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The Arctic

The Arctic is the area of the far north that is characterized by distinctively polar conditions of climate, plant and animal life, and other physical features. The term is derived from the Greek *arktos* ("bear"), referring to the northern constellation of the Bear. It has sometimes been used to designate the area within the Arctic Circle—a mathematical line that is drawn at latitude 66°30′ N, marking the southern limit of the zone in which there is at least one annual period of 24 hours during which the sun does not set and one during which it does not rise. This line, however, is without value as a geographic boundary, since it is not keyed to the nature of the terrain.

While no dividing line is completely definitive, a generally useful guide is the irregular line marking the northernmost limit of the stands of trees. The regions north of the tree line include Greenland (Kalaallit Nunaat), Svalbard, and other polar islands; the northern parts of the mainlands of Siberia, Alaska, and Canada; the coasts of Labrador; the north of Iceland; and a strip of the Arctic coast of Europe. The last-named area, however, is classified as subarctic because of other factors.

Conditions typical of Arctic lands are extreme fluctuations between summer and winter temperatures; permanent snow and ice in the high country and grasses, sedges, and low shrubs in the lowlands; and permanently frozen ground (permafrost), the surface layer of which is subject to summer thawing. Three-fifths of the Arctic terrain is outside the zones of permanent ice. The brevity of the Arctic summer is partly compensated by the long daily duration of summer sunshine.

International interest in the Arctic and subarctic regions has steadily increased during the 20th century, particularly since World War II. Three major factors are involved: the advantages of the North Pole route as a shortcut between important centres of population, the growing realization of economic potentialities such as mineral (especially petroleum) and forest resources and grazing areas, and the importance of the regions in the study of global meteorology.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* sections 511, 961, 964, and 973, and the *Index.*

The article is divided into the following sections:

Physical geography

THE ARCTIC OCEAN

The Arctic Ocean and its marginal seas (the Chukchi, East Siberian, Laptev, Kara, Barents, White, Greenland, and Beaufort; some oceanographers also include the Bering and Norwegian Seas) are the least-known basins and bodies of water in the world ocean owing to their remoteness, hostile weather, and perennial or seasonal ice cover. This is changing, however, because the Arctic may exhibit a strong response to global change and may be capable of initiating dramatic climatic changes through alterations induced in the oceanic thermohaline circulation by its cold, southward-moving currents or through its effects on the global albedo resulting from changes in its total ice cover.

The Arctic Ocean is by far the smallest of the Earth's oceans, having only a little more than one-sixth the area of the next largest, the Indian Ocean. Its area of 5,440,000 square miles (14,090,000 square kilometres), however, is five times larger than that of the largest sea, the Mediterranean. The deepest sounding obtained in Arctic waters is 18,050 feet (5,502 metres), but the average depth is only 3,240 feet.

Distinguished by several unique features, including a cover of perennial ice and almost complete encirclement by the landmasses of North America, Eurasia, and Green-


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Minimum extent of sea ice
Dams
Glaciers
Swamps and marshes
Points of interest
Spot elevations in metres (1 m = 3.28 ft)
Scale 1: 30,694,000
1 inch equals approx. 484 miles
0 100 200 300 400 mi
0 200 400 600 km
Azimuthal Equal-Area Projection
105°
90°E
75°
60°
150°
165°
180°
165°
150°
135°
120°
105°
90°W
75°
60°
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CENTRAL SIBERIAN PLATEAU
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UNITED STATES
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land, the north polar region has been a subject of speculation since the earliest concepts of a spherical Earth. From astronomical observations, the Greeks theorized that north of the Arctic Circle there must be a midnight sun at midsummer and continual darkness at midwinter. The enlightened view was that both the northern and southern polar regions were uninhabitable frozen wastes, whereas the more popular belief was that there was a halcyon land beyond the north wind where the sun always shone and people called Hyperboreans led a peaceful life. Such speculations provided incentives for adventurous men to risk the hazards of severe climate and fear of the unknown to further geographic knowledge and national and personal prosperity.

This section describes the Arctic Ocean and its marginal seas, discusses the physical characteristics and origin of the ocean floor, and outlines what is known about its physical oceanography and sea-ice dynamics.

Origin. The tectonic history of the Arctic Basin in the Cenozoic Era (66.4 million years ago to the present) is largely known from available geophysical data. It is clear from aeromagnetic and seismic data that the Eurasia Basin was formed by seafloor spreading along the axis of the Nansen Cordillera (Nansen Ridge). The focus of spreading began under the edge of the Asian continent, from which a narrow splinter of its northern continental margin was separated and translated northward to form the present Lomonosov Ridge. The origin of the Amerasia Basin is far less clear. Most researchers favour a hypothesis of opening by rotation of the Arctic-Alaska lithospheric plate away from the North American Plate during the Cretaceous Period (144 to 66.4 million years ago). Better understanding of the origin of the Arctic Ocean's basins and ridges is critical for reconstructing the paleoclimatic evolution of the ocean and for understanding its relevance to global environmental changes.

The sediments of the Arctic Ocean floor record the natural variability of the physical environment, climate, and ecosystems on time scales determined by the ability to sample them through coring and at resolutions determined by the rates of deposition. Of the hundreds of sediment corings taken, only four penetrate deeply enough to predate the onset of cold climatic conditions. The oldest (approximately 80-million-year-old black muds and 67-million-year-old siliceous oozes) document that at least part of the Arctic Ocean was relatively warm and biologically productive prior to 40 million years ago. Unfortunately, none of the available seafloor cores have sampled sediments from the time interval between 35 to 3 million years ago. Thus there is no direct evidence of the onset of cooling that produced the present perennial ice cover. All the other cores collected contain younger sediments that were deposited in an ocean dominated by ice cover. They contain evidence of terrigenous (land-derived) sediments formed by bordering glaciers and transported by sea ice.

Topography of the ocean floor. From the late 19th century, when the Norwegian explorer Fridtjof Nansen first discovered an ocean in the central Arctic, until the middle of the 20th century, it was believed that the Arctic Ocean was a single large basin. Explorations after 1950 revealed the true complex nature of the ocean floor. Rather than being a single basin, the Arctic Ocean consists of two principal deep basins that are subdivided into four smaller basins by three transoceanic submarine ridges. The central of these ridges extends from the continental shelf off Ellesmere Island to the New Siberian Islands, a distance of 1,100 miles (1,770 kilometres). This enormous submarine mountain range was discovered by Soviet scientists in 1948–49 and reported in 1954. It is named the Lomonosov Ridge after the scientist, poet, and grammarian Mikhail Vasilyevich Lomonosov.

Eurasia Basin and Amerasia Basin

The Lomonosov Ridge has an average relief of about 10,000 feet and divides the Arctic Ocean into two physiographically complex basins. These are referred to as the Eurasia Basin on the European side of the ridge and the Amerasia Basin on the American side. The Lomonosov Ridge varies in width from 40 to 120 miles, and its crest ranges in depth between 3,100 and 5,400 feet.

The Eurasia Basin is divided into two smaller basins by a trans-Arctic Ocean extension of the Mid-Atlantic Ridge. This Arctic segment of the global ridge system is called the Nansen Cordillera, which was named for Fridtjof Nansen after its discovery in the early 1960s. It is a locus of active ocean-floor spreading, with a well-developed rift valley and flanking rift mountains. The Fram Basin lies between the Nansen Cordillera and the Lomonosov Ridge at a depth of 14,070 feet. The geographic north pole is located over the floor of the Fram Basin near its juncture with the Lomonosov Ridge. The smallest of the Arctic Ocean subbasins, called the Nansen Basin, lies between the Nansen Cordillera and the Eurasian continental margin and has a floor depth of 13,800 feet.

The Amerasia Basin is divided into two unequal basins by the Alpha Cordillera (Alpha Ridge), a broad, rugged submarine mountain chain that extends to within 4,600 feet of the ocean surface. The origin of this seismically inactive ridge, which was discovered in the late 1950s, is undetermined and holds the key to understanding the origin of the Amerasia Basin. The Makarov Basin lies between the Alpha Cordillera and the Lomonosov Ridge, and its floor is at a depth of 13,200 feet. The largest subbasin of the Arctic Ocean is the Canada Basin, which extends approximately 700 miles from the Beaufort Shelf to the Alpha Cordillera. The smooth basin floor slopes gently from east to west, where it is interrupted by regions of sea knolls. The average depth of the Canada Basin is 12,500 feet.

The Arctic Ocean is unique in that nearly one-third of its total area is underlain by continental shelf, which is asymmetrically distributed around its circumference. North of Alaska and Greenland the shelf is 60 to 120 miles wide, which is the normal width of continental shelves. In contrast, the Siberian and Chukchi shelves off Eurasia range from 300 to 1,100 miles in width. The edge of the continental margin is dissected by numerous submarine valleys. The largest of these, the Svyataya Anna Trough, is 110 miles wide and 300 miles long.

Oceanography. Several factors in the Arctic Ocean make its physical, chemical, and biological processes significantly different from those in the adjoining North Atlantic and Pacific Oceans. Most notable is the covering ice pack, which reduces the exchange of energy between ocean and atmosphere by about 100 times. In addition, sea ice greatly reduces the penetration of sunlight needed for the photosynthetic processes of marine life and impedes the mixing effect of the winds. A further significant distinguishing feature is the high ratio of freely connected shallow seas to deep basins. Whereas the continental shelf on the North American side of the Arctic Ocean is of a normal width (approximately 40 miles), the Eurasian sector is hundreds of miles broad, with peninsulas and islands dividing it into five main marginal seas: the Chukchi, East Siberian, Laptev, Kara, and Barents. These marginal seas occupy 36 percent of the area of the Arctic Ocean, yet they contain only 2 percent of its water volume. With the exception of the Mackenzie River of Canada and the Colville River of Alaska, all major rivers discharge into these marginal shallow seas. The combination of large marginal seas, with a high ratio of exposed surface to total volume, plus large summer inputs of fresh water, greatly influences surface-water conditions in the Arctic Ocean.

As an approximation, the Arctic Ocean may be regarded as an estuary of the Atlantic Ocean. The major circulation into and from the Arctic Basin is through a single deep channel, the Fram Strait, which lies between the island of Spitsbergen and Greenland. A substantially smaller quantity (approximately one-quarter of the volume) of water is transported southward through the Barents and Kara seas and the Canadian Archipelago. The combined outflow to the Atlantic appears to be of major significance to the large-scale thermohaline circulation and mean temperature of the world ocean with a potentially profound impact on global climate variability (see Figure 1). Warm waters entering the Greenland/Iceland/Norwegian (GIN) Sea plunge downward when they meet the colder waters from more northerly produced fresh water and southward-drifting ice. An increase in this freshwater and ice export could shut down the thermocline convection in the GIN Sea; alternatively, a decrease in ice export might allow for convection and ventilation in the Arctic Ocean itself.

Low-salinity waters enter the Arctic Ocean from the Pacific through the shallow Bering Strait. Although the mean inflow seems to be driven by a slight difference in sea level between the North Pacific and Arctic oceans, a large source of variability is induced by the wind field, primarily large-scale atmospheric circulation over the North Pacific. The amount of fresh water entering the Arctic Ocean is about 2 percent of the total input. Precipitation is believed to be about 10 times greater than loss by evaporation, although both figures can be only roughly estimated. Through all these various routes and mechanisms, the exchange rate of the Arctic Ocean is estimated to be approximately 210

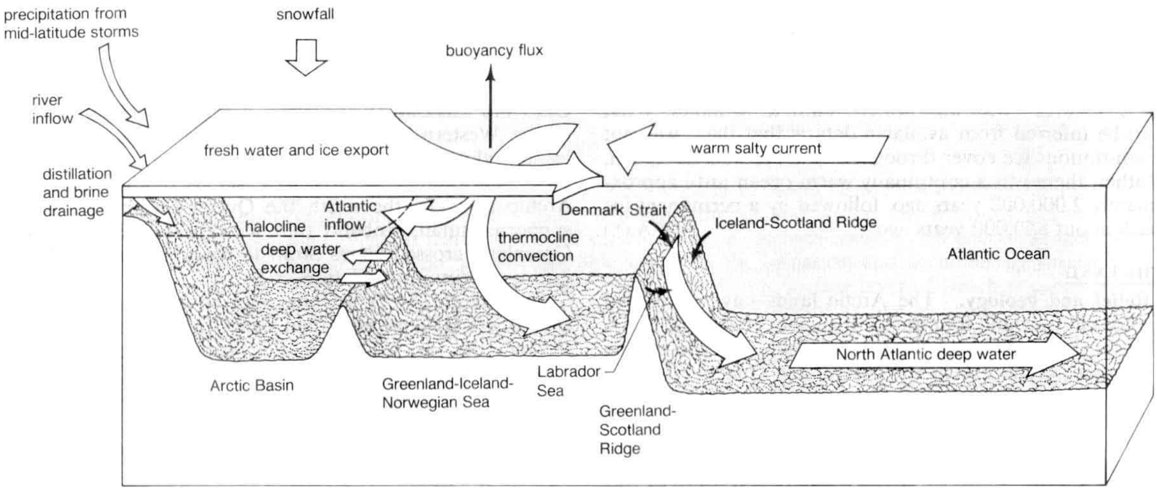


Figure 1: The possible damping influence of freshwater and ice export from the Arctic Ocean on convection in the Greenland/Iceland/Norwegian Sea.

From N. Untersteiner and E.C. Carmack, World Climate Research Programme, *Sea-Ice and Climate: Report of the Fourth Session of the Working Group on Sea-Ice and Climate* (July 1990)

million cubic feet (5.9 million cubic metres) per second.

All waters of the Arctic Ocean are cold. Variations in density are thus mainly determined by changes in salinity. Arctic waters have a two-layer system: a thin and less dense surface layer is separated by a strong density gradient, referred to as a pycnocline, from the main body of water, which is of quite uniform density. This pycnocline restricts convective motion and the vertical transfer of heat and salt, and hence the surface layer acts as a cap over the larger masses of warmer water below.

Major water masses

Despite this overall similarity in gross oceanographic structure, the waters of the Arctic Ocean can be classified into three major masses and one lesser mass.

1. The water extending from the surface to a depth of about 650 feet is the most variable and heterogeneous of all that in the Arctic. This is because of the latent heat of freezing and thawing; brine addition from the process of ice freezing; freshwater addition by rivers, ice melting, and precipitation; and great variations in insolation (rate of delivery of solar energy) and energy flux as a result of sea-ice cover. Water temperature may vary over a range of 7° F (4° C) and salinity from 28 to 34 grams of salt per kilogram of seawater (28 to 34 parts per thousand [‰]).

2. Warmer Atlantic water everywhere underlies Arctic surface water from a depth of about 650 to 3,000 feet. As it cools it becomes so dense that it slips below the surface layer on entering the Arctic Basin. The temperature of this water is about 34° to 37° F (1° to 3° C) as it enters the basin, but it is gradually cooled so that by the time it spreads to the Beaufort Sea it has a maximum temperature of 32.9° to 33.1° F (0.5° to 0.6° C). The salinity of the Atlantic layer varies between 34.5 and 35‰.

3. Bottom water extends beneath the Atlantic layer to the ocean floor. This is colder than the Atlantic water (below 32° F, or 0° C) but has the same salinity.

4. An inflow of Pacific water can be observed in the Amerasia Basin but not in the Eurasia Basin. This warmer and fresher water mixes with colder and more saline water in the Chukchi Sea, where its density enables it to flow as a wedge between the Arctic and Atlantic waters. The Pacific water, by the time it reaches the Canada Basin, has a temperature range of 31.1° to 30.8° F (−0.5° to −0.7° C) and salinities between 31.5 and 33‰.

Arctic waters are driven by the wind and by density differences. The net effect of tides is unknown but could have some modifying effect on gross circulation.

Surface-water movement

The motion of surface waters is best known from observations of ice drift. The most striking feature of the surface circulation pattern is the large clockwise gyre (circular motion) that covers almost the entire Amerasia Basin. Fletcher's Ice Island (T-3) made two orbits in this gyre over a 20-year period, which is some indication of the current speed. The northern extremity of the gyre bifurcates and jets out of the Greenland-Spitsbergen passage as the East Greenland Current, attaining speeds of 6 to 16 inches per second. Circulation of the shallow Eurasian shelf seas seems to be a complex series of counterclockwise gyres, complicated by islands and other topographic relief.

Circulation of the deeper Atlantic water is less well known. On entering the Eurasia Basin, the plunging Greenland Sea water appears to flow eastward along the edge of the continental margin until it fans out and enters the Amerasia Basin along a broad front over the crest of the Lomonosov Ridge. There seems to be a general counterclockwise circulation in the Eurasia Basin and a smaller clockwise gyre in the Beaufort Sea. Speeds are slow—probably less than two inches per second.

The circulation of the bottom water is unknown but can be inferred to be similar to the Atlantic layer. Measured values of dissolved oxygen show that the bottom water is well ventilated, dissolved oxygen everywhere exceeding 70 percent of saturation.

Sea ice. The cover of sea ice suppresses wind stress and wind mixing, reflects a large proportion of incoming solar radiation, imposes an upper limit on the surface temperature, and impedes evaporation. Wind and water stresses keep the ice pack in almost continuous motion, causing the formation of cracks (leads), open ponds (polynya), and pressure ridges. Along these ridges the pack ice may be locally stacked high and project downward into the ocean many feet. Besides its deterrence to the exchange of energy between the ocean and the atmosphere, the formation of sea ice generates vast quantities of cold water that help drive the circulation of the world ocean system.

Sea ice rarely forms in the open ocean below a latitude of 60° N but does occur in more southerly enclosed bays, rivers, and seas. Between about 60° and 75° N the occurrence of sea ice is seasonal, and there is usually a period of the year when the water is ice-free. Above a latitude of 75° N there is a more or less permanent ice cover. Even there, however, as much as 10 percent of the area consists of open water owing to the continual opening of leads and polynyas.

In the process of freezing, the salt in seawater is expelled as brine. The degree to which this rejection takes place increases as the rate of freezing decreases. Typically, newly formed sea ice has a salinity of 4 to 6‰. Even after freezing the process of purification continues but at a much slower rate. By the time the ice is one year old, it is sufficiently salt-free to be melted for drinking. This year-old, or older, salt-free sea ice is referred to as polar pack. It can be distinguished by its smoother, rounded surface and pale blue colour. Younger ice is more jagged and grayer in colour. Because the hardness and strength of ice increases as the salts are expelled, polar pack is a special threat to shipping. First-year ice has a characteristic thickness of 6 feet, whereas multiyear ice averages 12 feet in thickness.

There is no direct evidence as to the onset of the Arctic

Ocean ice cover. The origin of the ice pack was influenced by a number of factors, such as the formation of terrestrial ice caps and the interaction of the Arctic and North Atlantic waters—with their different temperature and salinity structures—with atmospheric climate variables. What can be inferred from available data is that there was not a continuous ice cover throughout the Pleistocene Epoch. Rather, there was a continually warm ocean until approximately 2,000,000 years ago, followed by a permanent ice pack about 850,000 years ago. (N.A.O.)

THE LAND

Relief and geology. The Arctic lands have developed geologically around four nuclei of ancient crystalline rocks. The largest of these, the Canadian Shield, underlies all the Canadian Arctic except for part of the Queen Elizabeth Islands. It is separated by Baffin Bay from a similar shield area that underlies most of Greenland. The Baltic (or Scandinavian) Shield, centred on Finland, includes all of northern Scandinavia (except the Norwegian coast) and the northwestern corner of Russia. The two other blocks are smaller. The Angaran Shield is exposed between the Khatanga and Lena rivers in north-central Siberia and the Aldan Shield is exposed in eastern Siberia.

In the sectors between the shields, there have been long periods of marine sedimentation, and consequently the shields are partly buried. In some areas thick sediments were subsequently folded, thus producing mountains, many of which have since been destroyed by erosion. Two main orogenies (mountain-building periods) have been recognized in the Arctic. In Paleozoic times (570 to 245 million years ago) there developed a complex mountain system that includes both Caledonian and Hercynian elements. It extends from the Queen Elizabeth Islands through Peary Land and along the east coast of Greenland. Mountain building occurred during the same period in Svalbard, Novaya Zemlya, the northern Urals, the Taymyr Peninsula, and Severnaya Zemlya. There is considerable speculation as to how these mountains are linked beneath the sea. The second orogeny occurred during the Mesozoic (245 to 66.4 million years ago) and Cenozoic (66.4 million years ago to the present) eras. These mountains survive in northeastern Siberia and Alaska. Horizontal or lightly warped sedimentary rocks cover part of the shield in northern Canada, where they are preserved in basins and troughs. Sedimentary rocks are even more extensive in northern Russia and in western and central Siberia, where they range in age from Early Paleozoic to Quaternary (1.6 million years ago to the present).

It is evident that the polar landmasses have been transported on lithospheric plates through geologic time and that their positions relative to each other and to the North Pole have changed, with significant modification to ocean circulation and to climate. Motion of plates in the Tertiary Period (66.4 to 1.6 million years ago) led to igneous activity in two regions. One was associated with mountain building around the North Pacific, and active volcanoes are still found in Kamchatka, the Aleutian Islands, and Alaska. The other area of igneous activity extended across the North Atlantic and included the whole of Iceland, Jan Mayen Island, and east Greenland south of Scoresby Sound; it was probably connected to west Greenland north of Disko Bay and to east Baffin Island. Volcanism continues in Iceland and on Jan Mayen, and hot springs are found in Greenland.

Little is known about the climate of the northern lands in early Tertiary times; it is possible that the tree line was at least 1,000 miles farther north than at present. During the Tertiary, however, the polar lands became cooler and permanent land ice formed, first in the Alaskan mountain ranges and subsequently, by the end of the Pliocene (5.3 to 1.6 million years ago), in Greenland. By the onset of the Quaternary Period, glaciers were widespread in northern latitudes. Throughout the Quaternary, continental-scale ice sheets expanded and decayed on at least eight occasions in response to major climatic oscillations in high latitudes.

Formation of Pleistocene ice sheets

Detailed information available for the final glaciation (80,000 to 10,000 years ago) indicates that in North America the main ice sheet developed on Baffin Island and swept south and west across Canada, amalgamating with smaller glaciers to form the Laurentide Ice Sheet, covering much of the continent between the Atlantic Ocean and the Rocky Mountains and between the Arctic Ocean and the Ohio and Missouri river valleys. A smaller ice cap formed in the Western Cordillera. The northern margin of the ice lay along the Brooks Range (excluding the Yukon Basin) and across the southern islands of the Canadian Archipelago. To the north the Queen Elizabeth Islands supported small, probably thin, ice caps. Glacier ice from Greenland crossed Nares Strait to reach Ellesmere Island during maximum glaciation.

The Atlantic Arctic islands were covered with ice except where isolated mountain peaks (nunataks) projected through the ice. In Europe the Scandinavian Ice Sheet covered most of northern Europe between Severnaya Zemlya in Russia and the British Isles. Northeastern Siberia escaped heavy glaciation, although, as in northern Canada, the ice sheet had been more extensive in an earlier glaciation.

As the ice sheets melted, unique landforms developed by the ice were revealed. Although not restricted to the present Arctic, they are often prominent there and, in the absence of forests, are clearly visible. In areas of crystalline rocks, including large parts of the northern Canadian Shield and Finland, the ice left disarranged drainage and innumerable lakes. In the lowlands deep glacial deposits filled eroded surfaces and produced a smoother landscape, often broken by low ridges and hills of glacial material, drumlins, rogen (ribbed) moraines, and eskers. In the uplands the characteristic glacial landforms are U-shaped valleys. Near the polar coasts these have been submerged to produce fjords, which are well developed in southern Alaska, along the east coast of Canada, around Greenland, in east and west Iceland, along the coast of Norway, and on many of the Arctic islands.

Because of their enormous weight, continental ice sheets depress the Earth's crust. As the ice sheets melted at the close of the Pleistocene Epoch (1,600,000 to 10,000 years ago), the land slowly recovered its former altitude, but before this was completed the sea flooded the coastal areas. Subsequent emergence has elevated marine beaches and sediments to considerable heights in many parts of the Arctic, where their origin is easily recognized from the presence of marine shells, the skeletons of sea mammals, and driftwood. The highest strandlines are found 500 to 900 feet above contemporary sea level in many parts of the western and central Canadian Arctic and somewhat lower along the Baffin Bay and Labrador coasts. Comparable emergence is found on Svalbard, Greenland, the northern Urals, and on the Franz Josef Archipelago, where it reaches more than 1,500 feet. In many emerged lowlands, such as those south and west of Hudson Bay, the raised beaches are the most conspicuous features in the landscape, forming hundreds of low, dry, gravel ridges in the otherwise ill-drained plains. Emergence is still continuing, and in parts of northern Canada and northern Sweden uplift of two to three feet a century has occurred during the historical period. In contrast, a few Arctic coasts, notably around the Beaufort Sea, are experiencing submergence at the present time.

Polar continental shelves in areas that escaped glaciation during the ice ages were exposed during periods of low sea level, especially in the Bering Strait and Sea (Beringia), which facilitated migration of people to North America from Asia, and in the Laptev and East Siberian seas.

Although the detail of the terrain in many parts of the Arctic is directly attributable to the Pleistocene glaciations, the major physiographic divisions reveal close correlation with geologic structure. The two largest shield areas, the Canadian and the Baltic, have developed similar landscapes. West of Hudson Bay, in southwestern Baffin Island, and in Karelia the land is low and rocky with countless lakes and disjointed drainage. Uplands, generally 1,000 to 2,000 feet above sea level and partially covered with glacial deposits, are more widely distributed. They form the interior of Quebec-Labrador and parts of the Northwest Territories in Canada, and the Lapland Plateau in northern Scandinavia. The eastern rim of the Canadian Shield in Canada from Labrador to Ellesmere Island has been raised by crustal changes and then dissected by glaciers to produce fjords that separate mountain peaks more than 6,000 feet high. The surface of the shield in Greenland has the shape of an elongated basin, with the central part, which is below sea level, buried beneath the Greenland ice cap. Around the margins, on the east and west coasts, the mountainous rim is penetrated by deep troughs through which local and inland-ice glaciers flow to the sea. The mountains are highest in the east, where they exceed 10,000 feet.

In shield areas where sedimentary rocks mantle the crystalline variety, as in north-central Siberia, the southern sector of the Canadian archipelago, and Peary Land, the topography varies from plains to plateaus, with the latter deeply dissected by narrow valleys. Far beyond the margins of the shields, extensive plains have evolved on soft sedimentary rocks. In North America these form the Mackenzie Lowlands, Banks and Prince Patrick islands, and the Arctic Plains section of northern Alaska; in northern Europe they form the Severnaya Dvina and Pechora Plains. In Siberia the Ob delta, its northeastern extension to the Laptev Sea, the North Siberian Lowland, the West Siberian Plain, and farther east the Lena-Kolyma plains (including the New Siberian Islands) have also developed on sedimentary rocks. Although there are differences in degree, these terrains are essentially flat, occasionally broken by low rock scarps, and covered with numerous shallow lakes. The plains are crossed by large rivers that have laid down deep alluvial deposits.

The strongly folded rocks associated with the two orogenic periods in the Arctic form separate physiographic regions. The original mountains of the older, Paleozoic folding were long ago destroyed by erosion, but the rocks have been elevated in recent geologic time, and renewed erosion, often by ice, has produced a landscape of plateaus, hills, and mountains very similar to the higher parts of the shields. In Ellesmere Island the mountains are nearly 10,000 feet high. In Peary Land and Spitsbergen maximum elevations are about 6,000 feet, while in eastern Svalbard and on Novaya Zemlya and Severnaya Zemlya the uplands rarely exceed 2,000 feet. The younger groups of fold mountains of northeast Siberia and Alaska are generally higher. Peaks of 10,000 feet are found in the Chersky Mountains, 15,000 feet in Kamchatka, and even higher in southern Alaska. Characteristic of this physiographic division are wide intermontane basins drained by large rivers, including the Yukon and Kolyma.

Throughout the Arctic, excluding a few maritime areas, the winter cold is so intense that the ground remains permanently frozen except for a shallow upper zone, called the active layer, which thaws during the brief summer.

Permafrost

Permanently frozen ground (permafrost) covers nearly one-quarter of the Earth's surface. In northern Alaska and Canada scattered observations suggest that permafrost is 800 to 1,500 feet deep; it is generally deeper in northern Siberia. The deepest known permafrost is in northern Siberia, where it exceeds 2,000 feet. The depth of the permafrost depends on the site, climate, vegetation, and recent history of the area, particularly whether it was covered by sea or glacier ice. Very deep permafrost was probably formed in unglaciated areas during the extreme cold of the ice ages. To the south in the subarctic, the permafrost thins and eventually becomes discontinuous, although locally it may still be 200 to 400 feet thick; along its southern boundary, permafrost survives under peat and in muskeg. In areas of continuous permafrost the active layer may be many feet thick in sandy well-drained soils with little vegetation but is usually less than six inches thick beneath peat.

Permafrost occurs in both bedrock and surface deposits. It has little effect in most rocks, but in fine-grained, unconsolidated sediments, particularly silts, lenses of ice, called ground ice, grow by migration of moisture, and in extreme cases half the volume of Arctic silts may be ice. Ground ice is often exposed in riverbanks and sea cliffs, where it may be 20 to 30 feet thick. In northern Siberia fossil ice has been reported up to 200 feet thick, although it may be glacier or lake ice that has subsequently been buried under river deposits. If ground ice melts, owing to a change in climate, hollows develop on the surface and quickly fill with water to form lakes and ponds. When frozen the silts have considerable strength, but if they thaw they change in volume, lose their strength, and may turn to mud. Variations in volume and bearing capacity of the ground due to changes in the permafrost constitute one of the major problems in Arctic construction.

Drainage and soils. Continuous permafrost inhibits underground drainage. Consequently, shallow lakes are numerous over large areas of the Arctic, and everywhere in early summer there is a wet period before the saturated upper layers of the ground dry out. During the summer waterlogged active layers on slopes may flow downhill over the frozen ground, a phenomenon known as solifluction. It is ubiquitous in the Arctic but is particularly intense where the soils are fine-grained, as in the coastal plain of northern Alaska, or where the precipitation is heavy, as on Bear Island in the Norwegian Sea. The effect of solifluction is to grade slopes so that long, smooth profiles are common; slopes are normally covered with vegetation, but if the soil movement is too rapid plants may not be able to survive. Under these conditions the surface material is often graded, with narrow strips of pebbles and boulders separated by broader strips of finer particles.

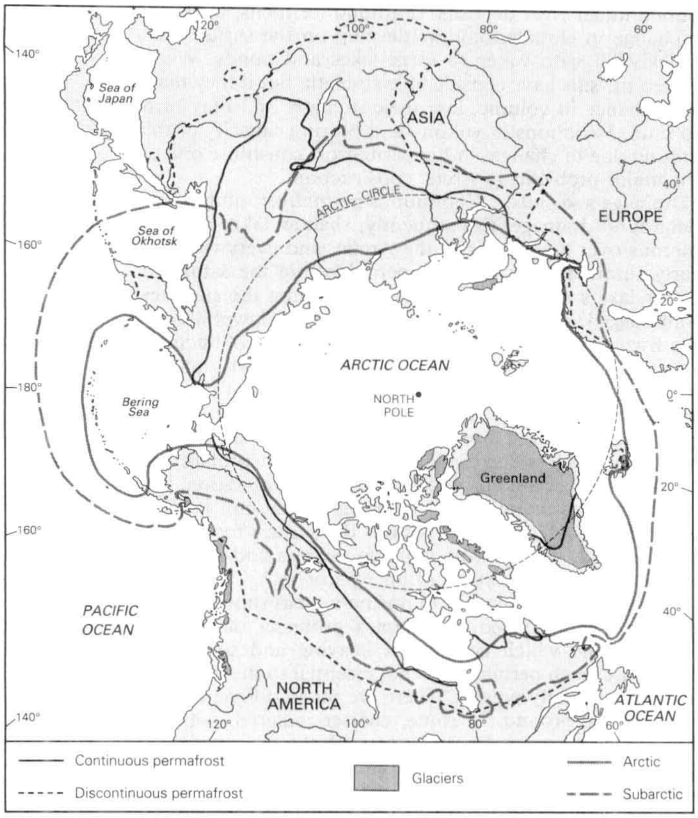
Formation of patterned ground

The surface of many soils in northern areas show distinctive patterns produced by complex processes of freezing and thawing, which cause frost heaving and sorting of debris; although permafrost is not essential to these formations, it is usually present. There are many different types of patterned ground. In some, coarser material, pebbles, and boulders form polygonal nets, with the finer materials concentrated in the centre. When sorting is widely spaced, stone circles develop. Another variety of pattern, formed in sands and muds, is outlined by frost-crack fissures or strips of vegetation. Individual polygons vary from about 1 foot to more than 300 feet in diameter. Mounds due to frost heaving in the soil also are widespread. They grow rapidly, disrupting leveled fields in a few years and limiting the use of farm machinery for haying. Elsewhere, notably in the Mackenzie valley and in parts of Alaska, removal of the natural vegetation—and, in isolated cases, plowing—has modified the soil climate. The ground ice has thawed, leading to disruption of drainage. Where the ice was wedge-shaped and in polygonal patterns, soil mounds several feet high may result. All Arctic terrains are sensitive to human-induced thermal disturbance, especially by vehicular traffic or oil-pipeline operations, and the preservation of the original soil climate is of great environmental importance.

The largest ice-covered mounds, which may reach 200 feet in height, are known in North America as pingos. Although they are widely distributed in the Arctic and subarctic, major concentrations are restricted to the Mackenzie delta, the Arctic slope of Alaska, and coastal areas near the deltas of the Ob, Lena, and Indigirka rivers. Submarine landforms resembling pingos are found beneath the Beaufort Sea.

Arctic soils are closely related to vegetation. Unlike soils farther south, they rarely develop strong zonal characteristics. By far the most common are the tundra soils, which are circumpolar in distribution. They are badly drained and strongly acid and have a variable, undecomposed organic layer over mineral horizons. Some of the drier heath and grassland tundras overlie Arctic brown soils, which have a dark-brown upper horizon with gray and yellowish brown lower horizons. The active layer in the permafrost is normally deep in them.

Many exposed rock surfaces in the Arctic have been broken up by frost action so that the bedrock is buried under a cover of angular shattered boulders. These mantles are known as felsenmeer (German: "sea of rock") and are found principally on Arctic uplands. Their continuity and depth varies with climate, vegetation, and rock type, but they may be as much as 12 feet deep. Felsenmeer are especially well-developed on basalts and are consequently numerous on the basaltic Icelandic plateaus. They also develop quickly on sedimentary rocks and are widespread in the Canadian Arctic, where they occur down to sea level.



Division of subarctic and Arctic regions showing distribution of permafrost and glaciers.

Glaciation. Although the Arctic is commonly thought to be largely ice-covered, less than two-fifths of its land surface in fact supports permanent ice. The remainder is ice-free because of either relatively warm temperatures or scant snowfall. Glaciers are formed when the annual accumulation of snow, rime, and other forms of solid precipitation exceeds that removed by summer melting. The excess snow is converted slowly into glacier ice, the rate depending on the temperature and annual accumulation of snow. In the Arctic, where most glaciers have temperatures far below freezing point, the snow changes into ice slowly. In northwestern Greenland a hole 1,400 feet deep was drilled into the ice sheet without reaching glacier ice. The hole showed more than 800 annual snow layers, from which it was possible to determine precipitation changes for the last eight centuries. An ice core 4,560 feet deep was recovered in the mid-1960s from Camp Century in northwestern Greenland, and a core 6,683 feet deep from Dye 3, southeastern Greenland, was recovered in 1981. The ice cores have been analyzed for paleoclimatic and paleoatmospheric information covering the 100,000 years since the last interglacial.

The elevation at which accumulation and melting of glacier ice are equal is known as the equilibrium line and is roughly equivalent to the snow line. It frequently varies greatly over short distances and from year to year on a specific glacier. On Baffin Island the equilibrium line is a little more than 2,000 feet above sea level in the extreme southeast, rising to more than 4,500 feet in the Penny Ice Cap 300 miles to the north and descending to about 2,000 feet in the north of the island. In Greenland the line is at about 6,000 feet in the south and decreases irregularly to about 3,300 feet in the north. The summits of some ice caps are well below the snow line, but they continue to survive because of their low internal temperatures; the winter snowfall melts completely but refreezes in contact with the cold ice before flowing off the glacier. This phenomenon, first observed on the Barnes Ice Cap of Baffin Island, is now known to be widespread in the high Arctic.

The glaciers of the north polar regions can be divided into two groups depending on the source of their snow. The larger group is around the North Atlantic and its marginal seas; the smaller is nourished by moisture from the North Pacific Ocean. The largest ice sheet, the Greenland Inland Ice, is second in area only to the Antarctic Ice Sheet. It extends about 1,570 miles from north to south and has a maximum width of some 600 miles and an average thickness of about 5,800 feet, reaching 11,000 feet in the middle of the island. It covers an area of more than 650,000 square miles, nearly 80 percent of Greenland, and is contained within a basin by the mountains around the margins. In the northern interior the base of the ice is 1,000 feet below sea level. This discovery has led to the suggestion that Greenland is an archipelago rather than one large island. Although this might be so for a short time if the ice melted, the land would soon rise when the ice mass disappeared, forming an upland surface with an elevation of about 3,000 feet.

Mountains project through the ice sheet near the edges, while the interior is composed of smooth, gently rolling snowfields, often covered with wind-drifted formations called sastrugi. The surface of the ice sheet slopes downward to the sides, reaching the sea in a 240-mile front along Melville Bay in the northwest. Elsewhere, outlet glaciers pour out through fjords between the marginal

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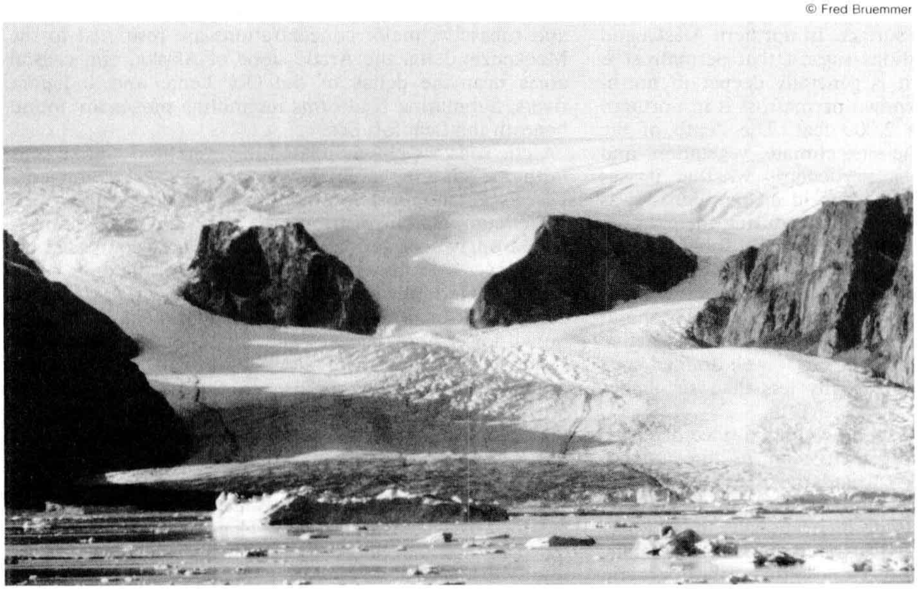

Mountain peaks (nunataks) project through the ice sheet at the edge of Hart Glacier, along the northwest coast of Greenland, east of Qaanaaq (Thule).

mountains, particularly at Disko and Umarrak bays in the west and in the southeast. Where the ice calves into the sea, it produces vast numbers of icebergs. Those in the northwest cross Baffin Bay and are carried south in the Labrador Current to the Atlantic shipping lanes.

There are three major ice-free zones in Greenland: in the southwest, where the inland ice is separated by 100 miles from Davis Strait; north of Scoresby Sound in the east; and in Peary Land in the north.

Location of ice caps

In Arctic Canada glacier ice is restricted, with few exceptions, to the northeast as a consequence of the greater relief and precipitation around Baffin Bay and Davis Strait. The most southerly ice is found in the Torngat Mountains of northern Labrador, where there are small cirque glaciers at the base of the mountains. Immediately north of Hudson Strait on the plateau south of Frobisher Bay, there are two small ice caps. Larger ice caps and highland ice (through which mountains project) are present farther north along the east of Baffin Island and on Bylot Island; only the Barnes Ice Cap lies west of the coastal group. North of Lancaster Sound the ice is more extensive, and large parts of Devon, Ellesmere, and Axel Heiberg islands are glacierized. In many ways these ice caps are small versions of the Greenland Inland Ice, with a central dome-shaped section and outlet glaciers flowing through the mountains toward the sea. The ice cap on Meighen Island, the most westerly of the group, is an exception, as it is circular in shape and lies on low ground. Except for three small glaciers on Melville Island, there are no glaciers in the Canadian western Arctic. Few Canadian glaciers reach the sea and form icebergs. In the Arctic Ocean off northwestern Ellesmere Island there is an area of floating shelf ice that may at one time have been joined by glaciers, but the glaciers no longer reach the sea. This shelf ice has been the principal source of the ice islands of the Arctic Ocean.

Other glaciers are found north and east of the Atlantic Ocean and its continuation in the Norwegian and Barents seas. Iceland has five major ice caps, the largest of which, Vatna Glacier, covers more than 3,000 square miles. All have small outlet glaciers, although none reaches the sea. The ice caps owe their survival to heavy snowfall. The western part of Vatna Glacier buries a volcano, Grímsvötn (Gríms Depression), which erupts every 6 to 10 years; the heat of the eruption forms a subglacial lake that bursts in great floods over the margins of the glacier.

North of Iceland, Jan Mayen Island supports a glacier on the volcano Mount Beeren. The glaciers of Svalbard cover about 90 percent of the land. On the largest island, Spitsbergen, the plateaus are covered with highland ice from which outlet glaciers reach the sea; there are also numerous independent valley and cirque glaciers. North East Land, the second largest island, supports two ice caps on its plateaus. On the east side of the Norwegian Sea, precipitation is heavy over the Scandinavian highlands, but temperatures are also high, and the total area of ice is only about 2,000 square miles, a small part of which is in northern Sweden and the remainder in Norway. To the northeast beyond the Barents Sea, precipitation is less, but the summer is shorter and permanent ice is widespread.

Farthest north in this group are the islands of the Franz Josef archipelago. Although at no point are they higher than 2,500 feet, probably more than 90 percent of their area is covered with ice; some of the smaller islands are completely buried by glaciers. The southern island of Novaya Zemlya supports a few small glaciers; on the northern island they are more numerous, and the northern four-fifths of the island is ice-covered, with large outlet glaciers reaching the sea. Cyclonic depressions penetrate from the Barents Sea into the Kara Sea beyond Novaya Zemlya and produce sufficient snow for glaciers to form on Severnaya Zemlya. There are four major and many minor islands in the group. Although they are low-lying, consisting primarily of plateaus less than 2,000 feet high, all the larger islands have ice caps that cover less than half the total area. Outlet glaciers reach the sea and are an occasional source of icebergs. Elsewhere the Russian northern areas are remarkably free of glacier ice. Small cirque glaciers are found in the northern Ural Mountains and the Byrranga Mountains of the Taymyr Peninsula.

The glaciers around the North Pacific are concentrated in Alaska. The glaciers of southern Alaska are Alpine rather than Arctic and include some of the most spectacular mountain glaciers in the world. All types of ice are present, from small valley glaciers to highland ice that almost buries mountain ranges, with piedmont glaciers spreading out in the lowlands. The largest ice fields are around the Fairweather Range, the St. Elias Mountains, and the Chugach Mountains. Glaciers in these areas include the Hubbard, 90 miles long, intermontane glaciers such as the Seward, and piedmont glaciers such as the Malaspina. Smaller glaciers also occur inland on the Alaska Range and in the Brooks Range of northern Alaska; there is more ice farther east in the Romanzof Mountains, where one glacier, the Okailak, is 10 miles long, and in a similar situation in the Selwyn and Ogilvie mountains of Canada's Yukon Territory. There are a few small glaciers in the Aleutian Range and on the Aleutian Islands. On the northwest side of the Pacific basin there are small glaciers in the East Siberian Mountains and on the volcanic peaks of the Kamchatka Peninsula.

The overwhelming majority of Arctic glaciers for which precise data are available have experienced negative mass balances (*i.e.,* reduction in mass) in the 20th century broken only by temporary cool phases in the 1960s and '70s. The effect has been a general retreat of glacier fronts and thinning of ice around the margins. The Greenland Inland Ice may be an important exception to this generalization.

In Iceland, where glacier fluctuations are well recorded, the ice appears to have been restricted from the 10th until about the 16th century. The ice then advanced, reaching a maximum about 1750. A second advance followed a minor retreat, culminating about 1850, and a major retreat set in about 1890. The recession was slow at first, but by the 1930s it was generally rapid and has continued since, except locally for a brief interruption in the 1970s.

CLIMATE

The climates of polar lands vary greatly depending on their latitude, proximity of the sea, elevation, and topography; even so, they all share certain "polar" characteristics. Owing to the high latitudes, solar energy is limited to the summer months. Although it may be considerable, its effectiveness in raising surface temperatures is restricted by the high reflectivity of snow and ice. Only in the central polar basin does the annual net radiation fall below zero. In winter, radiative cooling at the surface is associated with extreme cold, but, at heights a few thousand feet above the surface, temperatures as much as 20° to 30° F (11° to 17° C) warmer can often be found. Temperature inversions such as this occur more than 90 percent of the time in midwinter in northwestern Siberia and over much of the Polar Basin. They also are common over the Greenland Ice Cap and in the sheltered mountain valleys of the Yukon and Yakutia. The lowest surface temperature ever recorded in North America was observed at Snag, Yukon Territory (−81° F, −63° C), and even lower temperatures have been observed in Yakutia (−90° F, −68° C) and northern Greenland (−94° F, −70° C).

It has been customary to divide polar climates into two large groups, those corresponding to the climate of ice caps, in which no mean monthly temperature exceeds 32° F (0° C), and the tundra climates, with at least one month above 32° F but no month above 50° F (10° C). A more satisfactory division is to classify them as polar maritime climates, located principally on the northern islands and the adjacent coasts of the Atlantic and Pacific oceans, in which winter temperatures are rarely extremely low and snowfall is high; and the polar continental climates, as in northern Alaska, Canada, and Siberia, where winters are intensely cold and snowfall is generally light. Included in the polar continental climate type are the islands of the Canadian Arctic Archipelago, which are influenced only slightly by the sea in winter because of thick, unbroken sea ice. In addition to these two climates, there are smaller transitional zones, limited areas of "ice" climates, the climate of the polar basin, and, on the south side of the tree line, the subarctic climates.

In the polar continental areas, winter sets in toward the end of August in the far north and about a month later nearer the tree line. Temperatures continue to drop rapidly until about December. January, February, and early March have uniform conditions with mean temperatures about −35° F (−37° C) in the central Siberian Arctic and −30° to −20° F (−34° to −29° C) in North America. The lowest extreme temperatures in the winter are between −65° and −50° F (−54° and −46° C). A better indication of low temperatures as they affect humans is given by the windchill, a measurement of the cooling power of the atmosphere on human skin. It reaches a maximum north of Hudson Bay, where strong and persistent northwest winds, typical of the Canadian eastern Arctic, are combined with low air temperatures. This area is stormy in winter, with moderately high snowfall (50 to 100 inches [1,300 to 2,500 millimetres]), rapidly changing temperatures, and even occasional rain. Elsewhere the winter continental climate is quiet, with long periods of clear sky and low snowfall. Visibility may be poor locally if there are open channels of water in the sea ice, and it is universally reduced when the wind blows drifting snow. The lowest snowfall is in the polar deserts of the northern Canadian islands and northern Greenland, where the total annual precipitation is frequently less than the equivalent of four inches of water.

Winter in the maritime Arctic (the Aleutians, coastal southwestern Greenland, Iceland, and the European Arctic) is a period of storminess, high winds, heavy precipitation in the form of either snow or rain (the latter at sea level), and moderate temperatures. The mean temperature of the coldest month is rarely below 20° F (−7° C), and extremely low temperatures are unknown.

Summer temperatures are more uniform across the whole of the Arctic. On the southern margin the monthly mean temperature reaches 50° F (10° C), and in continental situations short spells of hot weather with temperatures in the 80s F (27°–32° C), continuous sunshine, and calm weather are not uncommon; such weather often ends with thunderstorms. In the maritime climates, along the coasts, and on the northern islands when there is open water in the sea ice, the summer is relatively cool. In the south the temperatures are about 45° F (7° C), decreasing north to 40° F (4° C) or less; a maximum of 60° F (16° C) is hardly ever reached except at the heads of fjords as in southwestern Greenland, where marine influences are less marked. Fog and low clouds are widespread in maritime areas, and at this time of the year these areas are the cloudiest in the world. In lands that experience continental winters, precipitation is heaviest during the summer months; light rain and snow showers are frequent, but the average fall is low. The summer is everywhere a time of sudden changes. Calm, clear weather with sunshine and temperatures of about 50° F (10° C) will be followed by sudden winds, often causing a temperature drop of 20° to 30° F (11° to 17° C) and accompanied by cloud and fog.

Frost-free and growing periods are relatively short throughout the Arctic. For the most part there is no true frost-free period; frost and some snow have been recorded in every month of the year. At a few places near the tree line, notably in the Canadian western Arctic, the frost-free period may be the same as the less favourable parts of the prairies.

South of the tree line in the subarctic, differences between continental (Mackenzie Basin, interior Yukon, and Alaska and northeastern Siberia) and oceanic (northern Quebec-Labrador, northern Scandinavia, and northern Russia) situations are marked. A summer maximum of precipitation and frequent high summer temperatures (July means exceeding 60° F [16° C] in northeastern Siberia) in the continental regions contrast with heavier precipitation, often with a fall maximum, and lower summer temperatures in the oceanic regions.

The central polar ocean, together with the Beaufort and East Siberian seas, have winters comparable to northern Alaska and northeastern Siberia. Conditions are stable for extended periods of low wind velocities, clear skies—especially bordering Siberia—and temperatures ranging from −20° to −40° F (−30° to −40° C). Occasional storms originating in the Barents and Bering seas may penetrate the adjacent sectors of the polar basin and bring a temporary rise in temperature accompanied by snow or blowing snow. There is a negligible area (less than 1 percent) of open water in the central polar basin in winter; by April, air temperatures are rising until in June melting of the snow and underlying sea ice begins. Mean summer temperatures fail to rise above 34° F (1° C) and are accompanied by almost continuous low cloud cover and fog.

The only extensive ice climate in the Northern Hemisphere is in Greenland. In the south the climate of the inland ice cap has maritime characteristics with heavy precipitation, mainly snow from passing cyclone disturbances. In the centre and north a continental situation develops, and the snowfall is less. Although the air temperature may sometimes rise to 32° F (0° C), the mean temperature is much lower than in the south. Strong winds blowing off the ice cap are common in all parts of the island.

Changes in polar climates

The evidence from glacier fluctuations suggests significant climatic change in polar latitudes in the past millennium. The first half of the 20th century saw climatic amelioration in the Arctic, with higher temperatures found particularly in winter and especially around the Norwegian Sea. In general, the magnitude of the warming increased with latitude, and in Svalbard winter temperatures rose by 14° F (8° C). Associated with climatic changes were a radical reduction of sea ice around Svalbard and off southwestern Greenland.

Birds, animals, and especially fish appeared farther north than before; in Greenland this led to a change in the economy, as its traditional dependence on seals yielded to dependence on fishing, particularly cod, which were caught north of the 70th parallel.

In the early 1940s, however, there was a downturn in polar temperatures. This widespread climatic cooling continued intermittently into the early 1970s. At this time sea ice failed to leave coastal areas in the summer in the eastern Canadian Arctic for the first time in living memory. A reversal of this trend followed in the next two decades, with the most noticeable temperature increases occurring in the lands to the north of the Pacific Ocean and around the Barents and Greenland seas (a change of +2.7° F [+1.5° C] in annual temperatures).

The underlying cause of the changes is not known, although they result directly from increased penetration of southerly winds into the polar regions.

PLANT AND ANIMAL LIFE

Vegetation. Two main vegetation zones are found in the polar lands. In the south is the subarctic, formed by the northern subzones of the circumpolar boreal forest. To the north is the Arctic proper, where the vegetation is generally referred to as tundra, from the Finnish word for an open rolling plain; in North America the descriptive term Barren Grounds is frequently applied. The two zones are separated by the tree line, or timberline, defined in this case (the term also applies to the upper limit of arboreal growth at high elevations) as the absolute northern limit of treelike species, although even beyond it the same species may be found in low shrubs and dwarfed forms. The tree line is composed of different species. In Alaska and northwestern Canada white spruce is dominant, while in Labrador-Quebec it is black spruce and occasionally larch. By contrast, in northern Europe and Siberia the tree line is formed by larch, pine, and fir. The tree line is related to summer warmth, which may be correlated closely with tree growth. Alexander Supan found good coincidence between the tree line and the 50° F (10° C) July isotherm, a figure later modified by Otto Nordenskjöld to allow for spring temperatures.

In North America the tree line extends from the shores of the Bering Strait along the Brooks Range of Alaska to the Mackenzie River delta and then curves southeastward across the Northwest Territories to Churchill and James Bay. East of Hudson Bay it crosses northern Quebec to Ungava Bay and then continues into Labrador. In western Scandinavia the tree line is within a few miles of the sea; it curves east and crosses northern Siberia 50 to 150 miles south of the Arctic Ocean.

Arctic plants must contend with a harsh environment including low temperatures, continuous daylight in summer, infertile and often mobile soil and permanently frozen ground, and in many areas strong, dry winds and blowing snow. The species that survive are few and are frequently dwarfed. Many plants grow in compact cushions for maximum protection from the climate. The growing season is so short that annuals are rare and perennials reproduce asexually by shoots or runners. Even so, Arctic plants have a rapid seasonal life cycle. Spring growth often begins when snow is on the ground and there are still heavy frosts; the flower and seed stages follow in a period as short as six weeks. The sudden blooming of flowers is spectacular, particularly along the southern edges of the tundra, and for a short time in July the Barren Grounds are covered with a mass of flowers. The species vary but typical are those in the western American Arctic, which include the blue-spiked lupine, wild crocus, mountain avens, arctic poppy, and saxifrage. By late August the cycle is complete, and the plants are awaiting winter.

At first sight many parts of the Arctic are polar deserts without soil or vegetation. Closer inspection shows that some plant life is always present, and even on permanent ice there are often algae. The bare rock surfaces support thin brown, black, or gray crustaceous lichens that swell and become soft when wet; some of the larger black lichens are edible and are generally known as "rock tripe." In the past these lichens have been used for food by starving explorers. Higher plants grow in rock crevices and succeed in forming tussocks on patches of soil. Close to the southern edge of the Arctic, dwarf shrubs are found in protected sites on these rock deserts.

Tundra vegetation

Tundra areas have a continuous cover of vegetation, and many different tundra associations (plant communities) may be recognized. In the drier and better-drained parts, heath tundra, made up of a carpet of lichens and mosses with isolated flowering plants, is dominant. In some areas, notably west of Hudson Bay, a similar environment results

Flowers blooming through the heath tundra near the Dempster Highway in the Richardson Mountains, Yukon Territory, Canada.

in tundra grassland. When there is more moisture, sedges and grasses become important and form tussock or hillock tundra; willow and dwarf birch may be found between the individual mounds. This type of tundra reaches its greatest development on the northern Alaskan coastal plain.

In the warmest parts of the Arctic, woody dwarf shrubs, willow, birch, juniper, and, locally, alder are profuse. In the southern Arctic several of these shrubs modify the heath tundra, and low scrub woods may be extensive. On sheltered, south-facing slopes, tall thickets of willow, birch, and alder develop, and under optimum conditions these bushlike "trees" may be more than 10 feet high. This type of vegetation is common in all circumpolar lands close to the tree line and is conspicuous in the inner fjords of southwestern Greenland and in northern Iceland. The bushes may be used in the western Canadian Arctic by the Eskimo (Inuit) for fuel or for mats, and in former times the wood was made into arrow shafts. It is unsuitable for bows, spears, or boat building; for these purposes the Eskimo either had to travel to the tree line or search for driftwood, which was formerly widely distributed along the Arctic coasts.

The tundra vegetation is the source of food for the northern grazing mammals but contains few foods of direct value to man. Berries are found throughout the southern Arctic. Most widely used by the native population has been the black crowberry (*Empetrum nigrum*), eaten either raw or mixed with animal oil. Europeans have found the cloudberry (*Rubus chamaemorus*), bilberry (*Vaccinium uliginosum*), and mountain cranberry (*V. vitisidaea minus*) more palatable. Mushrooms are widely distributed and can be used for a welcome change of diet.

South of the tree line is the subarctic forest-tundra. Its bare windswept ridges are covered with tundra associations, while in the sheltered valleys there are woodlands, which may become continuous near large rivers and, if the rivers flow north, may penetrate many miles into the Barren Grounds. These areas, known as *galeria* (gallery) forests, are found along the Coppermine River of Canada and the north Siberian rivers. The woods contain the same coniferous species as forms the tree line, together with several broad-leaved species, notably birch. (J.B.Bd.)

Animal life. Animal life in the Arctic, compared with that of warmer parts, is poor in the number of species but often rich in individual numbers. This is generally considered to be the result of at least two factors: the comparative novelty of polar glacial climates, allowing only a limited time for adaptation since their onset, and the much lesser variety of habitats available for colonization in the north as compared with the lower latitudes.

Fauna of the true Arctic Zone

The fauna considered in this section is from the true Arctic Zone only. On the land, this is the zone north of the tree line; in the sea, it is the area in which the upper water is of Arctic Ocean origin, without admixture of Atlantic or Pacific water. This excludes most of the west Greenland waters and the waters of west and southern Iceland, the Faeroe Islands, and Norway; it also excludes the Labrador Sea and the waters of the Labrador coast south of Hudson Strait.

Animals of the land and fresh water. The typical and best-known Arctic land mammals and birds are those highly successful forms, most of them circumpolar in distribution, that survived the Pleistocene glaciations probably both south and north of the ice sheets: south along the ice perimeter and north in ice-free refuges such as northern Alaska, the Bering Strait (then dry land) and northeastern Siberia, certain of the Arctic Islands, and probably northernmost Greenland. These include the polar bear (as much a marine as a terrestrial animal), caribou, arctic wolf, arctic fox, arctic weasel, arctic hare, brown and collared lemmings, ptarmigan, gyrfalcon, and snowy owl. This fauna, together with the vegetation that feeds the lemming, ptarmigan, and caribou, forms a tight ecological system that is virtually self-sufficient. During the winter and during periods of low lemming population, which occur every three to five years, the carnivores make some use of seashore life and (through the agency of the polar bear) of seal and fish. In extreme starvation conditions, there is a tendency for the snowy owls and gyrfalcons

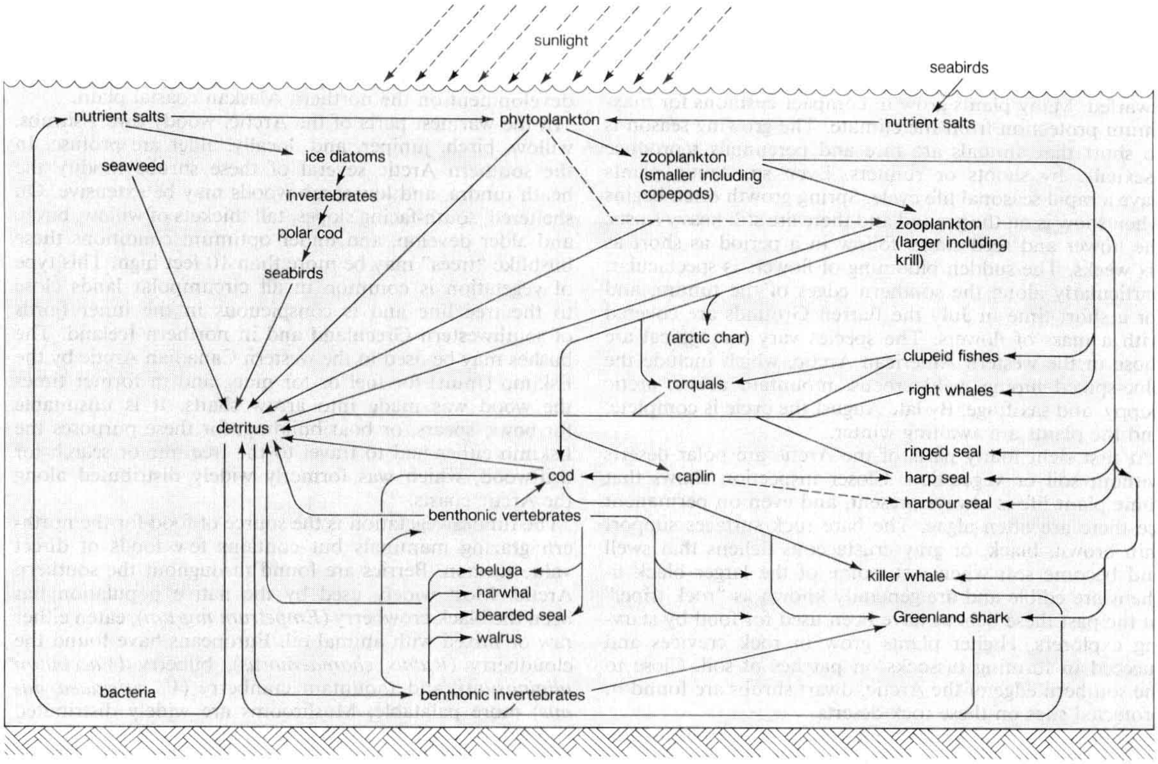

Figure 2: The food web in the Arctic and subarctic marine zones.
After M.J. Dunbar in L. Rey (ed.), *The Arctic Ocean* (1982), 233-261, Comite Arctique International, Macmillan Press, London and Basingstoke

to go south in winter and for the foxes and wolves to become scavengers.

The caribou is a migrant, but only between the Arctic tundra and the conifer (subarctic) zone to the south, and there are far northern groups of caribou whose migrations are more restricted. The musk-ox is a special case. Now restricted to the North American Arctic (including northern Greenland), it was formerly more widespread and is probably a "refugee" species, chased into the far north and on the defensive in the evolutionary sense. It has been established domestically in Alaska and western Greenland, on an experimental basis, with promising results.

Hibernation is not a phenomenon of animal behaviour in the Arctic, because frost-free refuges are not available; all the nonmigrant, warm-blooded animals therefore must remain active all winter. Any incipient hibernation, shown for instance by the arctic ground squirrel, proves abortive, as the animals will shiver themselves awake after only a few days.

Most of the birds of the Arctic Zone are migrants, coming from wintering grounds as far away as the southern United States, Central America, Brazil, or even the subantarctic zone. By migration the birds obtain the advantage of the long northern summer days and of the high productive capacity of plant foods in the short but intense growing season. There is increasing evidence that food is not a limiting factor on summer bird populations in the Arctic, except in the case of strictly predaceous species during years of scarcity of prey. Typical land and freshwater birds of the Arctic Zone are the redpoll, Lapland longspur, snowbird, wheatear, pipit, certain plovers and sandpipers, loons, rock ptarmigans, ducks, and geese.

There are no reptiles in the Arctic Zone, owing to the absence of frost-free winter refuges, but one amphibian, the wood frog, does penetrate just north of the tree line in Arctic Canada. It breeds in July and early August in ponds and small lakes and spends the rest of the year buried in the mud at the bottom. The mud does not freeze, and the frogs are able to breathe through their skin, which the reptiles cannot do.

Freshwater fishes in the Arctic are represented by a few species only: whitefish, lake trout and speckled trout, Arctic grayling, two species of stickleback, the Alaskan blackfish, and the arctic char. In some regions the burbot, northern pike, and Atlantic salmon penetrate north of the tree line.

The invertebrate fauna of the Arctic land and fresh water consists largely of insects, including the chief scourges of the north, mosquitoes and blackflies. Among the most northern navigators are certain species of spiders that winter even in northern Ellesmere Island. Crustacea are represented by the branchiopods, which form an important part of Arctic pond life, and by the copepods. There is, in addition, a very considerable number of smaller species belonging to many phyla.

Marine fauna. The Arctic Circle, a parallel of latitude, has little value in understanding the distribution and limits of the marine Arctic flora and fauna. Its only significance lies in its relationship to the seasonal behaviour of light, which is of only limited importance and has nothing to do with temperature—which is extremely important—or, in the case of marine fauna, with salinity. The marine Arctic is defined as an area in which the upper layer (650–825 feet) is derived directly from the upper layer of the Arctic Ocean (Central Basin); the subarctic is the region in which Arctic and non-Arctic (Atlantic or Pacific) waters are found in close association or as mixed water. The subarctic marine fauna is much richer than the Arctic fauna, with which this article deals. The Arctic marine fauna is illustrated in terms of the whole ecosystem in Figure 2.

The fact that mammals are warm-blooded (homoiothermic) was clearly a great advantage when the climate cooled during the Pleistocene glaciations, and even now they dominate the macrofauna. Among the whales, the beluga, or white, whale and the narwhal are Arctic water species. The bowhead, in much depleted numbers, is found in the Beaufort Sea and in Baffin Bay and occasionally in Hudson Bay. Other whales, of worldwide distribution, appear in Arctic water occasionally (blue whale, little finback or lesser rorqual, finback, sperm whale, and killer whale). The killer whale is a fairly frequent visitor. The phocids, or hair seals, are represented principally by the ringed and the bearded seals, typical Arctic species, and by the migrant harp and hooded seals. The harp seal exists in three separate populations, breeding respectively in the Newfoundland region, the White Sea, and the waters south of Jan Mayen on sea ice in March and April. The fur seals, which are not strictly Arctic, appear in the North

Mammals

Pacific, breeding in Alaskan and Russian waters. A special ecological place is occupied by the polar bear, which is at home in the sea, on the sea ice, and on land but which is essentially an aquatic animal.

Fishes are not abundant in the Arctic zone, perhaps owing to the early competition with the homoiotherms. There are probably not more than about 25 species within the zone. The arctic char, an anadromous (river-ascending) migrant, is abundant and circumpolar, and the two small gadids, the polar cod and the arctic cod, are abundant throughout the region, their numbers being as yet only tentatively estimated.

Marine birds are abundant in summer, all of them migrants except, apparently, for a small proportion of the black guillemot population that winters in the Arctic, using the open water, such as the polynyas, for feeding areas. The seabirds in the true Arctic zone are represented by the auk family (murres, guillemots, auklets, and little auk), the sea duck (eider, scoter, old squaw), the gulls and terns (especially the glaucous and glaucous-winged gulls, many of the herring gull group of species, Sabine's gull, and the common and arctic terns), the jaegers (parasitic, pomarine, and long-tailed), and the waders (sandpipers, etc.). One of the petrel group, the fulmar, breeds on certain Arctic cliffs. The arctic tern, which breeds in the Arctic in the summer, makes a remarkable migration to subantarctic waters, where it winters.

Ice ecosystem

There is a special ecosystem associated with the sea ice that is based on algae (mainly diatoms) living within the ice itself in considerable concentrations, especially in the lowest few inches. This plant growth supports a food web ranging from worms and copepods to amphipod crustaceans, polar cod, birds, and seals. The algae develop earlier in the season than do the planktonic algae (phytoplankton). (M.J.Du.)

The people

The Arctic, or circumpolar, peoples are the indigenous inhabitants of the northernmost regions of the world. For the most part, they live beyond the climatic limits of agriculture, drawing a subsistence from hunting, trapping, and fishing or from pastoralism. Thus climatic gradients, rather than simple latitude, determine the effective boundaries of the circumpolar region, and these gradients have their counterparts in the major environmental transitions. Of these transitions, the most important is the tree line, which marks the northern margin of the coniferous forest, or taiga. Between this limit and the coasts of the Arctic Ocean, the land consists of open tundra, though, in regions of high altitude, pockets of tundra lie enclosed within the forest zone.

Arctic environments are commonly imagined to be barren and inhospitable, habitable only by virtue of the extreme physical endurance and technical virtuosity of the peoples who dwell in them. Though their possession of these qualities is not in doubt, this view of the far north rests on a misconception. The image of the remote wilderness, to be conquered through a struggle for survival, belongs to the language of the alien explorer, not to that of the native. For indigenous people, the circumpolar environment is neither hostile nor forbidding but familiar and generous, offering the gift of livelihood to those who would treat it with consideration and respect.

Seasonal variations in resources

Though there are indeed seasons of scarcity, these alternate with periods of extraordinary abundance. The continuous daylight of the warm Arctic summer, coupled with ample surface water from melting snow, allows for a phenomenal rate of growth of surface vegetation, and this in turn attracts a multitude of animals, many of them of migratory species. Warm ocean currents around some of the Arctic coasts are likewise conducive to an abundance of marine fauna. It is not, then, scarcity that characterizes the Arctic environment but rather its seasonality. The resources available for human subsistence—which are primarily faunal rather than vegetable—tend to occur in great concentrations at particular times of year, rather than being widely dispersed and continuously available. These fluctuations naturally affect the settlement patterns and movements of human populations, as do the marked seasonal variations in the length of day and night and in the opportunities afforded by the landscape for transport and travel.

Adaptations to local environments. The three major environmental zones of forest, tundra, and coast, and the transitions between them, establish the range of conditions to which the ways of life of the circumpolar peoples are adapted. These conditions are strikingly uniform across both northern North America and Eurasia, and this uniformity is matched by remarkable similarities in cultural adaptation throughout the circumpolar region. Broadly speaking, it is possible to class these adaptations into four kinds. The first is entirely confined within the forest and is based on the exploitation of its fairly diverse resources of land animals, birds, and fish. Local groups tend to be small and widely scattered, each exploiting a range of territory around a fixed, central location. The second kind of adaptation spans the transition between forest and tundra. It is characterized by a heavy, year-round dependence on herds of reindeer or caribou, whose annual migrations from the forest to the tundra in spring and from the tundra back to the forest in autumn are matched by the lengthy nomadic movements of the associated human groups—whether these be of hunters (as in North America), who aim to intercept the herds on their migrations, or of pastoralists (as in Eurasia), who are in continuous association with them. The third kind of adaptation, most common among Inuit (Eskimo) groups, involves a seasonal movement in the reverse direction, between the hunting of sea mammals on the coast in winter and spring and the hunting of caribou and fishing on the inland tundra in summer and autumn. Fourth, typical of cultures of the northern Pacific coast is an exclusively maritime adaptation. People live year-round in relatively large, coastal settlements, hunting the rich resources of marine mammals from boats in summer and from the ice in winter.

Identification of Eastern and Western Arctic cultures. In northern North America the forest and forest-tundra modes of subsistence are practiced only by Indian peoples, while coastal and coastal-tundra adaptations are the exclusive preserve of the Inuit and of the Aleut of the northern Pacific islands. Indian cultures are thus essentially tied to the forest, whereas Inuit and Aleut cultures are entirely independent of the forest and tied rather to the coast. Conventionally, this contrast has been taken to mark the distinction between peoples of the subarctic and those of the Arctic. Thus in this article, of the indigenous peoples of northern North America, only the Inuit and Aleut are considered to be Arctic, whereas the Indian groups are dealt with separately in the article AMERICAN INDIANS: *American subarctic cultures.* A division of this kind, however, cannot be applied to the indigenous peoples of northern Eurasia. Apart from the Siberian Yupik (Eskimo), and perhaps some coastal Chukchi and Koryak inhabiting the northeastern tip of Siberia, there are no exclusively Arctic peoples in Eurasia. As among the Indians of the American subarctic, forest and forest-tundra adaptations predominate. For this reason, it has been necessary to treat the Eurasian Arctic and subarctic together as a single culture area. It should be noted, moreover, that the southern limits of this area are defined more by considerations of environmental adaptation than by culture per se. A number of Eurasian peoples are distributed over regions that span the transition between the taiga forest and the grassland steppe to the south. In such instances, only the forest-dwelling groups of these peoples will be considered here.

Domestication of the reindeer in Eurasia

Apart from the absence of a cultural division corresponding to the environmental division between Arctic and subarctic, the north of the Old World is distinguished from that of the New in two major respects. The first lies in the domestication of the reindeer, the second in the history of settlement and European contact. The domestic reindeer is ubiquitous throughout Arctic and subarctic Eurasia (except the Pacific coast), whereas the North American caribou—which is virtually identical to the Eurasian wild reindeer—has never been domesticated. As a domestic animal, the reindeer is unusual both in that it has not been