The impacts of the Cordilleran Ice Sheet and alpine glaciations on the hypsometry of the Canadian Cordillera

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Motivation

Understanding the ability of glaciers and ice sheets in shaping the landscape is important for evaluating the interactions between climate and tectonic processes in creating topography. Hypsometry, i.e., the frequency distribution of elevations, can be used to evaluate the dynamic balance of tectonic uplift and erosion, and assess the erosional efficiency of both glacial and fluvial processes across the landscape. Recent studies that have evaluated the hypsometry of glaciated mountains suggest that where glacier erosion is concentrated around and above the mean long-term equilibrium line altitude (ELA), it effectively limits mountain height, a phenomenon known as the glacial buzzsaw (e.g., Brocklehurst and Whipple, 2004; Mitchell and Montgomery, 2006; Egholm et al., 2009). These studies have all focused on mountain (alpine) glaciers; to date, none has assessed the impact of an ice sheet on the shape of the landscape.

In this study, the hypsometry of the Canadian Cordillera is examined in relation to the development of the Cordilleran Ice Sheet (CIS) from the alpine advances 25,000 ^{14}C yr B.P. to its maximum ice sheet extent during the Last Glacial Maximum (LGM). The Canadian Cordillera provides a unique setting to look at the relative impacts of both alpine and ice sheet glaciation on the development of topography.

Research Questions

- How are different elevation histogram shapes distributed across the Canadian Cordillera?
- Can the influences of alpine and ice sheet glaciations be seen in the hypsometry of the Canadian Cordillera?

Study Area

The study area is the Canadian Cordillera, which was completely covered by the Cordilleran Ice Sheet during the LGM (Figures 1 and 2).

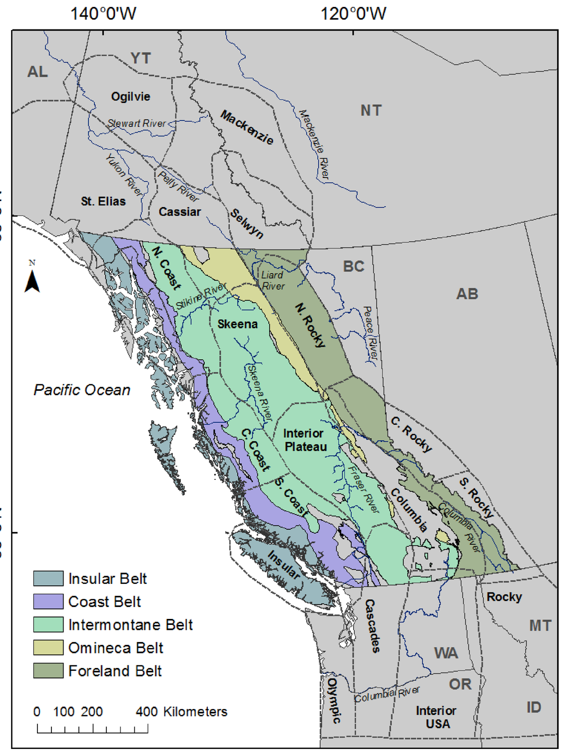


Figure 1. The Canadian Cordillera and part of NW United States with tectonic belts from Church and Ryder (2010).

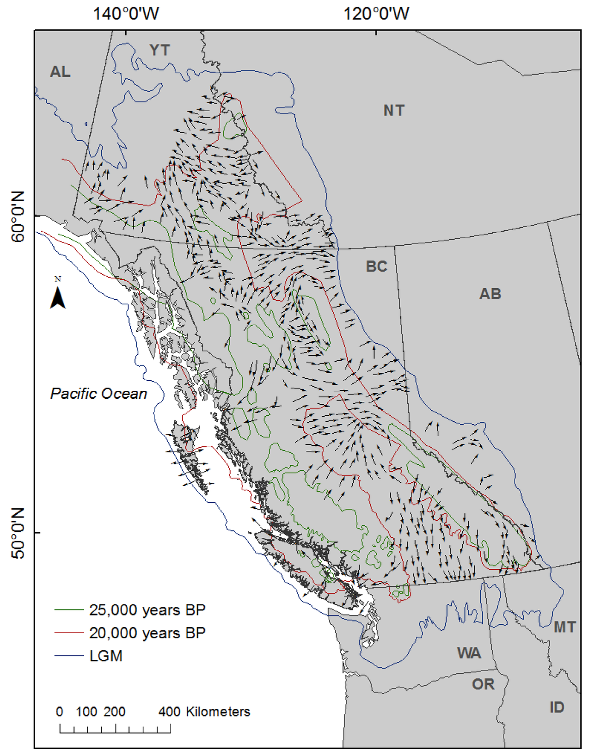


Figure 2. Glaciation extents and ice flow (Modified from Clague, 1989 and Booth et al., 2003).

Methodology

The hypsometry of the study area is compared to the late glacial history of the region and cirque-floor elevations are estimated as a proxy for the ELA during the alpine glacial phase of the last glaciation. Data (250m DEMs) are obtained from the National Topographic Database (Canada) and the U.S. Geological Survey.

For each 7.5 min quad across the Canadian Cordillera:

- Histograms of elevation frequency are created using 100 m bins (n = 398)
- Histograms are classified into shape categories
- Hypsometric integrals are calculated using the elevation-relief ratio

For each mountain range:

- 10 to 20 cirques with similar aspect are identified using Google Earth (n = 190)
- Cirque floor elevations are extracted using elevation and slope contours for identification (Principato and Lee, 2014)

Results

Histogram Shape Distribution:

Regions with a histogram shape of a single sharp peak are predominantly concentrated at low elevations near the coastline, in the Chilcotin Plateau Basalts, and in areas outside of the LGM extent of the Cordilleran Ice Sheet (Figure 3).

Regions characterized by a single wide peaked histogram shape are concentrated mainly in smaller mountain ranges (i.e. Cassiar, Skeena, Selwyn) within the LGM ice sheet extent, but outside of the alpine glaciation phase (25,000 years BP) (Figure 3).

Histograms that are classified as a single peak with a left skew are predominantly found in the Rocky Mountains, the Coast Mountains, and the St. Elias ranges (Figure 3).

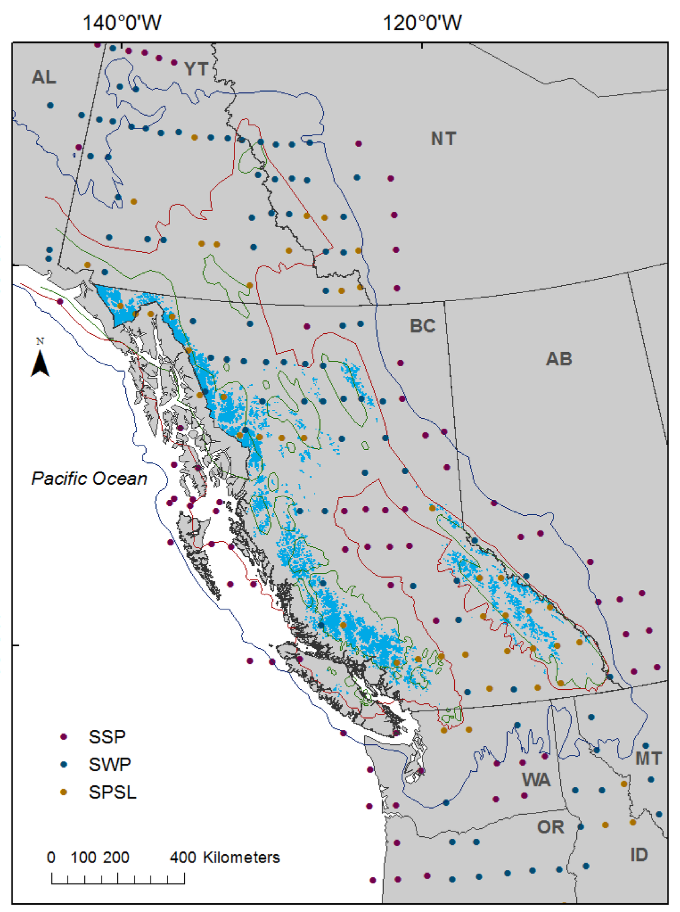


Figure 3. Histogram distribution for single sharp, wide, and left skewed peaks.

Cirque-floor Elevations:

Cirque-floor elevations are lowest near the coast and follow a strong, rising linear trend from west to east across the Coast Mountains, and from south to north in the Rocky Mountains (Figure 4). Cirque-floor elevations also closely mirror trends in ninetieth percentile elevations across the study area.

Hypsometric Integral:

Areas with low hypsometric integrals (0.08—0.28) are concentrated mainly along the coastline within the Insular tectonic belt, as well as in areas characterized by flood basalts, such as the Chilcotin Plateau Basalts in the Canadian interior and the Columbia River basalts in Washington (Figure 5).

Areas with high hypsometric integrals (0.44—0.59) are concentrated mainly within the interior plateaus between large mountain ranges (Intermontane tectonic belt), as well as along the landward edges of the LGM ice sheet extent. These areas also fall mainly outside of the alpine glaciation phase (Figure 5).

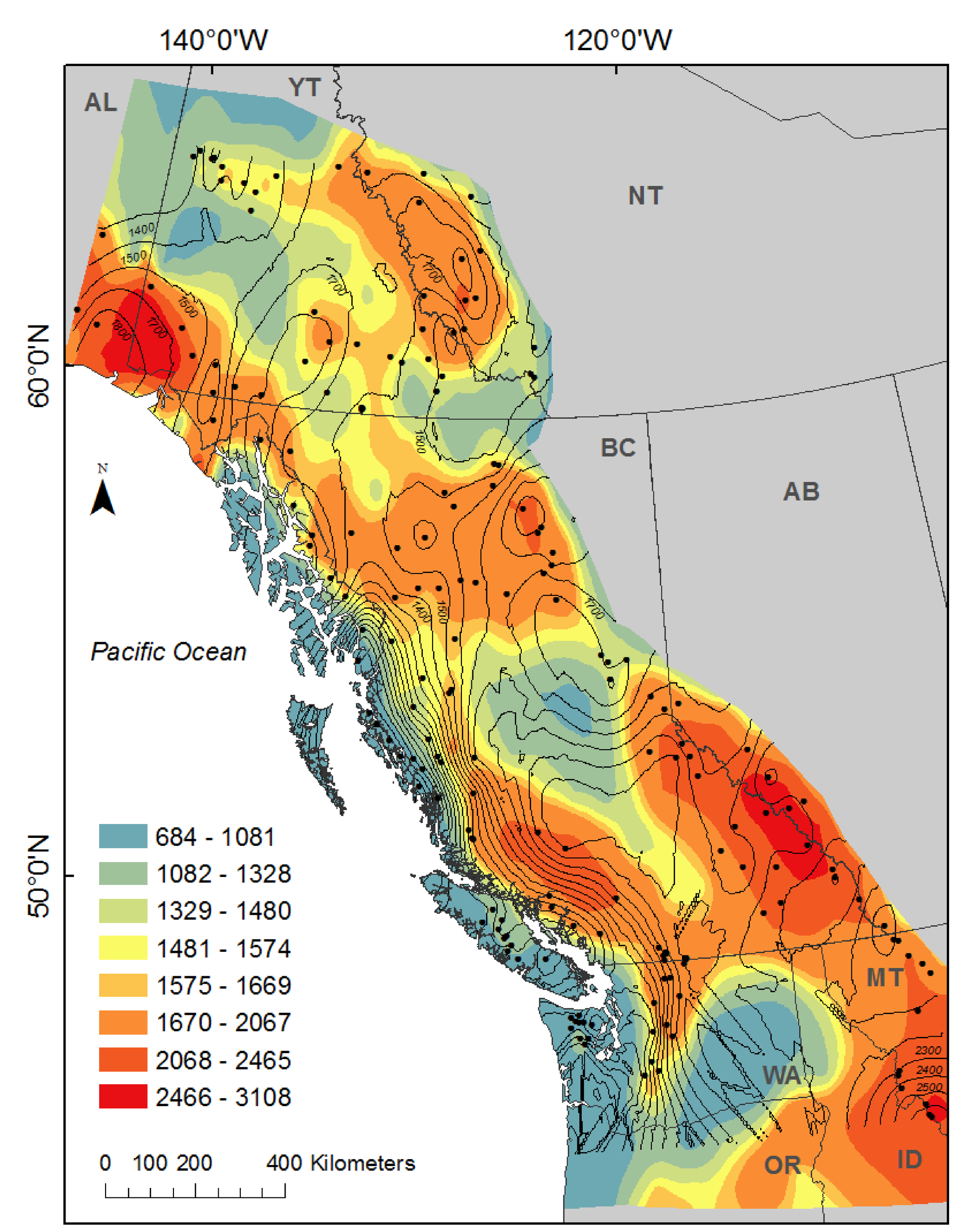


Figure 4. Ninetieth percentile elevation (m a.s.l.) with cirque-floor elevation contours and cirque locations.

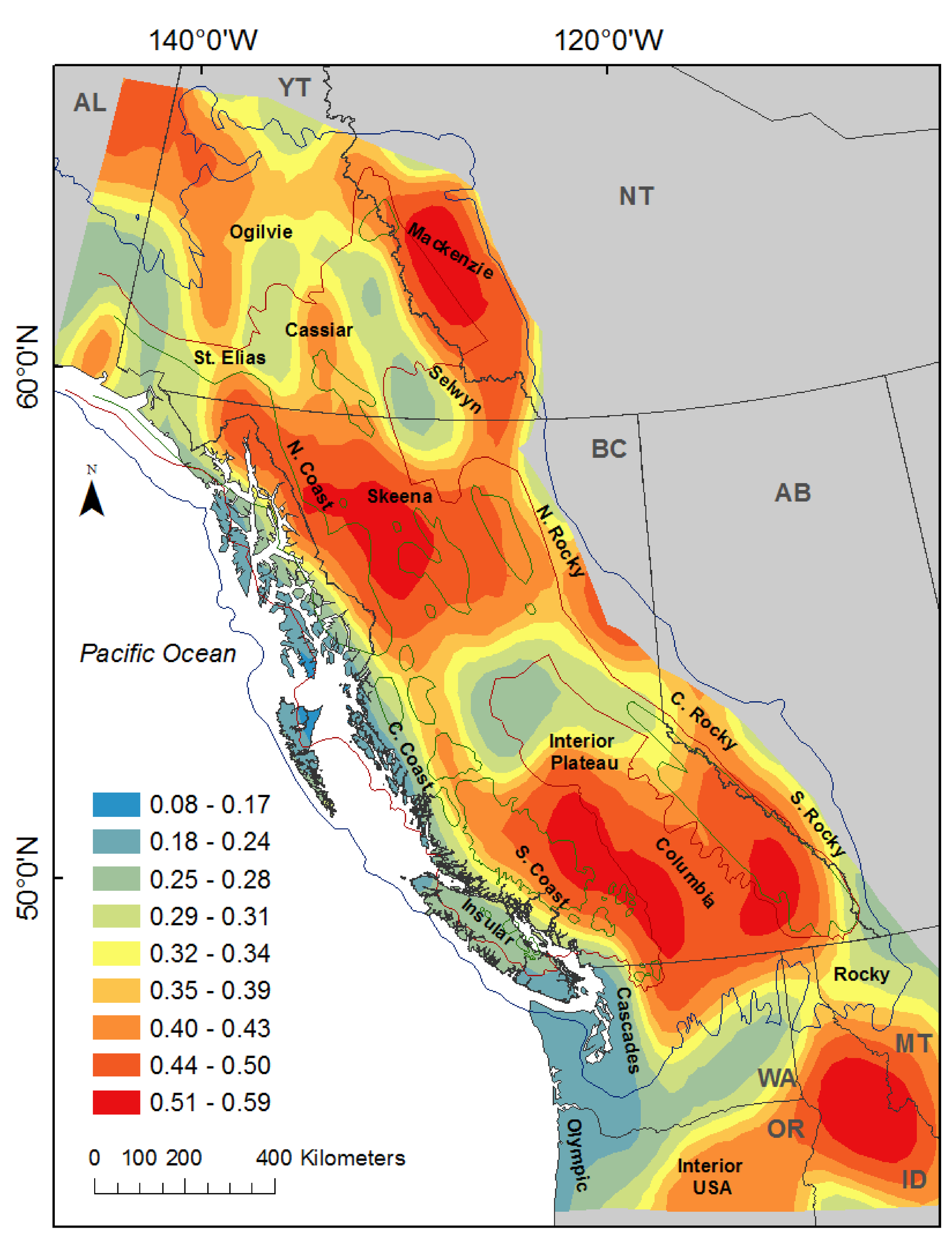
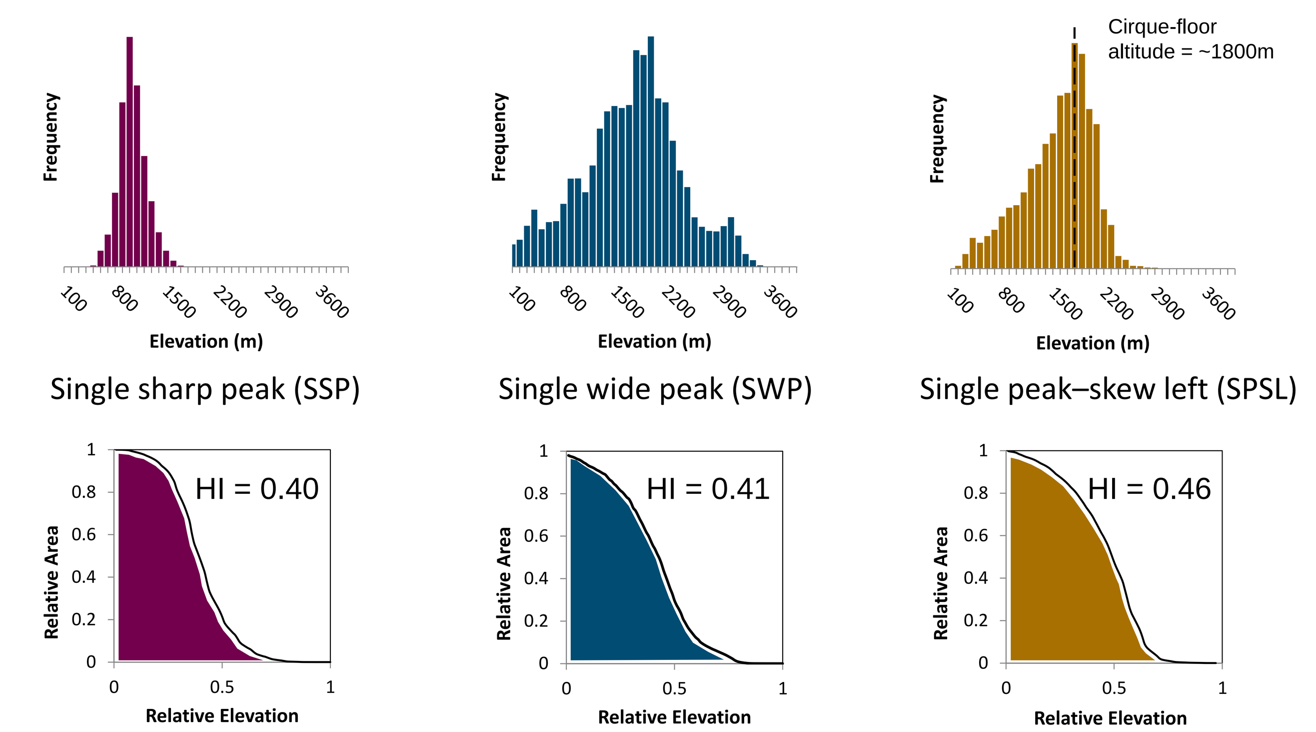


Figure 5. Hypsometric integrals, with CIS extents and major mountain ranges labeled for reference.

Histogram Shape Classifications



Interpretations

In the interior, the sharp, single peaked histograms are interpreted as areas flattened by flood basalts and, due to locations coinciding with CIS ice domes, as zones of maximum CIS extent erosion. On the coast, these histograms are interpreted as scoured fjord areas where CIS ice streams produce erosion dominated landscapes. The broad distribution of elevation seen in wide, single peaked histograms is interpreted as a result of CIS glacial erosion with no previous alpine glacial erosion.

Coastal and inland trends in cirque-floor elevations are due to distances from a moisture source as well as temperature gradients with latitude. The mirroring of cirque-floor elevations with H90 elevations and the characteristics of left-skewed histograms indicate the presence of the glacial buzzsaw effect, as seen in the Cascade Range of central Washington (Mitchell and Montgomery, 2006). This suggests that local climatic variations exert a greater influence on limiting mountain height than tectonic uplift (Egholm et al., 2009 and Sternai et al., 2011).

Areas with low hypsometric integrals have less than half of potential material present post-erosion, indicating intense erosional zones correlating with LGM ice flow paths. Located within the Insular tectonic belt, these areas have large relief differences, indicating previously high rates of erosion. Areas with intermediate integrals demonstrate the glacial buzzsaw effect, with integral values larger than non-alpine glaciated areas (as seen in Brocklehurst and Whipple, 2004). Areas with high hypsometric integrals have roughly half of potential material present post-erosion, suggesting younger landscape regions with high erosion potential (Strahler, 1952).

Conclusion

The signals of the phases of glaciation leading up to the LGM ice sheet extent can be seen in the hypsometry of the Canadian Cordillera. Regions which experienced early and late alpine glaciation are reflected in the hypsometry of the Cordillera. In contrast, those regions that were only ice covered during the LGM ice sheet phase exhibit little difference in their hypsometric indicators from non-glaciated regions to the south (southern WA, OR and ID) and north (eastern AK, YT, and NT).

Outstanding questions include the influence of uplift rates across the region as well as the influence of the redistribution of sediment from uplands to adjacent lowlands by glacier transfer on the hypsometry of the region.

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Acknowledgements

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