



# Geological structure and acoustic properties of sediments in Effingham Inlet

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## NONTECHNICAL SUMMARY

This study examines a glacially carved fjord, Effingham Inlet, located in Barkley Sound of Vancouver Island, Canada. The complex geology of Vancouver Island was formed by the Cascadia thrust fault zone. Long-term geological processes have formed a series of mountain ridges parallel to the subduction plane which now has an effect on the shorter-term geomorphological processes of the inlet. Glaciation and other geomorphological process have had a significant impact on the Effingham Inlet region over the last 15 ka. To examine the past and present geomorphological processes affecting Effingham Inlet, the bathymetry and acoustic backscatter intensity were measured using multibeam echosounder surveying. Four elevated seabed features and correlating high backscatter intensity values suggest that there are a series of glacially deposited moraines. However, there is little difference in the backscatter intensity of similar seabed features at different locations in the fjord. In conclusion, the findings of this study suggest that short-term processes of sedimentation and enduring glacial remnants have a larger effect on the backscatter intensity compared to long term geological processes and small differences in geological position.

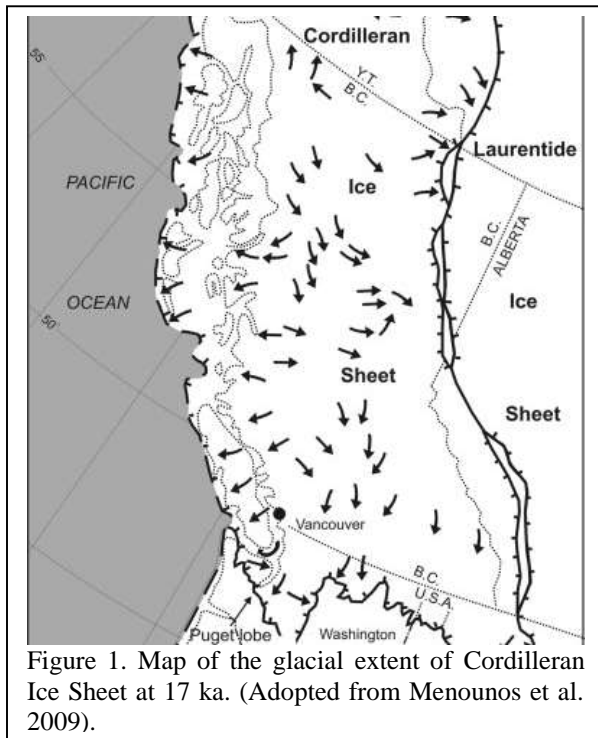
## ABSTRACT

Effingham Inlet is a unique fjord landscape located in Barkley Sound of Vancouver, Canada that was uncovered by glaciers around 15 ka. In this study, multibeam echosounder bathymetric and backscatter intensity values were recorded aboard the *R/V Thompson* on the University of Washington Oceanography Senior Cruise to Barkley Sound. The goal of this research study is to describe the acoustic properties of sediments seen along the Effingham Inlet fjord section and to relate patterns in acoustic properties to past and present geomorphological processes affecting the fjord. Four elevated seabed features and correlating high backscatter intensity values interpreted to be glacially deposited moraines supporting the known glacial history of the region. However, little difference in the backscatter intensity values of similar seabed features at different locations in the fjord suggest that short-term processes of sedimentation and enduring glacial remnants have a larger effect on the backscatter intensity compared to long term geological processes and small differences in geological position. Geological processes create the complex topography of a region influencing the geomorphological processes. This cascade of effects makes it difficult to quantify the effects of geological processes over geomorphological processes affecting a fjord.

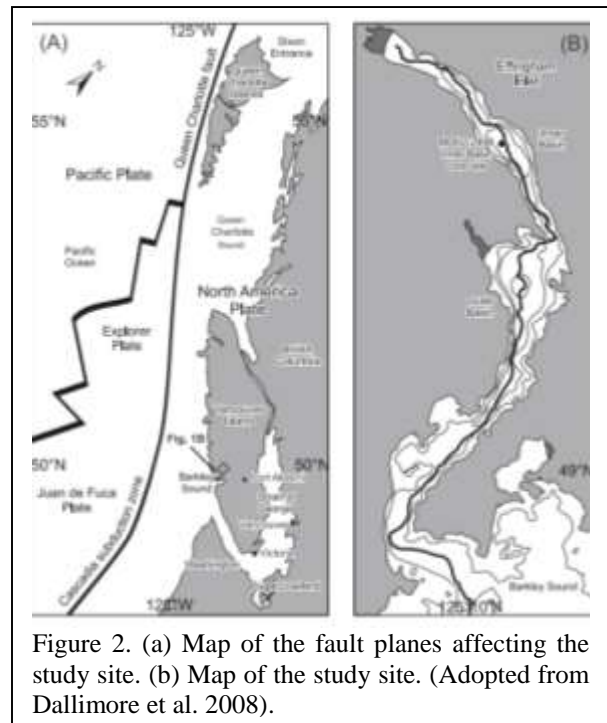
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## INTRODUCTION

Earth is an ever-changing planet. Long-term broad geological processes shape landscapes giving rise to short-term local geomorphological processes. Glaciation, a geomorphological process, is greatly affected by geological processes; the global climate primarily controls the broad range of glacier extent, but the topography of a landscape controls local glacier extent and dynamics (Benn and Evans 2010). As glaciers retreat and advance over time, the supporting landscape is changed by deposition of sediments, isostatic rebound and subsidence, and erosional processes (Benn and Evans 2010). Studying regions once covered by glaciers provides insight on glacial and other geomorphological processes affecting the region since the last glaciation period. 17 ka ago the Cordilleran Ice Sheet reached its maximum extending to the Pacific Ocean (Figure 1, adopted from Menounos et al. 2009). At 15 ka the glacier started its rapid retreat (Dallimore et al. 2008; Menounos et al. 2009). Now only alpine glaciers remain covering only the highest peaks, only 3% of the British Columbia area (Menounos et al. 2009). The glacial history of Vancouver Island, Canada makes it a prime region to study the effects of glaciation and other geomorphological processes in the last 15 ka.



This study examines the glacially carved fjord, Effingham Inlet, located in Barkley Sound of Vancouver Island, Canada (Figure 2, adopted from Dallimore et al. 2008). The structure of Effingham Inlet differs slightly from the characterized linear shape of typical fjords (Glasser and Ghiglione 2009). Effingham Inlet is a unique fjord landscape that has a distinct turn at the mouth of the Inlet (Figure 2). The turn of at the mouth may have formed during the glacial retreat or even earlier by geological processes. To investigate potential causes of the turn, backscatter intensity and bathymetry data were measured using a Kongsberg EM302 multibeam echosounder (MBES). Interpretations of past and present geological and geomorphological processes acting on the Inlet were made using analyses of the backscatter intensity and bathymetric data. Scaled backscatter intensity and bathymetry give a good idea for the bottom type of a fjord.



Previous studies have examined the backscatter strength and corresponding bottom types using MBES data compared to ground truth (coring) maps (Butman et al. 2003; Lamarche et al. 2011; Micaleff et al. 2012). Strong backscatter signals corresponded with rocky coarse grained bottom types and weak backscatter signals

corresponded with muddy or clay fine grained bottom types (Butman et al. 2003, Lamarche et al. 2011). Results of previous studies have shown backscatter intensity values do a good job in qualitatively describing ground truth maps (Butman et al. 2003, Lamarche et al. 2011). This study is based on the assumption that the findings of the previous studies hold true for other regions; backscatter intensity values were assumed to provide a good qualitative bottom type map.

Interpretations were made to answer several questions about the past and present processes affecting Effingham Inlet and to help provide insight to future studies. The main question for this study, does a difference in geological setting change the acoustic properties of sediments in a fjord environment, was investigated by comparing backscatter intensity values similar features at different positions within a fjord. My hypothesis for this study is that there are no differences in the backscatter intensity values for similar features at different positions within a fjord because short-term geomorphological processes have a greater effect on the backscatter intensity. Also, this study has several implications on the typical coring processes used to make sediment ground truth maps. The number of sediment cores required to make a ground truth map is greatly reduced assuming that backscatter intensity maps provide a good qualitative bottom type map. Actual coring may be limited to selected sites to get a good idea of sediment type for each scaled backscatter intensity value.

## METHODS

### *Multibeam echosounder data collection*

MBES data was collected in Effingham Inlet aboard the *R/V Thompson* on February 1, 2013. A Kongsberg EM302 MBES was used at an operating nominal sonar frequency of 30 kHz with an angular coverage sector of 150 degrees and 864 soundings per ping. Survey lines were run from the mouth of the inlet to the lower part of the outer basin and back to the entrance of the inlet (Figure 2). The *R/V Thompson* cruised at approximately three knots, the typical survey speed near the middle of the inlet in order to get high resolution bathymetric and backscatter data. Raw data was

saved on the cruise and brought back to the University of Washington to be further analyzed.

### *Post processing – bathymetry*

The raw MBES data soundings were imported in to *Caris Hips and Sips 7.1* (Caris) to create a base surface. A combined uncertainty and bathymetry estimator (cube) base surface was created at a 15m resolution. A cube surface is created in Caris by using an algorithm that generates a surface containing multiple hypotheses representing potential depths of the seafloor. The finished cube base surface was then exported to *ArcGIS 10.1* (Arc).

### *Post processing – backscatter data*

A backscatter intensity base surface was created as a mosaic using the geological backscatter raster (GeoBaRs) tool in Caris. The data was then exported to Arc as a .tiff file. The raw data soundings in Caris were in decibel values which were converted to scaled intensity values when exported to Arc.

### *Post processing – ArcGIS 10.1 and Microsoft Excel*

The processed cube base surface and backscatter intensity base surface were analyzed in Arc. The cube base surface had workable data and was easily added as a layer to the Arc workspace. The backscatter intensity .tiff file was slightly altered in Arc. The *aggregate* tool was used to create an average of data points. Base surfaces were added as layers to the Ocean Base map in Arc. Profiles that examined the backscatter intensity and bathymetry versus distance were created using the *3D Analyst interpolate line* and *profile graph* tools. Data from the *3D Analyst interpolate line* and *profile graph* tools was exported and further manipulated in *Microsoft Excel* (Excel). Maximums, minimums, averages and standard deviations were calculated in Excel.

## RESULTS

A bathymetric map and backscatter intensity map were produced in Arc as explained above (Figure 3). Four elevated seabed features are found in the study region (Figure 3). Profiles

that examine the backscatter intensity and bathymetry versus distance are traced across the elevated seabed features (Figure 3). The elevated seabed features range in height from ~20-30 m above the seafloor (Figure 4). The lengths of the elevated features are ~200 m across except for the fourth elevated seabed feature which is ~1000 m across (Figure 4d). Scaled backscatter intensity values of the study region range from 9.21-25.24 with a mean of 17.59 +/- 4.32 (Table 1).

The elevated seabed features are separated into five different sections (front, front slope, top,

backslope and back) based on the change in bathymetry. The front and back sections of the elevated seabed features have the lowest average scaled backscatter intensity values, 14.88 and 15.62, respectively (Table 2). The slope and top sections of the elevated seabed have higher average scaled backscatter intensity values (Table 2). The back section of the elevated feature four has a higher average scaled backscatter intensity (Table 2). All other sections have similar scaled backscatter intensity values (Table 2).

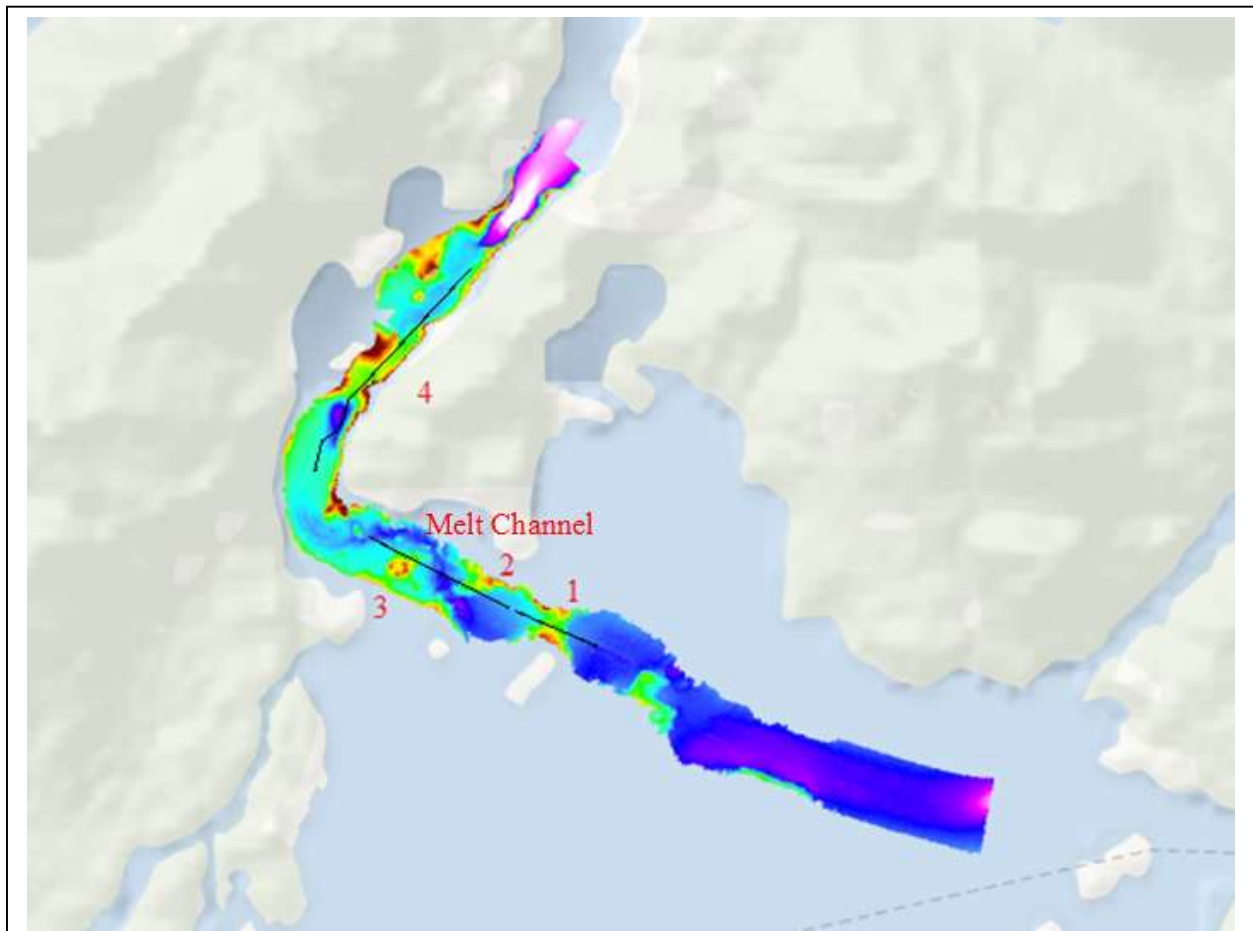


Figure 3. Bathymetric map of the surveyed region and labeled elevated seabed features. Profile sections are drawn in black. Warm colors indicate areas of high bathymetry; cool colors indicate low lying bathymetry.

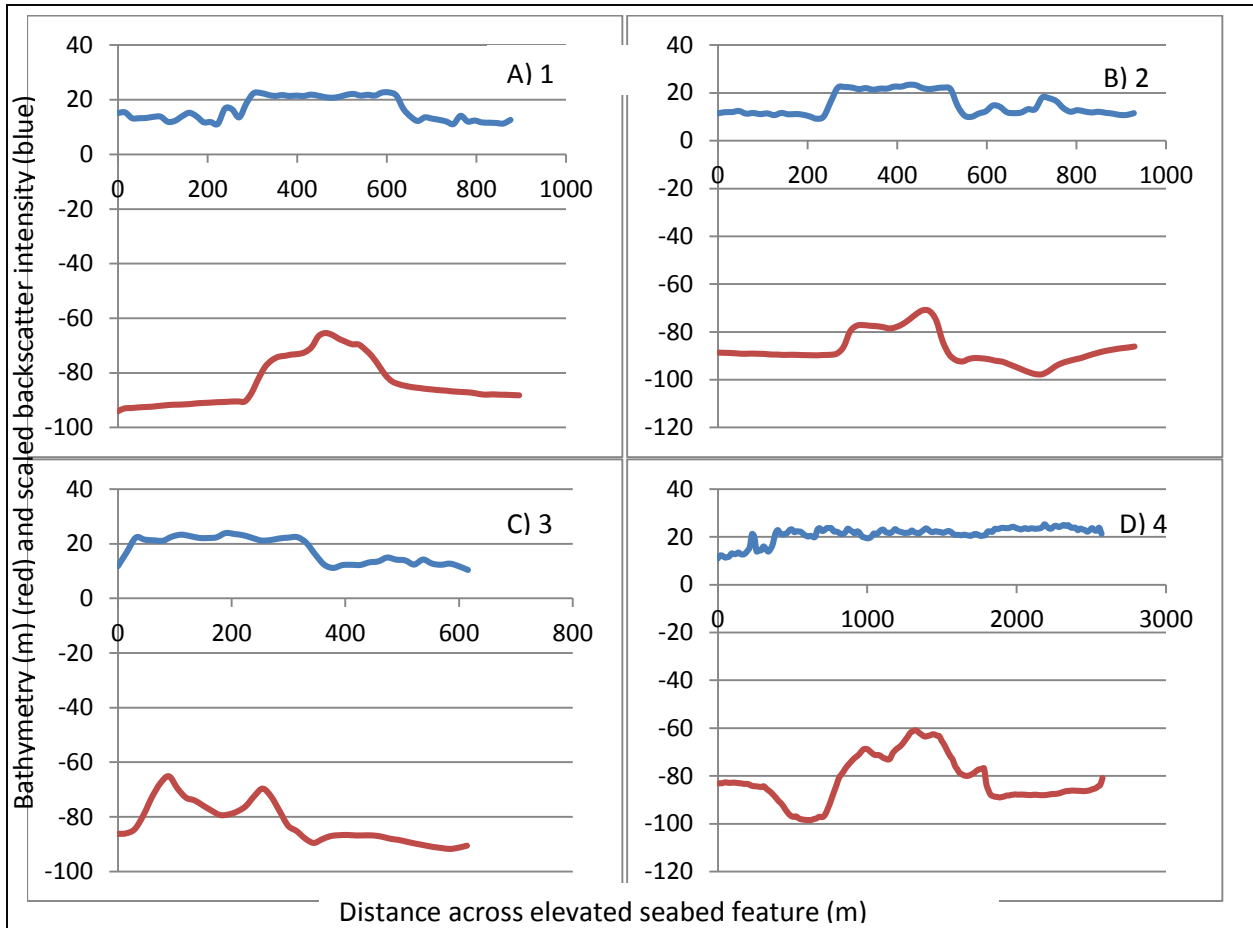


Figure 4. Backscatter intensity and bathymetry versus distance profiles of the elevated seabed features. Distance(m) is positioned on the x-axis. Scaled backscatter intensity (blue) and bathymetry (m) (red) are positioned on the y-axis.

	1	2	3	4	average
max	22.71	23.43	23.91	25.24	23.82
min	11.13	9.21	10.40	11.03	10.45
mean	16.54	15.09	17.62	21.10	17.59
stddev	4.32	4.83	4.79	3.34	4.32

	1	2	3	4	average
front	13.76	11.46	17.00	17.30	14.88
fslope	21.37	22.35	21.52	22.51	21.94
top	21.49	22.25	22.80	22.04	22.15
bslope	22.07	21.99	21.57	21.34	21.74
back	13.22	12.81	12.91	23.55	15.62

## DISCUSSION

Current studies conducted in glacially carved regions provide evidence for geological and geomorphological processes that once shaped the region. In a sense, the past is a key to the present assuming all governing processes in the

past occurred at the same rate at which they occur today (Alley 2001). The glacial history of the Vancouver Island, Canada region is well documented in the literature (Dallimore et al. 2008; Menounos et al. 2009). However, the local glacial history of the Effingham Inlet region has not been thoroughly investigated. 15 ka, the last

glacial maximum, sea level was up to 50 m lower than present day sea level in the Effingham Inlet region (Dallimore et al. 2008). As the climate warmed, glaciers melted and sea level continued to rise until about four ka, areas once exposed are now hidden under the sea (Dallimore et al. 2008). So, the first clues to the glacial history of the Effingham Inlet region are the current bathymetric and topographic maps.

Bathymetric maps in this study reveal several clues about the glacial history of the Effingham Inlet region. From the bathymetric map included in the results, it is clear that there are four elevated seabed features (Figure 3). The elevated seabed features are characterized by higher backscatter intensity values compared to the low backscatter intensity of the seabed (Figure 4). It can be inferred that the elevated seabed features are glacial moraine deposits with knowledge of the glacial history of the Vancouver Island region and known characteristics of glacial moraines. Lateral moraines are composed of rock and soil debris deposited at the glacial front (Benn and Evans 2010). The high backscatter intensity values observed for the elevated seabed features can be explained by the hard rock texture of the moraines. It is likely that as the climate warmed and the glacier coving Effingham Inlet retreated following the topography, moraine deposits were left at the glacial front during times of glacial stall. The scaled backscatter intensity values are similar for the different seabed features (Table 2). There is no difference in the acoustic properties of sediments of similar seabed features at different positions within a fjord. This would suggest that short-term processes of sedimentation and enduring glacial remnants have a larger effect on the backscatter intensity compared to long term geological processes and small differences in geological position.

Past studies have examined the relationship between scaled backscatter intensity values and bathymetry from MBES surveying and compared the results with known ground truth maps (Butman et al. 2004; Lamarche et al. 2011). A study by Butman et al. (2004) displayed several glacial features in Western Massachusetts Bay which was uncovered by glaciers ~14-18 ka (Butman et al. 2004; Odale et al. 1993).

Stellwagen Bank, an interpreted glacial moraine, has similar characteristics to the interpreted moraines found in this study. Stellwagen Bank is a ~20-30m tall lateral moraine with relatively high scaled values of backscatter intensity (Butman et al. 2004). Stellwagen Basin, a flat seafloor area, has much lower scaled backscatter intensity which can be compared to low scaled intensity values of the basins found in this study (Butman et al. 2004). In general, high backscatter intensity is associated with hard bottom types or coarse grain sediments and low backscatter intensity is associated with soft bottom types such as mud or clay fine grained sediments when comparing ground truth maps and maps created using MBES data (Lamarche et al. 2011; Butman et al. 2004).

A glacial melt channel seen on the bathymetric map also supports times of glacial stall and moraine deposit deposition related to the glacial history (Figure 3). 15 ka when the climate started to warm and the glacier started to retreat there must have been a substantial amount of melt water. Glaciers typically form one large subglacial river system due to the pressure constraints associated with multiple river channels (Benn and Evans 2010). During the glacial retreat the glacier would have left a u-shaped valley channel through the fjord. As the glacier retreated, glacial melt water would take the path of the carved glacial valley incising through past glacial debris such as terminal moraines (Figure 3). The scaled backscatter intensity values for the channel bed and banks showed little variation from the seafloor (Figure 4). This would suggest that there are other processes affecting the backscatter intensity values other than just remnant glacier features.

Processes of high sedimentation in the fjord help explain the similar scaled backscatter intensity values for each section of the elevated seabed features at different positions of the fjord (Table 2). Temperate fjords are known to have high sedimentation rates compared to other areas of the ocean (Benn and Evans 2010). If there is high sedimentation deposition within Effingham Inlet it is likely that the sediment would be able to settle fairly easily because there are low tidal variations and bottom currents in Effingham (Dallimore et al. 2008). A similar sediment deposition pattern at different positions within the

fjord would explain the similarity seen in the backscatter intensity values. There are no large river inputs close to the regions of study (Figure 2). Processes contributing to sedimentation are likely from hill slopes close to the vicinity of the elevated features and suspended sediment settling. A blanket of suspended sediment would explain the low scaled backscatter intensity values seen in the basins of the fjord.

While there are improvements that can be made on this study, there are implications that this study has on future studies. Various studies have been conducted which compared measured MBES backscatter data and ground truth maps (Butman et al. 2003; Simons and Snellens 2009). Similar MBES backscatter intensity values at different sites had the same true bottom type when compared to earlier ground truth cores (Butman et al. 2003; Simons and Snellens 2009). Assuming that this trend holds true for all regions, actual coring ground truth maps may not be necessary to get a good idea of bottom type. MBES mapping coupled with very selective coring to get a bottom type for each scaled backscatter intensity value may be much more effective and efficient than actual bottom truth mapping techniques. MBES mapping offers the advantage of 100% coverage compared to selective point mapping and interpolations used in ground truth mapping (Butman et al. 2003). In addition to coring or MBES mapping, ROV photography and videoing have offered another verification method to bottom type mapping (Micallef et al. 2012). The efficiency, accuracy and cost analysis benefits of MBES surveying coupled with selective coring may be the future of bottom type mapping techniques in the future.

## CONCLUSIONS

Bathymetric and backscatter intensity data were taken using MBES techniques on the University of Washington Oceanography senior cruise to Barkley Sound. With the backscatter intensity and bathymetric data several interpretations were made about Effingham Inlet and the geological and geomorphological process which have shaped the Inlet. First, differences in the scaled backscatter intensity values correlate with changes in the bathymetry. The high

backscatter intensity and high bathymetry correlation suggests that these features are glacial moraine deposits. There was little variation in the difference between the glacial moraine deposits at different positions in the fjord. This finding suggests short-term processes of sedimentation and enduring glacial remnants have a larger effect on the backscatter intensity compared to long term geological processes and small differences in geological position. While this may be true, the geology of a region has a big effect on shaping a region and ultimately controls the geomorphological processes. So, assessing whether the geology or geomorphology has a bigger effect on the sediment properties of an inlet cannot be answered in a quantitative way but only on a qualitative scale.

## ACKNOWLEDGEMENTS

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