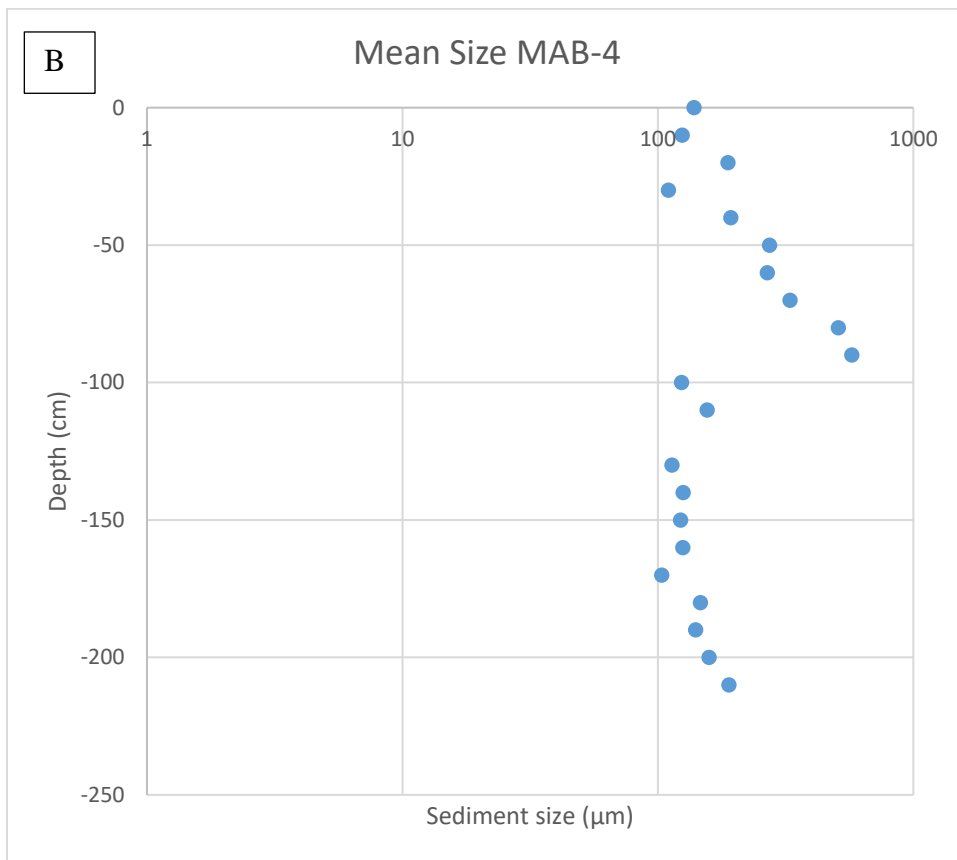
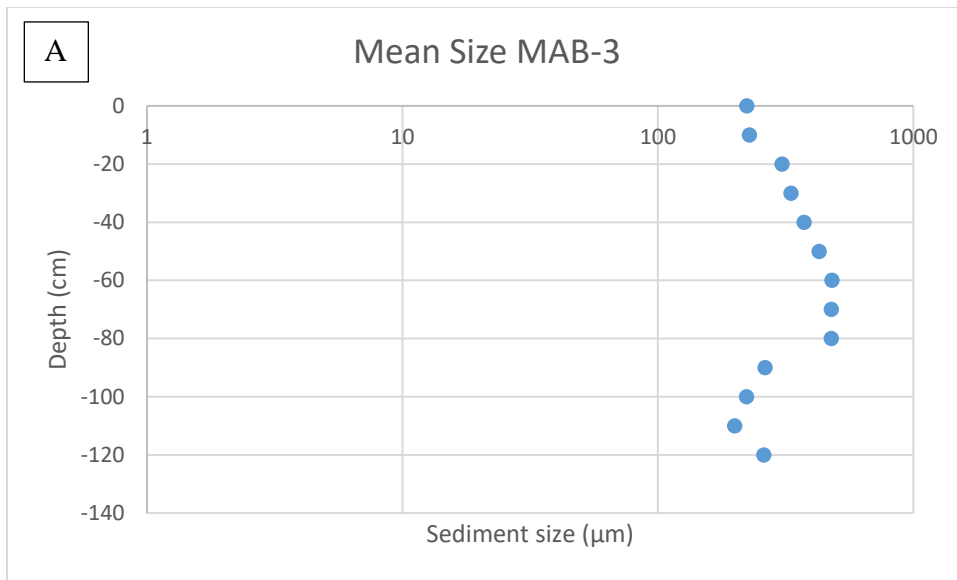


Figure 8. Mean grain size with depth of the bay sediments

A. Mean grain size with depth at MAB-3.

B. Mean grain size with depth at MAB-4.

The grain size analysis of the bay sediments reveals a fining upwards sequence in both locations. The coarsest sands are seen at 80cm depth at both sites.

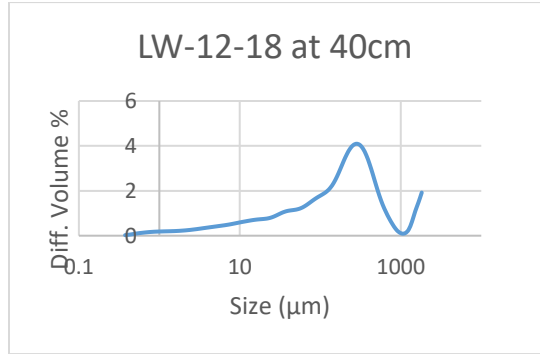
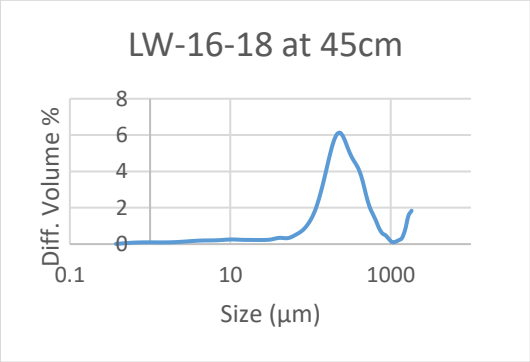
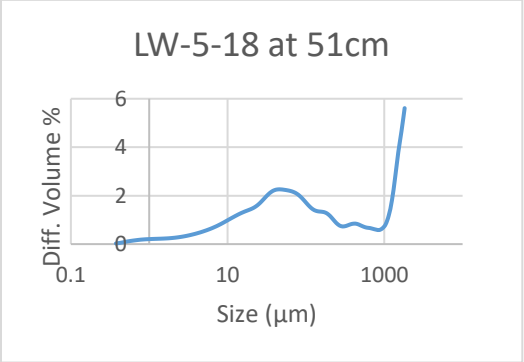
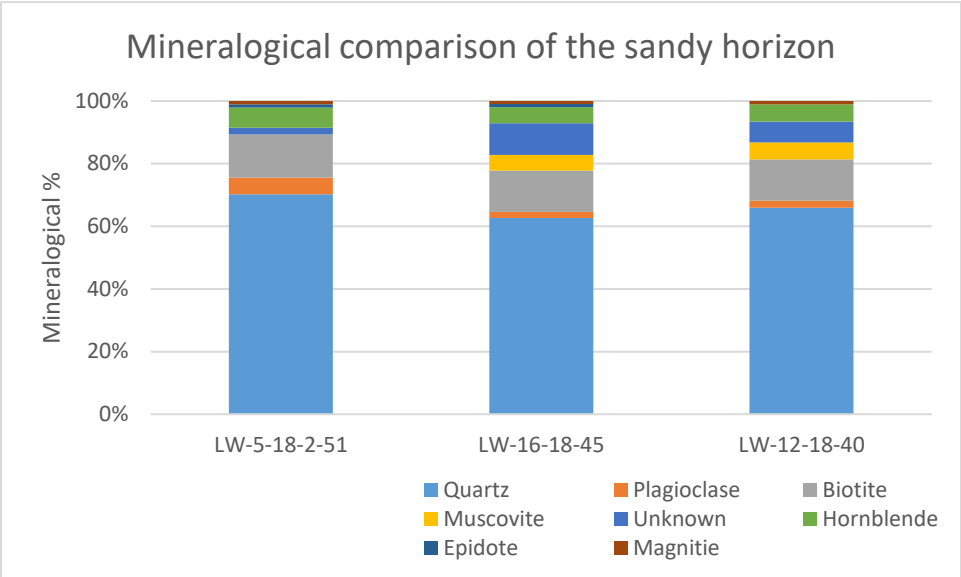


Figure 9. Comparing the mineralogy and size distribution of the sandy horizon sediments  
 The sandy horizon, LW-5-18 section 2 at 51cm depth, LW-16-18 at 45cm, LW-12-18 at 40cm.

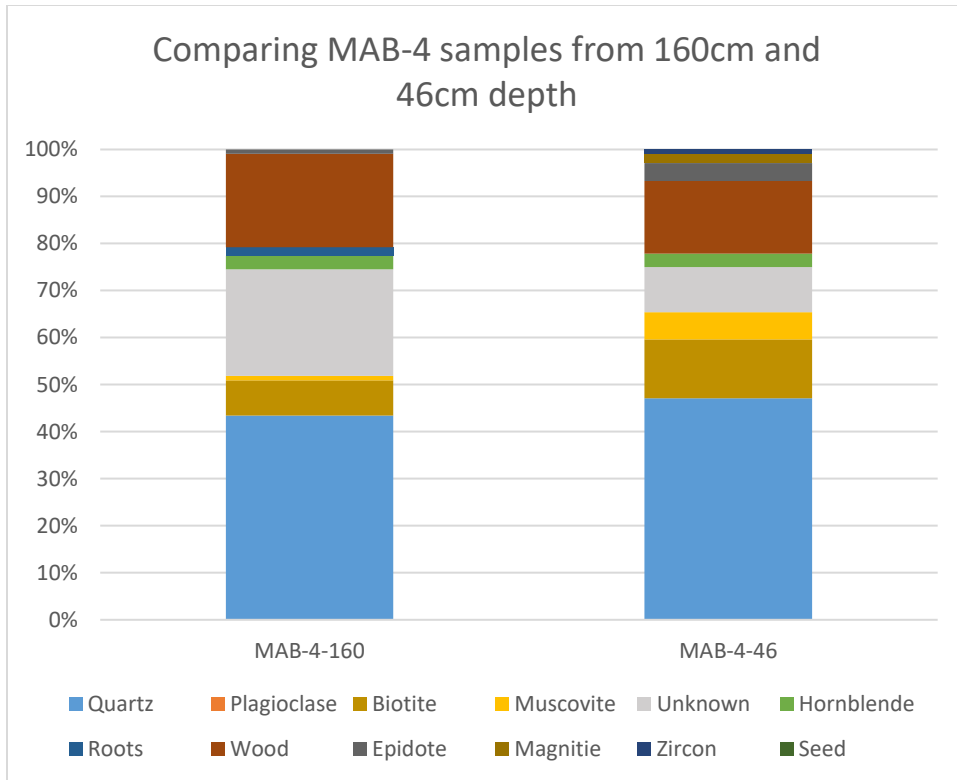


Figure 10. Mineralogical assemblages of the bay

The lower bay sediment is on the left and the upper bay sediment is on the right. They have similar quartz percentages but the upper sediment has more mica.

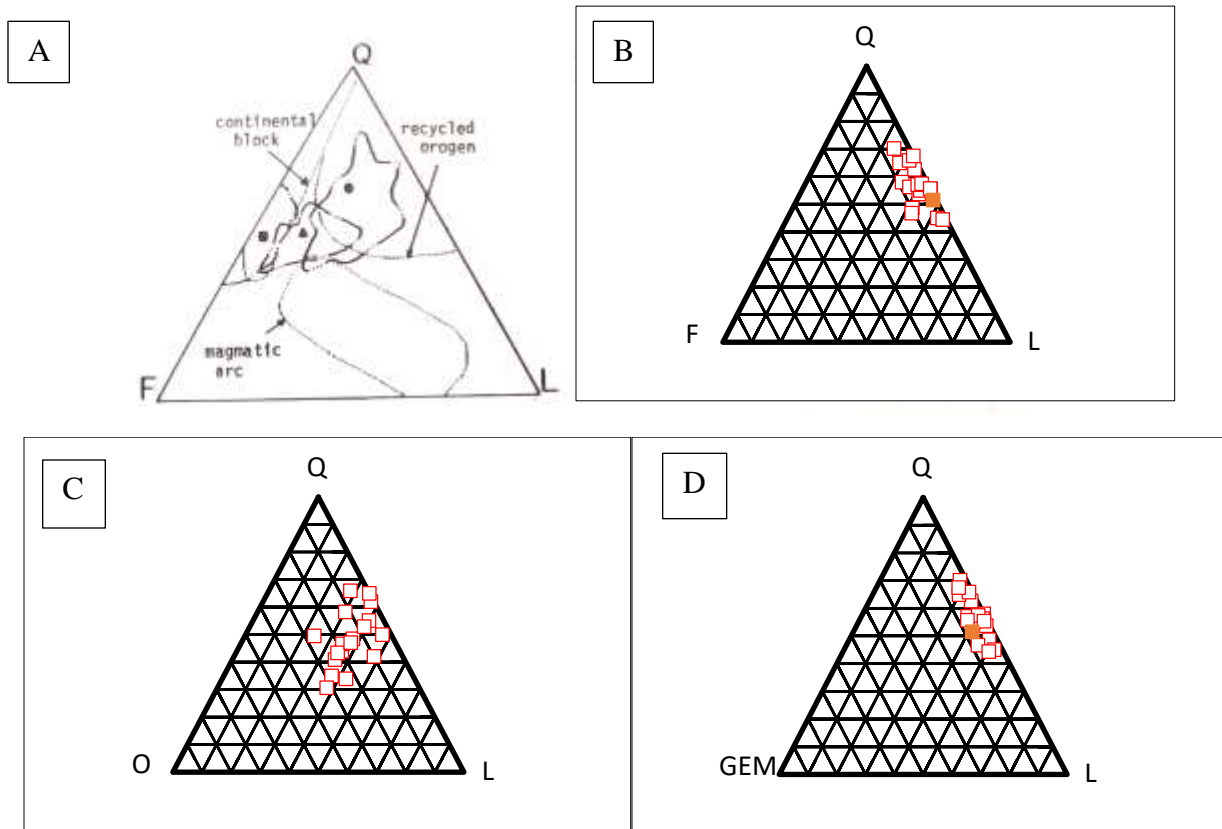


Figure 11. Ternary plots

A. QFL diagrams of the Chuckanut Formation (Johnson, 1982).

B. QFL diagram of Mud Bay sediment. Comparing quartz, feldspar, and lithic content of all samples. The solid orange dot is LW-18-18 the glacial deposit alongside Chuckanut Creek

C. Q O L ternary plot. This shows quartz, organics, and lithics. There does not appear to be a distinction with depth between low to medium organic material.

D. Q GEM L ternary plot. This is looking at quartz, garnet/epidote/magnetite, and lithics, the orange spot is LW-18 (the glacial deposit along the creek).

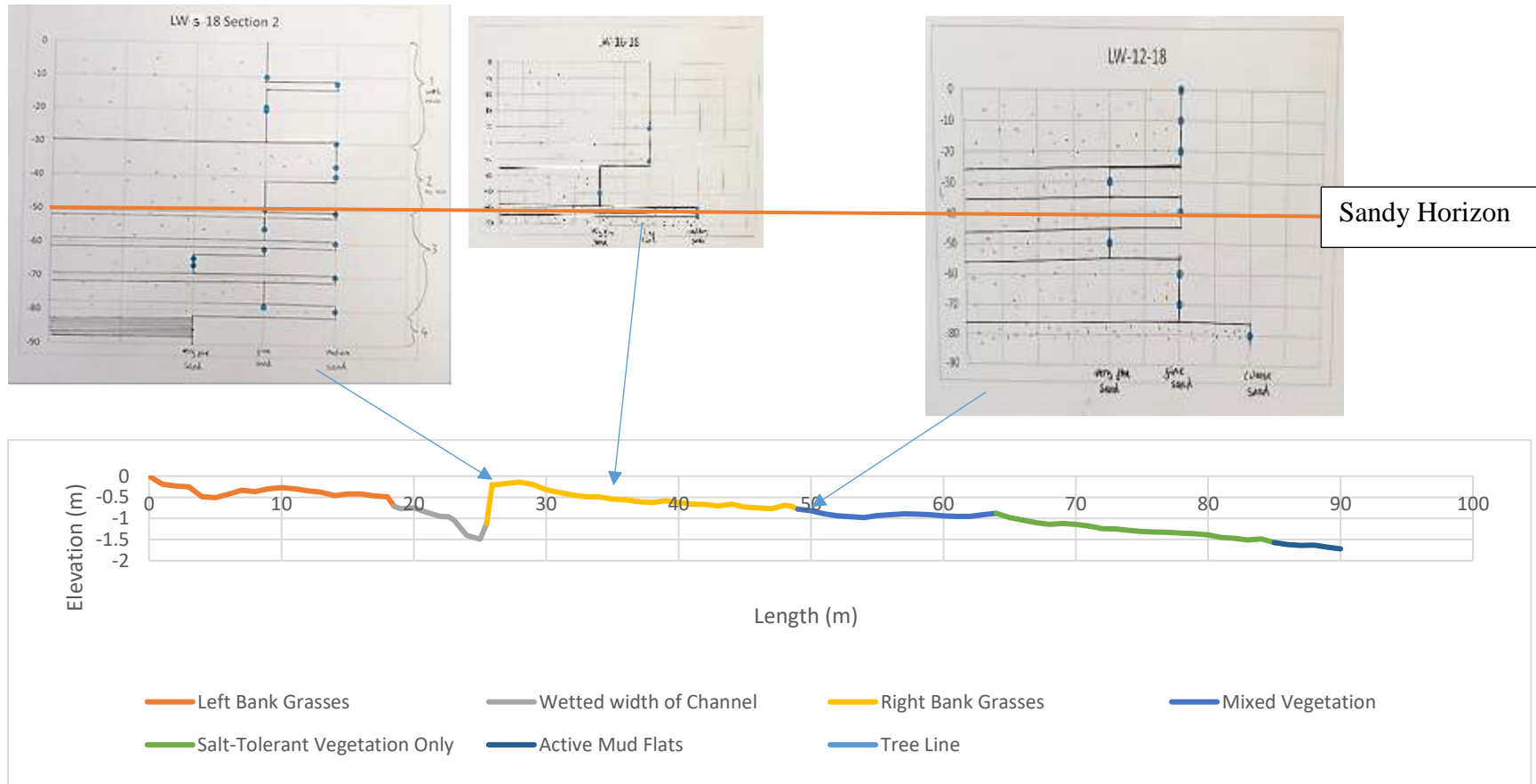


Figure 12. Hand level transect with stratigraphic columns.

Hand level transect from the tree line on the left west into the bay. Transect was performed on August 19<sup>th</sup>, 2018 with +/- 5cm of accuracy.

Stratigraphic columns across the top show grain size across the transect. Orange line indicates similar layer looking at point count data

Table 1. Point count data from Chuckanut Formation (Johnson, 1982)

TABLE 1. SANDSTONE PETROGRAPHY OF THE CHUCKANUT FORMATION<sup>1</sup>

Member	Bellingham Bay		Governors Point		Padden						Slide		Maple Falls		Warnick		Bald Mountain			
					Mainland		Lunmi Is.		Sucia Is.		Total									
	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.	$\bar{X}$	s.d.		
Number of samples	27		4		13		2		4		19		8		8		2		7	
Monocrystalline quartz	35.4	5.1	30.0	3.6	29.9	7.3	34.5	3.5	29.8	2.8	30.4	6.3	34.1	7.2	17.8	6.0	41.0	2.1	12.1	8.1
Polycrystalline quartz	2.8	2.2	3.8	1.0	5.5	2.6	4.5	0.7	2.3	1.7	4.8	6.0	2.9	1.6	9.0	3.7	2.0	0.0	14.7	3.6
Chert	1.7	1.5	0.8	0.5	8.4	5.0	7.5	2.1	4.3	1.7	7.4	4.5	2.1	1.6	24.4	11.6	2.5	0.7	28.4	17.0
Plagioclase feldspar	*35.2	6.7	35.5	3.0	26.2	4.5	27.5	9.2	36.0	4.9	28.4	6.2	37.8	9.9	11.1	4.7	35.5	2.8	15.6	11.4
Potassium feldspar	*10.0	3.5	11.3	2.2	3.3	2.0	7.5	2.1	7.3	2.6	5.8	2.5	6.8	3.7	1.5	1.1	9.0	4.2	0.9	1.5
Sedimentary lithic	1.0	1.3	1.5	1.3	2.8	1.8	1.5	0.7	2.0	1.4	2.5	1.7	1.0	1.2	4.1	3.0	0.0	0.0	4.3	4.3
Volcanic lithic	0.6	0.7	1.3	1.0	9.0	4.1	6.0	0.0	3.5	1.3	7.5	4.2	1.0	0.5	10.8	5.6	0.5	0.7	10.0	4.0
Metamorphic lithic	1.5	1.6	0.3	0.5	2.4	1.5	4.0	0.0	3.8	1.5	2.7	1.5	2.6	1.8	3.3	4.6	1.0	1.4	5.4	4.5
Mica	8.7	3.7	13.5	6.2	4.0	3.3	1.5	0.7	5.0	4.2	4.0	3.3	8.1	3.8	2.1	2.1	5.0	1.4	1.9	2.9
Accessories	2.0	1.4	1.5	1.9	3.7	2.7	5.5	0.7	6.0	6.1	4.5	3.7	2.9	2.9	7.5	9.6	1.0	1.4	3.5	2.7
Matrix	0.6	1.6	0.5	1.0	2.6	2.2	1.0	0.0	0.5	0.6	1.7	1.8	0.4	0.5	8.1	11.3	1.5	2.1	3.3	2.6
F/F	*0.78	0.08	0.76	0.04	0.83	.06	0.79	.10	0.84	.04	0.83	0.07	0.85	0.09	0.87	0.07	0.80	0.06	0.95	0.09
QFL	45,51,4		41,55,4		50,34,16		50,38,12		41,49,10		48,38,14		45,51,4		60,16,23		50,48,2		60,18,22	
QaPK	44,44,12		29,46,15		50,44,6		50,40,10		41,49,10		47,44,9		43,48,9		58,37,5		48,41,11		42,55,3	
QaFLt	40,51,9		36,55,9		34,34,33		37,38,25		33,49,18		34,38,28		39,51,10		22,17,61		45,48,7		12,18,69	
QpLvLs	74,10,16		62,18,20		54,35,11		62,31,8		55,29,16		56,34,10		71,14,14		68,24,8		90,10,0		75,17,8	
QmQpL	82,11,7		80,12,8		52,24,24		59,21,20		65,14,21		55,22,23		80,12,8		28,43,29		92,5,3		16,58,26	

<sup>1</sup>Percentage of grain types is presented as a mean ( $\bar{X}$ ) with standard deviation (s.d.). Statistical parameters calculated after Dickinson and Suczek (1979) and Dickinson (1970). Percentages based on point counts of more than 300 grains per sample.

\*Does not include samples in which potassium feldspar has been albited.

Table 2. Station and sample statistics

Field Observations					Lab Analyses		
Station	Sample-Depth (cm)	Date Collected	Type	Setting	Grain Size	General Content	Point Count
MAB3	MAB3-0	6/28/2018	Gouge Core	Bay	X		
	MAB3-10	6/28/2018	Gouge Core	Bay	X		
	MAB3-20	6/28/2018	Gouge Core	Bay	X		
	MAB3-30	6/28/2018	Gouge Core	Bay	X		
	MAB3-40	6/28/2018	Gouge Core	Bay	X		
	MAB3-50	6/28/2018	Gouge Core	Bay	X		
	MAB3-60	6/28/2018	Gouge Core	Bay	X		
	MAB3-70	6/28/2018	Gouge Core	Bay	X		
	MAB3-80	6/28/2018	Gouge Core	Bay	X		
	MAB3-90	6/28/2018	Gouge Core	Bay	X	X	
	MAB3-100	6/28/2018	Gouge Core	Bay	X	X	
	MAB3-110	6/28/2018	Gouge Core	Bay	X	X	
	MAB3-120	6/28/2018	Gouge Core	Bay	X	X	X
MAB4	MAB4-0	6/28/2018	Gouge Core	Bay	X		
	MAB4-10	6/28/2018	Gouge Core	Bay	X		
	MAB4-20	6/28/2018	Gouge Core	Bay	X		
	MAB4-30	6/28/2018	Gouge Core	Bay	X		
	MAB4-40	6/28/2018	Gouge Core	Bay	X		X
	MAB4-50	6/28/2018	Gouge Core	Bay	X		
	MAB4-60	6/28/2018	Gouge Core	Bay	X		
	MAB4-70	6/28/2018	Gouge Core	Bay	X		
	MAB4-80	6/28/2018	Gouge Core	Bay	X		
	MAB4-90	6/28/2018	Gouge Core	Bay	X		
	MAB4-100	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-110	6/28/2018	Gouge Core	Bay	X	X	

	MAB4-130	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-140	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-150	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-160	6/28/2018	Gouge Core	Bay	X	X	X
	MAB4-170	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-180	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-190	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-200	6/28/2018	Gouge Core	Bay	X	X	
	MAB4-210	6/28/2018	Gouge Core	Bay	X	X	
LW-5-18-1	LW-5-18 creek bed	10/13/2018	Grab (bed)	Creek bed			
	LW-5-18-1-20	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-1-30	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-1-40	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-1-50	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-1-60	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-1-70	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-1-80	9/2/2018	Grab (bank)	Creek bank		X	
LW-5-18-2	LW-5-18-2-10	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-12	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-19	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-20	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-30	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-37	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-40	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-50	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-51	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-56	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-60	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-62	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-65	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-67	9/2/2018	Grab (bank)	Creek bank	X	X	X

	LW-5-18-2-70	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-5-18-2-79	9/2/2018	Grab (bank)	Creek bank	X	X	X
	LW-5-18-2-80	9/2/2018	Grab (bank)	Creek bank	X	X	
LW-5-18-3	LW-5-18-3-10	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-20	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-30	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-40	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-50	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-60	9/2/2018	Grab (bank)	Creek bank		X	X
	LW-5-18-3-70	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-80	9/2/2018	Grab (bank)	Creek bank		X	
	LW-5-18-3-87	9/2/2018	Grab (bank)	Creek bank		X	
	LW-11-18	LW-11-18-0	8/19/2018	Gouge Core	67m along transect, salt tolerant plants	X	X
LW-11-18-10		8/19/2018	Gouge Core	67m along transect, salt tolerant plants	X	X	
LW-11-18-20		8/19/2018	Gouge Core	67m along transect, salt tolerant plants	X	X	
LW-11-18-28		8/19/2018	Gouge Core	67m along transect, salt tolerant plants	X	X	
LW-12-18	LW-12-18-0	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-10	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-20	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-30	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-40	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	X
	LW-12-18-50	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-60	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-70	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
	LW-12-18-80	8/19/2018	Gouge Core	50m along transect, mixed vegetation	X	X	
LW-13-18	LW-13-18 river bed	10/13/2018	Grab (bed)	Creek bed			
LW-13L-18	LW-13L-18-10	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-13L-18-20	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-13L-18-30	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-13L-18-40	9/2/2018	Grab (bank)	Creek bank	X	X	

	LW-13L-18-50	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-13L-18-60	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-13L-18-70	9/2/2018	Grab (bank)	Creek bank	X	X	
	LW-13L-18-80	9/2/2018	Grab (bank)	Creek bank	X	X	
LW-13R-18	LW-13R-18-10	9/2/2018	Grab (bank)	Creek bank		X	
	LW-13R-18-20	9/2/2018	Grab (bank)	Creek bank		X	
	LW-13R-18-30	9/2/2018	Grab (bank)	Creek bank		X	
	LW-13R-18-40	9/2/2018	Grab (bank)	Creek bank		X	
	LW-13R-18-50	9/2/2018	Grab (bank)	Creek bank		X	
	LW-13R-18-60	9/2/2018	Grab (bank)	Creek bank		X	
	LW-13R-18-70	9/2/2018	Grab (bank)	Creek bank		X	
LW-14-18	LW-14-18 river bed	10/13/2018	Grab (bed)	Creek bed			X
	LW-14-18-10	9/2/2018	Grab (bank)	Creek bank		X	
	LW-14-18-20	9/2/2018	Grab (bank)	Creek bank		X	
	LW-14-18-30	9/2/2018	Grab (bank)	Creek bank		X	
	LW-14-18-40	9/2/2018	Grab (bank)	Creek bank		X	
	LW-14-18-50	9/2/2018	Grab (bank)	Creek bank		X	
	LW-14-18-60	9/2/2018	Grab (bank)	Creek bank		X	
	LW-14-18-70	9/2/2018	Grab (bank)	Creek bank		X	
LW-14-18-80	9/2/2018	Grab (bank)	Creek bank		X		
LW-15-18	LW-15-18-0	9/2/2018	Grab (test pit)	On right bank of creek between salt only and mixed vegetation		X	
	LW-15-18-4	9/2/2018	Grab (test pit)	On right bank of creek between salt only and mixed vegetation		X	
	LW-15-18-20	9/2/2018	Grab (test pit)	On right bank of creek between salt only and mixed vegetation		X	
	LW-15-18-27	9/2/2018	Grab (test pit)	On right bank of creek between salt only and mixed vegetation		X	
	LW-15-18-37	9/2/2018	Grab (test pit)	On right bank of creek between salt only and mixed vegetation		X	
LW-16-18	LW-16-18-20	9/2/2018	Grab (test pit)	36m along transect, in grasses on right bank	X	X	

	LW-16-18-30	9/2/2018	Grab (test pit)	36m along transect, in grasses on right bank	X	X	
	LW-16-18-40	9/2/2018	Grab (test pit)	36m along transect, in grasses on right bank	X	X	
	LW-16-18-45	9/2/2018	Grab (test pit)	36m along transect, in grasses on right bank	X	X	X
	LW-16-18-47 (bottom)	9/2/2018	Grab (test pit)	36m along transect, in grasses on right bank	X	X	X
LW-17-18	LW-17-18 river bed	10/13/2018	Grab (bed)	Creek bed			
LW-18-18	LW-18-18 (Clay Bank)	10/13/2018	Grab (bank)	Glacialmarine drift deposit	X		X

Table 3. Sediment size analysis

Station	Sample-Depth (cm)	Grain Size mean ( $\mu\text{m}$ )	Grain size mode ( $\mu\text{m}$ )
MAB3	MAB3-0	223.15	168.87
	MAB3-10	227.88	185.38
	MAB3-20	306.17	203.51
	MAB3-30	331.77	185.38
	MAB3-40	373.92	390.96
	MAB3-50	428.03	269.22
	MAB3-60	479.80	356.14
	MAB3-70	477.93	1908.87
	MAB3-80	477.93	1908.87
	MAB3-90	263.09	324.43
	MAB3-100	222.62	168.87
	MAB3-110	199.55	168.87
	MAB3-120	259.98	324.43
MAB4	MAB4-0	138.41	87.90
	MAB4-10	124.61	87.90
	MAB4-20	188.09	96.50
	MAB4-30	109.89	87.90
	MAB4-40	193.08	80.07
	MAB4-50	273.92	96.50
	MAB4-60	268.25	80.07
	MAB4-70	328.98	1908.87
	MAB4-80	509.16	1908.87
	MAB4-90	573.83	1908.87
	MAB4-100	123.61	96.50
	MAB4-110	155.88	96.50
	MAB4-130	113.59	87.90
	MAB4-140	125.58	87.90
	MAB4-150	122.89	87.90
	MAB4-160	125.12	87.90
	MAB4-170	103.56	96.50
	MAB4-180	146.66	105.93
	MAB4-190	140.52	96.50
	MAB4-200	158.66	96.50
MAB4-210	189.89	96.50	
LW-5-18-2	LW-5-18-2-10	241.43	203.51
	LW-5-18-2-12	251.37	295.54
	LW-5-18-2-19	241.93	168.87
	LW-5-18-2-20	226.09	105.93
	LW-5-18-2-30	292.66	223.40
	LW-5-18-2-37	399.00	269.22

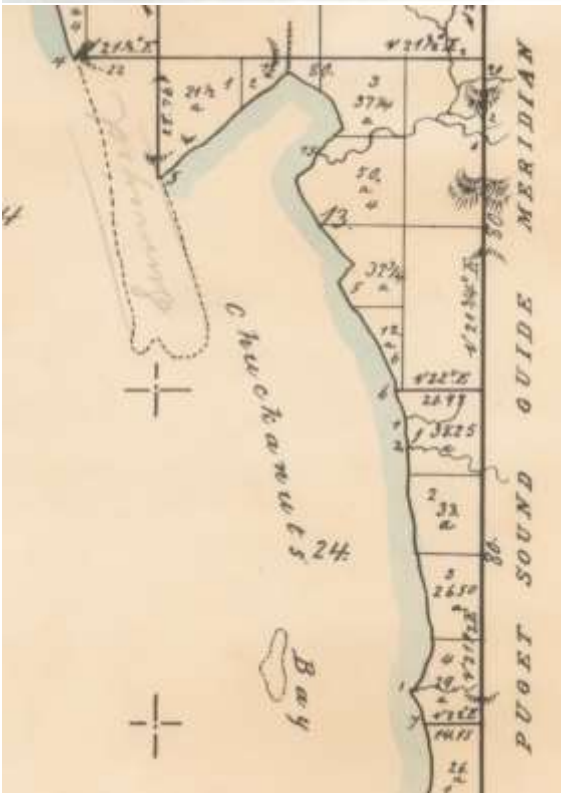
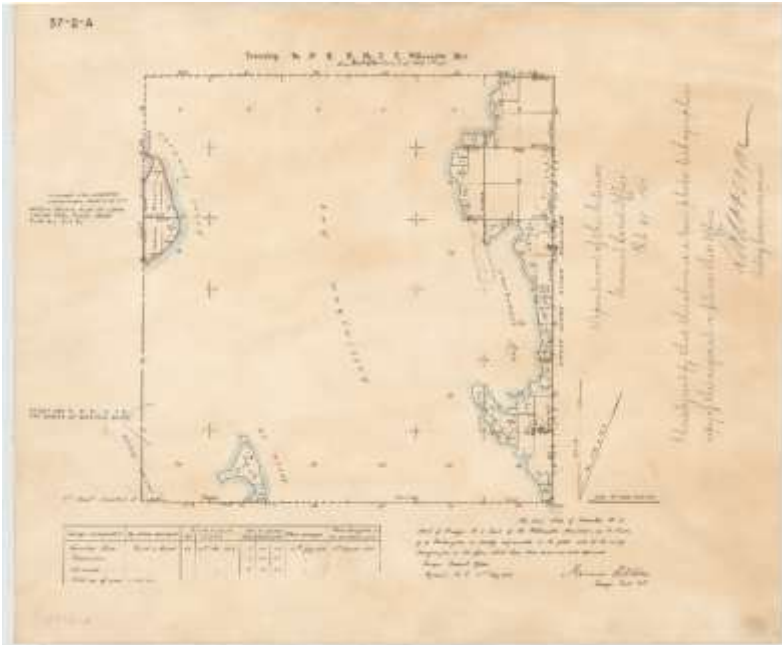
	LW-5-18-2-40	260.70	96.50
	LW-5-18-2-50	236.30	45.76
	LW-5-18-2-51	434.44	1908.87
	LW-5-18-2-56	125.28	168.87
	LW-5-18-2-60	288.20	223.40
	LW-5-18-2-62	178.41	223.40
	LW-5-18-2-65	120.39	80.07
	LW-5-18-2-67	76.42	87.90
	LW-5-18-2-70	337.52	1908.87
	LW-5-18-2-79	148.13	80.07
	LW-5-18-2-80	318.32	1908.87
LW-11-18	LW-11-18-0	213.00	153.83
	LW-11-18-10	257.08	153.83
	LW-11-18-20	203.11	185.38
	LW-11-18-28	224.40	223.40
LW-12-18	LW-12-18-0	203.64	41.68
	LW-12-18-10	174.04	87.90
	LW-12-18-20	136.77	203.51
	LW-12-18-30	124.03	168.87
	LW-12-18-40	296.88	295.54
	LW-12-18-50	64.83	55.14
	LW-12-18-60	243.78	96.50
	LW-12-18-70	235.02	50.23
	LW-12-18-80	294.19	324.43
LW-13L-18	LW-13L-18-10	141.81	153.83
	LW-13L-18-20	172.78	96.50
	LW-13L-18-30	201.73	168.87
	LW-13L-18-40	186.76	203.51
	LW-13L-18-50	133.71	168.87
	LW-13L-18-60	168.14	185.38
	LW-13L-18-70	210.18	223.40
	LW-13L-18-80	299.66	356.14
LW-16-18	LW-16-18-20	166.71	72.94
	LW-16-18-30	130.45	50.23
	LW-16-18-40	96.24	96.50
	LW-16-18-45	340.51	245.24
	LW-16-18-47 (bottom)	371.16	295.54
LW-18-18	LW-18-18 (Clay Bank)	132.98	203.51

Table 4. Point counts data

Sample	Quartz	Plagioclase	Biotite	Muscovite	Unknown	Hornblende	Roots	Wood	Epidote	Magnetite	Zircon	Seed	Totals
LW-5-18-2-10	54	8	15	7	4	5	2	3					98
LW-5-18-2-12	49	6	17	7	5	2	6	8	1				101
LW-5-18-2-19	35	7	15	2	6	5	6	22	2				100
LW-5-18-2-37	43	10	13	10	5	4	5	5	4	3			102
LW-5-18-2-51	66	5	13		2	6	6		1	1			100
LW-5-18-2-56	43	4	15	4	9	4	20	5	1				105
LW-5-18-2-62	32	2	15	2	14	4	20	13	2				104
LW-5-18-2-67	36	1	17	2	15	4	6	19	4		2		106
LW-5-18-2-79	44	3	18	2	5	3	5	15	4		1		100
LW-5-18-3-60	48	3	13	4	6	5	9	10	4	1			103
LW-16-18-45	62	2	13	5	10	5	1		1	1			100
LW-16-18-47	65	6	8	6	9	1			3	2			100
LW-12-18-40	60	2	12	5	6	5	2	10		1			103
MAB-3-120	54	2	10	9	11	6		8	2				102
MAB-4-160	46		8	1	24	3	2	21	1				106
LW-18-18 (Clay Bank)	50	1	11	4	23		3		6	1	1		100
LW-14-18, river bed	52				20	2	1	26	1	2		1	105
MAB-4-46	49		13	6	10	3		16	4	2	1		104

Appendices

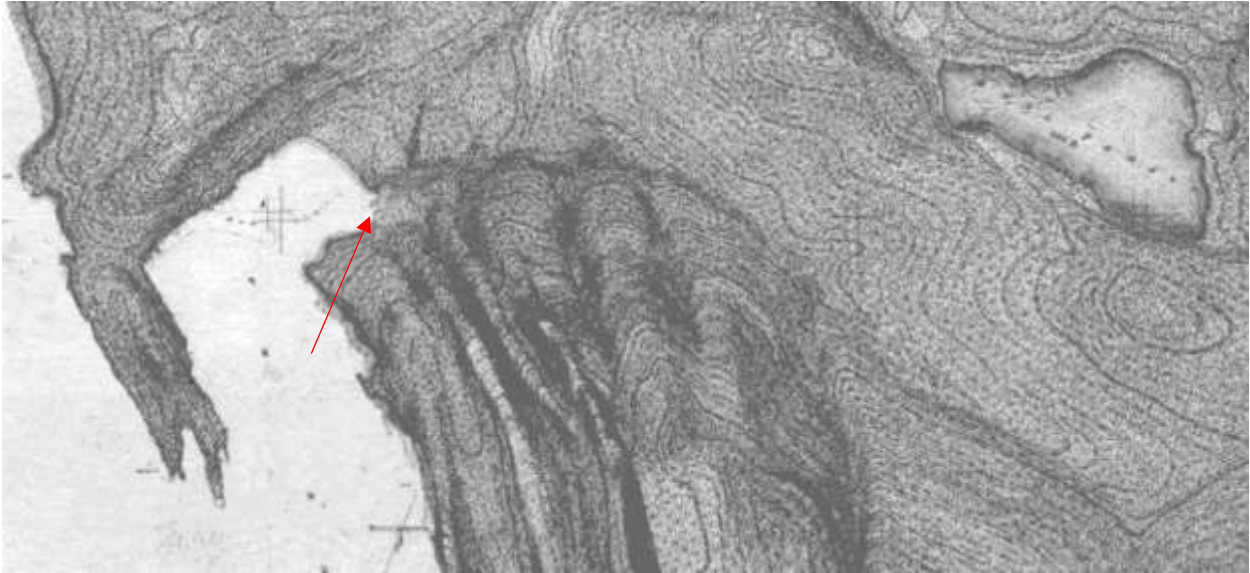
Appendix A – Charts and Aerial Photos



1860 Cadastral Survey Map

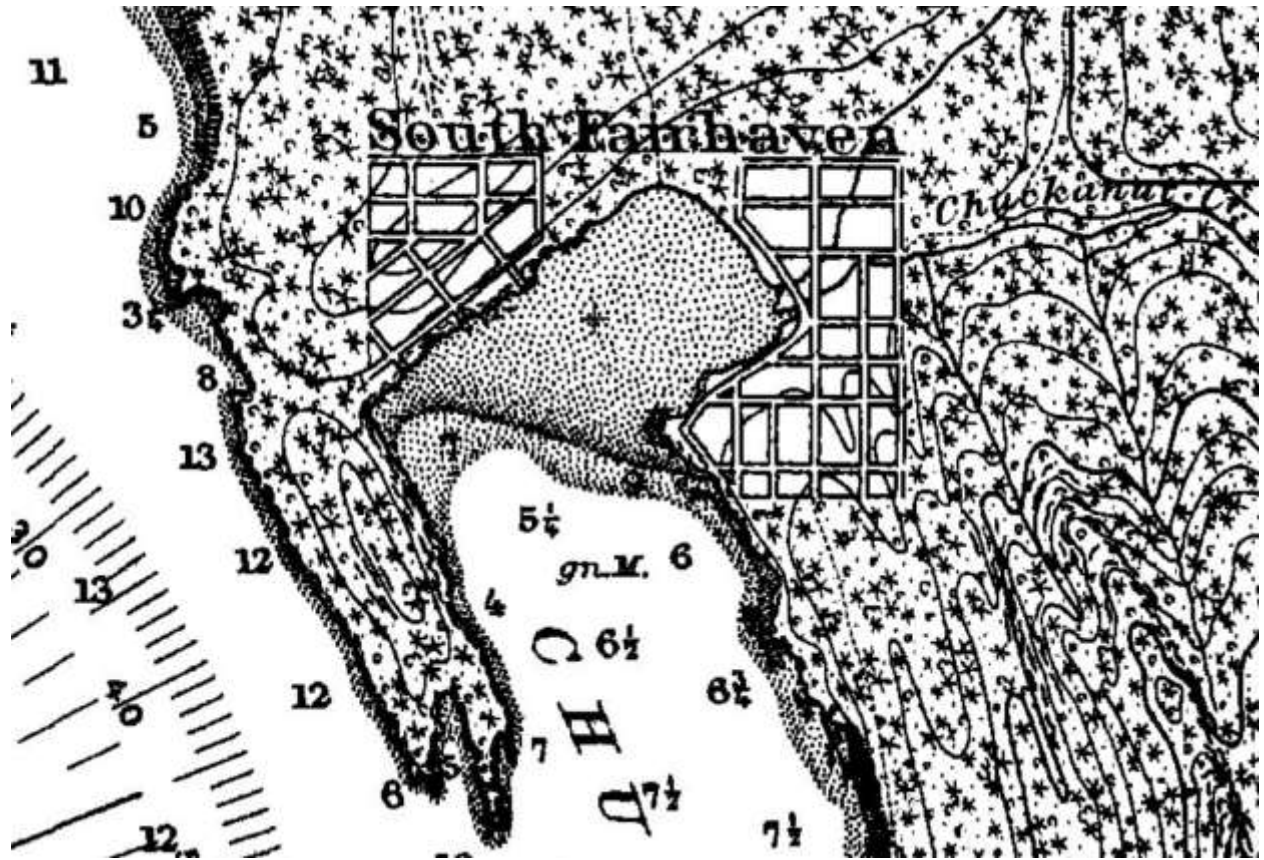
A. 1860 Cadastral Survey Map of Township No. 37N, RNo. 2E Willamette Meridian (Tilton, 1860).

B. enlarged section showing Mud Bay within Chuckanut Bay and the placement of Chuckanut Creek at #15. When the tide is low this is roughly where Chuckanut Creek still enters Mud Bay.

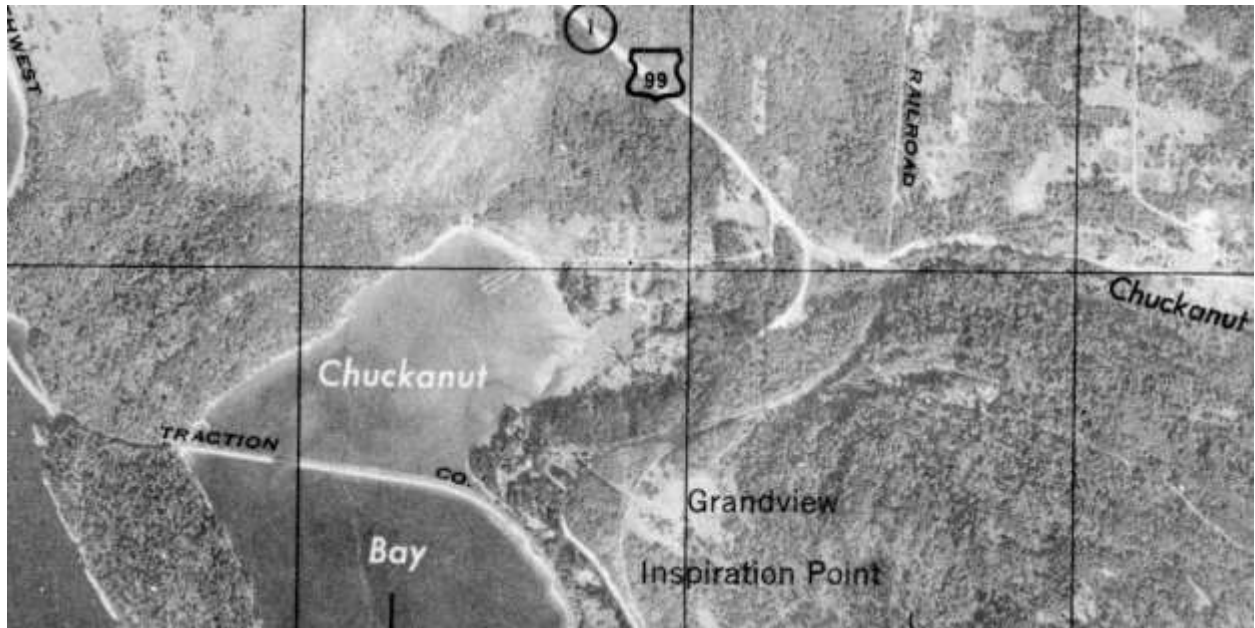


1887 T-Sheet map

At the mouth of Chuckanut Creek a small delta appears to be building (Gilbert, 1887).



1898 Nautical map of Bellingham Bay.



1944 U.S. Army aerial photograph of Chuckanut Bay

With Mud Bay around the word Chuckanut. Much of the forest has been clearcut and is growing back at this time. Chuckanut Village is a small community. (U.S. Army, 1944).



1962 aerial photo of Mud Bay.

Trees are growing on the north side of the bay, and the channel still has a few distributaries. (WA DOT, 1962)



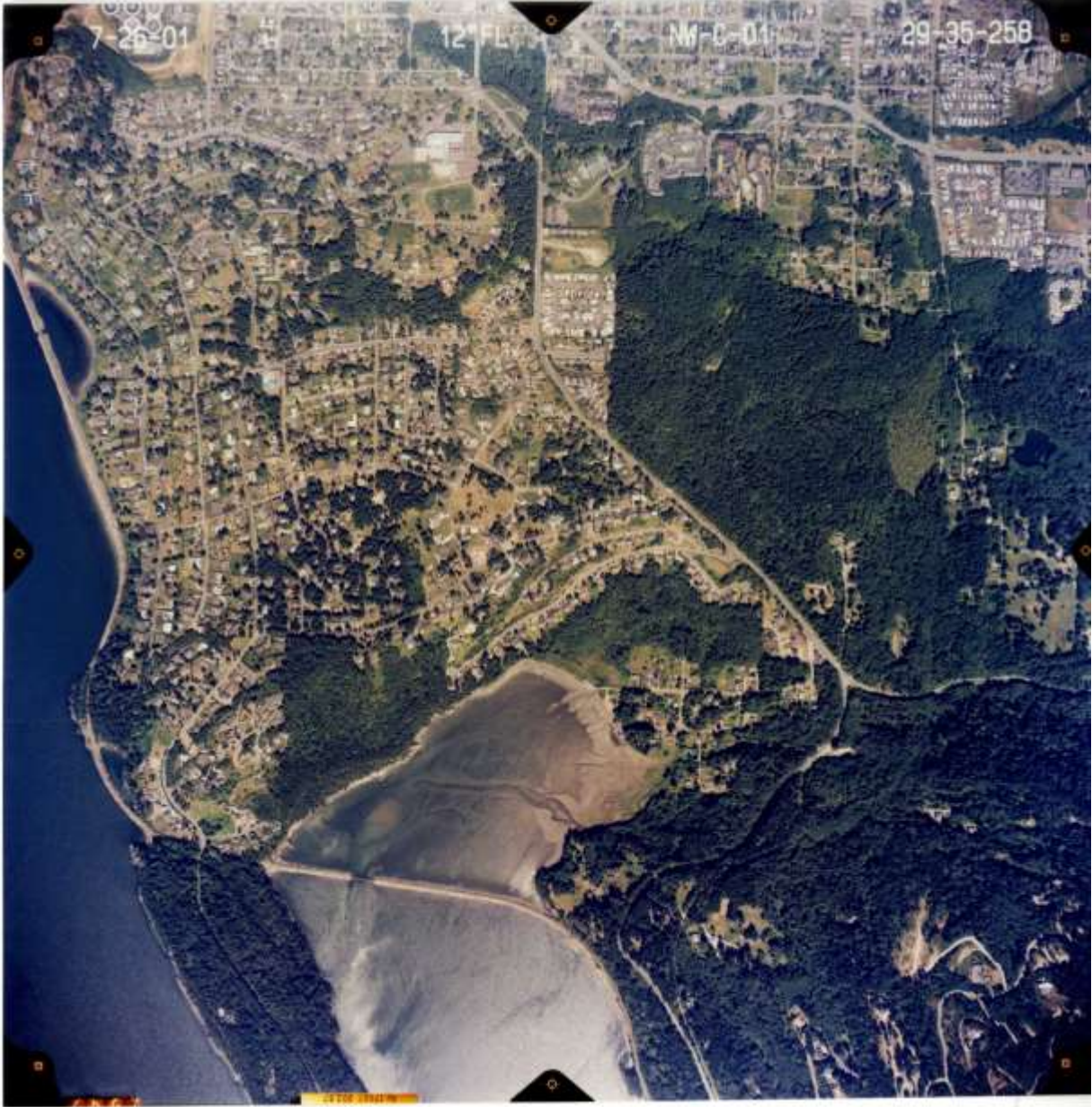
1978 aerial photo.

Trees have regrown considerably, but housing is also growing and a development is forming on the ridge north of the bay. Chuckanut Creek has formed one main channel out into the bay. (WA DNR, 1978).



1998 GoogleEarth image

The main channel of Chukanut Creek has stabilized into most of the bay but quite in the very middle (USGS, 1998).



2001 aerial photo.

Housing is much denser in this photo. The channel of Chuckanut creek has not significantly moved from 1978 but more of it is delineated as sediment has built up in the bay and a channel has formed. A small meander in the middle of the bay, present in the 1998 USGS photo, has been cut off at this point (WA DNR, 2001).



March 2018 GoogleEarth image

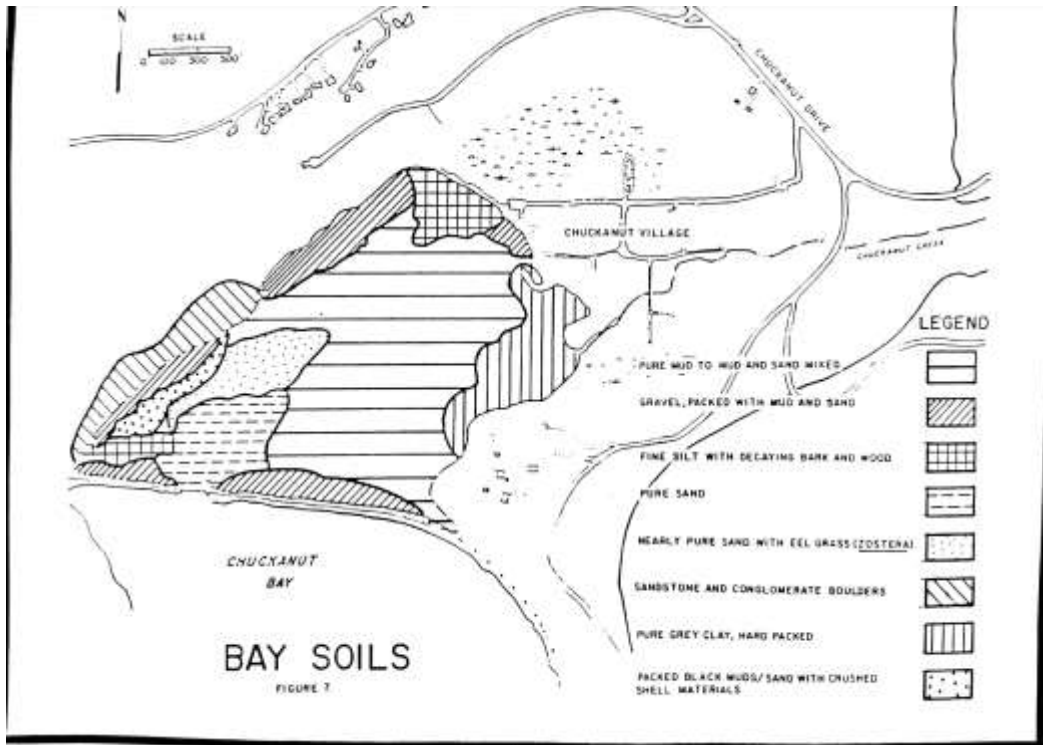
A 2018 satellite image of Mud Bay. Slightly higher housing density than the 1998 image. The channel has not noticeably shifted from the 2001 photo (GoogleEarth, 2018).

## Appendix B – Geologic/Anthropological Maps



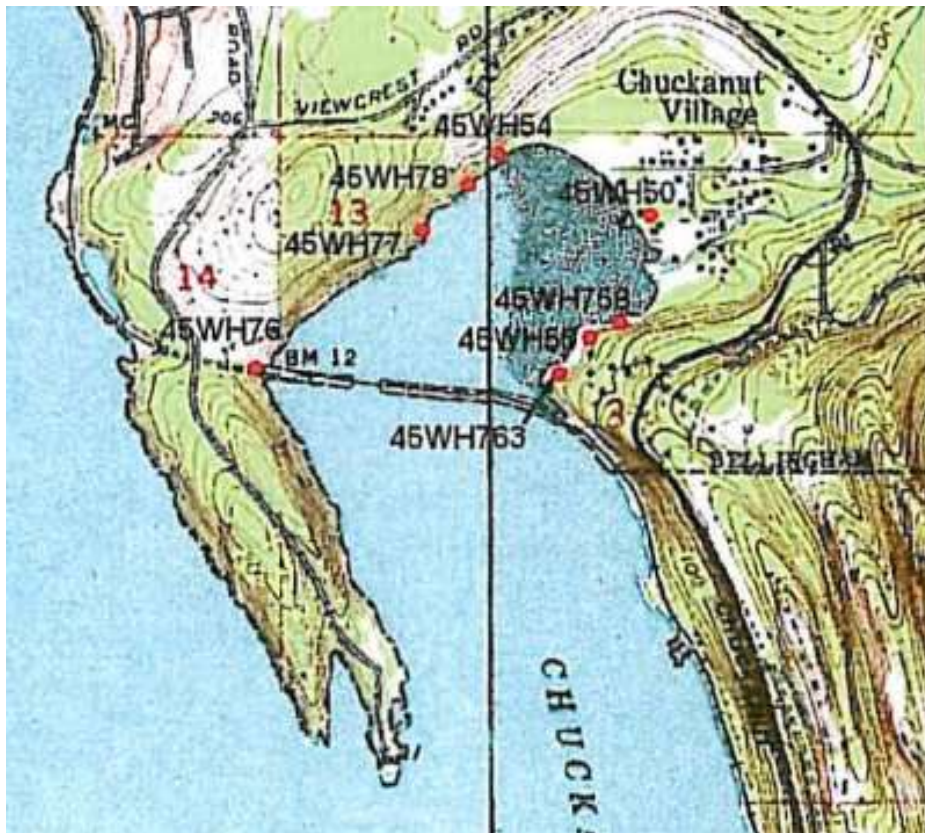
Geological Map of the Chuckanut Formation

Focusing on the Chuckanut Creek watershed (Johnson, 1982). Chuckanut Creek is picked up in blue and flows over the Bellingham Bay member (Tcb) and Padden member (Tcp) of the Chuckanut Formation.



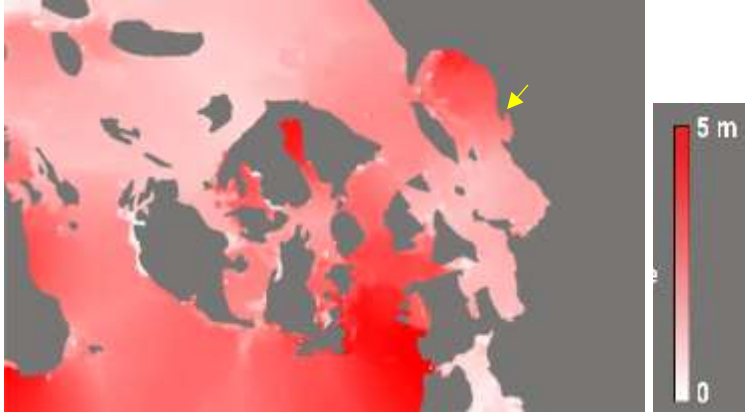
1989 geological map of Mud Bay soils.

Notice the amount of pure mud and sand mixed, and the presence of eel grass along the western edge (Farrow et. al).



Locations of shell middens

Campbell, 2010 Eliza Island Quad Map and Bellingham South Quad Map with midden site locations from the Campbell, 2010 archeology report



Tsunami modeling predictions, yellow arrow points to Mud Bay. Image courtesy of Carrie Garrison-Laney. Red intensity predicts height of tsunami flood inundation. (Garrison-Laney, 2017)

## Appendix C – Station Photos and Graphs



Transect.

Opposite ends of the hand level transect. Left photo taken from the tree line looking West. Right photo 90m from the tree line on the mud banks looking East. Photos taken August 19<sup>th</sup> 2018.



Cleared bank of station LW-14-18.

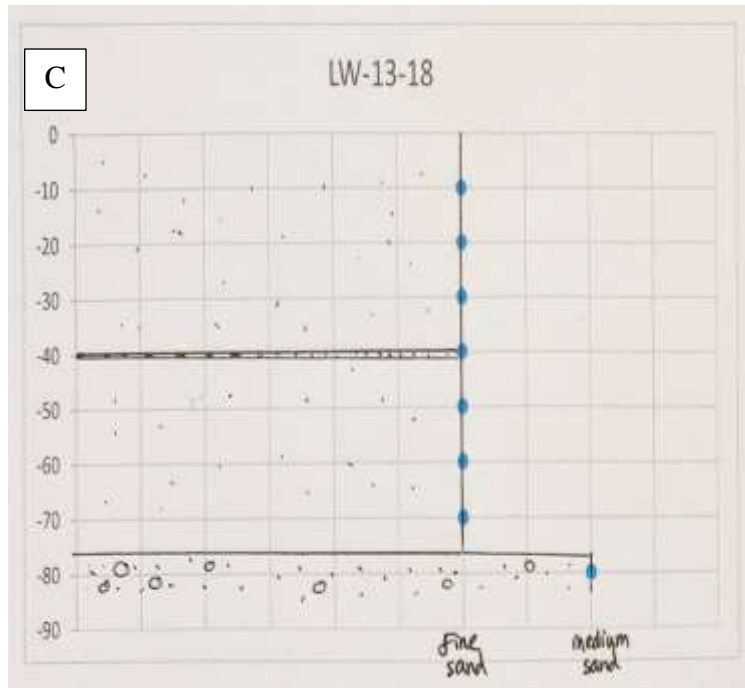
LW-14-18 cleaned section. Gravel outcrops further up the bank than seen downstream. Gravel lenses visible in the cleaned section. Sand layers not as visible. Though layers present. Photo taken September 2<sup>nd</sup>, 2018.



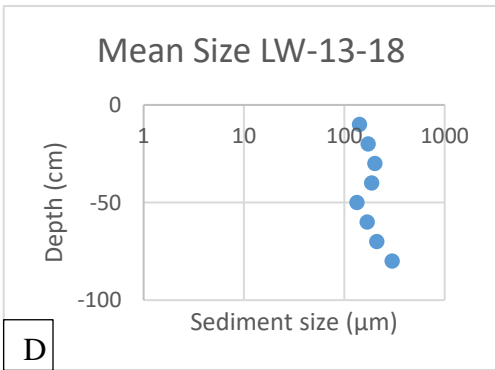
A



B



C



D

Cleared bank of station LW-13-18.

- A. LW-13-18 right bank some horizontal sand bedding, gravel and cobbles at the bottom of the section. These sand layers are not as continuous as lower down in the stream and cannot be followed as far. Photo taken September 2<sup>nd</sup>, 2018.
- B. LW-13-18 left bank. Similar to the right bank with visible sand layers and gravel with cobbles at the bottom of the cleared section. Photo taken September 2<sup>nd</sup>, 2018
- C. Stratigraphic plot showing specific layers within the cut bank and their grain size of LW-13 left bank.
- D. Mean grain size of LW-13 left bank.



Uncleaned bank at LW-5-18.

A. LW-5-18. Taken from the left bank looking at the right bank before cleaning the bank. Erosion of sand layers obvious across the length of the bank. 9m of measuring tape stretched across the top of the bank. Taken September 1<sup>st</sup>, 2018.

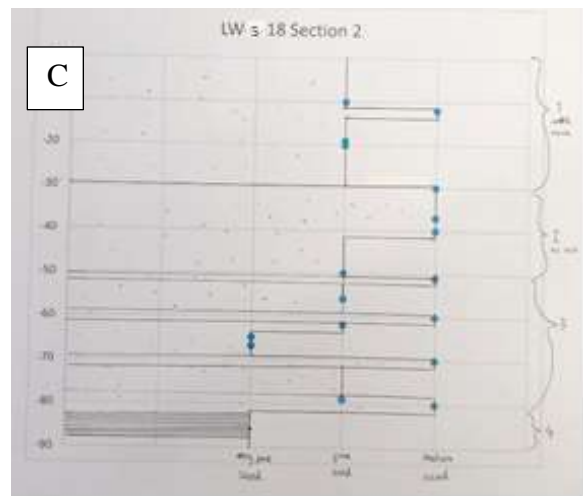
B. LW-5-18, taken May 4<sup>th</sup>, 2018. Main cut bank section studied on the first visit before it is cleared. The different layers of sedimentation are visible in the preferential erosion of specific layers.



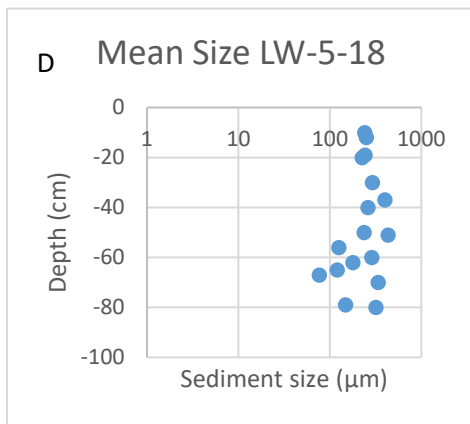
A



B



C



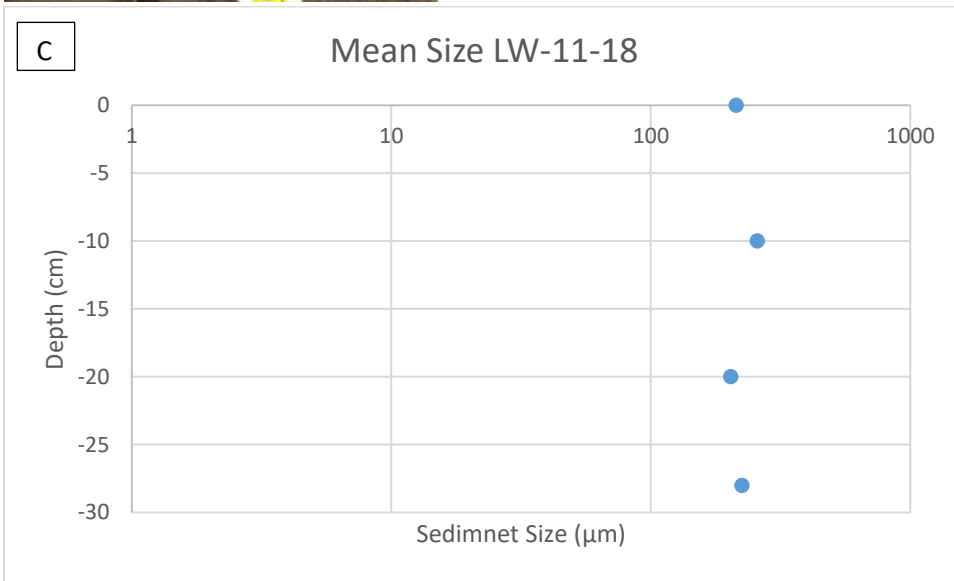
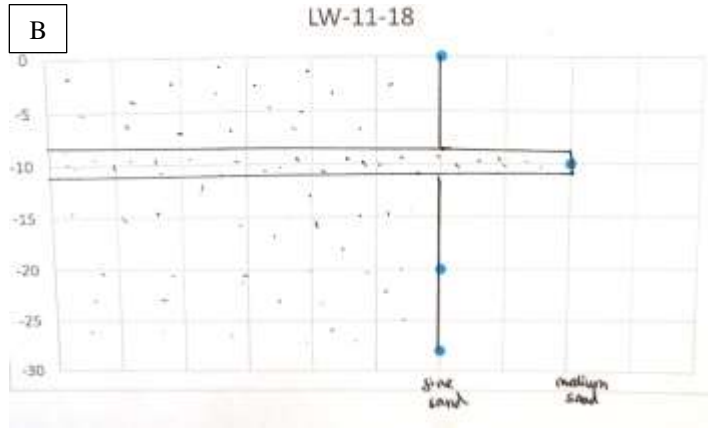
D Mean Size LW-5-18

LW-5-18 cleaned bank

A. Cleared bank of station LW-5-18. LW-5-18 full bank cleaned in three sections. Left behind the slumped section middle and right. Visible at this distance is staining on the banks and some of the sand layers that have preferentially eroded. Photo taken September 1<sup>st</sup> 2018.  
 B. Close up of the cleared bank at LW-5-18 station 2, with shovel handle for reference. Photo taken September 1<sup>st</sup> 2018.

C. Stratigraphic column of the sediments at LW-5-18, showing the vertical sections of the sample. 1 has roots and is a generally fine sand. 2. Has no roots and is a fine to medium sand. 3. Has roots again and eroded coarser layers. 4. Is the layered very fine sand and organic material.

D. Mean grain size with depth at LW-5-18.

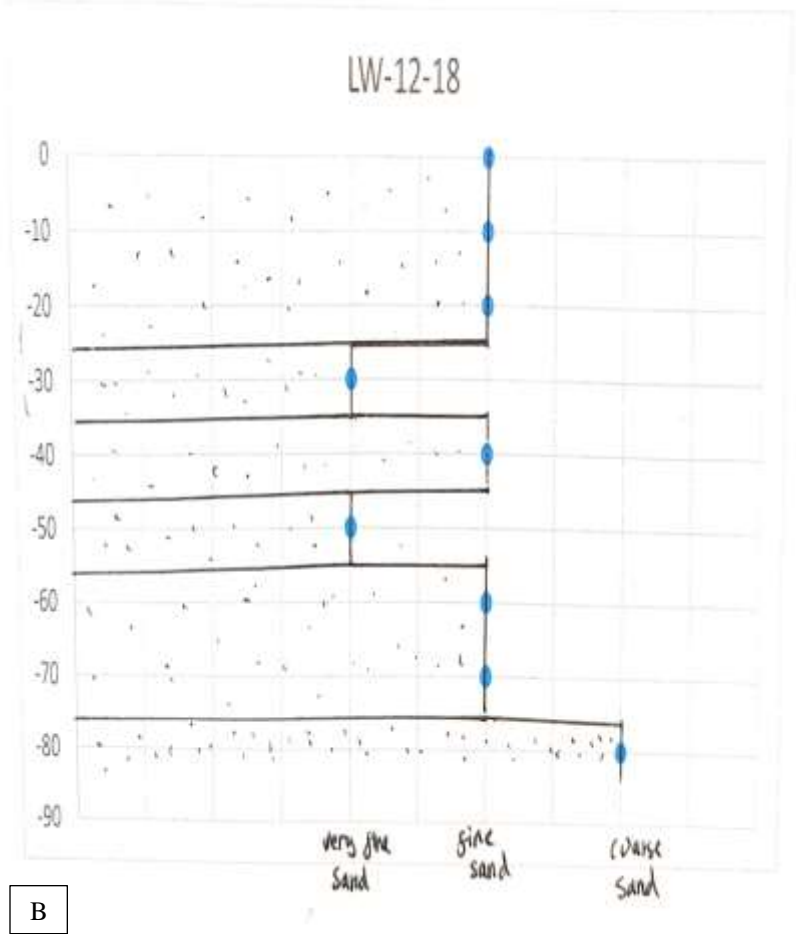


Gauge core LW-11-18

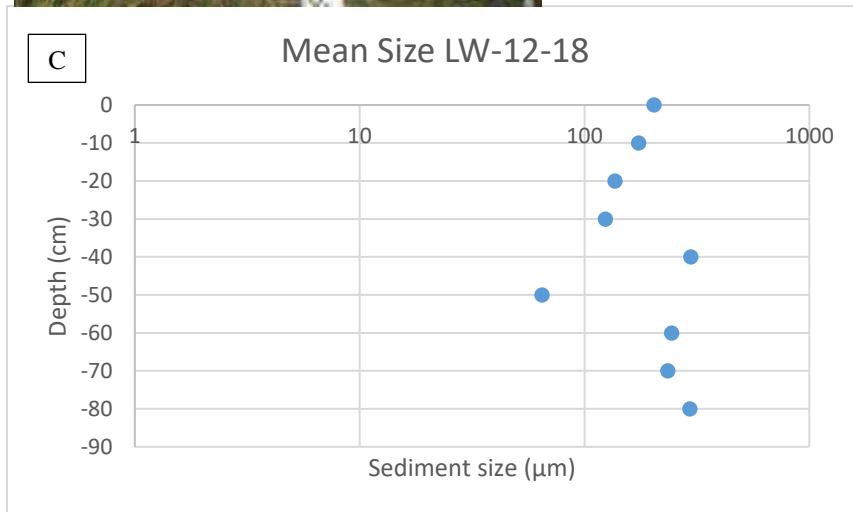
- A. Core LW-11-18, gauge core sample taken in at 67m along the hand level transect in salt tolerant vegetation. Only 29cm of core was recovered. Photo taken August 19<sup>th</sup>, 2018
- B. Stratigraphic column at LW-11-18. Sands are mostly fine sands with a medium sand at 10cm depth.
- C. Mean grain size at LW-11-18.



A



B



C

Gauge core LW-12-18,

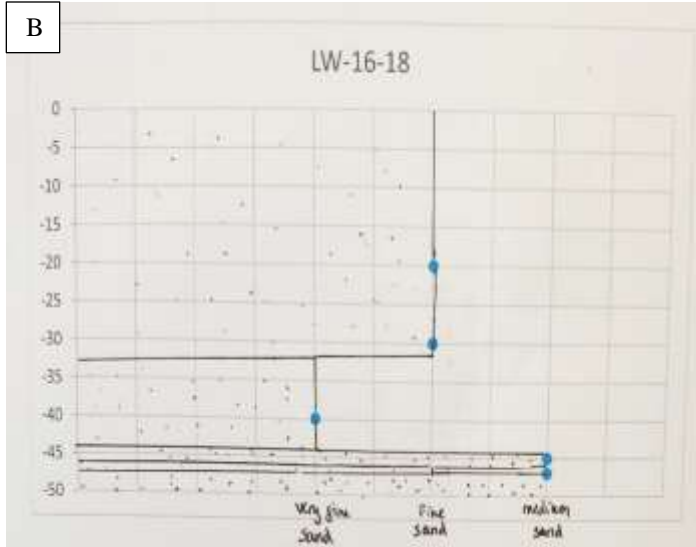
gauge core sample taken at 50m along the hand level transect. 85cm collected. Photo taken August 19<sup>th</sup>, 2018  
 B. Stratigraphic column at LW-12-18. Sample was mostly very fine sand to fine sand except around 40cm and 80cm which were fine sand. A gap in roots throughout the core was observed from 45-59cm.

C. Mean grain size at LW-12-18



Test pit LW-15-18.

LW-15-18 A test pit dug into the area between the mixed vegetation and salt tolerant only vegetation along the hand level transect. No break in the roots was observed at this location but sand horizons were visible. Pink glass is 20cm tall. Photo taken September 2<sup>nd</sup> 2018.

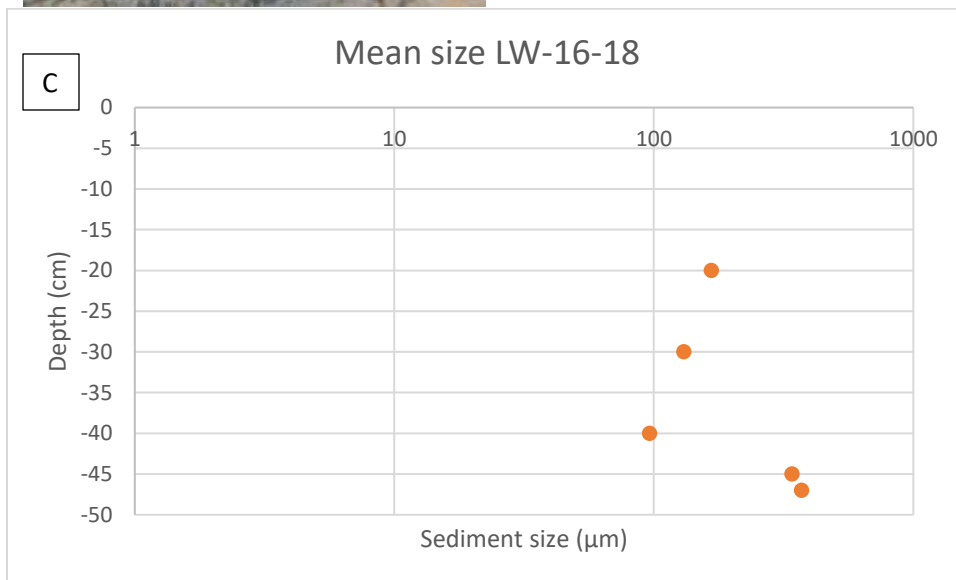


Test pit LW-16-18.

Test pit dug into right bank grasses, 36m into hand level transect. Pit measures 46cm. Photo taken September 2<sup>nd</sup>, 2018.

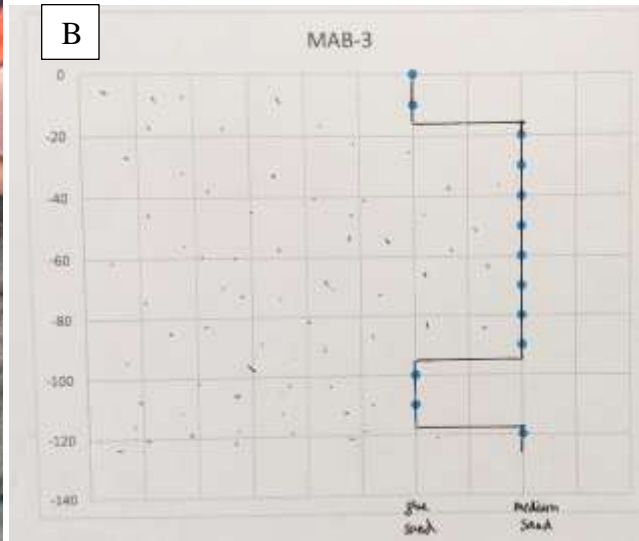
B. Stratigraphic column at LW-16-18. There are two sand bands that cross this pit one around 40cm and the other at 46cm deep. The lower sand band is a medium to fine sand.

C. Mean grain size at LW-16-18, from specific layers.

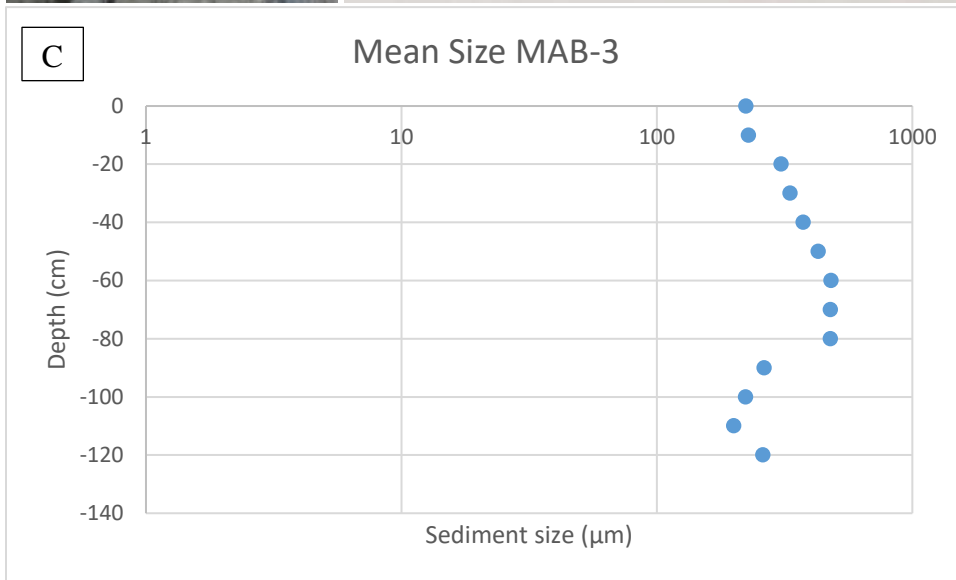




A



B



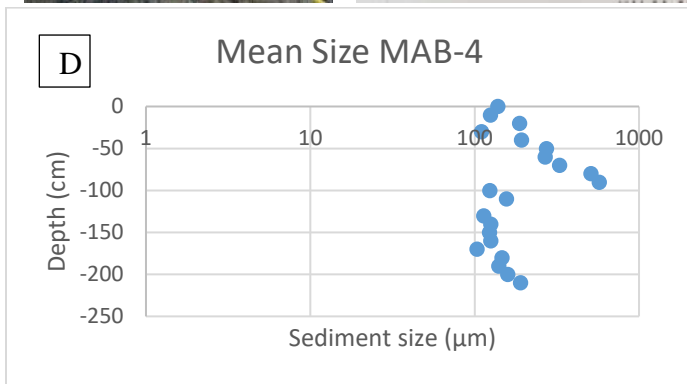
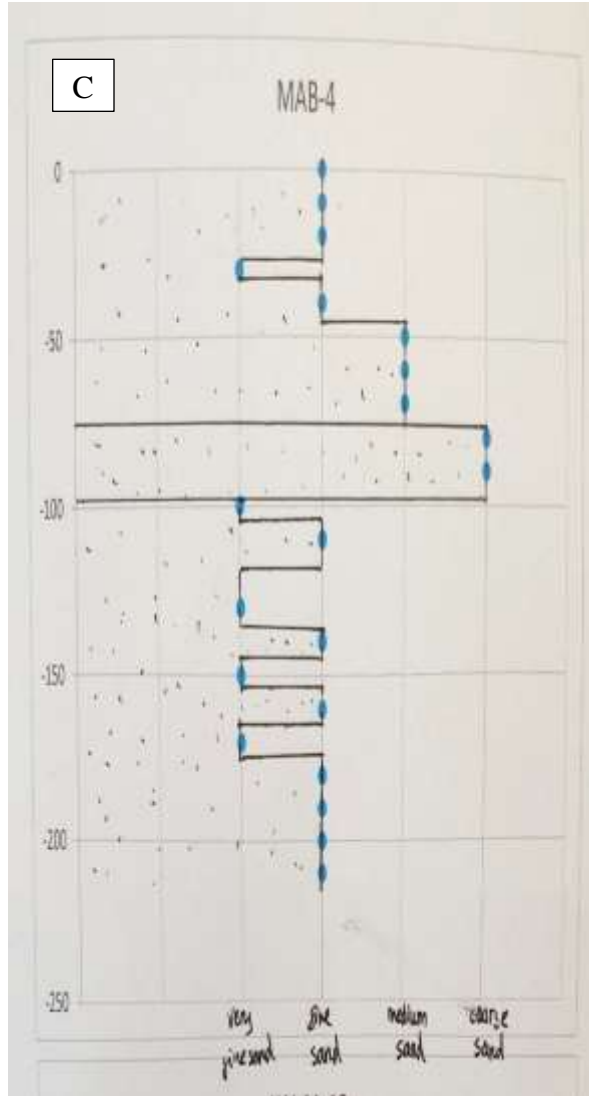
C

Core from MAB-3,

A. Gouge core from 0-1m, 45cm of loss in the 2<sup>nd</sup> meter. Core taken out in the middle of the bay. Photo taken 28<sup>th</sup> of June 2018.

B. Stratigraphic column showing fine sand to medium sand at MAB-3.

C. Mean grain size at MAB-3.



Gouge core from MAB-4.

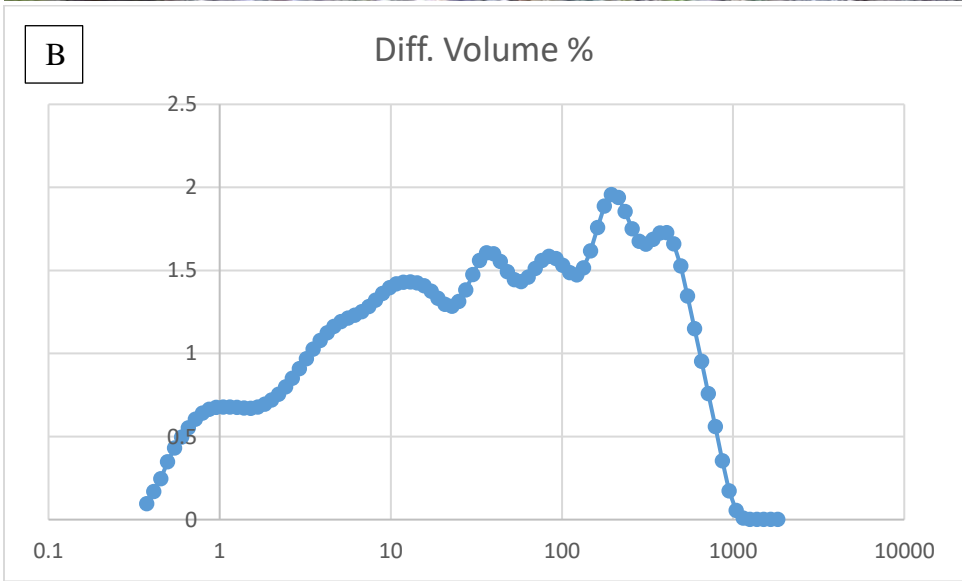
A. gouge core from 0-1m. B. gouge core from 1-2m. Layers of fine sand out in the most protected part of the bay. Very little wave and creek action to move sediment. No obvious individual layers seen, however a little coarse sand and fine gravel mixed in with the fine sand from 1.76m to 2.1m. Taken 28<sup>th</sup> of June 2018.

C. Stratigraphic column of MAB-4

D. Mean grain size with depth at MAB-4.



A



B

LW-18-18

A. LW-18-18 the colloquially named clay bank, a glaciomarine drift deposit. LW-18-18 the clay bank. This is an exposed bank of glacial-marine drift, that Chuckanut Creek flows through. Source for sediment in Chuckanut Bay along with the Chuckanut Sandstones. Photo taken October 13<sup>th</sup>, 2018.

B. Grain distribution for sand sized particles and smaller of the glaciomarine drift at LW-18-18.

## Appendix D – Notes from initial mineralogical screening

On next page due to formatting.

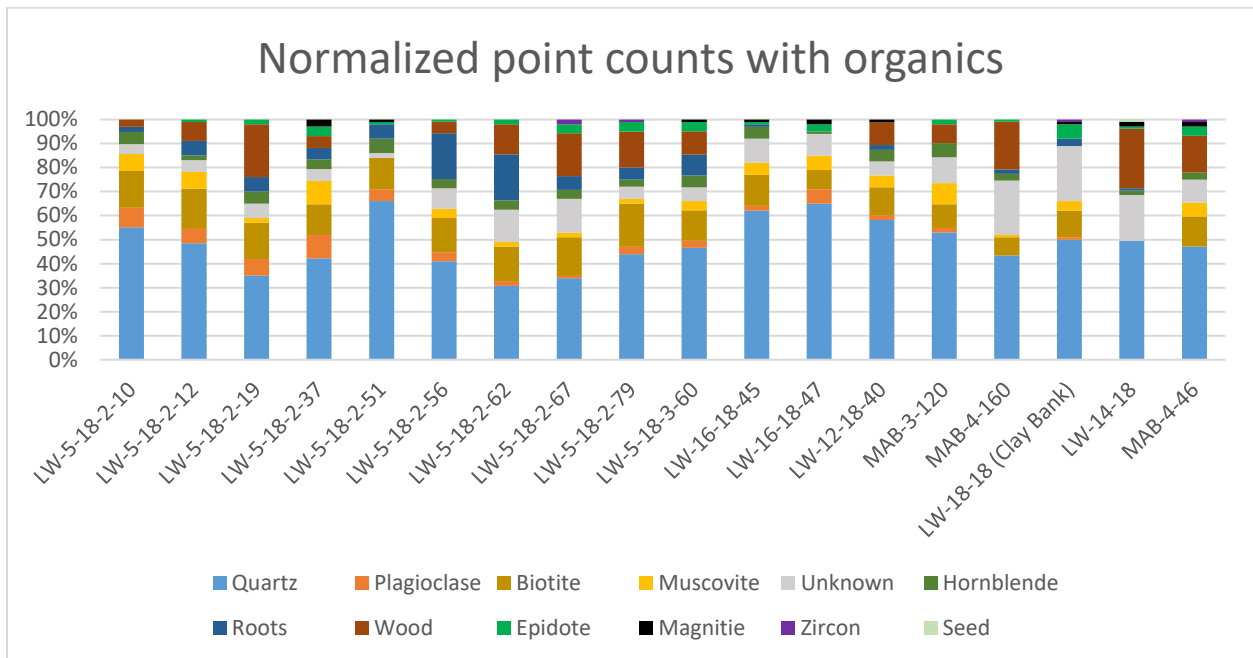
Location	Depth (cm)	Notes	Roots observations
9-1	20	mica-muscovite, quartz, plag angular grains, silty SAND, lots of small roots and organics	
	30	sandy SILT with muscovite flakes that are larger, quartz, plag, smaller roots, hornblende	
	40	silty SAND muscovite, quartz, plag, fewer roots, bits of wood, and hornblende	
	50	sandy SILT, lots of small roots, smaller pieces of mica, quartz, small pieces of wood	
	60	sandy SILT, lots of small roots, smaller pieces of mica, quartz, small pieces of wood, hornblende	roots are hollow, and fibrous
	70	can't tell if silt or sand definitely particulates some smaller mica, quartz hornblende. Clumps like silt but that could be the organic content so much mica	
	80	sandy silt, fibrous roots, plag, quartz, cant tell about the mica	
	9-2	10	subangular sand yellowish in color. Quartz, plag, hornblende yellowish tinge to quartz, red and green rock lithics, (could be magnetite and epidote)
12		yellow subangular fine SAND (def SAND) quartz, plag, yellowish quartz, mica-biotite, hornblende, red lithics	
19		finer brown SAND some silt, quartz, plag, mica-muscovite, wood/plant debris	
20		subangular silty SAND, finer than 10cm quartz muscovite	roots are round, not to wide mm or less and solid
30		silty SAND subangular, quartz yellowish tint to some pieces, muscovite, biotite, hornblende	roots are round, not to wide mm or less and solid
37		coarser yellowish SAND, quartz (yellowish) plag, mica-biotite/muscovite, hornblende	
40		fine grained SAND with silt, quartz, muscovite, hornblende, plag	roots are round, not to wide mm or less and solid
50		fine grained SAND with silt SILT, quartz, hornblende, plag, darker gray in overall color	roots are round, not to wide mm or less and solid, not many though
51		fine grained SAND, with SILT, quartz, hornblende, plag, mica-musc, wood fragments, darker gray	
56		SAND, salt and pepper, gray ish, quartz, plag, hornblende, biotite mica, no yellow	
60		gray overall color, no yellowish quartz, gray quartz, hornblende, Plag, red lithic? - looks a bit like a brick	roots hollow and fibrous
62		SAND, salt and pepper, gray ish, quartz, plag, hornblende, biotite mica, no yellow	
65		fine grained gray SAND/Silt cant really tell anything individual, quartz, mica	
67		gray Salt and Pepper fine grained SAND woody material, black minerals, hornblende, quartz,	
70	woody material in a mat??? Small fine sand/silt, quartz, plag, mica-musc?	roots hollow and fibrous, and thin and solid	
79	gray fine fine SAND woody debris can't pick out much quartz, black minerals hornblende		
80	fine SAND muscovite larger than rest of sand grains, quartz, woody debris		
9-3	10	subangular yellow/brown SAND, quartz, musc, plag, hornblende	roots are round, not to wide mm or less and solid
	20	subangular yellow SAND, quartz - yellowish in some cases, plag, mica-muscovite	roots are round, not to wide mm or less and solid

	30	subangular yellow finergrained SANDsome silt, quartz, plag,	
	40	subangular yellow fine grained SAND feels quite silty, muscovite, quartz plag, hornblende	
	40??	smaller yellow ish SAND, yellow colored quartz, plag, mica musc and bio, hornblende?, rock lithics	
	50	sandy SILT woodfragments, muscovite larger flakes than surrounding grains quartz, can't tell muchelse	
	60	gray overall color, finer grained, plag, quartz is larger grained thanother sand, red lithic, hornblended	roots hollow andfibrous
	70	gray fine grained sand/silt possibly SILT but SAND, quartz, mica plag wood fragments, hornblende	
	80	yellowish gray fine grained sand , quartz-yellow tinge to some pieces, plag, mica - biotite	roots hollow andfibrous
	87	water logged, fine gray sand, quartz, hornblende, muscovite, wood fragments	
13Right	10	finer grained yellowish SAND quartz,plag, small mica(musco)wooddebris, magnetite	roots are round, not to wide mm or less and solid
	20	finer grained yellowish SAND quartz,plag, small mica(musco)wooddebris, magnetite	
	30	fineergrained yellow SAND, quartz, plag, small mica (biotite, possibly musc), red lithics,	roots are round, not to wide mm or less and solid
	40	finerg grained yellowish SAND, quartz-yellowish, plag, wood debris, mica-biotite	
	50	finergrained yellowish SAND, quartz-yellowish, plag, mica - biotite, magnetite, wood debris, epidote	
	60	mostly finer grained SAND but some larger coarse sand (lithic?) finer is quartz,plag, magnetite, biotite, wood fragments	
	70	fine SAND with gravel (dark lithic), sand is quartz, plag, mica-biotite/muscovite, magnetite, coarser sand in there too(quartz and lithics)	
13Left	10	fine SAND quartz,plag, mica-musc	grasses
	20	fine SAND quartz,plag, mica-musc	
	30	fine SAND quartz,plag, mica-musc, wood fragments, dark mineral hornblende more likely than mag but water stronger thanweak magnetite	
	40	fine SAND quartz,plag, mica-musc, small green (epidote), wood fragments	
	50	fine SAND quartz,plag, mica-musc, wood frag, epidote	
	60	fine SAND quartz,plag, mica-musc, wood frag, epidote, poss magnet	
	70	slightly coarser SAND quartz, mica-musc, plag, red lithics, black minerals porb magnetite	
	80	gravely SAND (possibly SW) dark rock lithics are the gravel and coarse sand, smaller sand quartz, plag, hornblende, magnetite, epidote	
14	10	brown fine SAND quartz, plag mica-possibly biotite	
	20	brown fine SAND quartz, plag mica- biotite/musovite	
	30	brown fine SAND quartz, plag mica- biotite/musovite, black minerals hornblende possibly mag	
	40	slightly coarser SAND brown, quartz,plag, mica, black minerlas hornblende, possibly mag, epidote	
	50	coarser yellow SAND, yellow colored quartz, plag, biotite, larger lithics (up to coarse SAND) green, and quartz, large biotite, wood frag, magnetite	
	60	fine brown sand, quartz, plag, not seeing any mica, black meneralns though	
	70	fine brown SAND with gravel, large gravel lithics, fine sand is quartz, plag, mica-musc, epidote	

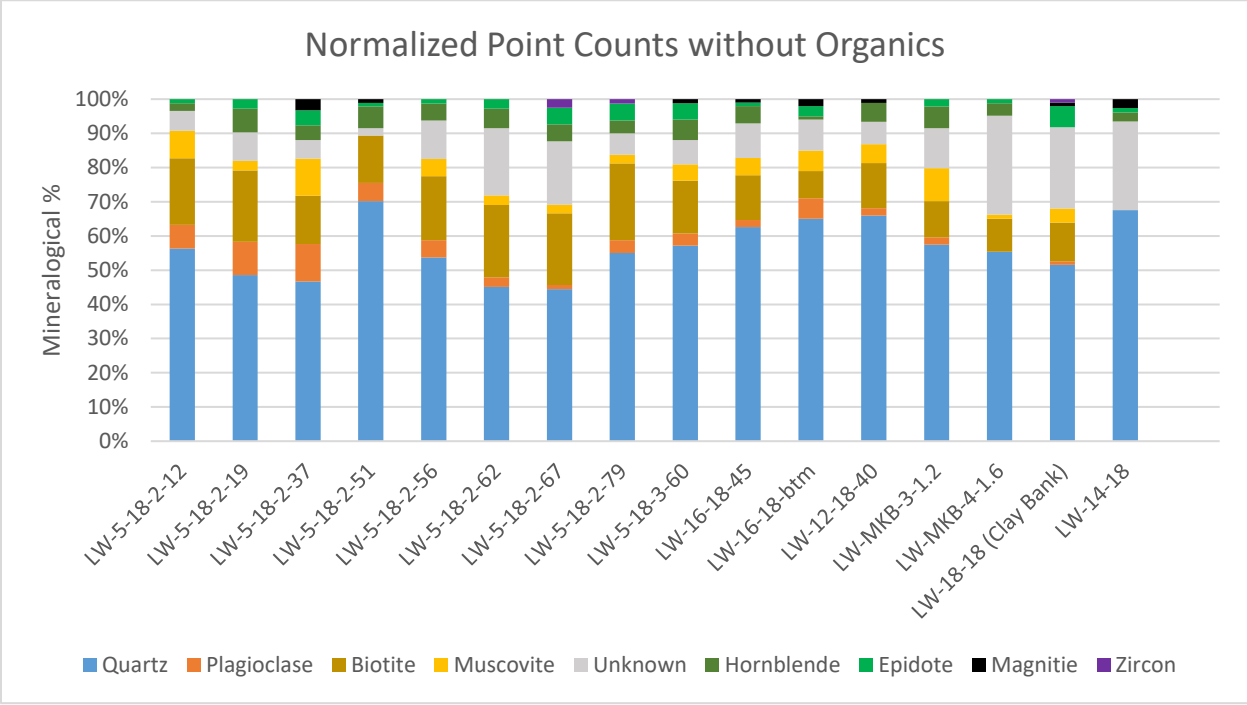
	80	coarser SAND with gravel, quartz, plag, dark lithics, dark minerals (hornblende mag, epidote, muscovite wood fragments)	
15	0	salt and pepper fine SAND, quartz, plag dark minerals magnetite, hornblende, mica-musc	
	4	fine SAND quartz, plag, dark minerals. mica-musc, wood fragments	
	20	yellower SAND quartz yellow tinged, plag, mica -muscovite, epidote, hornblende, magnetit	
	27	fine yellow/brown SAND, quartz, plag, mica-muscovite, hornblende	
	37	yellower coarser SAND quartz yellow tinged, plag, mica-muscovite, epidote, hornblende, magn, red lithic	
16	20	fine yellowish SAND. Quartz, plag, mica-muscovite, wood debris, black minerals	
	30	fine yellowish SAND. Quartz, plag, mica-muscovite, wood debris, black minerals	
	40	salt and pepper fine but coarser than 30 SAND, quartz, plag, black minerals, mica but small muscovite	
	45	yellow coarser SAND, yellow quartz, plag, red lithics, black minerals, hornblende, mica-muscovite	
	bottom	salt and pepper coarser SAND a bit of yellowish quartz, plag, larger grains of quartz and lithics, black minerals, epidote, a little bit of mica-biotite	
11	0-2	salt and pepper SAND fairly fine, quartz, plag, mica-muscovite, hornblende, wood debris	
	10	yellowish tinge SAND fineish, quartz, plag mica-muscovite/biotite, hornblende, organic debris	
	20	yellowish tinge SAND fineish, quartz, plag mica-muscovite/biotite, hornblende, organic debris wood bits	
	27-29	yellowish tinge SAND fineish, quartz, plag mica-muscovite/biotite, hornblende, organic debris wood bits, epidote, red lithics, yellow quartz	
12	0-2	very fine can't really tell much, but mica for sure, quartz and spiral shells ~1mm maybe,	roots are hollow, and fibrous
	10	very fine can't really tell much, but mica for sure muscovite and biotite slightly larger than background, quartz and plag	hollow and solid roots
	20	fine SAND quartz, plag, hornblende, mica biotite/muscovite	
	30	not fine SAND, quartz, plag, hornblende, biotite	
	40	gray overall color, SAND quartz, plag, epidote???? (faint green) mica-biotite/muscovite quartz is larger than everything else	
	50	gray fine SAND, mica small can't tell Musc/biotite, hornblende quartz plag, red lithic, wood debris	
	60	gray fine SAND, mica small musc/biotite, quartz, plag, red lithics, wood debris, hornblende	
	66	gray fine SAND, muscovite, quartz, plag, hornblende, wood debris	hollow fibrous roots.
	70	gray fine SAND, muscovite, quartz, plag, hornblende, wood debris red lithics	
	80	coarser SAND salt and pepper, hornblende, quartz, plag, biotite, muscovite, rock fragments-coarse SAND	
MAB-3	90	salt and pepper SAND coarse as far as these samples go, biotite/muscovite, quartz, hornblende, plag (white long mineral plag? Not sure)	
	100	salt and pepper SAND finer than 90 biotite/muscovite is large, quartz is large too, hornblende plag, red lithics,	
	110	gray SAND finer, quartz, hornblende, plag, muscovite, biotite, red lithics	
	120	gray fine SAND, quartz, hornblende, muscovite/biotite, plag, wood debris, red lithics,	
MAB-4	100	gray fine SAND, quartz, hornblende, mica ( muscovite, biotite) plag	
	110	gray fine SAND quartz, hornblende muscovite plag, finer than 100	

	120		
	130	gray fine SAND quartz, honrblenede muscovite plag, finerthan100	
	140	gray fine SAND quartz, honrblenede muscovite/biotite plag, finerthan130	
	150	gray fine SAND quartz, honrblenede muscovite plag, finerthan100	
	160	gray fine SAND, quartz, honrblenede, muscovite/biotite, plag, coarser sand grains in there too	
	170	gray fine SAND, quartz, honrblenede, muscovite/biotite, plag, coarser sand grains in there too	
	180	gray fine SAND, quartz, honrblenede, muscovite/biotite, plag, coarser sand grains in there too and gravel	
	190	gray fine SAND, quartz, honrblenede, muscovite/biotite, plag, coarser sand grains in there too, red lithic?	
	200	gray fine SAND, quartz, honrblenede, muscovite/biotite, plag, coarser sand grains in there too and gravel	
	210	gray fine SAND, quartz, honrblenede, muscovite/biotite, plag, coarser sand grains in there too and gravel more gravel	

## Appendix E – Point Count Graph



Normalized point count analysis of samples.



Normalized table of samples with organic materials taken out.