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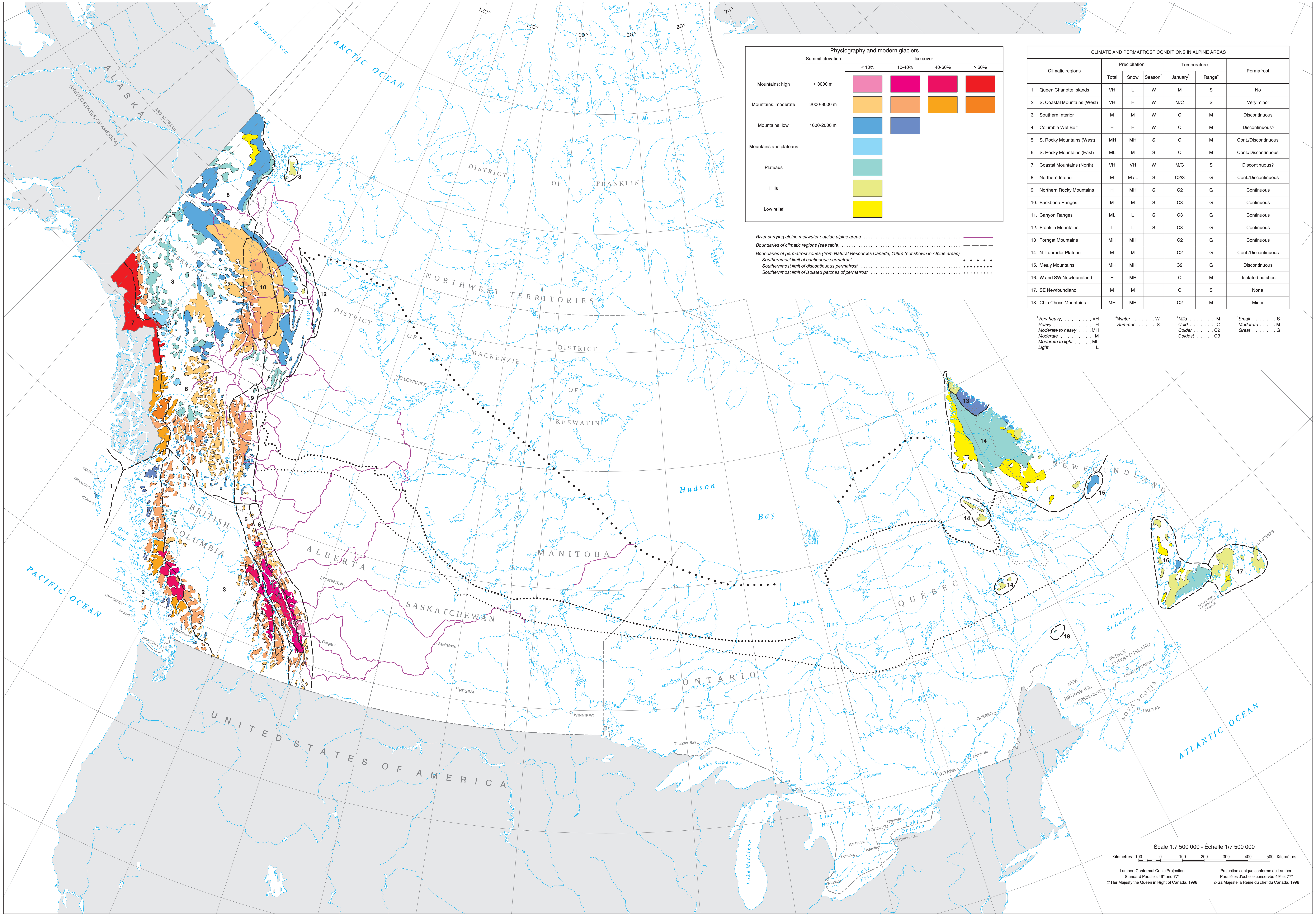
GEOLOGICAL SURVEY OF CANADA · COMMISSION GÉOLOGIQUE DU CANADA




## Physiography and modern glaciers

| | Summit elevation | Ice cover < 10% | Ice cover 10-40% | Ice cover 40-60% | Ice cover > 60% |
|---|---|---|---|---|---|
| Mountains: high | > 3000 m | ■ | ■ | ■ | ■ |
| Mountains: moderate | 2000-3000 m | ■ | ■ | ■ | ■ |
| Mountains: low | 1000-2000 m | ■ | ■ | | |
| Mountains and plateaus | | ■ | | | |
| Plateaus | | ■ | | | |
| Hills | | ■ | | | |
| Low relief | | ■ | | | |

*River carrying alpine meltwater outside alpine areas*

*Boundaries of climatic regions (see table)*

*Boundaries of permafrost zones (from Natural Resources Canada, 1995) (not shown in Alpine areas)*

*Southernmost limit of continuous permafrost*

*Southernmost limit of discontinuous permafrost*

*Southernmost limit of isolated patches of permafrost*

## CLIMATE AND PERMAFROST CONDITIONS IN ALPINE AREAS

| Climatic regions | Precipitation[1] Total | Precipitation[1] Snow | Precipitation[1] Season[2] | Temperature January[3] | Temperature Range[4] | Permafrost |
|---|---|---|---|---|---|---|
| 1. Queen Charlotte Islands | VH | L | W | M | S | No |
| 2. S. Coastal Mountains (West) | VH | H | W | M/C | S | Very minor |
| 3. Southern Interior | M | M | W | C | M | Discontinuous |
| 4. Columbia Wet Belt | H | H | W | C | M | Discontinuous? |
| 5. S. Rocky Mountains (West) | MH | MH | S | C | M | Cont./Discontinuous |
| 6. S. Rocky Mountains (East) | ML | M | S | C | M | Cont./Discontinuous |
| 7. Coastal Mountains (North) | VH | VH | W | M/C | S | Discontinuous? |
| 8. Northern Interior | M | M / L | S | C2/3 | G | Cont./Discontinuous |
| 9. Northern Rocky Mountains | H | MH | S | C2 | G | Continuous |
| 10. Backbone Ranges | M | M | S | C3 | G | Continuous |
| 11. Canyon Ranges | ML | L | S | C3 | G | Continuous |
| 12. Franklin Mountains | L | L | S | C3 | G | Continuous |
| 13 Torngat Mountains | MH | MH | | C2 | G | Continuous |
| 14. N. Labrador Plateau | M | M | | C2 | G | Cont./Discontinuous |
| 15. Mealy Mountains | MH | MH | | C2 | G | Discontinuous |
| 16. W and SW Newfoundland | H | MH | | C | M | Isolated patches |
| 17. SE Newfoundland | M | M | | C | S | None |
| 18. Chic-Chocs Mountains | MH | MH | | C2 | M | Minor |

[1] *Very heavy* . . . . . . . . . VH
*Heavy* . . . . . . . . . . . H
*Moderate to heavy* . . . . MH
*Moderate* . . . . . . . . . M
*Moderate to light* . . . . . ML
*Light* . . . . . . . . . . . . L

[2] *Winter* . . . . . . . W
*Summer* . . . . . S

[3] *Mild* . . . . . . . M
*Cold* . . . . . . . C
*Colder* . . . . . . C2
*Coldest* . . . . . C3

[4] *Small* . . . . . . . S
*Moderate* . . . . . M
*Great* . . . . . . . G

Scale 1:7 500 000 - Échelle 1/7 500 000

Kilometres 100 0 100 200 300 400 500 Kilomètres

Lambert Conformal Conic Projection
Standard Parallels 49° and 77°

Projection conique conforme de Lambert
Parallèles d'échelle conservée 49° et 77°



## NOTES

Geomorphological processes in alpine areas range from dramatic events, such as debris flows and snow avalanches, to the imperceptible downslope movement of soil and the slow flow of glaciers. In one way or another, all of these processes affect human endeavours in the alpine zone, and they are all, in some manner, linked to climate. Increases in atmospheric greenhouse gases are predicted to lead to significant climate changes, resulting in related changes in the nature, frequency, or rates of operation of geomorphological processes. For example, avalanches and debris flows may occur in areas not affected before, and more catastrophic floods may occur in valleys carrying glacier meltwater.

The objective of the report is to provide information about geomorphological processes in alpine areas in Canada, especially processes that impinge on human activities, and to estimate how they may be affected by predicted climate change. This study is not intended as a focused prediction of what can be expected, rather, it provides a starting point for defining problems of dealing with global change in a rather sensitive environment and deciding where future work should be directed.

For the purpose of this study, alpine areas are defined as regions lying above the upper limit of continuous forest: *timberline* is the boundary of the alpine areas shown in this figure. The alpine zone includes subalpine parkland, alpine tundra, glaciers and snowfields, and barren rocky ground. Mountainous areas in the Arctic are excluded because, unlike high-elevation areas farther south, they are not distinguished from adjacent lowlands by distinctive geomorphological processes or their sensitivity to climate change.

Estimates of the effects of future climate change on alpine geomorphological processes are tentative for several reasons: the anticipated climate modification has been defined only in very general terms; the exact nature of climate controls on most geomorphological processes is not well understood; and the relations between climate and geomorphological processes are complex. The broad climatic predictions on which this report is based indicate that warming in high northern latitudes will exceed the predicted global mean increase of 2.5°C in winter but will be closer to the average in summer; that continental areas will warm more than maritime regions; that precipitation and evaporation will increase throughout the year in high latitudes and in winter in mid-latitudes; and that net effects will result in a decrease in the area of seasonal snow cover.

Geomorphological processes are dynamic actions or events that occur at the Earth's surface due to the application of forces generated by atmospheric processes, such as rainfall and temperature variations, and terrestrial effects, such as gravity (expressed as slope steepness) and seismic shaking. Thus the processes under review include erosion and deposition by flowing water and ice, rockfalls and soil creep influenced by freezing and thawing, landslides triggered by torrential rain or melting permafrost, and avalanches following heavy snowfall. A major difficulty in determining the response of a process to climate change is that many of the significant climatic variables, such as precipitation intensity during major storms and the annual number of freeze-thaw cycles, are neither routinely measured at most climate stations nor referred to in climate predictions. Consequently, only tentative and qualitative suggestions about the likely effects of climate change can be provided.

Timberline, the lower limit of the alpine zone, is a dynamic boundary. Its elevation is controlled primarily by summer temperatures and the duration of winter snowpack. Climate warming will probably result in increasingly favourable conditions for trees at high elevations, and thus timberline will rise, although other changes, especially increasing snowfall, could have opposing effects. A rise in timberline will result in a reduction in the extent of alpine areas, especially alpine meadows, and the alpine zone will disappear altogether on mountains and plateaus which rise only a short distance above the present limit of trees.

The extent of permafrost in alpine areas has not been mapped in detail, although it is well known that frozen ground is most widespread in more northerly regions and in continental (inland) mountains, where winters are relatively cold and the winter snowpack is thin. Modification of permafrost due to climate warming is likely to take place slowly over many centuries because the ground is well insulated from the atmosphere by soil and vegetation. Effects are likely to be complex, because soil characteristics, especially moisture content, and vegetation will also be modified. Climate warming will be most effective where permafrost is relatively warm and thin (discontinuous permafrost regions). The result will be a thickening of the seasonally thawed soil (*active layer*), and the development of a zone of unfrozen ground between the active layer and the top of the permafrost. Thin permafrost may disappear. The results of ground warming will be noticeable in areas underlain by ice-rich permafrost, which is probably not extensive in many alpine areas. Where ice lenses are present, melting will result in subsidence of the land surface, collapse of peat plateaus in bogs, slope instability, and mudflows. Such effects, once initiated, may persist at specific sites for several decades or longer. Other typical problems that might be expected are an increase in road ditch maintenance and increasing pressure on building foundations as the rates of soil creep increase due to warming permafrost and a thickening active layer. In general, however, direct human actions, such as removal of insulating soil and vegetation, are potentially of greater significance for localized permafrost degradation than the effects of climate change.

Frost action (daily freezing and thawing) is most effective in continental and high latitude mountains where seasonal snow cover is thin. It contributes to shattering of bedrock, heaving and churning of soil, and slow downslope creep of the unfrozen soil mantle in summer. The effects of climate change on these processes are hard to estimate, but they are likely to be minor in comparison with the normal place to place variations in frost action intensity that result from differences in slope steepness, aspect, soil moisture, vegetation cover, and snow depth.

In mountainous regions with relatively mild winter temperatures (see table), the combined effects of winter warming and increased precipitation will result in a rise in elevation of the winter snowline, a decrease in the extent of seasonal snowcover at low elevations, and increased snowfall at higher elevations. An adverse effect on low-elevation ski areas (shorter season, wetter snow conditions, increased rain) is expected, whereas increased snowfall may benefit resorts at higher elevations. In relatively cold mountain regions, a more general increase in snowfall is expected. Activities such as transportation and mining in alpine areas will also be affected by changing snow conditions, with the adverse effects of increased snowfall perhaps being more widespread than the beneficial effects of less snow and a shorter snow season.

In regions where snowfall will increase, snow avalanche activity might also be expected to increase. However, this tendency may be offset by the effects of warmer atmospheric temperatures, which could reduce temperature gradient in the snow pack thereby increasing its stability, and tree colonization of initiation zones formerly above timberline. Future changes in storm patterns, including wind strengths and directions, will also have effects that cannot be predicted yet. In areas close to snowline, avalanche hazards are likely to decrease.

The extent of permanent snow and ice cover, in the form of glaciers and icefields, is controlled both by snowfall amounts, which determine ice accumulation, and by summer temperatures, which determine melting. In general, and especially in warmer areas, the effects of increased temperature are expected to dominate, resulting in glacier recession. Quantitative estimates of the change in elevation of the summer snowline suggest that many small, relatively low-elevation glaciers will disappear, and larger glaciers and icefields will experience drastic retreat. Thus the appearance of alpine landscapes will change dramatically, possibly with long-term impacts on tourism in national parks.

During glacier recession, hazards from floods and debris flows are likely to increase. Catastrophic floods that far exceed flows generated by rainstorms and snowmelt result from the bursting of glacier dams and moraine dams. On steep slopes, outburst floods may be transformed into debris flows, and debris flows may also be generated by intense precipitation on steep moraines recently uncovered by glacier recession. Flows and floods generated in alpine areas may travel downstream below timberline for many tens of kilometres, posing a hazard to humans and structures such as bridges and roads.

The effects of climate change on gravitationally induced processes, such as landslides, rockfalls, and nonglacial debris flows, are hard to predict. Increased precipitation, particularly high intensity rainfall, may increase the frequency of some types of mass movement, such as debris slides and flows. Warmer temperatures and increased evaporation, on the other hand, may increase the stability of some slopes by reducing soil moisture and reducing the intensity of freeze-thaw action and related processes, such as frost shattering and rock fall. (The intensity of mass movement processes is proportional, in a very general sense, to the elevations of the mountains.)

If, as is likely, climate warming is accompanied by increasing storminess and intense rainfall, then peak stream discharges are likely to increase, resulting in increased erosion, sediment transport, and deposition downstream. Increased sediment input to streams in recently deglaciated areas will augment these effects, and, like outburst floods, effects may become apparent at considerable distances downstream from alpine areas. In both cases, hazards will include increased flooding (possibly both magnitude and frequency), rise of the stream bed causing increased elevation of flood waters, and increased bank erosion and lateral instability of river channels.

Where snow packs are reduced, the water storage capacity and the spring and early summer water yield of drainage basins will be reduced. This figure shows major rivers with spring and summer flow levels that are significantly augmented by snowpack and glacier melt. Where glacier recession reduces the extent of permanent snow and ice, late summer water yield will be reduced also, and the buffering capacity of a glacier to reduce year-to-year variations in runoff from precipitation will also decline. These potential changes are particularly significant in areas that are dry in summer, such as the Okanagan Valley in south-central British Columbia, where agriculture and industry receive their water supply from adjacent mountains. Where snow accumulation is increased, water storage and runoff will be augmented.

*Figure compiled by J.M. Ryder, 1995*

*Digital cartography by Mario Hudon, Geoscience Information Division*

*Any revisions or additional geological information known to the user would be welcomed by the Geological Survey of Canada*

*Digital base supplied by GeoAccess Division, Geomatics Canada, modified by the Geoscience Information Division*

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**Figure 1: Characteristics of alpine regions in Canada**