Geography and Physical Processes of the Circumpolar World

DEVELOPED BY
BRUCE FORBES, SENIOR SCIENTIST, ARCTIC CENTRE, ROVANIEMI, FINLAND
AND
STEVE YOUNG, DIRECTOR, CENTER FOR NORTHERN STUDIES, UNITED STATES

Contents

Key Terms and Concepts

- Arctic Eight
- Arctic Region
- Glaciation
- Isotherm
- North Pole
- Peatlands
- Permafrost
- Sea Ice
- Taiga
- Treeline
- Tundra

Learning Objectives/Outcomes

Upon completion of this module students will:

- Be able to describe the geography and general features of the Circumpolar North and the processes that have combined to give the Circumpolar North its present geography and physical features;
- Recognize the importance of ice, its formation, persistence, and melting in the physical processes of the North;
- Describe and explain the importance of water, as both liquid and ice, in the physical processes of the northern landscape;
- Achieve an awareness of permafrost, its extent, and its influence on the northern landscape;
- Describe ice-wedge polygons, pingos, peatlands, and volcanism;
- Define and explain the significance of the terms: glaciation, permafrost, sea ice, palsa, and aurora borealis.

Overview

Many of the physical features and processes found in the Circumpolar World are unique to this part of the earth. As an overview statement, it would be safe to say that the major factors involved in the physical features and processes of the North are:

- The climate, including very low winter temperatures, relatively high summer temperatures, and the subsequent freeze-thaw cycle;

- The long-term glaciation cycle and the current position in that cycle; and
- The presence or absence of water and the dynamics and influence of water, both as liquid and ice, on the northern landscape.

The module gives a brief introduction to the physical features and processes of the Arctic region and highlights the significant factors that influence those features and processes.

Lecture

The Circumpolar North, containing the Arctic and Subarctic regions, is not an easily definable geographic area such as North America or the Mediterranean Sea. Rather, it is a sort of free-form cap on the globe, roughly centered on the North Pole and extending southward to or beyond the Arctic Circle in an irregular fashion, sometimes nearly half way to the Equator. Traditionally, we thought of the Arctic as being mainly the treeless coastal regions and islands around the fringes of the Arctic Ocean. The forested regions deep within the continents were called the Subarctic. Many of these southern lands are colder (at least in winter) and more inaccessible than the "true" Arctic, and we will consider both parts to be entirely within the scope of this course.

Included within the Circumpolar North are parts of eight countries (often called the Arctic Eight, see the map on page 5) on three continents, an entire ocean, the largest island in the world, and many seas, straits, bays, islands, rivers, and mountain ranges.

Map of the Circumpolar World

Your map of the North Circumpolar Region is produced by the Government of Canada. Because Canada is a bilingual country (English and French), many of the features in Canada and the United States on the map are named in both those languages. Many of the place names in the other circumpolar countries are shown in their local languages or, in the case of Russian, transliterated into the Roman alphabet (see, for example, Karskoye More, sometimes called the Karsk Sea in English, but more usually, the Kara Sea). Many of the names we'll be using in this course are the English ones. There's a short list of the local and English names of the more important places at the end of this module.

Latitude and Longitude

The printed map you are using in this course (see the map on the next page) is a polar projection map. The North Pole (90° North latitude) is located at the centre of the map. Canada is at the bottom, and Russia is at the top. The network of thin black lines (the graticule) on the map shows the latitudes and longitudes. Because they are lines on a sphere (the Earth), they are measured in degrees.

Lines of latitude circle the globe parallel to the Equator (see Figure 1), which is called 0° North and South. The North and South Poles are 90° North and South respectively. There are 180 lines of latitude, then, between the North and South poles. The more brightly coloured part of your map, showing the North Circumpolar Region, covers the top of the globe from 55° North (often 55° N.) to the pole, which is located at 90° N. The spaces between degrees of latitude are measured in minutes (') and seconds("). There are 60 minutes in a degree, just as with time, and 60 seconds in a minute. The format for writing positions of latitude is this: 71° 17' 26" N. (That is, 71 degrees, 17 minutes, and 26 seconds north from the Equator.)

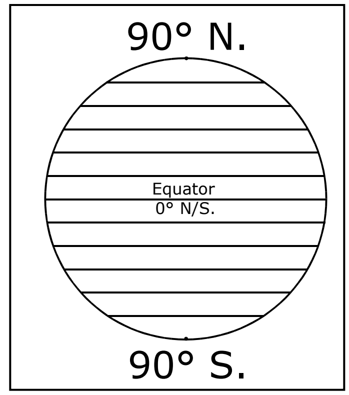


Figure 1. Lines of latitude

Lines of longitude are measured from 0° East and West (Figure 2), which runs through Greenwich, England (also referred to as the Prime Meridian or International Meridian). You can find this line running through the North Sea on your map. There are 360 lines of longitude, all of which converge at the North and South Poles (see Figure 2). Their measurements run for 180° westward and eastward from 0°, meeting at 180° West and East, which passes through the Chukotka Peninsula and the Bering Sea. A location with a longitude of 20° West (or 20° W.) in Iceland is closer to England and the Prime Meridian than a place with a longitude of 110° W., in Canada. Locations with eastern longitudes are located east of England (e.g., Svalbard, Norway and Sweden lie on the line of 20° E., and the Taymyr Peninsula, and a part of the Sakha Republic lie on the longitude 110° E.). The spaces between lines of longitude are also measured in minutes and seconds. The format for writing positions of latitude is the same as for latitude: 156° 47' 19" W. (That is 156 degrees, 47 minutes, and 19 seconds west from the Prime Meridian.)

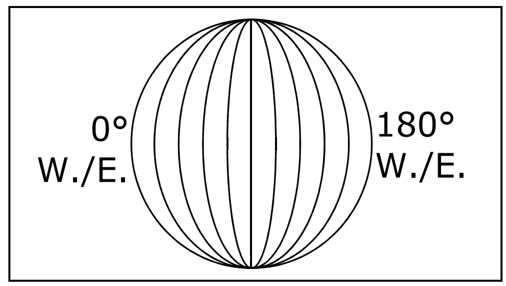


Figure 2. Lines of longitude.

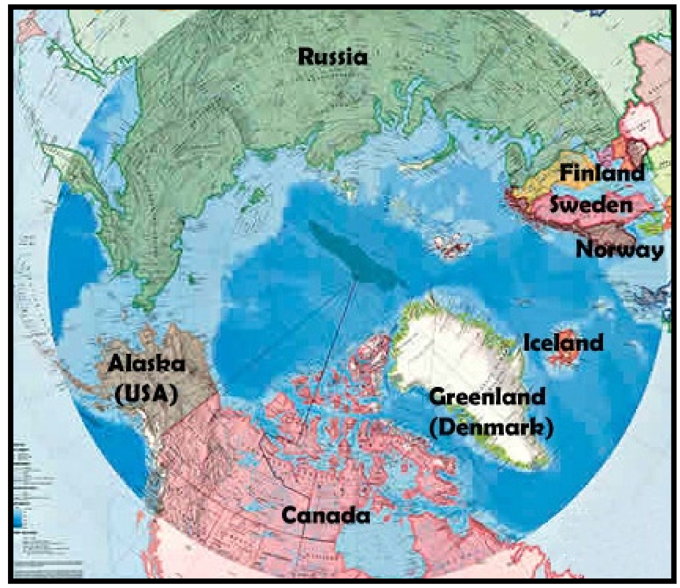
The Prime Meridian at Greenwich, England.

To specify the location of a particular place on the globe, the position north or south of the Equator is given first, and the location east or west of the Prime Meridian is given second, in the form, 71° 17' 26" N., 156° 47' 19" W. (Can you locate this community? Note that the lines on your map are 10 degrees apart, so you'll have to estimate a bit.) Sometimes you will not be given the seconds measurements, so the location can look like this: 71° 17' N., 156°

47' W. In some places in the module texts, you may find references to place names. Some of them will also include their locations in latitude and longitude so you can locate them on your maps, even if the place name does not appear.

Activity

Locate your community on your map and describe its location in degrees North and degrees East or West. Note that, because of the scale of your map, it is difficult to calculate minutes or seconds of latitude and longitude. Can you find the official location?



The Arctic Eight. (Source: Canada, MCR-001.)

A Brief Overview of the Geography of the Circumpolar North

Eight countries have territory within the circumpolar region north of 55° N., surrounding the Arctic Ocean. These are, from the Prime Meridian eastward: Norway (including Jan Mayen Island and the Svalbard Archipelago), Sweden, Finland, Russia, United States (Alaska), Canada, Denmark (Greenland, Faeroe Islands (Føroyar), and Iceland. Along the coasts of each of these countries lie the seas of the Arctic Ocean and the northern seas of the Atlantic or Pacific oceans.

Eastward from the Prime Meridian are the Norwegian Sea, Barents Sea, Kara Sea (Karskoye), Laptev Sea (Laptevykh), East Siberian Sea (Vostochnos-Siberskoye), Chukchi Sea, Sea of Okhotsk (not an Arctic Ocean sea), Bering Sea (a North Pacific sea), Gulf of Alaska (a North Pacific gulf), Beaufort Sea, Labrador Sea, Greenland Sea. Other smaller seas, straits and bays are also shown on your map.

There are a number of very large rivers that flow northward into the seas of the Arctic Ocean. Eastward from the Prime Meridian they are the Ob, Yenisey, Lena, and Kolyma in Russia, and the Mackenzie in Canada. The Yukon River is certainly a large northern river, but it empties into the Norton Sound of the Bering Sea. There are, of course a great many other rivers that flow northward; these are the really big ones.

You can also see on the map that there are a great many lakes in the region. The four largest are (eastward from the Prime Meridian) Ladoga (Ladozhskoye), Onega (Onezkskoye), Great Bear Lake, and Great Slave Lake.

There are a great many islands in the region. The largest, and the largest in the world, is Greenland, a province of Denmark. Iceland is the only northern island that is a sovereign nation. The other large ones belong to four of the Arctic Eight: the Svalbard island group belongs to Norway, Novaya Zemlya (New Land), Zemlya Frantsa-Iosifa (Franz Josef Land), Novosibirskiye Ostrova (New Siberian Islands), and Ostrov Vrangel (Wrangel Island) belong to Russia, St. Lawrence Island and Kodiak Island belong to Alaska (United States) and Banks Island and parts of Victoria Island belong to the Northwest Territories, while Baffin and Ellesmere islands belong to Nunavut (Canada). Most of the other islands of the Canadian Arctic Archipelago belong to Nunavut, as you can see from the map.

Activity

Locate the places named above. Identify the communities nearest or along each. Guestimate latitudes and longitudes for the communities.

Naming the Arctic and the Subarctic

The word "arctic" is derived from *arctos*, the Greek word for bear. In the northern sky, two constellations circle endlessly around the one fixed point in the heavens: Polaris, or the North Star. In Latin, the two constellations are called Ursa Major and Ursa Minor, the Great Bear and the Little Bear; they contain the familiar figures usually called in English the Big and Little Dippers. Most northern people have myths and legends about these groups of stars that gaze frostily down upon us in the long Arctic winter nights.

Activity

On a clear night, go out and identify Ursa Major and Ursa Minor. Find the "pointer stars" and use them to locate Polaris. Use an astronomy text or website if you need help. Try http://www.astropix.com/HTML/C_SPRING/URSAS.HTM *This image was taken from a southern perspective: in northern locations, Polaris will be just north of straight up.*

The Arctic regions have changed enormously, even in the past few tens of thousands of years since modern humans have been around. The last Ice Age ended only about 10,000 years ago, by which time people were beginning to grow crops and domesticate animals in parts of the Near East and Mesopotamia. At that time, Arctic conditions still existed in much more of the globe than at present. It is only during the latter part of the Pleistocene, or the last several hundred thousand years, that the tundra bioregion, or **biome**, began to appear in its present form. We know from studying pollen cores that major elements of the present tundra flora existed previously in places they are not found now but migrated ahead of advancing ice sheets or behind retreating ice sheets in Europe, eastern and central Russia, and Alaska

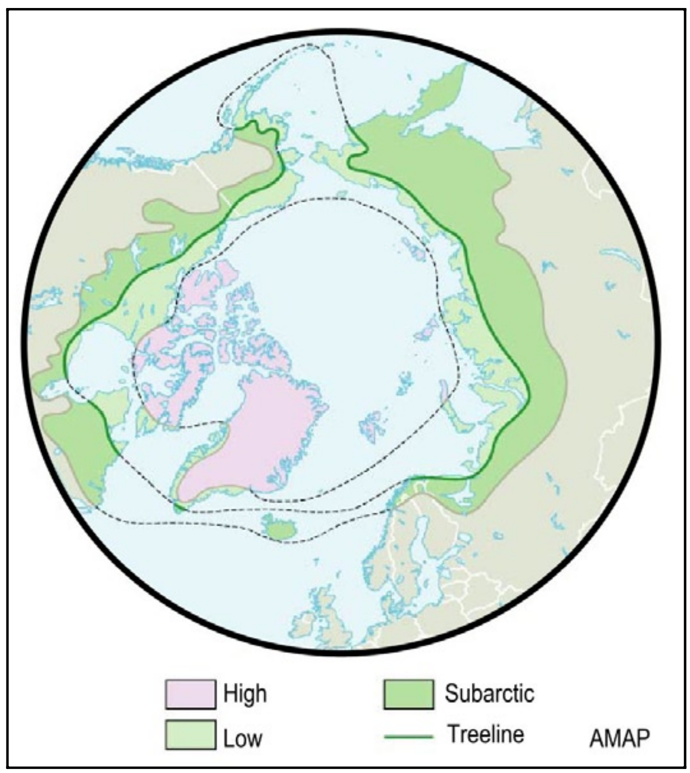


Figure 3. Map of the Circumpolar North showing the High and Low Arctic and the Subarctic. The treeline divides the two.

and Canada.

Activity

Has the biome changed in and around your community during your lifetime, or during the lifetime of older residents? If so, how has it changed and what do you think caused those changes? Remember, a biome includes all the natural plants and animals that are adapted to the conditions in which they live.

The Subarctic region lies to the south of the Arctic. Its name is formed by adding the Latin prefix, *sub*, meaning below, or underneath, to Arctic. The Subarctic lands are characterized chiefly by the presence of the boreal forest. As an easier climate than the Arctic, it is more populated and better served today by roads and other infrastructure than the Arctic.

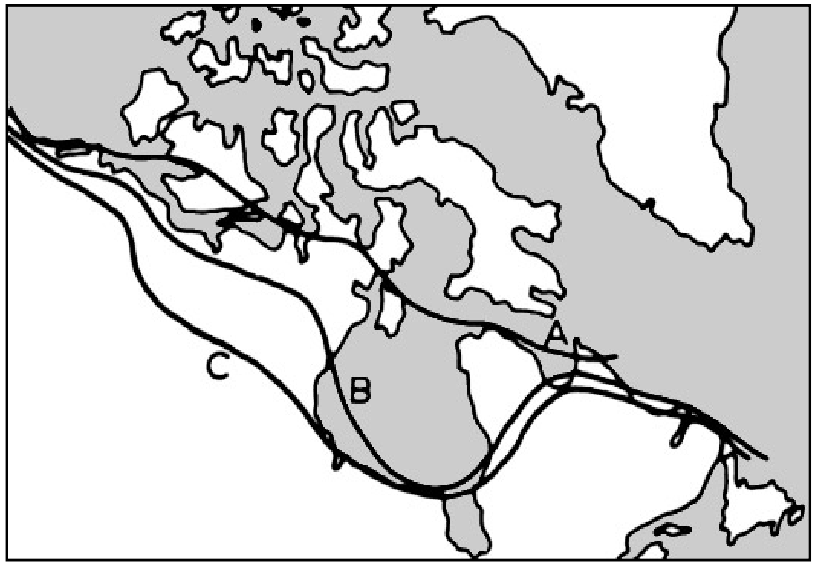


Figure 4: The 10º July isotherm. *The position of the July isotherm of 10ºC in Canada during the warmest year in the 1950s (A), and during the coldest year (C); (B) marks the average position (after Thomas, 1960). In northern Europe, a similar variation can be noted; in certain years, the July isotherm of 10ºC runs along lat. 62ºN., in very warm years along lat. 70ºN.*

Figure 5: North Slope of Alaska. *Low Arctic tundra with virtually closed cover by heath shrubs and sedges.*

Figure 6: High Arctic sedge meadows showing late-lying snow.

Geographic Zones

Dividing the North: The 10°C July Isotherm

It has become traditional to divide the terrestrial North into two zones (see the map, in Figure 3), the tundra (Figures 5 and 6) and the taiga, or boreal forest (Figure 7). It is usually accepted that the boundary between the two zones is the **timberline**, the line beyond which there are no significant forest or woodlands of coniferous trees. This idea was supported by a growing recognition that the timberline is related to climatic factors. Coniferous woodlands seldom extend into regions in which the mean (average) temperature for the whole of the warmest month of the year is less than 10ºC.

A line dividing these two zones on the basis of summer temperature is the 10°C July isotherm, which fairly closely approximates the location of the timberline (Figure 4). An **isotherm** is a line that joins places of similar temperature, in this case the places where the temperature averages 10°C in July. In this figure, we see it in North America, but it is important to realize that the line on the map actually represents a dynamic situation, and that the actual position of the isotherm fluctuates over time.

Figure 7: The taiga, or boreal forest. *The taiga is neither a dense nor a contiguous belt of forest around the globe, as it may appear. It is patchy, and large gaps exist interspersed with peatlands, lakes, and burned areas.*

The Arctic and Subarctic / Tundra and Taiga

In recent decades, we have begun to play down the importance of a clear delineation between the Arctic and the Subarctic. The mere presence or absence of trees is often of little significance in understanding the nature of a particular area or ecosystem. It is particularly important to be aware that there are treeless "tundra" areas in the higher mountains far to the south of the "true" Arctic. These alpine regions often have a great deal to tell us about the history of the Arctic environment. It is also important to be aware that many coastal treeless areas are very different from the regions more traditionally considered to be Arctic tundra. The Faeroe Islands and the central Aleutian Islands lie hundred of kilometres south of the Arctic ice pack, and winter temperatures drop only slightly below freezing.

Figure 8: Interior of Devon Island. Note the late-lying snow patches. The underlying soils are well drained and once the snow melts or evaporates, the moisture will be gone.

This brings us to a concern with efforts to delineate and subdivide the marine Arctic and Subarctic regions. Such definitions as there are involve oceanographic concerns such as the boundaries of water masses, the presence and duration of **sea ice** cover (see Figure 10), and the nature of ocean currents. Most Arctic marine scientists would consider most of the Arctic Ocean to be truly Arctic. The major exception would be in the Norwegian and Barents Sea region, where warm water from the tropical Atlantic penetrates deeply northward as the North Atlantic Drift. This also demonstrates the relationship between maritime and terrestrial conditions. The far northern part of Scandinavia has many aspects of a temperate region because of the climatic effects of this powerful ocean current. Conversely, the coast of eastern Canada and even New England in the United States is beset with **pack ice** each year, and the cold waters associated with the Labrador Current support many Arctic marine species far to the south of their usual range.

Dominant Features

Temperature

Most of the features that we think of as being typical of the Arctic physical environment are, directly or indirectly, the result of the Arctic climate. Everyone is aware of the Arctic as being a cold place, but it is equally important to recognize that it is a place where **seasonality**, the difference between summer and winter, is often very great (see Table 1). Arctic summers may be as warm or warmer than those of many coastal regions in western Europe. Winters in Arctic areas deep within continental landmasses are almost unbelievably cold, but winters in some marginally Arctic regions near marine coasts may have mean temperatures above freezing for even the coldest months. The nature of any particular northern area is likely to be largely dependent on the climate: the dominance of forest or tundra is closely associated with summer temperatures, for example.

As in the case of the biological features we will discuss in the next module, the state of water—whether it is a solid or a liquid—is the dominant defining feature of most of the physical features and processes that are specific to the North. Almost every important and defining characteristic of the North is a result of the presence of ice in some form—as **glaciers**, as sea and lake ice, as snow, or as buried ice in and under the surface of the soil. Almost equally important in understanding the northern physical environment is the fact that water in the North is constantly changing between states: from solid to liquid, or even gas (water vapor), and back again.

Region	Mean daily Jan. temp. (°C)	Mean daily July temp. (°C)	Mean annual total precip. (cm)	Mean annual snowfall (cm)
High Arctic	-33	5	10	70
Mid-Arctic	-29	7	20	110
Low Arctic	-29	9	15	80
High Subarctic	-29	13	35	190
Low Subarctic	-29	13	50	310
Atlantic Subarctic	-5 to -15	12-15	85-130	270-460
High Boreal	-23 to -25	13-16	40-70	160-260
Mid-Boreal	-20	17-19	50-80	120-280
Low Boreal	-13	18	95	250
Atlantic Boreal	-5 to -20	13-18	95-135	190-450

Table 1. Mean daily temperature and mean precipitation values in the wetland regions of Canada. Source: National Wetlands Working Group (1986b) (from Tarnocai & Zoltai 1988). *Precipitation is the second most important limiting factor for vegetation after temperature. This diagram shows mean temperature and precipitation values in the different wetland regions in northern Canada. Wetlands are defined as sites that remain moist or wet throughout the growing season and, in the Arctic, are almost invariably* ***peatlands*** *of some sort. As we move north, the Arctic generally becomes drier and wetlands become exceedingly rare.*

Activity

Determine the mean annual precipitation and mean annual temperature in your community or region. Try using an Internet search engine and typing in <"mean annual temperature" Norway> (or whatever your country is). Governments usually gather and publish this information.

Precipitation

We can make a fairly clear separation between two kinds of ice. The first is that which falls out of the sky as snow, and that forms seasonal snow cover, as well as glaciers and ice caps that can develop from it. The other kind of ice forms "on site" as seas, lakes, and rivers freeze over, and the ground freezes deeply. Ice that falls as precipitation (snow) is a part of the **hydrologic cycle**; that is, it originates as water vapour evaporated from the surface of oceans and lakes and ultimately returns to these water bodies, repeating the process indefinitely.

Snow forms in the upper atmosphere throughout the earth, but, in temperate and tropical regions, it usually melts before reaching the ground, and thus falls as rain. During much of the year in the North, all precipitation is in the form of snow. If the snow doesn't build up too deeply, and if the summers are warm enough, there are several snow-free months each year and living things can survive, grow, and reproduce. Throughout most of the North in present times, the presence of the **annual snow pack** is the normal situation.

Ice

Glaciation

If more snow falls than can melt each year, it begins to accumulate in deeper and deeper snow beds. This is particularly likely to happen in mountains, where the air is colder, where wind can blow the snow into deep drifts in hollows on the face of slopes, and where the sun may only shine for a short time each day if the slope faces to the northward. If, over the years, the snow becomes so deep that it compressed into ice, and begins to flow under its own weight, it becomes a **glacier**. Glaciers can expand to enormous size, and even cover continents during the long cold periods called **Ice Ages**. The processes occurring on glaciers, and especially within them, are very complicated. Their study is called glaciology.

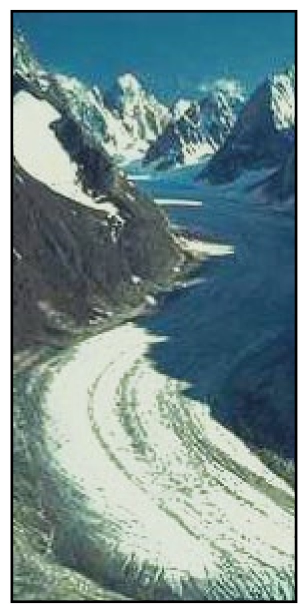


Figure 9: A mountain glacier in the Yukon.

Because glaciers are part of the hydrologic cycle, they are constantly in motion; immense masses of ice, flowing always toward the lowlands, and, ultimately, the sea. If the glacier ice reaches the sea before it melts, it breaks off into the sea in huge chunks called **icebergs**. Just as do liquid rivers, glaciers are continually sculpting the landscape. Much of the processes happen deep under the ice, and the results can only be seen during warmer periods of the earth's history (see Table 1: Glacial epochs, Module 3) such as the comparatively warm period we are living in now. Huge areas in the North owe their nature to the now-vanished glaciers that have carved the landscape into a wide array of easily identifiable features. The study of glaciated landscapes is called glacial geology. It involves not only the study of the erosion of the landscape by the moving ice, but also of the enormous deposits of material that are carried down from the mountains and left behind as the ice melts.

Activity

Determine whether your area was glaciated during the last ice age. If so, how did the ice affect the landscape? If not, how is your area different than areas that were glaciated? How do geographers determine whether particular regions were glaciated?

Sea Ice

Ice that forms on the surface of water bodies is very different from glacier ice. Because it mainly forms by freezing from the top down, there is a limit to how thick it may become. What is particularly important here is the fact that when water freezes into ice, it actually expands and becomes less dense, so that ice always floats on the surface of water. If this were not the case—if ice sank—lakes and rivers would fill up with ice, and nothing could live in them. Ice forms over much of the northern seas each winter. In the past few years, it has been easy to study the changes in the extent of sea ice from month to month, and from year to year, using satellite imagery. Studies of this sort can be very useful in learning about changes in the earth's climate. Ocean currents, wind, and tide affect sea ice (see Figure 10). As it moves under these forces, it becomes rugged and broken, and is then called **pack ice**. Much of the Arctic Ocean pack ice is carried in a slow clockwise circle, because of the water currents underneath it, and moves out of the Arctic Ocean off the east coast of Greenland into the western North Atlantic Ocean, where it may extend southward to the Gulf of Maine. In the eastern North Atlantic, by contrast, pack ice seldom reaches even the northernmost shores of Scandinavia, and ships can travel to the Russian Arctic port of Murmansk throughout the year. Pack Ice forms south of the Bering Strait in the Bering Sea, and in the Sea of Okhotsk between Kamchatka Peninsula and the coast of the Russian Far East.

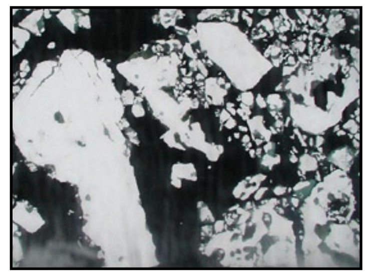


Figure 10: Sea ice.

Figure 11: Ice scouring of the shoreline in the Mackenzie River delta, Northwest Ter-ritories, Canada. *In such north-flowing rivers, rearrangement of much of the delta annually is normal. See how the trunks of the white spruce (Picea glauca) trees have been ripped apart by ice. Small islands and gravel/sand bars within the delta can easily be stripped of vegetation or be completely demolished by the combination of ice and water. Nevertheless, plant regrowth in these disturbed areas can be quite rapid. Willows and grasses typically grow in the most frequently disturbed places.*

Lake and River Ice

Lakes and rivers in the North are often frozen for many months of each year. Only the largest lakes, however, develop anything approaching true pack ice. During winter, most northern rivers have a flat, smooth, ice cover. But when **spring breakup** arrives, huge masses of ice are carried downstream by currents, where they may pile up as massive ice dams, flooding enormous areas, eroding river banks (see Figure 11) and even causing major rivers to alter their channels. This is particularly true in the many large rivers that flow northward into the Arctic Ocean, where melting may occur weeks earlier in their upstream (southern) portions than at their mouths. In winter, the flow of even fairly large rivers may be reduced to very little, since the headwater streams are often frozen solid. Fish may survive in isolated pools that are all that remains of liquid water in the river. Smaller rivers may build up tremendous quantities of ice in their streambeds. This **overflow ice** may last through much of the following summer.

Permafrost

Characteristics

When the mean annual temperature of an area is below freezing, the ground that freezes during the winter may not entirely thaw during the succeeding summer. This perennially frozen ground is called **permafrost**. Permafrost is defined as a **substrate** that is at or below 0°C for more than two years. It is important in terms of ecosystem structure and function and affects many landscape processes at a variety of scales. Frozen ground is a critical consideration in any overview touching on Arctic geomorphology and even has its own sub-field, periglacial geomorphology.

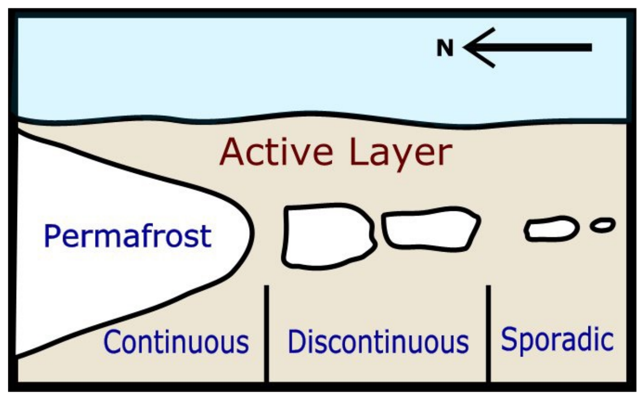


Figure 12: Idealized latitudinal gradient of permafrost. *This idealized cross-section shows changes in permafrost and in the active layer from north to south.*

Permafrost is particularly deep in parts of northeastern Asia and northern Alaska. Here, winters are extremely cold, and a covering of glaciers never insulated the ground during the Ice Ages. The frozen ground may extend many hundreds of meters deep. In areas where there is a deep layer of frozen sediments, such as sea floor, river deposits, and dunes, various processes may allow the buildup of great amounts of nearly pure ice in the soil. If this ice should melt, from rising sea level or changing climate, for example, huge land areas could sink beneath the sea and vanish almost without a trace. This has occurred in the areas that are now the Laptev and East Siberian seas, north of Siberia.

Extent

Permafrost underlies the surface of most Arctic regions (see Figure 13), the exceptions being coastal areas where winters are relatively mild. Permafrost has enormous effects on the northern environment. It keeps water from draining away through the soil, and this is largely responsible for the fact that much of the tundra is actually wetland. The creation and destruction of permafrost is often a highly dynamic situation; it can easily become destabilized by human activity and cause great destruction to buildings, pipelines, and roads built upon it. The melting out of ice-rich ground can also occur naturally; in either case, the result is known as **thermokarst**.

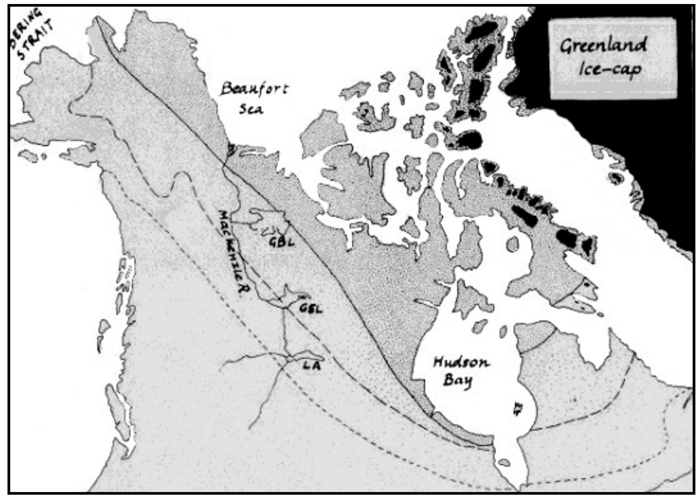


Figure 13: Permafrost zones in North America. The Arctic ice caps are shown in black with the three permafrost zones—continuous, discontinuous, and sporadic—shown from north to south.

Activity

Determine whether your area is over permafrost and, if so, whether it is continuous, discontinuous, or sporadic. What effects has permafrost had on construction in your community?

Geomorphological Features

Many of the processes that build up ice in the soil lead to various kinds of patterns on the surface of the ground. Among the commonest are ice-wedge polygons, which are found almost everywhere in the tundra areas of Alaska, western Canada, and Siberia. Perhaps the most spectacular of permafrost features are small, steep-sided hills rising above otherwise flat tundra. These are called **pingos**, and they have a very interesting origin (see "Pingo Origin," Supplementary Reading).

Figure 14: Pingo in Central Yamal. *Pingos are larger versions of the palsas (ice-cored mounds) seen in many Subarctic areas, including northern Finland, that do not necessarily have permafrost but have an active free-thaw cycle that can rework both organic and mineral materials into small hills. Pingo is an Inuktitut word.*

There are many kinds of **patterned ground**, and the different kinds are often distributed according to the climate and depth of permafrost (see Figure 15). In particular, peatlands near the borders of permafrosted areas often display a variety of interesting characteristics and formations. Other kinds of patterned ground are associated with intense freeze-thaw cycles, where the variation in temperature is more important than the actual annual mean temperature. Alpine slopes often show a wide variety of networks and rings of stones and frost-shattered rubble.

Figure 15: Low-centred polygons in the northern Yukon. *This is a form of patterned ground.*

Freeze-thaw cycles, often in conjunction with underlying permafrost and aided by gravity, can be the mechanism for moving large quantities of soil and rubble rapidly downslope. The general name for this process is **gelifluction** (movement of frozen material, which can be seen as **solifluction lobes**). Gelifluction is responsible for the surface features of many northern landscapes.

A particularly interesting feature of permafrost is the fact that it may preserve organic material that would otherwise decompose and be lost. Sometimes even nearly intact bodies of large mammals such as woolly mammoths are found, with hair, meat, and even stomach contents still "fresh." There are serious suggestions that it might be possible to clone new individuals of these extinct animals, although the possibility is faint, and it will be far in the future, if it occurs at all.

Subsurface Geology

Bedrock

Although the climate and surficial geology of the North have many distinctive features, the underlying bedrock is usually very similar to that of temperate and tropical parts of the earth. Much of this similarity is related to the processes of **plate tectonics**, which is often associated with what is popularly called continental drift. Many Arctic lands were once located in more temperate regions. It is possible to find fossils from tropical forests near the edges of the Greenland Ice Cap. Another factor here is that the earth has been warmer throughout most of its history than it is at present. There is some indication that dinosaurs, which presumably needed a reasonably warm climate to survive, lived at Arctic latitudes some 100 million or more years ago. The accompanying diagram (Fig. 16) shows the locations of the various physiographic regions of the Circumpolar North.

Figure 16: Physiographic regions of the Circumpolar North. The shields (1) are shown in pink, the flat-bedded plains and plateaus (2) in white, and folded mountains (3) in green. Source: Sater, Ronhovde, and Van Allen, 1971, fig. 44. *The geology of the Arctic is not uniquely arctic since the earth's crust has migrated through geologic time.*

The Shield Regions

The Circumpolar North contains three ancient shield rocks (see Figure 16); the largest is the Canadian-Greenland Shield, which makes up much of the eastern two-thirds of Canada. The others are the Baltic or Scandinavian Shield and the Angara Shield in north-central Siberia. Although this kind of geological formation is not causally related to Arctic conditions, the presence of shields is important, since they are often rich in various important ores. Much of the pressure to exploit Arctic resources will continue to come from a desire to mine these ore bodies. The Arctic has also proven to be rich in petroleum resources, and the production of oil has driven much of the recent development of the North.

Activity

Determine what mineral resources, if any, have been found in your area. Has the exploitation of minerals affected your area? If so, how?

Volcanism

There are a few places in the North in which modern tectonic processes interact with specifically northern geological features such as glaciers. In Iceland, volcanoes sometimes form under its ice caps, melting vast amounts of glacier ice and causing enormous floods. Volcanoes can quickly alter entire landscapes by eliminating existing soil cover and plant and animal life. The Kamchatka Peninsula is also located on the Pacific "Ring of Fire," and experiences earthquakes and volcanoes regularly. Earthquakes in Alaska have triggered major avalanches and have caused glaciers to do strange and unexpected things.

This is but a short introduction to the incredibly complex shapes and processes of Arctic and Subarctic regions. Further information can be found in the following supplementary readings.

Supplementary Readings/Materials

Bliss, L.C. 2000. "Arctic Tundra and Polar Desert Biome." In M.G. Barbour and W.D. Billings (eds.) *North American Terrestrial Vegetation*, 2nd ed., Cambridge: Cambridge University Press, pp. 1–40.

Bone, R.M. 1992. *The Geography of the Canadian North*. Oxford: Oxford University Press.

CAFF. 2001. "Humans." In P. Kankaanpää et al. (eds.) *Arctic Flora and Fauna: Status and Conservation*. Helsinki: Edita. pp. 51-76.

Crampton, C.B. 1977. "A Study of the Dynamics of Hummocky Microrelief in the Canadian North." *Canadian Journal of Earth Sciences* 14, pp. 639–649.

Damas, D (Ed.) 1984. *Handbook of North American Indians. Vol. 5. Arctic*. Washington, DC: Smithsonian Institution.

French, H. M. and O. Slaymaker (eds.) 1993. *Canada's Cold Environments*. Montreal: McGill Queen's University Press.

Haq, B.U. And F.W.B. Va Eysinga. 1987. *Geological Time Tabl*e. Amsterdam: Elsevier Science.

Harris, S.A. et al. 1988. *Glossary of Permafrost and Related Ground-ice Terms*. Technical Memorandum No. 142. Ottawa: National Research Council of Canada.

Helm, J. (Ed.) 1981. *Handbook Of North American Indians. Vol. 6. Subarctic*. Washington, DC: Smithsonian Institution.

Hustich, I. 1979. "Ecological Concepts and Biogeographical Zonation in the North: The Need for a Generally Accepted Terminology." *Holarctic Ecology* 2: 208–217.

Krupnik, I. 1993. *Arctic Adaptations: Native Whalers and Reindeer Herders of Northern Eurasia*. Hanover, NH: University Press of New England.

Meldgaard, M. 2001. "Historical Ecology." In E.W. Born and J. Böcher (eds.) *The Ecology of Greenland*. Nuuk: Ilinniusiorfik. pp. 318–330.

Nuttall, M. And T.V. Callaghan (eds.) 2000. T*he Arctic: Environment, People, Policy*. Amsterdam: Harwood Academic Publishers.

Osterkamp, T.E., et al. 2000. "Observations of Thermokarst and its Impact on Boreal Forests in Alaska, U.S.A." *Arctic, Antarctic & Alpine Research* 32: 303–315.

Pingo Origin. n.d. *Simply Science*. Web document. Inuvik, NT: Aurora Research Institute. Available online at http://collections.ic.gc.ca/simply_science/scirep1k.htm

Romanovskii, N.N., et al. 1996. "Periglacial Processes as Geoindicators in the Cryolithozone." In A.R. Berger and W.J. Iams (eds.) *Geoindicators: Assessing Rapid Environmental Changes in Earth Systems*. Rotterdam: A.A. Balkema. pp. 47-68.

Sage, B. (Ed.) 1986. *The Arctic and its Wildlife*. New York: Facts On File. pp. 118-154.

Sater, John E., A. G. Ronhovde, and L. C. Van Allen. 1971. *Arctic Environment and Resources*. Washington, DC: Arctic Institute of North America.

Sharp, R.P. 1988. *Living Ice: Understanding Glaciers and Glaciation*. Cambridge: Cambridge University Press.

Tarnocai, C. and S.C. Zoltai. 1988. "Wetlands of Arctic Canada." In C.D.A. Rubec (ed.) *Wetlands of Canada*. Montreal: Polyscience.

Kious, W. Jacquelyne and Robert I. Tilling. 1996. *This Dynamic Earth: The Story of Plate Tectonics*. Washington, DC: US Department of the Interior, US Geological Survey. Available online at http://pubs.usgs.gov/publications/text/dynamic.html

Wielgolaski, F.E. (ed.) *Nordic Mountain Birch Ecosystems*. Paris: UNESCO.

Williams, P. J. and M. W. Smith. 1989. *The Frozen Earth: Fundamentals of Geocryology*. Cambridge: Cambridge University Press.

Woo, M.-K. 2000. "Permafrost and hydrology." In M. Nuttall and T.V. Callaghan (eds.) *The Arctic: Environment, People, Policy*. Amsterdam: Harwood Academic Publishers. pp. 57-96.

Young, S.B. 1989. *To the Arctic: An Introduction to the Far Northern World*. New York: Wiley Science.

Study Questions

- Has the biome changed in and around your community during your own lifetime, or during the lifetimes of older residents? If so, how has it changed, and what do you think are the causes of those changes? Remember, a biome includes all the natural plants and animals that are adapted to the conditions in which they live.
- Briefly describe the geography and general features of the Circumpolar North.
- Describe, in general terms, what natural forces combined to give the Circumpolar North its present geography and physical features.
- Briefly describe the geographic area included in the Circumpolar World and list the Arctic Eight.
- Define and explain the significance of the terms: tundra, taiga (boreal forest) timberline, Arctic and Subarctic, and North Pole.
- What is the importance of ice, its formation, persistence, and melting in the physical processes of the north?
- Describe and explain the importance of water, as both liquid and ice, in the physical processes of the northern landscape.
- Define permafrost and describe its influence on the northern landscape.
- Describe ice-wedge polygons, pingos, peatlands, and volcanism.
- Define and explain the significance of the terms: glaciation, permafrost, sea ice, palsa, and pingo.

Glossary

Annual snow pack: Snow that accumulates over the winter and melts or evaporates during the next summer (as opposed to snow that accumulates over many seasons and eventually forms glaciers).

Glaciers: Glaciers are large, moving masses of ice formed over land through the accumulation, compaction, and recrystallization of snow. Low temperatures, which allow the snow to accumulate over many years, are needed for the formation and persistence of glaciers. Movement is downslope or outward in all directions because of the stresses caused by the weight of ice as it accumulates. Glaciers may terminate on land as rivers, in lakes, or in the sea.

Hydrologic Cycle: This is the process by which water is recycled through the environment. Water in the air falls as precipitation. The water then infiltrates the earth's water tables or flows across the surface or below it as run-off. Transpiration by plants and evaporation of water returns the water to the air. Over seas and oceans, there is no infiltration or run-off. The cycle is much simpler: precipitation falls and the oceans evaporate.

Ice Ages: These are recurring periods of extensive glaciation that covered much of North America, Asia, and Europe. At present, glaciation covers about 10% of the earth's surface, mostly in Greenland and the Antarctic. During the last Ice Age, glaciers extended south to cover all of Canada parts of the northern United States and much of northern Europe and Russia. Much of Alaska and eastern Russia remained ice-free.

Icebergs: Large blocks of ice that break away from the edges of glaciers, in a process known as calving, and fall into the sea. The parent glaciers may be flowing into the sea or may be floating ice shelves (large floating glaciers that extend beyond the coastline). Less commonly, icebergs may emerge from below the sea as a result of forces acting on part of a glacier protruding beneath the surface. The major sources of icebergs in the North are: the Jacobshavn and other fast flowing glaciers in Greenland, the Ward Hunt Ice Shelf (Ellesmere Island), Svalbard, Novaya Zemlya, and the Columbia Glacier in southern Alaska.

Overflow Ice: Quantities of river ice that pile up along riverbeds during spring flooding and breakup. This ice, in sufficient quantities, may persist until late in the summer.

Pack Ice: Sea ice that has been broken and piled together by the action of wind, currents, and tide. Pack ice can be quite thick and rugged and may have crevasses and open water, making travel difficult.

Peatlands: Extensive wetland areas of living, decomposed, and partly decomposed organic material called peat, usually sphagnum moss, together with other plants. These plants may include grasses, sedges, shrubs, and trees such as willows and black spruce. Peat is formed by the slow decay of vegetation under anaerobic (oxygen-deficient) conditions. Peatlands are a common feature of the taiga and extend into the tundra. They began forming with the retreat of the Late Wisconsinan Ice Sheet, about 10,000 years ago. Peatlands are typically about 90 per cent water and are nourished almost entirely by precipitation. There are generally three layers: the surface; a continuous carpet of sphagnum which supports other plant life, an underlying layer of partially decomposed young peat, and a lower layer, of varying thickness, of dark, dense, putty-like mature peat.

Pingo: Dome-shaped mound found in permafrost areas, consisting of a layer of soil covering a large core of ice.

Plate Tectonics: A theory that proposes to account for the physical qualities of the Earth's surface. The fundamental premises of plate tectonics are that the Earth's surface is covered by a series of crustal plates; the ocean floors are continually, moving, spreading from the centre, sinking at the edges, and being regenerated; convection currents beneath the plates move the crustal plates in different directions. The source of heat driving the convection currents is radioactivity deep in the Earth's mantle (see Kious and Tilling, 1996).

Sea Ice: Ice that forms on the surface of the sea (as opposed to icebergs, which form on land, and river ice that is deposited in the sea during spring breakup).

Spring Breakup: This term generally refers to the annual breakup of river ice.

Substrate: A layer of soil, earth, clay, or rock lying beneath the surface.

Thermokarst: Topography in which melted permafrost has produced hollows, hummocks, and other features.

If you need explanations of other terms that appear in this module, ask your instructor, or consult an encyclopaedia, dictionary, or textbook of geology, physical geography, or geomorphology.

Gazetteer

Local language name	English name
Føroyar	Faeroe Islands
Zemlya Frantsa-Iosifa	Franz Josef Land (island group)
Novosibirskiye Ostrova	New Siberian Islands (island group)
Ostrov Vrangel	Wrangel Island
Karskoye More	Kara Sea
Laptevykh More	Laptev Sea
Severnaya Zemlya	Northern Land (island group)
Vostochnos-Siberskoye More	East Siberian Sea