Natural Resources Canada
Ressources naturelles Canada

THE NATIONAL ATLAS OF CANADA 5th EDITION

CANADA
PERMAFROST

Produced by the **National Atlas Information Service**, Canada Centre for Mapping, **Geomatics Canada**, and the **Terrain Sciences Division, Geological Survey of Canada**, Natural Resources Canada. Printed 1995.

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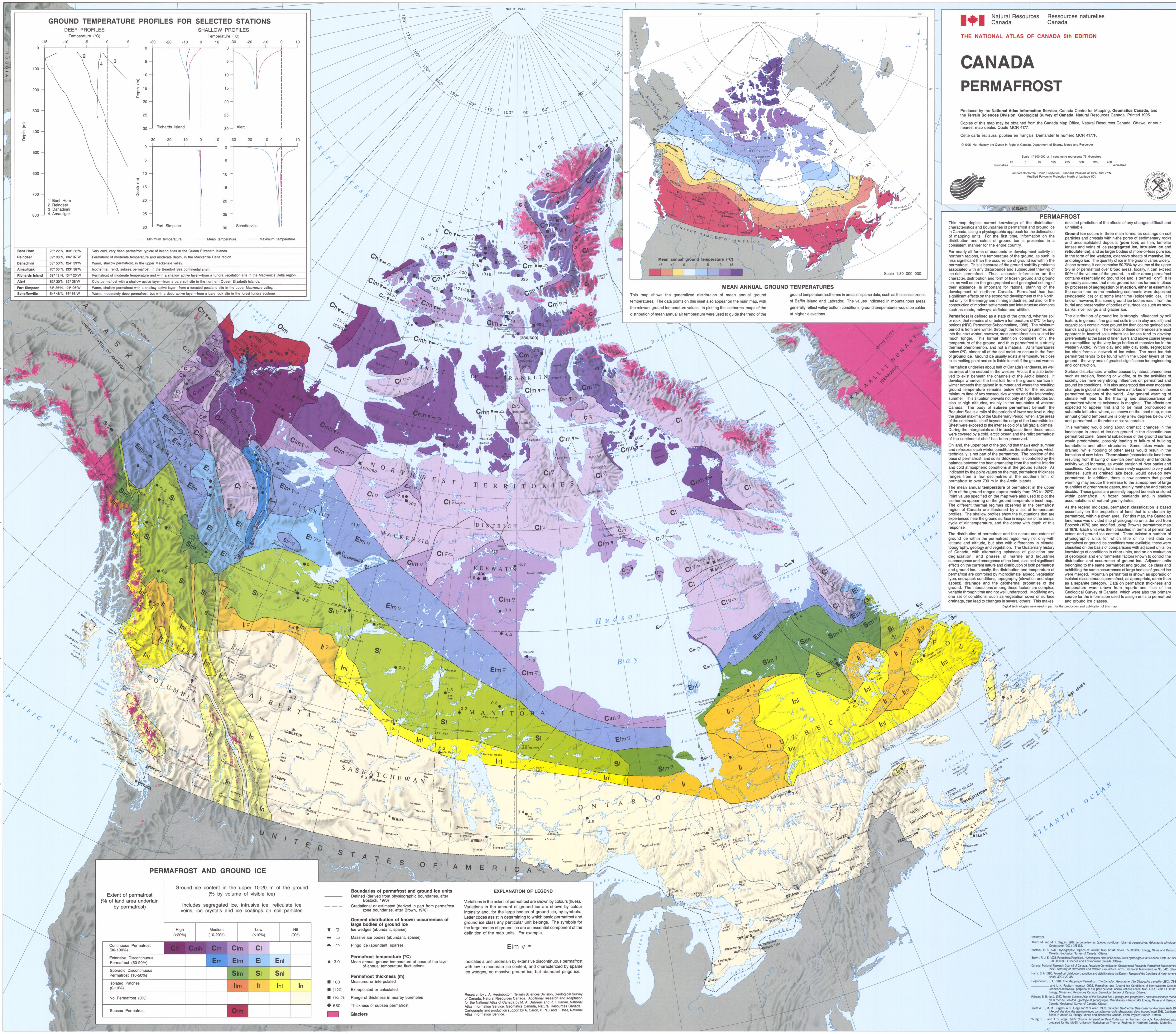
Scale 1:7 500 000 or 1 centimetre represents 75 kilometres

kilometres 75 0 75 150 225 300 375 450 kilometres

Lambert Conformal Conic Projection, Standard Parallels at 49°N and 77°N.
Modified Polyconic Projection North of Latitude 80°.



GROUND TEMPERATURE PROFILES FOR SELECTED STATIONS

Bent Horn	76° 22′N, 103° 58′W	Very cold, very deep permafrost typical of inland sites in the Queen Elizabeth Islands.
Reindeer	69° 06′N, 134° 37′W	Permafrost of moderate temperature and moderate depth, in the Mackenzie Delta region.
Dahadinni	63° 53′N, 124° 39′W	Warm, shallow permafrost, in the upper Mackenzie valley.
Amauligak	70° 03′N, 133° 38′W	Isothermal, relict, subsea permafrost, in the Beaufort Sea continental shelf.
Richards Island	69° 13′N, 134° 20′W	Permafrost of moderate temperature and with a shallow active layer—from a tundra vegetation site in the Mackenzie Delta region.
Alert	82° 30′N, 62° 26′W	Cold permafrost with a shallow active layer—from a bare soil site in the northern Queen Elizabeth Islands.
Fort Simpson	61° 36′N, 121° 06′W	Warm, shallow permafrost with a shallow active layer—from a forested peatland site in the upper Mackenzie valley.
Schefferville	54° 48′N, 66° 56′W	Warm, moderately deep permafrost, but with a deep active layer—from a bare rock site in the forest tundra ecotone.

MEAN ANNUAL GROUND TEMPERATURES

This map shows the generalized distribution of mean annual ground temperatures. The data points on this inset also appear on the main map, with the relevant ground temperature values. In plotting the isotherms, maps of the distribution of mean annual air temperature were used to guide the trend of the ground temperature isotherms in areas of sparse data, such as the coastal zones of Baffin Island and Labrador. The values indicated in mountainous areas generally reflect valley bottom conditions; ground temperatures would be colder at higher elevations.

PERMAFROST

This map depicts current knowledge of the distribution, characteristics and boundaries of permafrost and ground ice in Canada, using a physiographic approach for the delineation of mapping units. For the first time, information on the distribution and extent of ground ice is presented in a consistent manner for the entire country.

For nearly all forms of economic or development activity in northern regions, the temperature of the ground, as such, is less significant than the occurrence of ground ice within the permafrost. This is because of the ground stability problems associated with any disturbance and subsequent thawing of ice-rich permafrost. Thus, accurate information on the character, distribution and form of frozen ground and ground ice, as well as on the geographical and geological setting of their existence, is important for rational planning of the development of northern Canada. Permafrost has had significant effects on the economic development of the North, not only for the energy and mining industries, but also for the construction of modern settlements and infrastructure elements such as roads, railways, airfields and utilities.

Permafrost is defined as a state of the ground, whether soil or rock, that remains at or below a temperature of 0°C for long periods (NRC, Permafrost Subcommittee, 1988). The minimum period is from one winter, through the following summer, and into the next winter; however, most permafrost has existed for much longer. This formal definition considers only the temperature of the ground, and thus permafrost is a strictly thermal phenomenon, and not a material. At temperatures below 0°C, almost all of the soil moisture occurs in the form of **ground ice**. Ground ice usually exists at temperatures close to its melting point and so is liable to melt if the ground warms.

Permafrost underlies about half of Canada's landmass, as well as areas of the seabed in the western Arctic; it is also believed to exist beneath the channels of the Arctic Islands. It develops wherever the heat lost from the ground surface in winter exceeds that gained in summer and where the resulting ground temperature remains below 0°C for the required minimum time of two consecutive winters and the intervening summer. This situation prevails not only at high latitudes but also at high altitudes, mainly in the mountains of western Canada. The body of **subsea permafrost** beneath the Beaufort Sea is a relic of the periods of lower sea level during the glacial maxima of the Quaternary Period, when large areas of the continental shelf beyond the edge of the Laurentide Ice Sheet were exposed to the intense cold of a full glacial climate. During the interglacials and in postglacial time, these areas were covered by a cold, arctic ocean and the relict permafrost of the continental shelf has been preserved.

On land, the upper part of the ground that thaws each summer and refreezes each winter constitutes the **active layer**, which technically is not part of the permafrost. The position of the base of permafrost, and so its **thickness**, is controlled by the balance between the heat emanating from the earth's interior and cold atmospheric conditions at the ground surface. As indicated by the point values on the map, permafrost thickness ranges from a few decimetres at the southern limit of permafrost to over 700 m in the Arctic Islands.

The mean annual **temperature** of permafrost in the upper 10 m of the ground ranges approximately from 0°C to -20°C. Point values specified on the map were also used to plot the isotherms appearing on the ground temperature inset map. The different thermal regimes observed in the permafrost region of Canada are illustrated by a set of temperature profiles. The shallow profiles show the fluctuations that are experienced near the ground surface in response to the annual cycle of air temperature, and the decay with depth of this response.

The distribution of permafrost and the nature and extent of ground ice within the permafrost region vary not only with latitude and altitude, but also with differences in climate, topography, geology and vegetation. The Quaternary history of Canada, with alternating episodes of glaciation and deglaciation, and phases of marine and lacustrine submergence and emergence of the land, also had significant effects on the current nature and distribution of both permafrost and ground ice. Locally, the distribution and temperature of permafrost are controlled by microclimate, albedo, vegetation type, snowpack conditions, topography (elevation and slope aspect), drainage and the geothermal properties of the ground. The interactions among these factors are complex, variable through time and not well understood. Modifying any one set of conditions, such as vegetation cover or surface drainage, can lead to changes in several others. This makes detailed prediction of the effects of any changes difficult and unreliable.

Ground ice occurs in three main forms: as coatings on soil particles and crystals within the pores of sedimentary rocks and unconsolidated deposits (**pore ice**); as thin, lamellar lenses and veins of ice (**segregated ice, intrusive ice** and **reticulate ice**); and as larger bodies of more-or-less pure ice, in the form of **ice wedges**, extensive sheets of **massive ice**, and **pingo ice**. The quantity of ice in the ground varies widely. At one extreme, it can comprise 50-70% by volume of the upper 2-3 m of permafrost over broad areas; locally, it can exceed 90% of the volume of the ground. In other areas permafrost contains essentially no ground ice and is termed "dry". It is generally assumed that most ground ice has formed in place by processes of **segregation** or **injection**, either at essentially the same time as the enclosing sediments were deposited (syngenetic ice) or at some later time (epigenetic ice). It is known, however, that some ground ice bodies result from the burial and preservation of bodies of surface ice such as snow banks, river icings and glacier ice.

The distribution of ground ice is strongly influenced by soil texture; in general, fine grained soils (rich in clay and silt) and organic soils contain more ground ice than coarse grained soils (sands and gravels). The effects of these differences are most apparent in layered soils where ice lenses tend to develop preferentially at the base of finer layers and above coarse layers as exemplified by the very large bodies of massive ice in the western Arctic. Within clay and silty clay soils, segregation ice often forms a network of ice veins. The most ice-rich permafrost tends to be found within the upper layers of the ground—the very area of greatest significance for engineering and construction.

Surface disturbances, whether caused by natural phenomena such as erosion, flooding or wildfire, or by the activities of society, can have very strong influences on permafrost and ground ice conditions. It is also understood that even moderate changes in global climate will have a marked influence on the permafrost regions of the world. Any general warming of climate will lead to the thawing and disappearance of permafrost where its existence is marginal. The effects are expected to appear first and to be most pronounced in subarctic latitudes where, as shown on the inset map, mean annual ground temperature is only a few degrees below 0°C and permafrost is therefore most vulnerable.

This warming would bring about dramatic changes in the landscape in areas of ice-rich ground in the discontinuous permafrost zone. General subsidence of the ground surface would predominate, possibly leading to failure of building foundations and other structures. Some lakes would be drained, while flooding of other areas would result in the formation of new lakes. **Thermokarst** (characteristic landforms resulting from thawing of ice-rich permafrost) and landslide activity would increase, as would erosion of river banks and coastlines. Conversely, land areas newly exposed to very cold climates, such as drained lake beds, would develop new permafrost. In addition, there is now concern that global warming may induce the release to the atmosphere of large quantities of greenhouse gases, mainly methane and carbon dioxide. These gases are presently trapped beneath or stored within permafrost, in frozen peatlands and in shallow accumulations of natural gas hydrates.

As the legend indicates, permafrost classification is based essentially on the proportion of land that is underlain by permafrost, within a given area. For this map, the Canadian landmass was divided into physiographic units derived from Bostock (1970) and modified using Brown's permafrost map of 1978. Each unit was then classified in terms of permafrost extent and ground ice content. There existed a number of physiographic units for which little or no field data on permafrost or ground ice conditions were available; these were classified on the basis of comparisons with adjacent units, on knowledge of conditions in other units, and on an evaluation of geological and environmental factors known to control the distribution and occurrence of ground ice. Adjacent units belonging to the same permafrost and ground ice class and exhibiting the same occurrences of large bodies of ground ice were merged. Mountain permafrost is shown as sporadic or isolated discontinuous permafrost, as appropriate, rather than as a separate category. Data on permafrost thickness and temperature were drawn from reports and files of the Geological Survey of Canada, which were also the primary source for the information used to assign units to permafrost and ground ice classes.

Digital technologies were used in part for the production and publication of this map.

PERMAFROST AND GROUND ICE

Ground ice content in the upper 10-20 m of the ground (% by volume of visible ice)

Includes segregated ice, intrusive ice, reticulate ice veins, ice crystals and ice coatings on soil particles

Extent of permafrost (% of land area underlain by permafrost)	High (>20%)		Medium (10-20%)		Low (<10%)		Nil (0%)
Continuous Permafrost (90-100%)	Ch	Cmh	Cm	Clm	Cl		
Extensive Discontinuous Permafrost (50-90%)			Em	Elm	El	Enl	
Sporadic Discontinuous Permafrost (10-50%)				Slm	Sl	Snl	
Isolated Patches (0-10%)				Ilm	Il	Inl	In
No Permafrost (0%)							
Subsea Permafrost				Olm			

Boundaries of permafrost and ground ice units

Defined (derived from physiographic boundaries, after Bostock, 1970)

Gradational or estimated (derived in part from permafrost zone boundaries, after Brown, 1978)

General distribution of known occurrences of large bodies of ground ice

▼ ▽ Ice wedges (abundant, sparse)

Massive ice bodies (abundant, sparse)

Pingo ice (abundant, sparse)

Permafrost temperature (°C)

● -3.0 Mean annual ground temperature at base of the layer of annual temperature fluctuations

Permafrost thickness (m)

■ 100 Measured or interpolated

■ (120) Extrapolated or calculated

■ 140/175 Range of thickness in nearby boreholes

◆ 680 Thickness of subsea permafrost

Glaciers

EXPLANATION OF LEGEND

Variations in the extent of permafrost are shown by colours (hues). Variations in the amount of ground ice are shown by colour intensity and, for the large bodies of ground ice, by symbols. Letter codes assist in determining to which basic permafrost and ground ice class any particular unit belongs. The symbols for the large bodies of ground ice are an essential component of the definition of the map units. For example,

Elm ▽

indicates a unit underlain by extensive discontinuous permafrost with low to moderate ice content, and characterized by sparse ice wedges, no massive ground ice, but abundant pingo ice.

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