1 The Arctic and Antarctic – natural realms at the poles

> At first glance, the Earth's two polar regions appear to have much in common: Their terrestrial and marine landscapes are characterized by ice and snow, darkness dominates for half of the year, and survival is limited to those organisms that can adapt to very extreme conditions. But in spite of the striking parallels there are fundamental differences between the Arctic and Antarctic – ranging from their geography and history of ice formation to their conquest by humankind.

A brief history of the polar regions

> People are fascinated today more than ever by the polar regions of the Earth. One reason for this is that wide expanses of the Arctic and Antarctic have not been explored and are therefore still viewed as frontier regions. Another is that they both have very diverse histories with regard to their origins and ice formation. Their numerous aspects still pose many puzzles for science today.

The fascination of the high latitudes

The 21st century is the century of the polar regions. There are hardly any other natural landscapes that fascinate mankind as much as the distant land and marine regions of the Arctic and Antarctic. Most of the practically inaccessible ice and snow regions today are as yet unexplored. There are still no answers to many fundamental scientific questions such as: What exactly is hidden beneath the kilometre-thick ice sheets of Greenland and Antarctica? How did the Arctic Ocean originate?

Besides fascination, the world also views the polar regions with concern because, acting as cooling chambers, they play a crucial role in the planet's climate system and significantly impact the patterns of global air-mass and ocean circulation. Small changes in their complex structures can have far-reaching consequences. This is especially true for the large ice sheets of Greenland and Antarctica. Between them they contain 99 per cent of the ice on the Earth. If they melt, global sea level will rise. The melting of these two ice covers would raise water levels worldwide by around 70 metres, and long stretches of the Earth's coastlines would be flooded.

Today, the impacts of global climate change are more clearly observed in the polar regions than anywhere else, and this is particularly true for the Arctic. Since the middle of the 20th century it has been warming more than twice as fast as the rest of the Earth, and is thus seen as an early warning sign for climate change. Weather services and scientists therefore follow the events at high latitudes closely in real time – at least where satellites and measuring networks have made observations possible.

But the fascination of the polar regions also partly reflects the fact that there is nowhere else in the world where ice, snow, biting cold and the long darkness of the polar nights present such huge challenges for life. Both in the Arctic and the Antarctic, animals and plants have developed sophisticated survival strategies and impres-

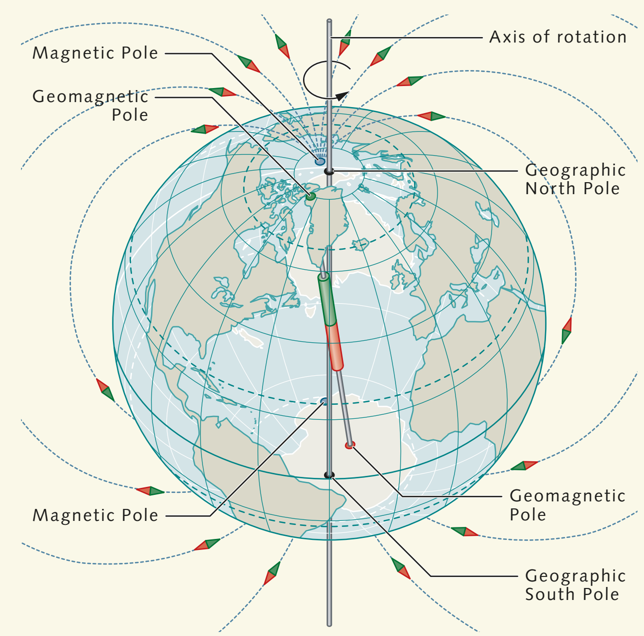
1.1 > A tourist ship on the coast of the Antarctic Peninsula. 42,000 cruise tourists visited Antarctica during the Antarctic summer of 2017/2018. That was 16 per cent more than the previous summer.

The Earth's wandering poles

The geographic North Pole has a fixed position. It corresponds to the northern intersection of the Earth's rotational axis with the Earth's surface. Its coordinates are thus "90 degrees north". It is not possible to locate this point, however, using a simple pocket compass. The compass needle actually aligns with the magnetic field of the Earth. This field originates because liquid iron located in the outer core of the Earth circulates and swirls in response to the internal temperature differences and rotation of the Earth. The magnetic field extends into space for a distance of many Earth radii. It shields the planet from dangerous radiation and particles from outer space, and it also possesses a north and south pole. These are defined as the two points where the magnetic field lines extend into the Earth perpendicular to its surface. One of these points is located in the northern hemisphere and the other in the southern hemisphere, but their positions are not exactly diametrically opposed on the globe. Neither of them can be assigned a fixed geographical position because, due to magnetic storms and constant variations in the circulation of iron in the liquid outer core, their locations are constantly changing. The changing results of positional measurements indicate that these poles are wandering. When the North Magnetic Pole was discovered in 1831, it was located near the Boothia Peninsula in the Canadian Arctic. From there, it has since wandered to the northwest and is now moving at a speed of around 55 kilometres per year. It is currently located north of the 85th parallel in the middle of the Arctic Ocean and is approaching Russia.

Interestingly, the Earth's magnetic field reverses itself at irregular time intervals. The magnetic north becomes south and vice versa. For the sake of clarity, therefore, specialists use the term North Magnetic Pole to refer to the magnetic pole located in the northern hemisphere, even when it is a magnetic south pole according to the conventional physics definition, as is currently the case. It is not known why this reversal occurs, but it is known that the change occurs over a period of several thousand years. Scientists also define the geomagnetic poles, which cannot be established through direct measurements but only theoretically calculated. These are based on the assumption that there is an infinitely small bar magnet at the centre of the Earth. The geomagnetic poles are located at the intersection of the axis of the bar magnet with the Earth's surface. These are very important because they form the basis of the geomagnetic coordinate system. This system is used for navigation underwater, underground, and for every mobile phone compass app.

1.2 > The North Magnetic Pole is constantly moving. Scientists determine its position using measurements and calculations.



1.3 > The northern and southern hemispheres of the Earth each have three poles – one geographic, one magnetic, and one geomagnetic.

sive species diversity that people want to see for themselves. The number of tourists in the two polar regions is therefore increasing, just as economic interest in the exploitation of polar resources is growing. South of the 60th parallel, the Antarctic Treaty establishes strict limits for the major economic players. In the Arctic, on the other hand, the five bordering states alone will determine what happens. The competition for raw materials and shipping routes there has already been underway for some time.

So similar and yet so different

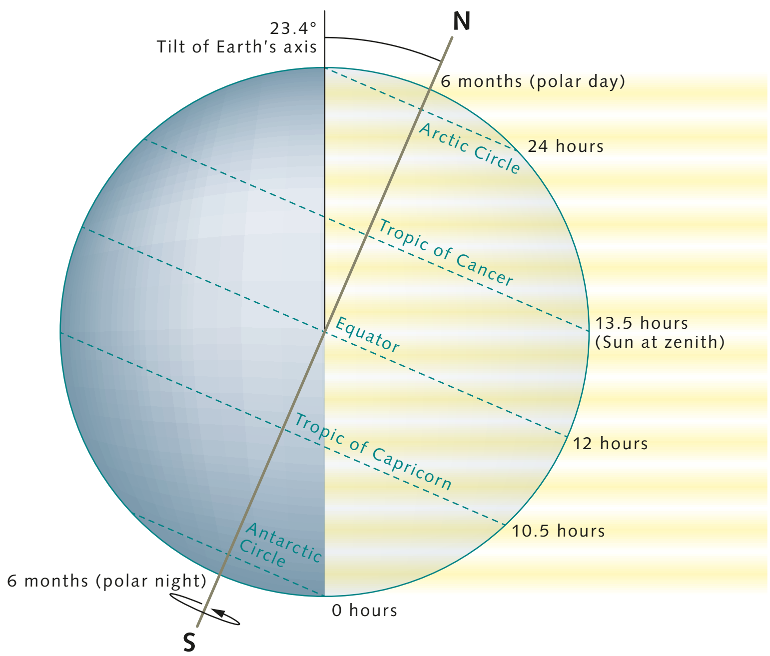
The regions of the Earth designated as polar are those areas located between the North or South Pole and the Arctic or Antarctic Circles, respectively. The northern polar region, called the Arctic, encompasses the Arctic Ocean and a portion of some surrounding land masses. The southern polar region, called the Antarctic, contains the continent of Antarctica and areas of the surrounding Southern Ocean. The diameter of each region is 5204 kilometres because both the Arctic and Antarctic Circles maintain consistent distances of 2602 kilometres from their respective geographic poles, which are not to be confused with the Earth's wandering magnetic poles.

On world maps the Polar Circles are generally marked by dashed lines at 66° 33' north and south latitude. This delineation was originally established based on the orientation of the sun. The Arctic Circle is thus defined as the latitude at which the sun does not set for exactly 24 hours during the summer solstice on 21 June each year. The winter solstice occurs in the southern hemisphere at the same time. Thus, the position of the Antarctic Circle is defined by the latitude at which the sun remains below the horizon for 24 hours.

The many parallels observed between the Arctic and Antarctic realms should not obscure the fact that the two polar regions are fundamentally very different from each other. In the far south, Antarctica is a vast landmass – a remote continent with an area of 14.2 million square kilometres, almost twice the size of Australia. 98 per cent of this area is covered by ice up to 4700 metres thick. The continent is completely surrounded by the Southern Ocean, also known as the Antarctic Ocean or Austral Ocean. This allows an active exchange of water masses among the Atlantic, Pacific and Indian Oceans, and large areas of it freeze over in the winter (seasonal sea-ice cover). This ocean not only separates Antarctica physically from the rest of the world, its clockwise-flowing water masses also insulate the continent climatically, which is one of the reasons why large parts of Antarctica are much colder than the Arctic. As a broad comparison: The average annual temperature at the South Pole is minus 49.3 degrees Celsius, while at the North Pole it is minus 18 degrees Celsius. Furthermore, the Antarctic is considered to be the windiest and driest region on the Earth. The extreme climate here, along with its remoteness, is also the reason why very few animal and plant species have been able to establish themselves on the frozen continent. People come only to visit for a short time. Apart from research stations, there are no permanent human settlements on the Antarctic continent today.

The Arctic, by contrast, is diametrically different in several respects. Here, land masses surround an ocean that is centred on the pole. The Arctic Ocean, also known as the Arctic Sea, is connected to the rest of the world's oceans by a limited number of waterways and, with an area of 14 million square kilometres, it is the smallest ocean in the world. In contrast to the Southern Ocean, the Arctic Ocean has a permanent sea-ice cover whose area varies with the seasons. It achieves its greatest extent at the end of winter and its smallest size at the end of summer, whereby scientists are observing a steady decrease in the extent of summer ice. Since the beginning of satellite measurements in 1979, the surface area of summer ice has shrunk by around three million square kilometres. This is an area about eight times the size of Germany. Because the continents of Europe, Asia and North America extend far into the Arctic region, the Arctic has been more successfully settled by plants, animals and people than the Antarctic. Historical evidence suggests that the first aboriginal people were hunting in the coastal regions of the Arctic Ocean 45,000 years ago. Today more than four million people live within the Arctic polar region.

1.4 > Winter in the Arctic fishing village of Reine, in the western Lofoten Islands of Norway. Due to branches of the warm Gulf Stream, the air temperature in this part of the Arctic does not fall much below freezing.



1.5 > On 21 June, the date of the summer solstice, the sun is at its highest elevation in the northern hemisphere. On the Arctic Circle it does not set for 24 hours, and on the Antarctic Circle it does not rise for 24 hours.

Where does the Arctic begin, where the Antarctic?

The term "Arctic" comes from the Greek word *arktos*, which means bear. Greek seafarers called the Arctic region, into which they had presumably already ventured for the first time around 325 BC, "land under the constellation of the Great Bear". Seamen at that time used the constellations of the northern sky, primarily Ursa Major and Ursa Minor, to aid them with orientation during their voyages of discovery.

Another celestial body, the sun, was decisive in defining a northern and later a southern polar circle as the boundaries of the polar regions. The two circles mark the geographic latitudes at which the sun does not set on the dates of the respective summer solstices. In the northern hemisphere the summer solstice usually falls on the 21st of June and in the southern hemisphere it is usually the 21st or 22nd of December. The precise positions of the polar circles are determined by the tilt angle of the Earth's axis. Because the degree of tilt of the axis (obliquity) fluctuates slightly with a rhythm of about 41,000 years, the locations of the polar circles are also constantly shifting. They are currently moving toward the geographic poles by around 14.4 metres per year.

The Arctic Circle has never become established, however, as the definitive southern boundary of the Arctic region. This is primarily because there is no natural feature coinciding with the astronomically determined path of the Earth-encircling line that clearly distinguishes the Arctic realm from regions to the south. On the contrary, if the Arctic were limited to the regions north of the Arctic Circle, the southern tip of Greenland and large portions of the Canadian Arctic would not be included.

For this reason scientists today define the natural region of the Arctic mostly on the basis of climatic or vegetational features. One southern boundary that is often employed is the 10° Celsius July isotherm. North of this imaginary line the long-term average temperature for the month of July lies below ten degrees Celsius. By this criterion the Arctic Ocean, Greenland, Svalbard, large parts of Iceland, and the northern coasts and islands of Russia, Canada and Alaska all belong to the Arctic realm. In the air above the Norwegian Sea, the 10° Celsius July isotherm shifts northward due to the heat of the **North Atlantic Current**, so that, on the basis of this definition, only the northern reaches of Scandinavia are included in the Arctic. In Siberia and North America, on the other hand, cold Arctic air pushes the temperature boundary further to the south, so that regions such as the northeastern part of Labrador, the Hudson Bay, and a large portion of the Bering Sea are included as part of the Arctic.

Another natural southern boundary sometimes used for the northern polar region is the Arctic tree line. As the name suggests, the present-day climate conditions north of this line are so harsh that trees are no longer able to survive. But because, in fact, the transition from contiguous forests to the treeless grass and tundra landscapes of the Arctic is often gradual, researchers tend to refer to a zone for the boundary rather than a sharply defined line. In North America, for example, this transition zone is a relatively narrow strip. In northern Europe and Asia, however, it can be up to 300 kilometres wide. The course of the northern tree line corresponds in large part with the 10° Celsius July isotherm. In some areas, however, it can be located as much as 200 kilometres to the south of the temperature boundary. According to this definition, western Alaska and the Aleutians would also belong to the Arctic, and the Arctic region would have a total area of around 20 million square kilometres.

A third natural boundary can be delineated based on ocean currents. According to this definition, the Arctic waters begin at the point where cold, relatively low-saline surface-water masses from the Arctic Ocean meet warmer more saline waters from the Atlantic or Pacific Ocean at the sea surface. In the area of the Canadian Arctic Archipelago, the island group between North America and Greenland, this convergence zone extends to 63 degrees north latitude. As it continues eastward, it turns to the north between Baffin Island and Greenland. In the Fram Strait, the marine area between East Greenland and Svalbard, it is located as far as 80 degrees north, i.e. well to the north of the Arctic Circle. On the other side of the Arctic Ocean, in the Bering Sea, the definition of a convergence zone is somewhat more difficult, because here the water masses from the Pacific and Arctic Oceans mix extensively with each other instead of one flowing over the other. On maps, therefore, this vague boundary line runs straight across the narrow Bering Strait.

Besides these three boundaries to the Arctic, which are all characterized by natural features, other boundaries have been defined according to different delineating criteria. Various working groups of the Arctic Council, for example, sometimes draw different boundaries. For the group of experts in the Arctic Monitoring and Assessment Programme (AMAP), for example, all of the land areas in Asia north of 62 degrees north latitude belong to the Arctic. On the North American continent they draw the line at 60 degrees latitude. The territory based on this method is significantly larger than the physiographic region defined by the tree line. The most generous definition of the Arctic is found in the Arctic Human Development Report (AHDR), where political and statistical aspects were considered in defining the area, which is why the boundary, especially in Siberia, extends further to the south than any other. According to this definition, the Arctic region has an area of over 40 million square kilometres, which is equal to around eight per cent of the total surface of the Earth.

In this *World Ocean Review*, the term "Arctic" will always refer to the physiographic region defined by the tree line on land and by the convergence zone in the seas. If, in special cases, other definitions of the Arctic region are necessary, this will be specifically pointed out.

In the southern hemisphere, the definition of the boundary is not as difficult. The fact that the continent of Antarctica is essentially an island and the presence of distinctive ocean currents allow a relatively clear delineation of the boundary of the southern polar region. The word "Antarctic", by the way, derives from the Greek word *antarktiké*, which means "opposite to the north". The Antarctic realm includes the continent of Antarctica and the surrounding Southern Ocean, whereby the tip of the Antarctic Peninsula and coastal areas of East Antarctica extend beyond the Antarctic Circle. The northern boundary, therefore, is often considered to be the line at 60 degrees south latitude, which was agreed to by the signatories of the Antarctic Treaty System in 1959.

The Antarctic region becomes somewhat larger if the zone of Antarctic Convergence is used to indicate the northern boundary. This is the encircling oceanic zone where cold, northward-flowing surface water from the Antarctic meets warmer southward-flowing water masses from the north. The cold, saline water sinks as a result of the density differences, and is diverted beneath the warmer water masses. For polar researchers the 32 to 48 kilometre-wide zone of the Antarctic Convergence represents the northern edge of the Southern Ocean because it clearly separates the Antarctic region from lower-latitude waters, and it delineates the natural biological associations of the two marine regions. Generally, the convergence zone is located at a latitude of around 50 degrees south, which means that this boundary definition would also include within the Antarctic region some subantarctic islands such as South Georgia and the South Sandwich Islands. The precise position of the convergence zone, however, varies somewhat depending on longitude, the weather and time of year, and can therefore shift regionally by as much as 150 kilometres to the north or south.

This *World Ocean Review* will conform to the delineation of the Antarctic polar region established in 1959 by the Antarctic Treaty unless otherwise noted. It thus comprises all land and marine regions south of 60 degrees south latitude.

Wandering continents

The fact that both polar regions of the Earth are covered with ice at the same time is an exceptional situation in the 4.6 billion-year history of our planet. Only a few times in the past have the Earth's continents been so arranged that the necessary cold climate conditions prevailed both in the north and the south. It was the migration of the continents, then, which provided the initial impetus for the icing over of the two polar regions.

The German polar researcher Alfred Wegener was the first to scientifically postulate that the continents are moving. In 1912 he published his hypothesis of continental drift, which geologists to this day have only been able to supplement and refine because Wegener's reconstructions of continental motion were so accurate. According to his theory the outer shell of the Earth, the crust, with a thickness of up to 60 kilometres, broke apart into large plates around three to four billion years ago. Since then, these have been moving independently of one another upon the Earth's mantle, which underlies the crust and is composed of molten rock, or magma. The plates travel at speeds up to ten centimetres per year. They collide with one another, are pushed atop one another at their margins or drift apart, creating trenches and fractures through which liquid magma can rise from the Earth's interior. In this way, new continental or ocean crust is formed at the fractures.

Climate researchers consider continental drift to be one of the most influential factors in the history of ice formation in the polar regions. After all, the relative positions of the continents and oceans determine the patterns of air and ocean currents, and thus the distribution of heat on the planet. This applies particularly to the two polar regions, whose geological structures and subsurfaces were shaped by completely different **plate-tectonic processes**.

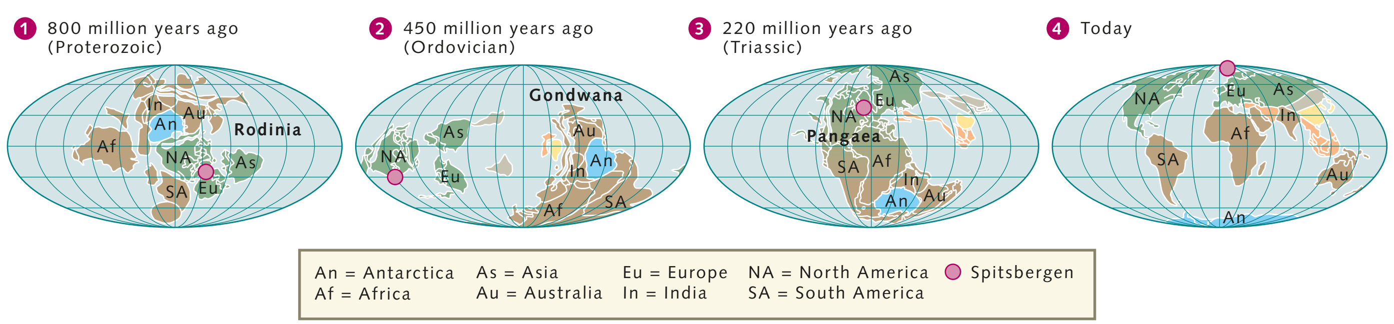
Antarctica – an ancient continent

In order to understand the origins of the southern polar region, it is necessary to know that the Antarctic continent actually consists of two parts: One is the relatively large, solid landmass of East Antarctica, which is composed of continental crust up to 3.8 billion years old and 40 kilometres thick. The other is West Antarctica, which comprises four considerably smaller and thinner crustal blocks. These four crustal fragments even today are not firmly connected to one another. They are constantly drifting.

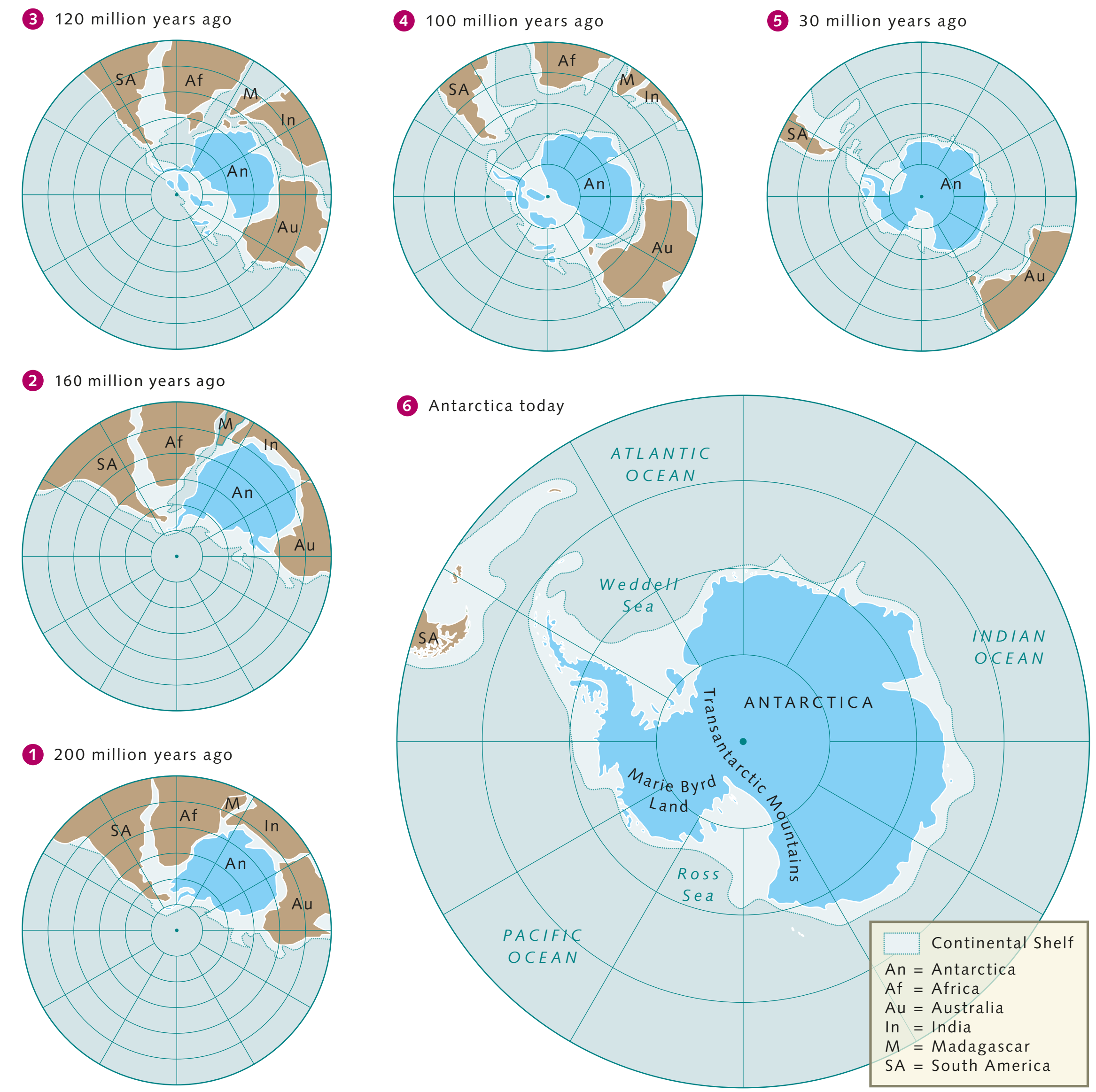
Although the land mass of East Antarctica and the crustal blocks of West Antarctica lie on a single continental plate, a wide trench separates the two parts from one another. The Transantarctic Mountains, on the East Antarctic side of the trench, rise to heights well over 4000 metres and extend for a length of 3500 kilometres.

The geographic position and remoteness of Antarctica are relatively recent phenomena from a geological perspective. For most of the Earth's history the Antarctic Plate has been positioned directly adjacent to other continents. At least twice, in fact, it has been located far from the South Pole at the centre of a supercontinent. The first time was around one billion years ago, when all of the continents united as a consequence of worldwide mountain building to form the supercontinent Rodinia. The land mass that is now East Antarctica formed its centrepiece and was located north of the Equator, presumably very near the Laurentian Plate, which was the primeval North America. Some reconstructions place it beside Australia or Mexico. Which scenario is correct is still being debated today.

Approximately 550 million years later, during the Ordovician geological period, the Antarctic Continental Plate again moved to the centre of a great continent. This time it formed the core area of the giant Gondwana continent. This land mass united all of today's southern continents as well as the Indian subcontinent, and was positioned such that Antarctica was located between the Equator and the Tropic of Capricorn. This time it was



1.6 > From a geological point of view, the current positions of Antarctica and Spitsbergen near the poles represent only a momentary glimpse. In the past, parts of both regions have been located in the opposite hemispheres.

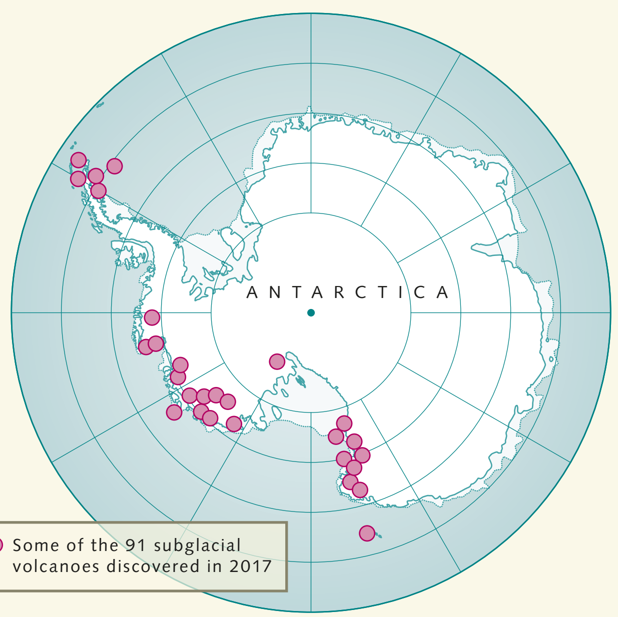


1.7 > As the supercontinent Gondwana began to break apart 200 million years ago, Antarctica gradually separated from the other tectonic plates and drifted toward the South Pole.

A volcanic landscape hidden below the ice

West Antarctica has recently been recognized as the region with the greatest density of volcanoes in the world. Scientists have counted 138 volcanoes so far. But the remarkable fact about this is that 91 of them lie as much as 2000 metres below the ice sheet, and they were first discovered in 2017 by a team of scientists from the University of Edinburgh. These subglacial volcanoes are 100 to 3850 metres tall and have basal diameters of 4.5 to 58.5 kilometres. Their numbers are particularly high near Marie Byrd Land and along an axis that runs parallel to the Transantarctic Mountains through the centre of the West Antarctic Rift System.

The news of the discovery of volcanoes beneath the ice attracted great worldwide interest. Scientists were concerned that the eruption of one or more of the subglacial volcanoes could lead to a rapid melting of the West Antarctic Ice Sheet. The direct result of this would be an abrupt global sea-level rise of several metres. Observations from other parts of the world suggest that volcanoes can become active when an overlying ice burden melts. Examples of subglacial volcanic activity have been observed in Iceland, for instance, where eruptions have led to melting on the underside of glaciers, causing a significant increase in the velocity of ice flow. It has not yet been definitively determined whether the volcanoes beneath the West Antarctic Ice Sheet are currently active.



1.8 > Most of the volcanoes in West Antarctica lie beneath the ice.

bounded by India and Australia to the west and South America to the south.

Gondwana existed for a period of more than 300 million years. Its landscapes were characterized by widely branching river systems, lakes, dense forests, and intermittently even by a thick ice shield, which covered the continent 300 million years ago near the end of the Palaeozoic Era. Around 180 million years ago Gondwana began to break apart again – accompanied and driven by numerous volcanic eruptions, deep fractures in the Earth's crust, and strong drift movements. These initiated the movement of the Antarctic Plate toward the south, which became possible as all of the neighbouring continents slowly broke off.

This began around 160 million years ago as the southern tip of Africa began to break away from the Antarctic continent, opening the rift that ultimately resulted in the formation of the Weddell Sea. The land masses of India and Madagascar then slowly drifted away toward the north, centimetre by centimetre. Then, between 90 and 80 million years ago, as New Zealand separated from Antarctica, the crustal blocks of West Antarctica were reorganized. Hot magma currents within the Earth began to lift the blocks along their border to East Antarctica. One consequence of this was the formation of the Transantarctic Mountains and the mountain range on Marie Byrd Land. Another was the creation of a fracture in the Earth's crust that still exists today as a vast trench, riddled with faults and extending from the Ross Sea to the Weddell Sea. Geologists call this fault trench that runs parallel to the Transantarctic Mountains the West Antarctic Rift System. It is 800 to 1000 kilometres wide, more than 2500 kilometres long, and is one of the largest continental trench fault systems on the Earth – comparable in size to the East African Rift Valley, which runs through Africa from the Red Sea to Mozambique.

The Antarctic continent could someday break apart along this active fault zone, but currently the trench is only widening by two millimetres per year, which is equal to about one metre every 500 years. In the recent geological past, however, relative movements of the plates and the drifting apart of West and East Antarctica have caused the Earth's crust to become thinner along the fracture zone and deep basins to form in the Ross Sea. This explains why large parts of the subglacial surface in West Antarctica today lie one to two kilometres below sea level, and without their unifying ice sheet would not look like a continuous surface but an assemblage of islands of various sizes.

The formation of the West Antarctic Rift zone about 80 million years ago was not the last tectonic milestone in the drift history of the Antarctic Continental Plate. Two others followed, almost synchronously with one another, and both were again driven by the spreading processes in the Earth's crust. One occurred at the plate boundary between South America and the Antarctic Peninsula where the spreading increased significantly 50 million years ago. Around 41 million years ago the Drake Passage opened here, an oceanic strait that is about 800 kilometres wide today and connects the Pacific and Atlantic Oceans.

The second notable spreading process occurred on the other side, in East Antarctica, where Australia was drifting away from the Antarctic Plate. Researchers today find this separation fascinating because it occurred in part, at least from a geological perspective, at breath-taking speed.

It is now believed that the Australian Plate separated from the Antarctic Plate in two steps. Initially, 95 to 60 million years ago, the southern coast of Australia detached itself from East Antarctica, while the part that is now called Tasmania was still in contact with Victoria Land in the Antarctic via a land connection that was at times flooded by shallow water. This land bridge, however, already bordered on a long, shallow gulf that was formed between the two plates. Around 34 million years ago, the sea floor in the area of the land bridge subsided within a period of just one to two million years, presumably because the drift direction of the Pacific Plate had changed. A strait was created that opened a pathway for cold oceanic deep water from the Southern Ocean, which could now flow unimpeded between Australia and Antarctica. The ring of water around Antarctica was now complete and the Southern Ocean was born. The continuous band

Gulf
Large marine embayments, semi-enclosed seas, or marginal seas that are largely surrounded by land masses are called gulfs. Well-known examples include the Gulf of Mexico, a marginal sea of the Atlantic Ocean enclosed by the coasts of the USA, Mexico and Cuba, and the Persian Gulf – a 1000 kilometre-long inland sea as much as 300 kilometres wide between the Persian Plateau and the Arabian Peninsula.

1.9 > Skansen Mountain, at the entrance to the Billefjorden, Spitsbergen, has clearly defined sediment layers that enable geoscientists to trace the history of the island's origins. The limestone layers visible here, for example, dating from the Middle Carboniferous to Lower Permian Periods, are 320 to 290 million years old.

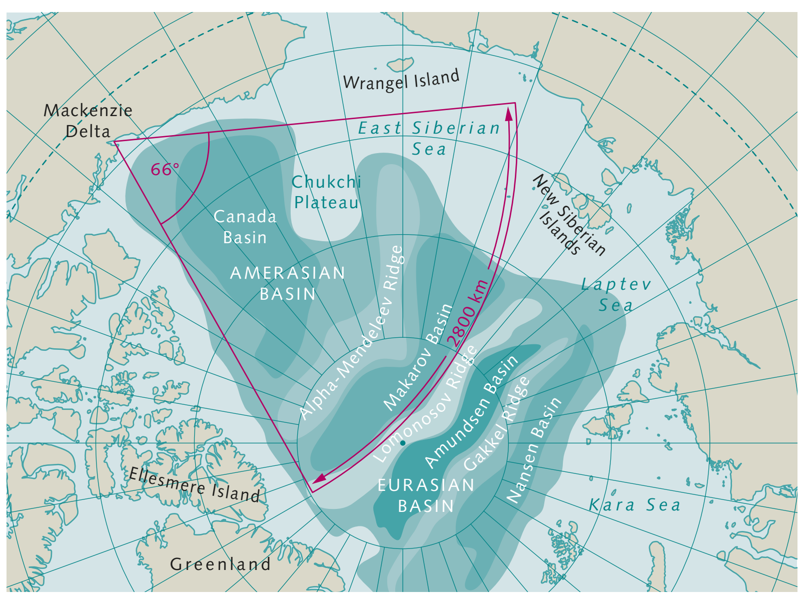
of current today still climatically insulates the southern continent from the rest of the world, and this same situation significantly contributed to the initiation of ice formation in Antarctica 34 million years ago.

The Arctic – an ocean opens

The land masses in the present-day Arctic region have undergone a much longer voyage than that experienced by the Antarctic continent. 650 million years ago the island of Spitsbergen, for example, as a part of a larger land mass, was located near the South Pole, as evidenced by thick glacial-period deposits that scientists can still find on the island today. Since then Spitsbergen has drifted 12,000 kilometres to the north at an average speed of less than two centimetres per year. Evidence for the wandering history is found in the various rock layers on the island.

Rust-coloured rock faces are the vestiges of a time 390 million years ago, when Svalbard was part of a large desert near the equator. 50 million years later, at the beginning of the Carboniferous Period, the region was located in the northern subtropics. The climate was hot and humid, and dense rain forests grew on Svalbard.

1.10 > The history of the origins of the Arctic Ocean has not been fully researched. One possible explanation is that the continental plates of North America and Siberia drifted apart rotationally, thereby creating room for the Amerasian Basin.

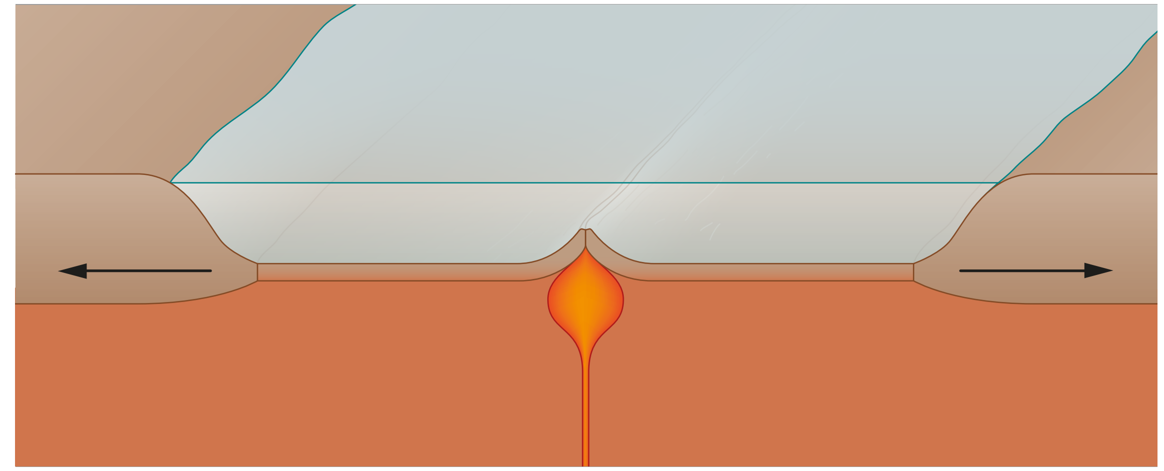


1.11 > Palaeontologists pose beside the fossil remains of marine reptiles found on Spitsbergen.

When the age of dinosaurs began 225 million years ago, the land mass of Svalbard was covered by a sea in which first ichthyosaurs, and a few million years later 20-metre-long plesiosaurs swam and hunted their prey. Researchers have discovered large numbers of the skeletons of both of these marine reptiles.

At the same time, rivers that existed then must have transported large amounts of sediment and organic material into the sea. These sank to the bottom and produced kilometre-thick deposits in large basins. These sediment layers play an important role today in the search for natural-gas and oil reservoirs.

In the Late Jurassic epoch, 150 million years ago, plate-tectonic processes began to act that led to the formation of the Arctic Ocean and the present-day configuration of the continents. At this time, the supercontinent Pangaea split into the southern continent of Gondwana and the northern continent of Laurasia. The latter comprised the continental plates of present-day North America, Europe and Asia, a composite that likewise began to break up around 145 million years ago. Geologists believe that at that time a small ocean basin formed between North America and Siberia, which was the beginning of a division and the subsequent rotational spreading between the two plates. Based on present knowledge, the exact motions that occurred in this scenario can only be surmised. It is certain that between Canada and Alaska on one side and Siberia on the other, the present-day Arctic Ocean originated with the opening of the triangular Amerasia Basin, which is now the oldest part of the ocean.



1.12 > Because the two continental plates are moving away from each other, the sea floor is split open. At the opening a mid-ocean ridge has formed where magma rises from the Earth's interior and forms new sea floor.

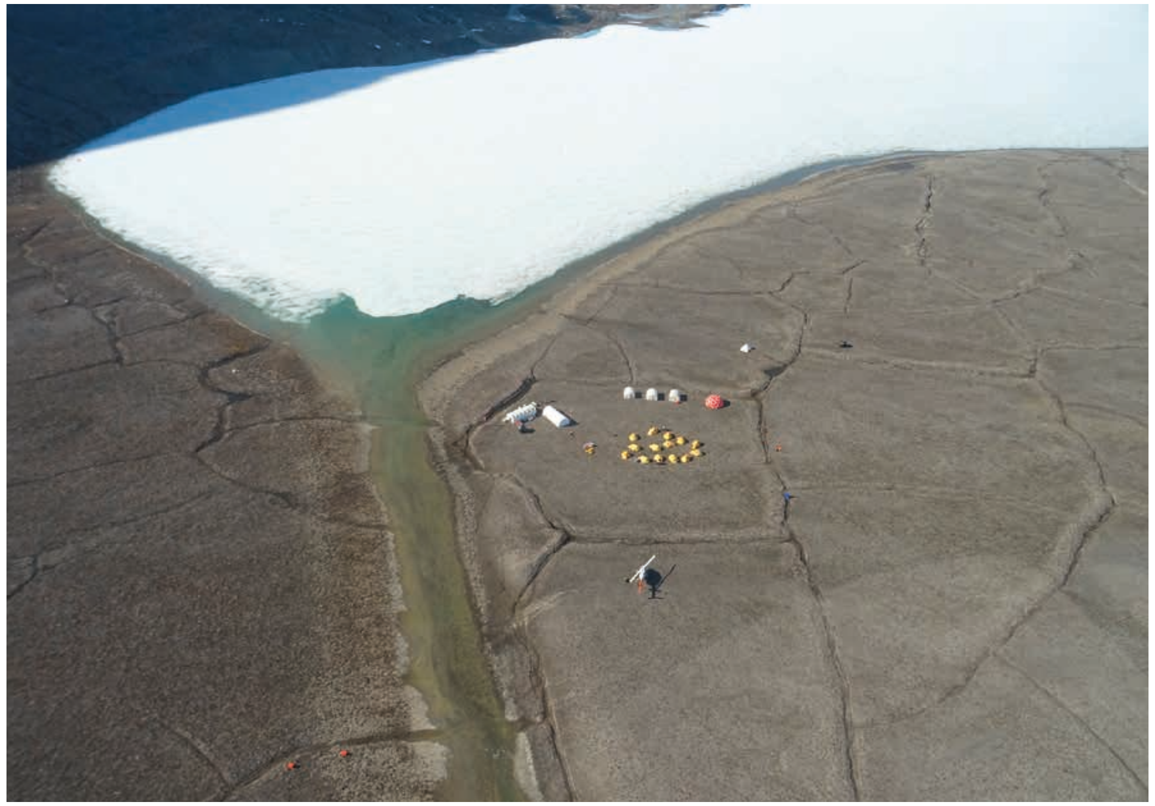
Along the margins of this basin, Franz Josef Land, Svalbard, North Greenland and the Canadian Arctic were sites of intense volcanic activity. Liquid magma penetrated from below into the Earth's crust to form volcanic pathways. Some lava masses also escaped to the surface and formed volcanoes.

About 110 million years ago the opening of the Amerasia Basin came to an abrupt end when the western edge of a piece of Alaska, called the Alaska-Chukotka microcontinent, collided with Siberia. At this time, Svalbard had reached its position in the high latitudes, but was still a part of the large land mass of Laurasia, which, like all of the areas surrounding the new Arctic Basin, was covered with dense forests of giant redwoods. The climate must have been very warm and the vegetation lush because thick coal deposits formed throughout these regions. On Ellesmere Island in the Canadian Arctic, scientists have found the fossil remains of turtles and crocodiles from this time. These are also indicative of the tropical conditions in the high north.

Laurasia began to break apart completely as crustal spreading between Canada and Greenland around 95 million years ago created the Labrador Sea and Baffin Bay. 40 million years later a new phase of repositioning of the continental plates began, during which the North Atlantic opened. At around the same time, 55 million years ago, an 1800 kilometre-long submarine mountain range, named after the Russian natural scientist Mikhail Vasilyevich Lomonosov, detached from the Eurasian continental margin and began to drift toward its present position at the North Pole.

In the process of this separation, the Eurasian Basin of the Arctic Ocean opened between the continental margin of Eurasia and the Lomonosov Ridge. In its centre there is an active mid-ocean ridge today, the Gakkel Ridge, named after the Russian oceanographer Yakov Yakovlevich Gakkel. This ridge is a continuation of the North Atlantic Ridge. It extends from the north coast of Greenland to near the Lena River Delta and divides the Eurasian Basin into the northerly Amundsen Basin and the Nansen Basin, which lies to the south and thus nearer to the coast.

As is typical of mid-ocean ridges, the Gakkel Ridge is a tectonic spreading zone. This means that the ocean floor is spreading apart along the 1800 kilometre-long ridge. Magma flows out of the Earth's interior and creates new sea floor in the rift zone of the ridge. At the Gakkel Ridge these tectonic processes are occurring more slowly than at any other mid-ocean ridge in the world. The sea floor is spreading here at a rate of only one centimetre per year. Nevertheless, it is enough to explain why hot seeps simmer on the sea floor and why the Eurasian Basin is continuously growing even today.



1.13 > In order to better understand the opening of the Arctic Ocean and the associated plate motions, geologists regularly carry out expeditions to the high latitudes of northern Canada. Here they have set up camp on a remote part of Ellesmere Island.

The fragmentation of Laurasia and the opening of the Eurasian Basin over the past 55 million years have induced very complex plate motions between Svalbard and the northern margin of North America. Where plates collide, large zones of deformation and buckling occur. Mountains fold upwards – for example, on the west coast of Svalbard, in northern Greenland and in the Canadian Arctic. Where plates slide past each other, kilometre-long, box-shaped valleys form near the coasts, which are useful for geoscientists in the identification of lateral continental drift. Such fault zones exist today on Banks Island and Ellesmere Island, for instance. Researchers have found that plate movements have shaped the entire continental margin of North America over the long term. This is supported by the fact that the margin of northern Canada is surprisingly straight from the Mackenzie Delta in the southwest to the northern edge of Greenland.

Ocean formation in the Labrador Sea and Baffin Bay ended around 35 million years ago. Greenland, which had existed for some time as a separate continental plate, now became part of the North American plate again. Just ten million years later, however, Spitsbergen detached itself from northern Greenland and drifted with the rest of Eurasia into its present position.

During this separation, 17 to 15 million years ago, a trench up to 5600 metres deep was created between the archipelago and the east coast of Greenland. This deep-sea trench, called the Fram Strait and named after Norwegian polar explorer Fridtjof Nansen's research ship *Fram*, remains to this day the only deep-water connection between the Arctic Ocean and the world's oceans, and is very important for the exchange of water masses.

Despite all of these geological indications, the history of the Arctic Ocean remains a plate-tectonic enigma. Many of the details are still not understood today. For example, geologists do not know the origin of the Alpha-Mendeleev Ridge. This undersea mountain chain divides the Amerasia Basin into the Makarov Basin in the north and the Canada Basin to the south. Ship expeditions to this vast marine region are extremely rare and expensive because, despite climate change, this part of the Arctic Ocean is covered with sea ice even in summer, making geological drilling particularly costly and risky.

Ice formation in Earth's history

In terms of climate history we are living in an exceptional time. For most of the approximately 4.6 billion years since its creation, the Earth has been too warm for the formation of ice covers on large areas of either the North or South Pole. The planet has been predominately ice-free. Large-scale glaciation in the high latitudes has only occurred during the glacial periods. These are defined as times when glaciers and inland ice masses cover extensive areas of the northern and southern hemispheres. The conditions for permanently ice-covered polar regions only exist during so-called ice ages.

The present ice age began with the icing of Antarctica around 40 to 35 million years ago. For about the past million years, colder and warmer periods have been alternating at intervals of about 100,000 years. Climate researchers designate these phases as glacials (ice periods) and interglacials (warm periods).

The Earth is currently in an interglacial period. That means we are experiencing a climate with mild winters, moderate summer temperatures, and glaciers in the two polar regions and in high mountainous areas.

There is much debate about what factors trigger an ice age. What is certain is that pronounced climatic changes are always accompanied by changes in the planet's energy balance. In general, there are four possible triggers:

- cyclical fluctuations in solar activity;
- changes in the Earth's orbital path around the sun;
- changes in the planetary albedo, the amount of solar energy reflected from the Earth back into space. This value is largely dependent on cloud cover and the lightness of the Earth's surface;
- changes in the composition of the atmosphere, particularly the concentrations of greenhouse gases such as water vapour, carbon dioxide, methane and nitrous oxide, or the amount of particulate matter in the air.

If one or more of these changes occurs, the various processes can work to amplify each other to some extent. A good example of this is the ice-albedo feedback: if ice sheets, glaciers and sea ice form as a result of cooling climate, the white areas of the ice surface grow larger, which increases the reflective effect from the Earth – the albedo. This means that a greater proportion of the incoming solar energy will be reflected back into space, causing the air temperature to cool further and resulting in the formation of more ice.

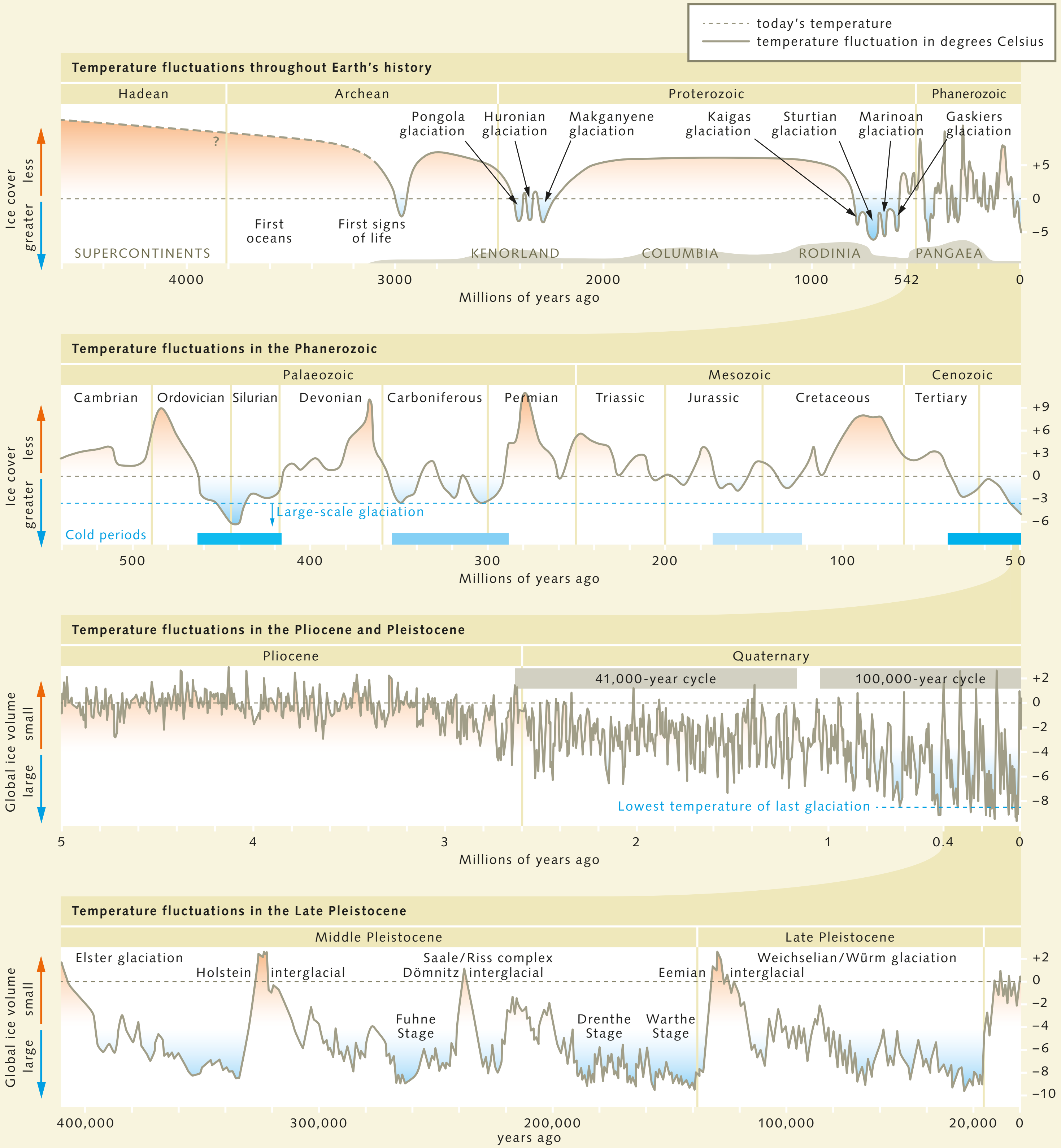
Beside these four main causes of climate change, however, there are additional factors that can influence the weather and climate of the Earth and thus also the extent of ice formation, either in the short or long term. These include:

- meteorite impacts, short-term volcanic eruptions, and regularly occurring marine current-pattern fluctuations such as the El Niño phenomenon;
- decades-long volcanic eruptions or changes in ocean circulation;
- long-term climate swings lasting for hundreds of thousands to hundreds of millions of years, which are mainly controlled by plate-tectonic processes that result in changes in ocean circulation and the carbon cycle.

All of these influencing factors must be taken into consideration when trying to understand why extreme glaciation has repeatedly occurred on the Earth throughout its history, alternating with repeated disappearances of the ice masses.

Climate extreme – snowball Earth

The largest areas of ice covered the Earth between 2.5 billion and 541 million years ago. During this time span there were repeated extremely long-term ice covers, with ice sheets and glaciers so expansive that they extended from



1.14 > In the course of the Earth's history its climate repeatedly cooled so extremely that extensive ice masses formed, beginning on the land masses at high latitudes and eventually resulting in the glaciation of large parts of the planet. The main reasons for the climate swings presumably were decreases and increases in greenhouse-gas concentrations in combination with plate movements.

the polar regions to the equator. This is supported by various lines of geological evidence that prompted researchers for the first time in the 1960s to suggest that the Earth must once have been under a complete cover of ice. Then, in 1992, the US American geologist Joseph L. Kirschvink formulated the hypothesis of the "snowball Earth", which said that the continents and seas were so extensively covered with ice that the planet viewed from space at those times would have looked like a snowball. According to this theory, the global average temperature during these extreme ice periods was minus 50 degrees Celsius. At the equator, with an annual average temperature of minus 20 degrees Celsius, it was as cold as present-day Antarctica, the theory holds.

Kirschvink's hypothesis is still widely debated today. One of the questions raised by critics is how existing organisms could have survived under a completely continuous ice cover. Another is that there is no satisfactory explanation for what processes would have been strong enough at the end of the cold period to return the climate from extremely cold back to "normal". Nevertheless, most of the geological evidence supports the existence of at least three occurrences of these snowball conditions. The first was at 2.3 billion years ago during the Makganyene glaciation. The second one, called the Sturtian glaciation, occurred between 760 and 640 million years ago, and the third, the Marinoan glaciation, around 635 million years ago.

The triggers for these extreme climate conditions are presumed to be a combination of tectonic plate motions, significantly lower greenhouse-gas concentrations in the atmosphere, and a strong ice-albedo feedback. In the build-up to the first snowball ice period, and preceding the later snowball events as well, large land masses were located in the tropical latitudes. This concentration of continental plates near the equator initiated two processes that led to immediate cooling. For one, in regions with humid climates the rainfall led to accelerated erosion of the young rocks and mountains that had been lifted up by plate motions. Whenever rainwater fell on the bare calcareous or silicate rocks, it reacted with carbon dioxide in the air to form carbonic acid, which was then able to dissolve minerals out of the rocks and thus break them down. By this process, the greenhouse gas carbon dioxide was fixed and thus removed from the atmosphere for a very long period of time. In climate models, researchers have been able to illustrate that the global formation of ice is initiated when the atmospheric carbon dioxide concentration is less than 40 ppm (parts per million, millionths).

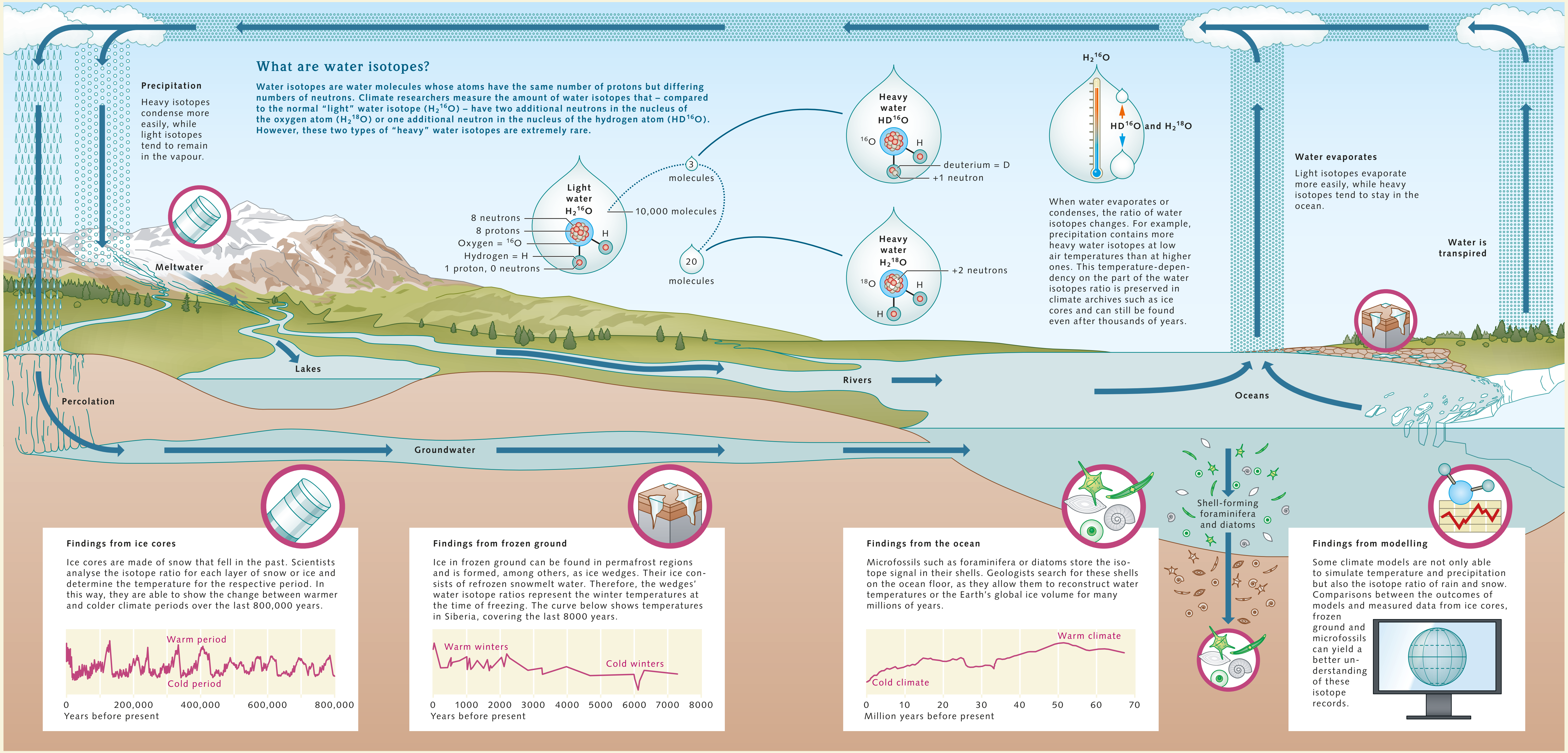
Secondly, the dense conglomeration of continents at the equator prevented the tropical ocean from absorbing a large amount of heat because there was less water surface available as a heat reservoir. The ocean currents therefore were not able to distribute as much heat around the globe. In addition, astrophysicists assume that since its genesis, and up to the present, the intensity of the sun has been increasing. For example, 800 million years ago the Earth was receiving six per cent less solar radiation than it is today.

Under these conditions, a large volcanic eruption ejecting millions of tons of ash particles into the atmosphere and thereby further reducing solar radiation would presumably have been sufficient to trigger the transition to a snowball state. It would only require the formation of the first glaciers. As their surface area increased, more of the incoming solar energy was reflected by the ice, thus promoting further cooling of the Earth.

Scientists can only speculate about the reasons why this spiral of cooling eventually ended. The reasons are probably related to renewed plate-tectonic movements and volcanic eruptions over a time frame of five to ten million years that increased greenhouse-gas concentrations in the atmosphere and brought a return to warmer conditions. Carbon dioxide concentrations in the atmosphere at the end of the third global glaciation reached a level of ten per cent, which is orders of magnitude greater than today's carbon dioxide level of 0.041 per cent (410 ppm). As a consequence, the world flipped from a snowball climate into a super greenhouse climate. Within just a few thousand years, the warmth of this super greenhouse melted the Earth's ice sheet, which probably had a thickness of up to 4000 metres. This theory is supported by characteristic rock deposits found, for example, in Oman and Australia, as well as by the results of various climate models.

Water isotopes – insights into past climate

Decoding the secrets of the Earth's climate history is one of the most difficult tasks for modern research. Reliable thermometers have only been available for around 300 years. Scientists therefore rely on water isotopes as climate tracers. Their occurrence allows us to reconstruct temperature, precipitation and ice volumes over many millions of years.



Icing of the polar caps

The recent climate history of the polar regions is like a puzzle with many pieces still missing. It is fairly well known that the present ice formation in Antarctica began around 40 to 35 million years ago. At this time there was a fundamental change in the Earth's climate. For one, a decline in atmospheric greenhouse-gas concentrations was accompanied by a drop in the air and water temperatures. Another crucial change was the opening of the Tasmanian Seaway in the southern hemisphere between Tasmania and East Antarctica, followed later by the opening of the Drake Passage. Since that time the Antarctic continent has been completely surrounded by a deep continuous pathway along which the waters of the Circumpolar Current flow. Still today they insulate Antarctica from the warm ocean currents to the north.

The first glaciers presumably formed in the high mountainous elevations of East Antarctica, specifically the mountains in the region of Queen Maud Land, the Transantarctic Mountains, and the Gamburtsev Mountain Range, which is completely covered today under the ice sheet and was named for the Soviet geophysicist Grigory Aleksandrovich Gamburtsev. Because it was cold enough at the time and sufficient amounts of snow fell, these glaciers must have grown rapidly. Climate data from deep-sea sediments suggest that Antarctica had one or more ice sheets as early as 34 million years ago that contained about half as much ice as it currently holds.

Antarctic ice masses subsequently expanded and declined depending on the development of global climate and the amount of incoming solar energy reaching the Antarctic. But the ice has never disappeared completely. The two currently existing ice sheets of East and West Antarctica attained their greatest extent at the climax of the Last Glacial Maximum about 19,000 years ago. The ice tongues extended to the outer edge of the continental shelf, and sea level was lowered by about 5 to 15 metres. By comparison, the West Antarctic glaciers extended about 450 kilometres further out into the Southern Ocean than they do today and transported so much ice that the tongues no longer floated (ice shelf), but lay on the seabed (ice sheet). The same was true for the glaciers in the Ross Sea and Weddell Sea regions. At the peak of the last glacial, global sea levels were about 120 metres lower than today.

Since 2004, the question of timing for the onset of ice formation in the Arctic can no longer be answered with confidence. Until then it had been assumed that the large-scale formation of glaciers in the northern polar region did not begin until 2.7 million years ago, which would be more than 30 million years later than in the Antarctic. In the summer of 2004, however, in sediment cores from the Lomonosov Ridge, scientists discovered coarse rock grains in deposits older than 44 million years that could not have been transported into the ocean by either wind or water. A number of researchers have concluded that there must have been icebergs floating on the Arctic Ocean carrying this debris at that time. This assumption implies that at that time there were already glaciers near the sea from which these icebergs had calved.

Since then there has been heated debate as to whether this interpretation, that the Arctic was glaciated earlier than the Antarctic, is really correct. The presence of firm evidence that forests were growing at the time in the Arctic, suggesting a climate much too warm for glaciers, is one of the arguments against the iceberg hypothesis. Other researchers maintain that sea ice could also have transported the rock grains. As further analyses of the Lomonosov Ridge cores have revealed, the Arctic Ocean may have been covered by an initial permanent sea-ice cover long before the first ice sheets formed in East Antarctica.

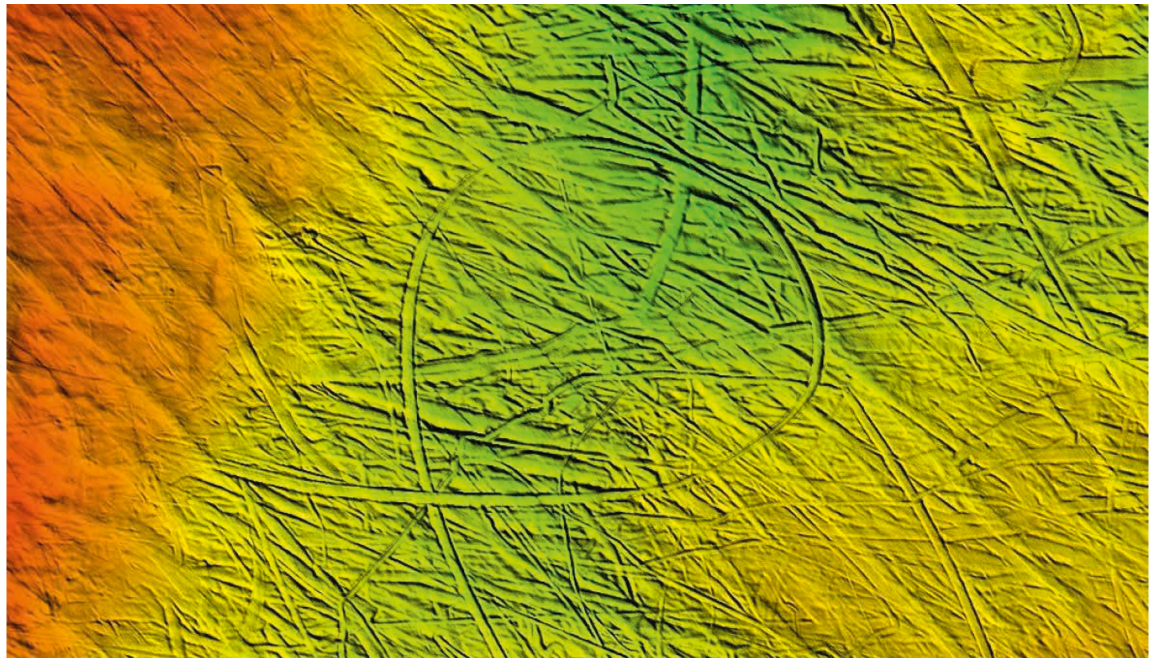
The first glaciers in the northern hemisphere formed during a significant cooling between 3.2 and 2.5 million years ago. Atmospheric carbon dioxide concentrations decreased at that time from about 400 to 300 ppm. At the same time the Panama Strait closed as a result of plate tectonic movements, ending the previously continuous exchange of water between the central Pacific and Atlantic Oceans.

The impact that this change had on Arctic climate is strongly debated. Recent and ongoing studies increasingly indicate that marine currents within the two oceans changed as a result of the interruption of water exchange between them. In the Atlantic Ocean the Gulf Stream was strengthened. Together with its branches, it now transported more saline water, heat and moisture to the far north. The surface waters cooled in the Fram Strait and then, cold and heavy, they sank toward the sea floor. These waters then travelled southward along the path of the global ocean conveyor belt. The heat and moisture above the ocean's surface, on the other hand, was transported by the west winds toward Europe and Siberia. There, it rained and snowed with increased frequency and rivers carried much more freshwater into the Arctic Ocean. During the cold winter months, it should be noted, seawater with a greater proportion of freshwater freezes more readily into sea ice.

Climate researchers believe that more ice floes formed at that time in the Arctic Ocean. The expanding ice area likewise reflected an increasing proportion of the incoming solar radiation back into space, thus inhibiting the storage of heat energy in the ocean. At the same time, around 3.1 to 2.5 million years ago, the tilt angle of the Earth relative to the sun was changing. The planet tilted slightly more away from the sun, so that the northern hemisphere received significantly less solar radiation than it does today. The seasons became colder and less snow melted in the summer, especially in the higher altitudes. Over time the remaining snow masses compacted into firn. Eventually, the ice of the first glaciers was formed from this.

During the subsequent glacial periods, kilometre-thick ice sheets covered large parts of North America, Europe and Siberia. Deep, parallel furrows on the seabed of the East Siberian Sea indicate that ice sheets have even formed in the Arctic Ocean itself within the past 800,000 years, not floating on the water surface like pack ice, but lying directly on the sea floor. These ice masses were at least 1200 metres thick and presumably extended over an area as large as Scandinavia.

This knowledge of the existence of such marine ice sheets raises many questions about the previous ideas regarding Arctic glaciation history. The furrows prove that large-scale freezing does not originate only at high altitudes on the continents, as was the case in Greenland, North America, northern Europe and Asia. Ice sheets can also develop in the seas. The question of what environmental conditions are necessary for this to occur, however, is one of the many uncertainties in solving the puzzle of glaciation in the polar regions.



1.15 > Wherever icebergs or shelf ice rest directly on the sea floor, they leave traces of their movements. These almost circular furrows on the seabed were made by an iceberg off the coast of Svalbard.

The many aspects of ice

Ice is formed when water freezes. There is great diversity in the manner in which this happens in the polar regions. Based on their different features, the following types of ice can be distinguished:

Permafrost

Researchers define permafrost, permafrost soil, or ground ice as the condition when the temperature within the soil remains below zero degrees Celsius for at least two consecutive years, and the water contained in the soil is frozen. The ground can consist of rocks, sediments, or soil, and contain variable amounts of ice. There are areas in the Arctic, in northeast Siberia for example, where the ground contains up to 70 per cent ice. Ground ice can extend to depths of 1.5 kilometres. Permafrost is currently found in as much as 25 per cent of the exposed land surfaces in the northern hemisphere.

1.16 > Most permafrost areas can be recognized by their polygonal patterns. These are formed by repeated freezing of the ground.

Glacier

A glacier is a large ice mass formed from snow that is slowly and independently flowing down a valley due to its great mass, and is then depleted in its lower reaches by the melting of the ice. Some glaciers are not much larger than a football field, while others can be hundreds of kilometres long. Today most glaciers are in Antarctica, Greenland and the Canadian Arctic. But there are also some in the high mountainous areas of the Alps, Andes and Himalayans, where they serve as an important source of drinking water for the surrounding regions. The world's largest glacier is the Lambert Glacier in East Antarctica. It is 400 kilometres long and 100 kilometres wide, and alone it transports eight per cent of the ice masses of the Antarctic ice sheet toward the ocean. Like an ice sheet, a glacier can grow or shrink, depending on how much snow falls on its surface in the winter and how much snow and ice melt in the summer.

1.17 > Icy winds acted quickly to refreeze an open-water area in the Weddell Sea.

Sea ice

Sea ice is formed when seawater freezes. Because of the salt content it must be cooled to minus 1.8 degrees Celsius for this to happen. Freshwater, by contrast, freezes at zero degrees Celsius. New sea ice contains large amounts of brine, which accumulate in droplet form between the ice crystals or in small brine channels. Over time this brine seeps through to the underside of the ice where it is released back into the water. This explains why perennial sea ice contains hardly any salt.

Sea ice begins to freeze with the formation of ice crystals three to four millimetres in size, called ice needles. These collect on the water surface and as their density increases they are mutually attracted to one another. If there is little or no wind a thin continuous crust called nilas is formed. With wind and wave action, however, the crystals eventually form into pancake-like ice plates, which constantly collide with one another and are thus somewhat turned up at the edges. This typical form of sea ice is called pancake ice.

Both the nilas ice and the pancake ice become thicker over time and form ice floes that can grow to thicknesses of up to 90 centimetres in the first year. Wind and waves tend to stack these floes on top of each other, creating pack-ice ridges ten to 20 metres thick. These are impassable obstacles even for icebreakers.

Sea ice forms primarily in the polar regions. It freezes in the winter and, for the most part, melts in the summer. In summer the southern polar ocean loses up to 80 per cent of its sea ice. The total area of ice shrinks from 18.5 million square kilometres (September, end of winter) to 3.1 million square kilometres (February, end of summer). By comparison, the Arctic Ocean loses only about half of its ice mass. Its sea-ice area in winter averages 14 to 16 million square kilometres, and in summer it is seven to nine million square kilometres, with a strongly falling trend.

1.18 > Pancake ice off the coast of Svalbard. The characteristic ice plates are created by surface wave motions.

Ice sheet

Ice sheets, also called ice caps or continental glaciers, are extensive ice shields formed from snow lying on a land surface where the total landscape is covered except for a few isolated peaks, and with an area of greater than 50,000 square kilometres. On the Earth there are currently two ice sheets, the Antarctic continental glacier with an area of 11.9 million square kilometres (without shelf ice), and the Greenland continental glacier with a size of over 1.71 million square kilometres. The Antarctic ice sheet is up to 4897 metres thick in some places and contains so much water that global sea level would rise by around 60 metres if it were to completely melt. The Greenland ice sheet has a thickness of up to 3200 metres and its melting would raise sea level by around seven metres.

Ice sheets are created in regions where the snow falling in winter does not completely melt in the summer. Over time the unmelted snow volumes grow layer by layer and are compacted, first to firn and ultimately to ice due to the increasing weight of the overlying masses with each snowfall. An ice sheet has the shape of a dome. It is thicker in the centre than on the edges. The masses of ice can be thought of as a viscous, unbaked cake batter. Due to their own weight, they flow from the centre of the ice shell toward the edges – just as a lump of cake dough will when it is removed from a bowl and placed on the countertop.

At the margins of an ice sheet, the ice masses usually flow into glaciers, ice streams or ice shelves, and are transported toward the open sea. There are some margin areas, however, where the ice does not move and the ice sheet ends abruptly.

As long as the amount of snow that falls on the surface of an ice sheet is equal to or greater than the amount lost at its margins, a sheet is considered to be stable. If less snow is deposited than is lost to the sea, then the ice shield shrinks.

Shelf ice

Shelf ice is the seaward projection of an ice sheet or glacier floating on the sea, i.e. the part that no longer rests on land or the seabed. The best-known shelf ice in the world is in the Antarctic, where the Filchner-Ronne Ice Shelf (around 422,000 square kilometres in area) and the Ross Ice Shelf (around 473,000 square kilometres), the two largest of their kind, are found.

The thickness of these ice bodies can vary from one ice shelf to another. It can range from 50 metres in the marginal area to 1500 metres in the transitional area between the anchor ice and shelf ice, which is called the grounding line. On the extreme margins of shelf ice, icebergs are constantly breaking off. This process is known as calving.

1.19 > A view of the calving front of the Ross Ice Shelf in Antarctica, the largest ice shelf in the world.

The human conquest of the polar regions

> In view of their extreme climatic conditions, no one ever ventured into the polar regions without good reason. 45,000 years ago, the prospect of abundant prey lured the first hunters into the Arctic. These were followed much later by adventurers and explorers in search of new trade routes. Then the hope of fame became the main impetus. Today – clear economic and political interests notwithstanding – curiosity and a thirst for knowledge have become key motives, and these have promoted peaceful cooperation. Even in politically fraught times, scientists from diverse countries are collaborating closely in the polar regions.

The great migration

The oldest human traces in the polar regions have been found in the Arctic. This is not surprising since, even today, because of its location and land connection, the Arctic is much easier for people and animals to reach than Antarctica, which is surrounded by the Southern Ocean.

Nevertheless, Russian scientists were amazed in the summer of 2012 when they discovered the cadaver of a young bull mammoth preserved in permafrost on the steep shore of the Siberian Taymyr Peninsula, between the Kara and Laptev Seas, and determined that the animal had been slain by humans around 45,000 years ago. This was 10,000 years earlier than hunters were previously believed to have been present in the Arctic. According to detailed reconstructions, the prehistoric hunters had wounded the mammoth with spears in the shoulder, stomach, rib cage and trunk areas so severely that it eventually died. The technique of aiming a spear at the trunk of an elephant is still used by hunters in some parts of Africa today. It has proven to be very effective because vital arteries and veins are located in this part of the head. When these are damaged the animals will soon bleed to death.

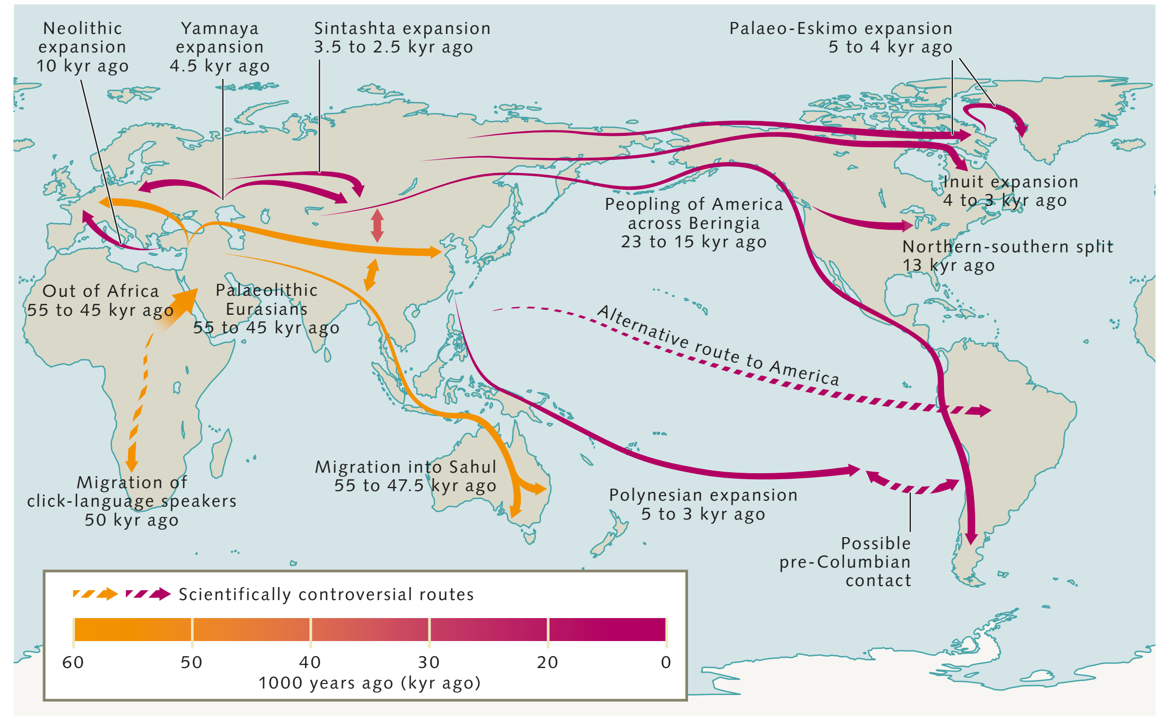
The prehistoric Arctic hunters, however, did not stalk only mammoths. Near the Jana River, about 1700 kilometres to the east, scientists have found the remains of several bison and woolly rhinoceroses. They also discovered the bones of a wolf. These animals were slain by humans about 29,000 years ago. These two excavations prove that modern humans must have roamed extensively in the Siberian Arctic long before the onset of the last glacial period.

This finding also sheds new light on our knowledge about the evolution and dispersal of modern man, *Homo sapiens*. Assuming, as some researchers do, that he left Africa, his continent of origin, for the first time only 65,000 to 50,000 years ago, only a few thousand years remained for the long and arduous migration to the north – a remarkable achievement.

Researchers today cannot say with any certainty how large the first hunting communities in the Siberian Arctic were. The hunters probably lived in small, roving groups at that time, advancing into areas north of the Arctic Circle during the summer, then retreating southward again with the onset of the cold season. Climate data from that period suggest that the average temperatures in the Arctic were somewhat less harsh than today. Nevertheless, people must have been able to sew warm clothes, build shelters and work together in groups. Otherwise they could hardly have survived the climatic conditions.

On their expeditions, the prehistoric hunters probably followed the banks of rivers, which were also followed by the animals of the steppes on their northward migrations. The animals found abundant grazing areas and water in the river valleys. The favourite prey of the early Arctic inhabitants were mammoths, reindeer and horses. Experts believe that it was the ability of the hunters to track the great mammals that made man's advance into the Siberian Arctic possible in the first place.

After the end of the last glacial period, the inhabitants of the Siberian Arctic region learned to make more sophisticated tools and weapons. They began to fish in the lakes and rivers, to catch birds, and even to hunt whales and seals off the coast. They thus had sufficient food and were able to become sedentary, establish settlements and enlarge their family groups.



1.20 > The major migration routes of modern humans as they left North Africa to settle the Earth. The migrating groups left traces in the human genome, which enable researchers today to reconstruct their movements. Their findings indicate that North America was settled from Siberia in three waves – the first time 23,000 years ago.

The first Americans

A comparison of today's Siberian coastline with the coastline at the time of the first Arctic hunters reveals distinct differences. At the peak of the last ice age around 21,000 years ago, global sea level was 123 metres lower than it is today. As a consequence, vast portions of the Siberian shelf seas as well as the area of today's Bering Sea were dry at that time. The Arctic coastlines of Siberia and North America were located further to the north than they are today. Furthermore, a broad strip of land, called the Bering Land Bridge, connected East Siberia with Alaska.

This land bridge had an area about twice the size of the American state of Texas. It stretched from the Lena River Delta in the west to the Delta of the Mackenzie River in the east, and thus extended far beyond the area that we now recognize as the strait between Siberia and Alaska. The region was probably cold, dry, and ice-free – in stark contrast to North America and northern Europe, which were covered by two- to four-kilometre-thick ice sheets at this time.

From sediment cores taken from the bed of the Bering Sea, it is known that the vegetation of the Bering Land Bridge was remarkably diverse. Bushes similar to those found today in the Alaskan tundra grew in the region, as did nutritious grasses and wildflowers that were adapted to cooler temperatures – ideal conditions for grazing animals such as mammoths, bison, arctic camels and reindeer. The question of what vegetation grew on the land bridge and what wild animals were native there is of interest for an important reason: The bridge served as a transit route for animals and humans to the North American continent.

Exactly when and how the first people crossed the land bridge to North America is a subject of much scientific debate and continuing research. Archaeologists search for evidence of settlements, palaeogeneticists reconstruct the migration routes of people based on their genetic make-up, and biologists, geologists and climate researchers study the environmental conditions and landforms of the time. One contentious theory, for example, suggests that the first hunters and gatherers did not cross the land

1.21 > Photograph of an Inuit family printed in the National Geographic journal in June 1917. The accompanying text praises „the tenderness and sense of responsibility" that the natives of the Arctic have in their dealings with their children.

bridge in one single move, but actually lingered in the area for several thousand years because glaciers and ice sheets blocked their way into the new world. It is also unclear whether the first immigrants made their way along the coast or through an ice-free corridor between the ice sheets. Recent studies indicate that the overland route opened up 15,000 years ago.

However, there is a general consensus that the first North Americans had Siberian ancestors who probably entered the area of the Bering Land Bridge (and here the debate is sparked anew) between 24,900 and 18,400 years ago. Then, about 16,000 years ago, the immigrants began to gradually settle the North American continent. Some of them migrated southward along the west coast and founded the well-known Clovis culture. Others settled in ice-free regions further inland. But none of these first Americans ventured to settle north of the Arctic Circle.

The first inhabitants of the North American Arctic arrived around 5000 years ago in a second migratory wave across the Bering Land Bridge, long after the large North American ice sheets had melted. Within a few hundred years, the people known as Palaeo-Eskimos had spread all the way to Greenland. They lived in small tent camps, hunted reindeer, musk oxen, seals and walruses with stone spears or knives, and had learned to freeze portions of their catch and store them in larder cellars or pits.

About 700 years ago, however, all traces of the Palaeo-Eskimos disappeared. The entire population became extinct. New immigrants from Siberia, called "neo-Eskimos", the ancestors of the modern Inuit, came to North America with boats around 1000 years ago in the third migratory wave, and gradually displaced the long-established reindeer hunters. The newcomers lived in large, well-organized village communities. They used dog sledges, bow and arrows, and knew how to build boats out of whale bones and sealskins. With these they ventured out onto the Arctic Ocean to fish for whales, a strategy that provided them with new, abundant food sources and guaranteed their survival in the far north reaches.

Pursuing the musk oxen

Around 4500 years ago, the prospect of better hunting probably motivated the Palaeo-Eskimos to cross the 30-kilometre-wide Nares Strait, a waterway between Greenland and Ellesmere Island in Canada. At that time, the Greenland Ice Sheet was somewhat smaller than it is today, so there were sufficient grazing lands for musk oxen and reindeer on its northern and eastern margins. Moreover, abundant ringed seals and harp seals lived in the fjords of the Greenland coast. The Palaeo-Eskimos, however, faced a difficult decision after landing on the inhospitable northwest coast of Greenland. They could either migrate southward along the coast and have to cross a 300-kilometre stretch of glacier-covered coastline in Melville Bay to reach the milder, greener areas of West Greenland, or they could follow the musk oxen northward to a region that was so cold that sea ice remained unmelted off the coast all year long, and where the sun remained hidden below the horizon for five months of the year.

The immigrants chose both options: Some of them moved south and founded the Saqqaq settlement in Disko Bay, whose population grew rapidly in the early centuries. The Saqqaq lived in comparatively large family groups, quickly settled all of the larger fjord systems and islands of West Greenland, and mainly hunted the caribou, harp seals, ringed seals and birds of the west coast. Archaeological digs in former Saqqaq settlements have uncovered the bones of 42 different animal species. Moreover, it is evident that the Saqqaq people dried meat and fish in order to maintain food supplies.

The second group of immigrants chose the northern route. This tribe of Palaeo-Eskimos, known as Independence I, settled on the Peary Land peninsula, where they were confronted with much harsher living conditions than those encountered by their relatives in West Greenland. Moreover, around the time these first immigrants arrived the climate of Greenland began to cool even more. The tundra-like coastal areas in the north gradually transformed into polar deserts. During the summer months, the 100 to 200 pioneers lived in small family clans and set up widely dispersed tent camps, in order to avoid rapidly depleting the sparse food resources offered by the barren landscape and sea ice. Their primary game were musk oxen, caribou, seals and arctic foxes. In winter, however, the people moved back together to spend the colder months in a communal camp.

The tents of these Palaeo-Eskimos were round or oval in shape, and measured three to four metres in diameter. Every third tent or so had a fireplace built of stacked stones. This "stove" in the middle of the tent served as a cooking station, a heating oven and the only source of light, especially during the cold and dark winter months. These inhabitants of the far north heated with what little driftwood was washed up, or with the bones and fat of slain land and sea mammals. The Saqqaq in the west, on the other hand, had sufficient driftwood, allowing them to make larger fires more often and thus heat fist-sized stones. The stones were used not only to heat the areas away from the fireplace, the hunters also used them to cook their meat and fish, because the Palaeo-Eskimos had no pots or other cooking utensils.

The Saqqaq occupied West Greenland over a period of almost 2000 years (from around 2400 to 800 BC). Their neighbours on the Peary Land peninsula, on the other hand, must have given up after just a few generations. Their traces ended about 3750 years ago.

Clovis culture
The Clovis culture is the oldest known culture in North America. It existed about 13,000 to 12,600 years ago across vast areas of North America. These people used stone tools, including spear points of chert with two-sided cutting edges. A number of these points were first discovered at an excavation in Clovis, New Mexico in the USA. The name is derived from this locality.

Arrival of the Vikings

The settlement of northern Europe probably began at the end of the last glacial period. It only became possible for people to advance northward after the large ice sheets had melted around 13,000 to 14,000 years ago. The hunters and gatherers thus migrated from central Europe along the coastline of Scandinavia and into the Arctic region around 10,000 years ago. Stone-age people only settled further inland away from the coasts after the growth of forests there which provided sufficient wood and food sources. In the area that is Finland today, the forests were birch, while in Norway coniferous trees predominated.

From Scandinavia and the British Isles, Nordic sailors then colonized Iceland thousands of years later. According to historical sources, the Vikings landed on the island between 870 and 930 and permanently changed its appearance: in one way by bringing plants and animals from their former homeland, and in another by beginning within a few decades of their arrival to clear the forests of Iceland to let their sheep graze in the highlands.

From Iceland, in the early 980s, the Viking Erik the Red explored the south coast of Greenland. Then, in 985, he set sail with a fleet of 25 ships with the aim of establishing a settlement in Greenland. The seafarers landed in the southern part of West Greenland and founded three settlements, where they mainly lived as cattle and dairy farmers. At that time the climate of Greenland was under the influence of the Medieval Warm Period. The temperatures were similar to today's conditions, so that agriculture was possible to some extent. But the settlers did not depend on their cattle alone. In the early summer they fished for cod, which they preserved by drying (stockfish), and in autumn they hunted reindeer and birds. In addition, the Vikings traded in walrus and narwhal ivory, and explored North America with the aim of obtaining wood there, which was not plentiful enough in Greenland.

At the height of the Viking settlements in Greenland (1300–1350 AD), an estimated 200 farms were inhabited by around 5000 people, although this figure has been disputed. There may well have been fewer than 5000 settlers.

Beginning around the early 14th century, climatic conditions began to worsen. The average temperature dropped by one degree Celsius. Expanding sea ice and increased frequency of storms made it difficult to travel by ship to Iceland and across the North Atlantic. The summer growing season became shorter, and animals that preferred warmer temperatures migrated to the south. Instead of cattle, the Greenland farmers now kept sheep and goats. However, since these did not provide enough meat, the Vikings became increasingly reliant on marine mammals. They hunted bearded, harp, hooded and harbour seals in the open waters. However, they were far less successful at this than the Thule, or proto-Inuit, who had inhabited Ellesmere Island and North Greenland since about 900 AD, and who had learned to lie in wait for ringed seals on the pack ice and kill them using a refined harpooning technique. When the ivory trade with Europe collapsed soon thereafter, the descendants of the Vikings gave up. The last family left Greenland in 1411.

1.22 > The Viking Erik Thorvaldsson, known as Erik the Red, sailed from Iceland to Greenland in 982 with a small group of followers, and three years later became the first European to establish a settlement on the island. He called it "Grönland" (green land), hoping that the attractive name would encourage settlers.

The Age of Discovery

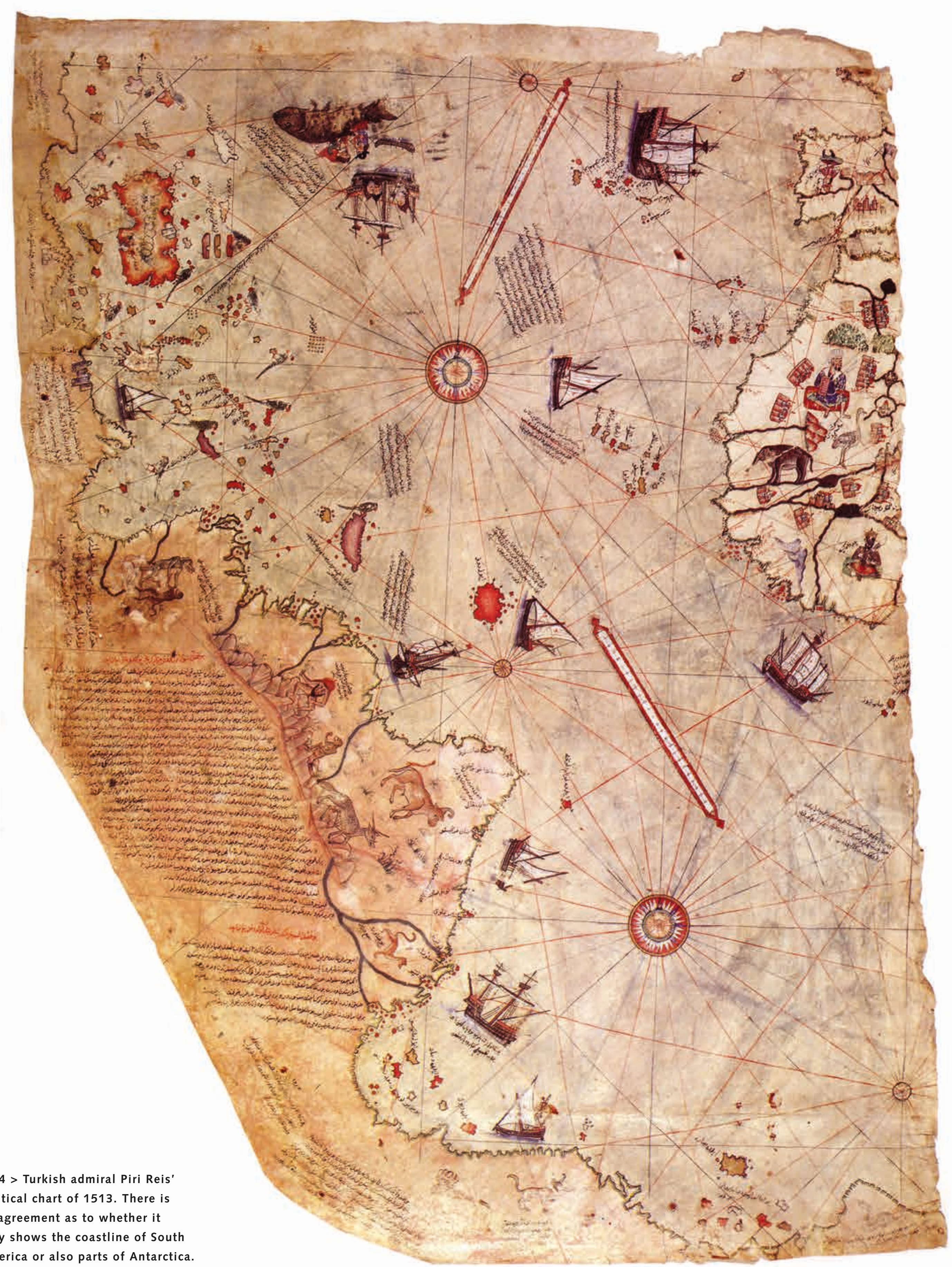
Soon after the Vikings withdrew from Greenland, an era of exploratory voyages to the far north began in Europe. Some of these expeditions were aimed at opening up new areas for whaling and seal hunting. However, most of them served only a single purpose: to discover an open sea route to Asia. Near the end of the 15th century, no merchant ship was allowed to use the southern sea route to India or China without Spanish or Portuguese permission. These two major powers had divided the world between themselves in 1494 with the Treaty of Tordesillas, which gave them control of the shipping routes across the Atlantic and Indian Oceans. For other emerging seafaring nations, such as England and Holland, the only alternative was to sail through Arctic waters if they wanted unchallenged trade with China and India. The conditions for finding a navigable route through the Northeast or Northwest Passage, however, could not have been more challenging – the few existing maps of the Arctic region contained gross inaccuracies.

1.23 > Shortly before his death, the cartographer Gerardus Mercator drew the Arctic Ocean as a sea with four large islands in the centre. However, the accuracy of this portrayal was questioned soon after the map was published in 1595.

First maps of the polar regions

Many coastal areas of the Arctic have been known and populated for thousands of years. However, around the year 1450 hardly anything was known in Europe about the areas north of Scandinavia. Svalbard, for example, was still undiscovered at that time. What surprises did the regions of the high north hold? Were there perhaps unknown continents waiting to be discovered? Did the pack ice really extend beyond the horizon, or was there, as some had speculated, an ice-free Arctic Ocean?

One of the first maps of the north polar region, drawn by cartographer Gerardus Mercator (1512–1594) and published after his death in 1595, shows four large islands in the Arctic Basin, separated only by narrow waterways. Only two years later their existence was cast into doubt



1.24 > Turkish admiral Piri Reis' nautical chart of 1513. There is disagreement as to whether it only shows the coastline of South America or also parts of Antarctica.

by the Dutch seafarer and discoverer of Spitsbergen, Willem Barents. But the idea of an ice-free polar sea persisted for much longer. As late as 1773, two British ships under the commands of Constantine J. Phipps and Skeffington Lutwidge attempted to sail via Spitsbergen to the North Pole – with the firm conviction that the Arctic Ocean must be navigable. Pack ice halted their progress at 81 degrees north latitude.

In contrast to the Arctic, Antarctica was just a theoretical concept in ancient times. The Greeks were convinced of its existence because the world would otherwise be in a state of disequilibrium. In their classical climate-zone model, they assumed that a cold, uninhabitable zone could not exist only in the north, but to satisfy the mass balance of the Earth there must be a corresponding similar zone located in the south.

In the Middle Ages, the Christian Church forbade the idea of a spherical Earth with an icy counterweight at the South Pole. Instead, the Church held the belief that the Earth was a flat disk. A circular map from that time shows the known continents of Asia, Europe and Africa surrounded by a ring-shaped ocean. Beyond this ocean, the Spanish Benedictine monk Beatus of Liébana (circa 730–798) introduced a new unknown continent to the south, with the notation: “Desertta tterra ... incognita nobis”.

The southern continent appeared on a world map for the first time in 1508. The Italian Francesco Rosselli drew it in his representation of the Earth. The first known geographical information about Antarctica is seen on the famous Ottoman map drawn by Piri Reis and dating from 1513, although the origins of this information are not known. Some experts suggest that the map shows actual features, including the sub-Antarctic islands south of Tierra del Fuego and islands in an ice-free western region of Queen Maud Land.

During the next two centuries, the still-hypothetical southern landmass became an entrenched feature of maps – usually under the name of Terra Australis Incognita, which awakened images of wealth and prosperity in many Europeans. According to popular legend, the mysterious southern continent promised gold and other rewards to its discoverers. This myth faded, however, when the English explorer and navigator James Cook (1728–1779) sailed around Antarctica for the first time on his second circumnavigation of the Earth (1772–1775), crossing the Antarctic Circle at three points without sighting land. At 71 degrees south latitude he had to turn back because of heavy ice. The explorer concluded that the presumed continent must lie further to the south, and was thus probably hostile and useless. With the Latin expression “nec plus ultra” (to this point and no further) Cook destroyed the legend of a southern land of riches.

New routes to India and China

In the Arctic, the race to traverse the Northeast and Northwest Passages was well under way. The Italian Giovanni Caboto (English name: John Cabot) led the first exploratory voyage in search of a route along the northern coast of America. He was convinced that the shortest passage between India and Europe would be found in the far north, and in 1497 he encountered the North American continent at the latitude of Labrador on an expedition financed by England. His son Sebastiano Caboto, together with his two associates Hugh Willoughby and Richard Chancellor, founded the Company of Merchant Adventurers to New Lands in 1551 to generate funds for the search for a Northeast Passage. The major motivation of the three businessmen was the prospect of new trade relations with Russia and China rather than the possible discovery of previously unknown regions.

In 1553, on their first Arctic expedition with three ships, Hugh Willoughby and his crew froze to death, but Richard Chancellor reached the White Sea and was invited to Moscow for an audience with the Russian Tsar. There, the Englishman obtained special trade concessions. Subsequent attempts by the trading company to advance further eastward by sea, however, all ended on the Arctic island of Novaya Zemlya, which was first visited by an expedition of the company in 1553. Later, the first explorer to travel beyond this point was the Dutchman Willem Barents, after whom the Barents Sea is named.

Bering – "Columbus of the Tsars"

Vitus Bering (1681–1741) had spent eight years at sea as a ship's boy before joining the Russian navy in 1703 as a second lieutenant. There he advanced quickly through the ranks, and near the end of 1724 Peter the Great commissioned him to explore the eastern part of the Russian Empire. At that time Siberia was still largely unexplored, and the Tsar wanted to know what mineral resources could be found in the region, which indigenous peoples lived there, where the borders of the Russian Empire were, and whether there was a land connection between Siberia and North America. Furthermore, there were rumours that the Cossack leader Semyon Ivanovich Dezhnev had already sailed around the eastern tip of Siberia in 1648 and was thus the first to pass through the strait later named after Bering. There was considerable doubt at the time, however, that these reports were true. The Tsar therefore wanted to be sure.

Vitus Bering and his expedition with 33 men set off on the First Kamchatka Expedition in 1725, which did not take them across the sea but over land. After two years of gruelling marches over mountains and rivers, through seemingly endless steppes and swamps, their trek ended in Okhotsk where the men built a small ship. With it, Bering crossed over to Kamchatka. He then crossed to the east coast of the peninsula and had another ship built there in 1728. With it he set off on 14 July 1728 and sailed northward along the east coast of Siberia. Almost four weeks later, on 13 August 1728, he sailed through the strait between America and Asia that is now named after him. There was no trace of a land connection between Asia and America. When the ship was above the Arctic Circle at 67 degrees north latitude, Bering gave the order to turn back. He was now convinced that America and Asia were two separate, unconnected continents.

However, because Bering had not seen the American coast with his own eyes due to thick fog, his reports were questioned in Saint Petersburg. The royal house wanted more scientific facts and gave Bering a second chance. The Second Kamchatka Expedition (Great Northern Expedition, 1733–1743), which he commanded, was intended to eclipse all previous voyages of discovery. Bering commanded an expeditionary team of 10,000 men, subdivided into several individual expeditions, to survey the northern coasts of Siberia and the Pacific, and to scientifically study the expanses of Siberia. Bering himself was commissioned to locate and map the west coast of North America.

After years of research work crossing through Siberia, Bering set sail in 1741 from Kamchatka with two ships heading south-eastward. He held this course until 46 degrees latitude, because he wanted to discover the legendary island of Gamaland with the streets of gold that were supposed to be found there.

Bering and Aleksei Ilyich Chirikov, the captain of the second ship, confirmed that the island was a fantasy that existed only in the imagination of seamen. The ships then changed course to the northeast to sail toward North America. But during a storm the two ships lost contact with one another. Chirikov subsequently discovered several Aleutian Islands and then, due to a dwindling supply of drinking water he turned and set a course for home. Vitus Bering continued to sail the *St. Peter* into the Gulf of Alaska. There he discovered land in July 1741. He had found North America, which earned him the nickname "Columbus of the Tsars", and he continued to sail along the coast to map its course.

The ship then set out for the return voyage to Kamchatka. However, due to bad weather, lack of food and navigation errors, this did not go as planned. The ship beached on an uninhabited island, today known as Bering Island, where the extremely weakened expedition leader died of scurvy on 19 December 1741 at the age of 60. A total of 46 members of his crew survived the winter. In the spring they built a small sailing ship from the wreckage of the *St. Peter* and made it back to Kamchatka, from whence, in the meantime, a search party led by Aleksei Chirikov had already set out.

A more complete exploration of the northwest coast of North America was accomplished in 1778 by the English circumnavigator James Cook. On his third and last major voyage, Cook reached the Bering Strait and mapped the coast of Alaska to 70 degrees north as well as the Chukchi Peninsula. The last large voids on the map of the Siberian-

Arctic coast were filled in by the Baltic German officer of the Russian navy, Ferdinand von Wrangel. In 1820, he and his followers began exploring the northern coast of East Siberia from land, using dog sledges, and mapping all of the coastal features. In this way, during his four-year expedition, Wrangel filled the remaining cartographic gap between the mouth of the Kolyma River in Eastern Siberia and the Bering Strait.

The first complete crossing through the Northeast Passage, however, was achieved by the Swede Adolf Erik Nordenskiöld (1832–1901) between 1878 and 1879. The polar explorer had already made a name for himself by exploring Spitsbergen and Greenland, and it took three attempts before he was able to realize his dream of a successful passage. On the first two attempts he made it to the mouth of the Yenisei River, and on his return from the second voyage he became the first traveller to transport commercial goods from Asia back to Europe via the northern sea route. On his third voyage, which began on 4 July 1878 in Gothenburg, he headed toward the Yenisei with four ships. Upon arriving at the estuary, he continued eastward with two ships and mapped the coast as far as Cape Chelyuskin on the Taymyr Peninsula, the northernmost point of mainland Asia. He then sent the companion ship *Lena* back with a message of success, but he himself continued heading eastward with his steam-powered vessel *Vega*, and was able to sail along the northern coast of Siberia before the onset of winter. However, a mere 115 nautical miles from his destination of the Bering Strait, the ship became frozen in the ice. Nordenskiöld and his men were trapped on the Chukchi Peninsula and forced to spend the winter there. About 300 days later, on 18 July 1879, the ice finally released the *Vega* again.

Nordenskiöld then sailed through the Bering Strait to Japan. Because the news of the successful voyage had spread like wildfire around the world, his journey home from there was a triumphant one, taking him through the Suez Canal, which was only ten years old at the time.

A shorter route to Australia?

The counterpart to the Northeast Passage, the approximately 5780-kilometre-long Northwest Passage, was first completely traversed 26 years after Nordenskiöld's triumph. After the pioneering expeditions by English and Portuguese explorers in the 16th and 17th centuries, there were no notable ship expeditions to this area for the next 200 years. This lack of interest was partly due to the

1.25 > The Danish explorer Vitus Bering drew this map on his First Kamchatka Expedition (1725–1730). After his return, the Russian Imperial Court requested further scientific facts from Bering proving that Asia and North America were separate continents. Bering therefore undertook the Second Kamchatka Expedition (1733–1743).

1.26 > The English seafarer James Clark Ross discovered the North Magnetic Pole at the age of 31. Ten years later he explored Antarctica and was the first man to advance into the region of the Ross Sea, which bears his name today.

discovery of Lancaster Sound and the Hudson Bay during previous voyages, regions that promised enormous profits for the fur trade due to their great biodiversity. Other potential explorers were distracted by the gold rush in North America.

The desire to find a sea route along the North American Arctic coast was revived only after it became known that the Arctic Ocean was indeed continuous along the northern margin of the continent. Hunters and fur traders had confirmed this by following the Mackenzie and Coppermine Rivers to their mouths. But before a ship could undertake this dangerous voyage three things had to be determined. First of all, there was no known western outlet from Baffin Bay. Secondly, the entryway into the Northwest Passage from the Pacific was not yet known. The Englishman James Cook had advanced into the Bering Strait to 70° 44' North on his third world voyage in 1778, before being blocked by a "12-foot-high wall of ice" to the north of Icy Cape. However, it was completely unknown how the coastline continued beyond that. Thirdly, no one knew whether there would be a navigable sea route through the island maze of the Canadian Arctic Archipelago to the east.

In order to fill these white patches on the map with information, a number of ship and land expeditions to the North American Arctic were undertaken during the first half of the 19th century. The British captain Frederick William Beechey explored the north coast of Alaska from Icy Cape to Point Barrow. The British explorer John Franklin (1786–1847), working on land, mapped the coast around the Mackenzie and Coppermine River Deltas during his first expedition (1825–1827).

An expedition led by John Ross sought to explore the missing area between Melville Island in the east and Franklin's mapping to the west. In the process, Ross' nephew James Clark Ross discovered the magnetic pole of the northern hemisphere in 1831.

Death in the island maze

For the third and ultimate task, the search for a way through the islands of the Canadian Arctic Archipelago, the British admiralty selected a man with previous Arctic experience. In February 1845 they commissioned the polar explorer John Franklin, who had meanwhile been promoted to the rank of Rear Admiral, to find the Northwest Passage. He was to sail with two ships around Greenland through the well-known Baffin Bay, and find a western branch that was believed to exist. The army provided the expedition leader with the two ships best suited for ice at the time: HMS *Erebus* and HMS *Terror*, two converted warships whose bows were reinforced with copper and iron to protect the wooden hulls. Both of the three-masters were equipped with a 25-HP steam engine, which drove a ship's propeller so that the expedition could continue to advance during periods of low wind. In addition, pipes were installed in the ships through which hot water could be pumped to heat the rooms on board. With a crew of 67 men on each ship and provisions for three years, they set sail from London on 19 May 1845.

In the Disko Bay of West Greenland, the crews divided supplies from a third escort ship between the two expedition ships, and set a course for Lancaster Sound, a strait between Baffin Island and Devon Island. After that, they were sighted twice by whalers. Then John Franklin and his men disappeared into the hostile labyrinth of islands, pack ice and rocky coasts, which was largely uncharted at the time.

More than 40 search missions were carried out in the years that followed to determine the fate of the two expedition ships and their crews. In the process, the search parties also made important geographical discoveries and completed Franklin's mission. Finally, in April 1853, two search teams coming from different directions – one led by Robert McClure, the other by Henry Kellett – met in Mercy Bay on the northern end of Banks Island, proving for the first time that the Northwest Passage truly existed.

The first traces of the Franklin expedition had already been found by search teams. In August 1850, shreds of clothing on Devon Island and three graves on Beechey Island were discovered. Four years later, Inuit in Pelly Bay on the Boothia Peninsula reported to the Arctic explorer and physician John Rae about white sailors who had starved to death some distance to the west. In May 1859, another search team, on the west coast of King William Island, discovered a stone marker hiding an expedition report by the ship's crew.

The remains of the two ships were discovered in 2014 and 2016. HMS *Terror* lay on the bottom beneath 24 metres of water in a bay on King William Island. According to reports, the three-master is in such good condition that it would float if it were raised and the water pumped out.

It was more than 50 years after Franklin's disappearance before the Norwegian Roald Amundsen (born 1872, disappeared 1928) became the first to succeed in traversing fully through the Northwest Passage with a ship. But he too was not able to complete the passage within a single year. It took Amundsen a total of three years with his vessel *Gjøa* (1903–1906). He was forced to wait out the winter more than once due to ice conditions. The severe winter ice conditions in the Northwest Passage were also the reason this route did not become a time-saving alternative to the shipping route through the Suez Canal and across the Indian Ocean. With the state of ship technology at that time, the route could not be navigated without spending at least one winter waiting for the ice to recede.

Thirst for knowledge replaces commercial interest

After it had been demonstrated that there was little point in sending merchant ships to Asia and Australia via the Northeast or Northwest Passage, the economic motivation for continued exploration of the North Polar region dissolved. In its place, however, scientific interest in the region increased. Driven by the desire for a more complete knowledge of all earthly realms, many countries intensified their research efforts in the polar regions.

In Germany, the geographer and cartographer August Heinrich Petermann (1822–1878) promoted research in one way by establishing the scientific journal *Petermanns Geographische Mitteilungen* in 1855. In it he published numerous articles and maps on polar research, thus providing scientists with an instrument for sharing their research. In addition, Petermann advocated hypotheses that gave new directions to Arctic polar research at the time. On the one hand, he argued, the Arctic Ocean could not freeze completely over even in winter due to a warm ocean current from the south, an extension of the Gulf Stream, and that an ice-free and navigable Arctic Ocean would be found to the north of the belt of drifting pack ice. Furthermore, he postulated that Greenland, which was still largely unexplored at the time, extended across the Pole to as far as Wrangel Island.

In 1868 Petermann succeeded in initiating the first German North Polar Expedition, led by Carl Christian Koldewey (1837–1908). On board the ship *Grönland* the expedition team was to survey the east coast of Greenland up to 75 degrees north latitude. But the plan did not succeed. Pack ice blocked the ship's path, so Koldewey and his crew changed course and sailed to Spitsbergen. There they carried out meteorological and hydrographic measurements, confirming that a branch of the Gulf Stream carried Atlantic water masses along the west coast of Spitsbergen toward the Arctic.

A second German North Polar Expedition (1869–1870) planned by Petermann also partially failed – due in part to the fact that one of the ships was crushed by the ice. And it was not the last voyage of discovery that would not fully achieve its objective. For example, the Austro-Hungarian North Pole Expedition (1872–1874) led by Carl Weyprecht (1838–1881), which set out to investigate the Arctic Sea north of Siberia, did discover Franz Josef Land but, contrary to plan, the party was forced to spend the winter and later to abandon the ship. Weyprecht, however, learned a lesson from the journey, and based on this experience he developed his basic principles of Arctic research. In his opinion, polar research was only worthwhile if it conformed to his six principles:

1. Arctic research is of the utmost importance to understand natural laws.
2. Geographical discoveries in these areas are only of major importance insofar as they pave the way for scientific research in its strict sense.
3. The detailed topography of the Arctic is of secondary importance.
4. The geographic pole is not of particularly greater scientific importance than any other location at high latitude.
5. Regardless of their latitude, observation stations are more advantageous the more intensively the phenomena for which the study is designed occur at the given site.
6. Individual observation series are of greater relative importance.

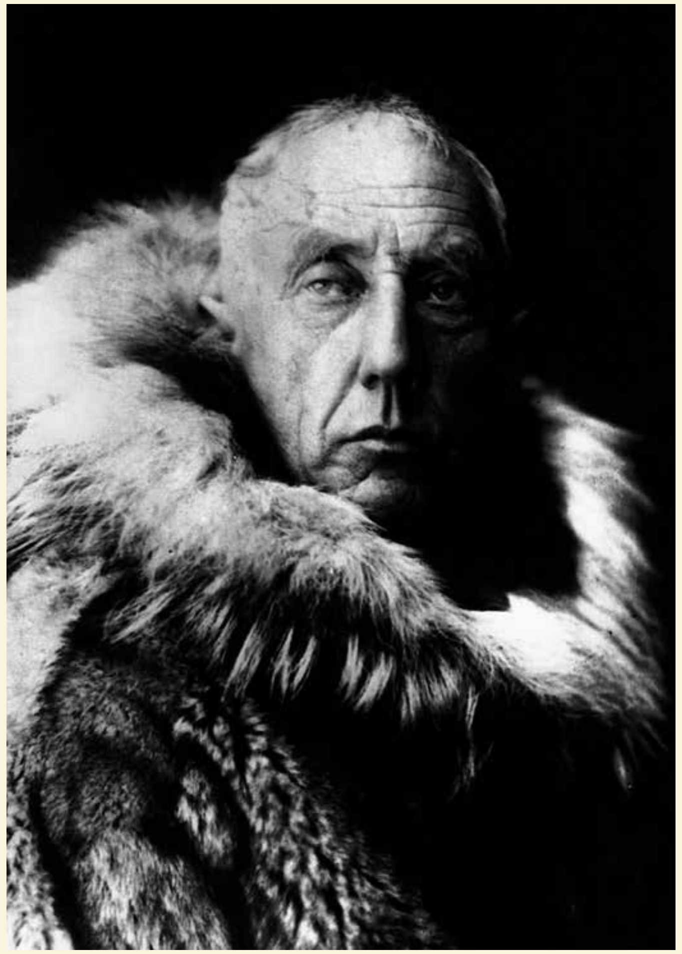
Weyprecht's approach was immediately well received by the research community. It would help to avoid additional costly and less efficient expeditions. He also worked closely with Georg von Neumayer (1826–1909), the director of the German Naval Observatory in Hamburg, on the first international Arctic measurement campaign. Their basic idea of "research stations instead of research voyages" remains one of the cornerstones of modern polar research, emphasising the importance of continuous long-term measurements rather than detailed isolated studies.

Neumayer and Weyprecht's campaign led to the foundation of the first International Polar Commission in 1879, which was chaired by Neumayer. The Commission organized the first International Polar Year (summer of 1882 to summer of 1883), during which eleven countries established a network of twelve meteorological and geomagnetic stations in the Arctic (Russia operated two stations). Two additional stations were set up in the Antarctic. However, to the detriment of science, only the individual results of each of the participating countries were

1.27 > During the first International Polar Year (August 1882 to August 1883) scientists carried out regular weather observations and measurements of the Earth's magnetic field at twelve research stations in the Arctic. A total of eleven countries participated.

Two lives under the spell of the ice

Ambitious, meticulous, obsessed with the poles – these traits describe the Norwegian Roald Amundsen as well as the German Erich von Drygalski. Both were pioneers of polar research, but they could hardly have been more different. While one was pursuing a record, the other was striving to understand the larger picture.



Roald Amundsen (1872–1928) – in pursuit of fame

Since the age of 15, South Pole conqueror Roald Amundsen had known only one ambition – to enhance our knowledge of the world's polar regions. He associated the word "knowledge", however, primarily with geographical information rather than a deeper understanding of the nature and climate of the polar regions. On his expeditions, the Norwegian mostly left scientific observations to the specialists, although he himself was competent in various measurement methods. Before his expedition to the Northwest Passage, for example, Amundsen spent several months learning theory from the German Georg von Neumayer, who at the time was a leading expert in geomagnetics. He wanted to learn how to measure the Earth's magnetic field. Furthermore, on a preparatory cruise for the same expedition, he collected oceanographic data for his mentor Fridtjof Nansen.

But science did not excite him. Amundsen was much more interested in the techniques and methods that could contribute to the success of his expedition plans. On the *Belgica* Expedition to Antarctica (1897–1899) Amundsen, as second officer, had learned that details could be crucial in the planning of an exploration cruise. The crew had survived the threat of scurvy, a disease caused by a deficiency of vitamin C, by following the advice of the ship's doctor Frederick A. Cook and eating fresh penguin meat during the winter instead of the stores of canned food.

Amundsen was fascinated by pragmatic solutions. During his voyage through the Northwest Passage (1903–1906), he learned from Eskimos how to build igloos and how to harness dogs to pull sledges. He marvelled at their windproof reindeer-skin clothing and wore it himself from that time on. For his march to the South Pole he successfully used dog sledges and skis as a means of transport, and for his airship flight over the North Pole he had a solar compass built in Berlin, which the pilot could use to accurately navigate northwards.

Amundsen was a born leader and also applied the highest standards in the selection of his team. His crew was always well trained and hand-picked, and comprised only as many men as were absolutely necessary for success. Everyone on board was given multiple duties. In this way Amundsen prevented boredom from becoming a problem, and increased the sense of responsibility in his men.

When it came to his reputation and honour as an explorer, however, he could make decisions without regard for the considerations of his companions. In 1910, for example, he informed most of the crew of his research vessel *Fram* at some point after leaving Oslo that he did not intend to sail towards the North Pole as they had all believed, but would instead set a course for Antarctica in order to be the first man to reach the South Pole. Because Frederick A. Cook in 1908 and Robert Peary in 1909 had purportedly already been to the North Pole – two reports which later turned out to be false, as both had only come close to the Pole – Amundsen at least wanted to achieve success in the south. Before their departure he had only revealed their true destination to his brother Leon, who was in charge of the business side of the expeditions, Captain Thorvald Nilsen, and the two helmsmen.

Throughout his life, Amundsen was driven by the desire to conquer frontiers and be the first person to achieve incredible feats. Towards this dream he not only borrowed heavily, he also trained obsessively, endured solitude, and knew better than anyone how to portray his projects in the media. His greatest strength, as described by historians, was his belief in himself. With this attitude, Roald Amundsen not only expanded our knowledge of the polar regions, he also made a name for himself in the history books alongside his role models Nansen and Franklin.

Erich von Drygalski (1965–1949) – in pursuit of knowledge

Erich von Drygalski was not much impressed by the media hype over the race to the South Pole. "For polar research, it is immaterial who is the first man at the Pole", commented the East Prussian and scientific whiz kid in reference to the race between Amundsen and Scott. In 1882, at the age of 17, Drygalski began studying mathematics and physics. Soon afterward, he discovered his passion for geography and ice, hiked through the largest glacial areas of the Alps for eight weeks, and at the age of 22 wrote his doctoral thesis on the distortion of the globe due to ice masses. Ice became the central focus of his life. He wanted to understand the glaciation of the North German lowlands as well as the structure, motion and effects of ice, and to mathematically describe the movements of large ice masses. He decided to address these problems by measuring the movement of glaciers in nature, ideally on a large ice sheet.

The largest and nearest ice mass was the Greenland Ice Sheet. The Geographical Society of Berlin financed a preliminary expedition (1890) and a full-scale expedition (1892–1893) to the Uummannaq Fjord on the western margin of this ice cap. Not only did Drygalski set up a research station there, where he and his two companions spent the winter, he also designed a very modern research programme for the team, which filled their days with a wide range of tasks.

For twelve months the scientists mapped and surveyed a number of glaciers in the region. By marking the ice, Drygalski was able to track its flow as well as its rise and fall. On sledging excursions, he was able to study how the ice formed. The scientists also collected meteorological data throughout the time they were there, including temperature, duration of sunshine, air pressure, humidity and wind, in order to understand the effects of ice on the climate. The team's biologist documented the flora and fauna in order to learn how the ice masses affected the biology of the fjord. In addition, geomagnetic measurements and gravity experiments were carried out. The dataset collected by the team was so immense by the end of the expedition that it took Drygalski four years to analyse it. He published the results in two volumes, advanced a fundamental concept of ice motion, and was named as professor within the top ranks of polar researchers.

Because of his extensive experience, three days after qualifying as professor he was chosen to lead the first German South Polar Expedition (1901–1903). His failure to set any records in his name during this excursion disappointed the German Kaiser and the public, but the scientific data he collected was of excellent quality, and Drygalski again retreated into the analysis of this huge body of data. Personal matters such as family planning were put off for the time being, and could only be addressed again after the analysis had been divided among the scientists, leaving him to deal with the geographical and oceanographic findings. To fail to complete a project he had begun would have been unthinkable for him. Straightforward and determined, he compiled the results of the expedition and published them step by step – a task that kept him busy for a total of 30 years. Roald Amundsen was correct when he assessed the significance of this work. Before his death, he said that Germany had every cause to be proud of the essential scientific results of the South Polar Expedition.

published. An all-inclusive overview, in which all weather data were summarized in monthly maps of air pressure and air temperature, did not appear until 1902 – and then only as a dissertation that received little attention instead of being published as a scientific article in a widely read professional journal.

Drifting toward the North Pole

The First International Polar Year was soon followed by a new era of polar research, in which individual initiative and a desire for knowledge became the primary motivating factors for scientific exploration. In 1888, the Norwegian zoologist Fridtjof Nansen (1861–1930) became the first to cross Greenland, proving that it was covered by a continuous ice sheet from the east to the west coast. Soon thereafter the German geographer and glacier researcher Erich von Drygalski (1865–1949) spent a winter on the west coast of Greenland, primarily to study the movements of small local glaciers and large inland ice flows, but also taking meteorological measurements and collecting biological specimens.

Achieving the next scientific milestone required an investigative instinct and a spirit of adventure. In 1884, Fridtjof Nansen, who had crossed Greenland, learned from a newspaper article that Inuit on the southwest coast of Greenland had found pieces of a ship that had sunk three years earlier north of the Siberian islands 2900 sea miles away. This discovery sparked Nansen's interest. He had a research vessel built with a hull shape that could not be crushed by the pack ice, called it *Fram* and, on 22 September 1893, allowed himself and the ship to be trapped in sea ice off the New Siberian Islands. Locked in the ice, the ship and crew drifted between the Siberian coast and the North Pole for months, travelling hundreds of nautical miles. The ice constantly changed direction, sometimes carrying them northward and then southward again. Although they were able to take many depth soundings of the Arctic Ocean, the men were concerned that they were not making any forward progress. Moreover, the moving ice did not take them as far to the north as Nansen had hoped. Thick pack ice blocked their path.

Transpolar Drift
Transpolar Drift is a wind-driven ice flow and surface-water current in the Eurasian part of the Arctic Ocean. It transports large volumes of Arctic sea ice from the shelf seas off the Siberian coasts across the North Pole toward the east coast of Greenland, where the ice floes generally enter the North Atlantic and melt after one or two years.

The *Fram* reached its most northward position (85° 57' North) on 16 October 1895. By this time, however, Nansen and his companion Hjalmar Johansen had already left the ship and set off for the North Pole on sledges, skis and kayaks. They did not make it very far on this solitary journey, however. The constantly shifting pack ice finally forced the two men to return to Franz Josef Land, where they spent the winter in a shelter made of stones. The following spring, the two explorers saw no other way out of their predicament than to head for home by kayak towards Spitsbergen. Fortunately, their kayak trip ended prematurely at Northbrook Island, which is also part of Franz Josef Land. By chance Nansen and Johansen met a British expedition under the leadership of Frederick George Jackson there, who rescued them and brought them back to Norway. Around the same time, northwest of Spitsbergen, the sea ice released Nansen's ship. On 9 September 1886, Captain Otto Sverdrup sailed the *Fram* back to its home port of Oslo, bringing with him valuable measurements from a region where no one before them had ever been.

Even though Nansen did not reach his desired destination of the North Pole, the scientific findings were still of great importance. For one, Nansen's expedition put to rest the long-debated theory of an ice-free Arctic Ocean. Secondly, his positional data confirmed the existence of the Transpolar Drift. Thirdly, the sounding data documented the depth of the Arctic Basin and proved that the offshore islands were part of the continents. Furthermore, the Norwegian found that the drift direction of the ice was never exactly parallel to the wind direction, rather the ice floes veered slightly to the right, a phenomenon which, in his opinion, was due to the rotational movement of the Earth (Coriolis Effect). Today we know that this assumption was correct.

In pursuit of seals in the south

While the north polar region had been extensively explored by the end of the 19th century, the southern polar region remained an empty patch on the map for many years after. The reason for this was basically a lack of interest. After James Cook had turned back in frustration, another 40 years passed before the next expedition ventured into the deep southern realm. Between 1819 and 1821, the Baltic German captain Fabian Gottlieb von Bellingshausen had circumnavigated the southern continent during a Russian Antarctic scientific expedition and encountered land in two different places. He discovered the present-day Princess Martha Coast, which borders the Weddell Sea, and two islands in the Bellingshausen Sea, which was named after him.

It was his belief that the mythical southern land was a large continent inhabited only by whales, seals and penguins, and was therefore useless in a geostrategic sense. British whalers and seal hunters who learned of Bellingshausen's reports, on the other hand, applying their good business sense, launched their first fishing expeditions to the south in the 1820s and 1830s. According to reports, they wiped out large seal populations within just a few years. One of these men was the mariner and seal hunter James Weddell, who sailed three times into the southern polar region. On his third voyage he had only modest hunting success, but the ice conditions were so favourable that his ship was able to penetrate as far as 74° 15' South and 34° 17' West into the marine area that bears his name today, the Weddell Sea.

The crews of the fishing vessels not only knew how to hunt and fish, they also carried out geographical surveys and mapped newly discovered islands and stretches of coastline. From the beginning of the 1890s surgeons accompanied the whalers and carried out further biological and hydrographic research. All of this mapping and surveying, however, yielded only limited and isolated results, for as long as the whalers and seal hunters could fill their ships' coffers with furs, fat and oil on the Antarctic Peninsula and in other regions north of the Antarctic Circle, they had no need to sail further south for exploration purposes.

The search for the South Magnetic Pole

Relatively early, in contrast to the whalers and seal hunters, scientists sought to venture far beyond the Antarctic Circle. As early as 1836, the German natural scientist Alexander von Humboldt (1769–1859) had given Antarctic research a new impetus by suggesting to the President of the Royal Society in London that simultaneous measurements of the Earth's magnetic field should be carried out in both the northern and southern hemispheres – from the equator to the poles – using the same instruments. Humboldt had supported the founding of the Göttingen Magnetic Society, a working group whose goal was to carry out simultaneous geomagnetic observations worldwide and which soon included 50 observatories.

Humboldt's proposal prompted an international race to locate the South Magnetic Pole, which became known as the Magnetic Crusade and during which many new regions of East Antarctica were discovered. The French polar explorer Jules Dumont d'Urville, for example, claimed the territory of Adélie Land not far from the presumed magnetic pole and extending to the coast, where the French research station Dumont d'Urville, named in his honour, is located today. In 1840, the American Charles Wilkes sailed with his ship along the 2000-kilometre coastline of what is today Wilkes Land. Just a few months later the Englishman James Clark Ross set a new record by crossing the line of 78 degrees latitude during his search for the magnetic pole in an unexplored marine region now called the Ross Sea.

On this voyage (1839–1843) Ross not only determined the position of the South Magnetic Pole, which, according to his measurements, lay at 75° 05' South and 154° 08' East, he also discovered the edge of the immense Ross Ice Shelf (later named after him), Victoria Land, and an island with two majestic volcanoes, which he named after his two ships: Erebus and Terror. Today, unsurprisingly, the island is named Ross Island.

A matter of national interest

After Ross's successful voyages, scientific interest in Antarctica waned. There was a lack of motivation and funds to organize expensive research expeditions to the southern polar region. But there were two exceptions. In 1874, the transit of Venus provided an opportunity to refine measurements of the distance from the Earth to the sun (the astronomical unit). To take advantage of this, England, Germany and the USA set up astronomical observatories on the Kerguelen Islands in the southern Indian Ocean. Eight years later, on the occasion of the First International Polar Year, Georg von Neumayer had an observatory constructed in South Georgia to observe the second transit of Venus during the 19th century. But the primary functions of the station were for weather observations and measurements of the Earth's magnetic field.

The enthusiasm of polar explorers was finally revived shortly before the turn of the century. In 1895, the initial impetus was given by the Sixth International Geographical Congress in London. There, leading scientists proposed the exploration of the still unknown Antarctic region as the ultimate challenge of the late 19th century. At that time, no one could say with certainty whether Antarctica was a continent covered with ice or a gigantic atoll with an ice-covered sea at its centre, which – as in the Arctic – could even be traversed.

This was the motivation for the *Belgica* Expedition (1897–1899), led by the rather inexperienced Belgian polar explorer Adrien de Gerlache de Gomery. For the first time, men spent the winter in the Antarctic pack ice, albeit involuntarily because they did not leave soon enough. Meanwhile, English and German researchers planned a number of major expeditions and divided Antarctica into four equal quadrants. The German area was in the Weddell Sea and the Enderby region, while the English wanted to concentrate on the Victoria and Ross quadrants. In addition, the polar researchers agreed to carry out simultaneous meteorological and magnetic measurements in order to compare the data and thus systematically investigate Antarctica according to Weyprecht's principles.

This close scientific cooperation between Germany and England was remarkable, considering that the two countries were engaged in intense economic competition. The era of colonial imperialism had begun, and international competition for markets and resources had intensified. Germany, as an emerging naval power, desired more international influence and prominence, and the United Kingdom wanted to maintain its hold on these. For this reason, the governments of both countries strongly supported the plans of their scientists. Antarctic research was regarded as a national duty and a cultural mission, the accomplishment of which promised merit and benefit. After prolonged pleading by the scientists, both countries provided state funds – but only for their own expeditions.

1.28 > In March 1902, during the first German South Polar Expedition, the German polar research vessel *Gauß* was immobilized by sea ice. Expedition leader Erich von Drygalski had tents and measurement instruments set up on the ice so that daily research could be carried out.

Scientific results from the five research cruises, in which ships from Sweden, Scotland and France also ultimately took part, were impressive: All the expeditions encountered new territory. Furthermore, it was now certain that Antarctica was a continent and not an atoll. Based on atmospheric pressure measurements the researchers were able to draw inferences regarding the elevation of the ice-covered land masses. According to these, Antarctica has an average elevation of 2000 metres, ± 200 metres.

However, after the scientists returned, fame and honour were bestowed only on the English. In Germany, both the Kaiser and the public viewed the results of the first German South Polar expedition (1901–1903) as disgraceful because the ship, under the scientific direction of Erich von Drygalski, became trapped in ice near the Antarctic Circle, and the scientists were not able to advance as far south as the British expedition under Robert Falcon Scott. In politically charged Berlin at that time, the traditional view still prevailed that the sole purpose of geographical research was to remove white patches from the map or to reach the pole. The value of the meteorological, magnetic, oceanographic and biological data that Drygalski had collected during his expedition was not greatly appreciated at the time. Yet the analyses took three decades and yielded substantial results. Results from the biological collection alone ultimately filled a total of 13 volumes instead of the three volumes that were originally foreseen, and these are still gaining in importance today in the light of modern biodiversity research.

The tragic races to the poles

The turn of the century also marked the beginning of the phase of polar research that has probably been the subject of most books up to now – the era of heroes and tragic losers in the competition for the most spectacular expedition, or for the title "First Man at the North or South Pole". In contrast to the state-organized Antarctic trips from 1901 to 1905, individualists were once again cast into a leading role. This generation of explorers, scientists and adventurers demanded the ultimate physical commitment from themselves and their companions. They were not always well prepared for their journeys, but they were prepared to take enormous risks for fame and honour – a heroic mentality that ultimately led to the deaths of many people, and made experienced polar explorers sceptical of the wisdom of such endeavours.

Fridtjof Nansen, for example, after the failed Spitsbergen expedition by the German officer Herbert Schröder-Stranz in 1912, deeply regretted that he had not been able to prevent the tragedy. He is quoted as saying, "If these people had just had a little experience in ice and snow all this misery could easily have been avoided! Travel to those regions truly entails enough difficulties without having to amplify them with inadequate equipment and an excess of ignorance".

The East Prussian Herbert Schröder-Stranz had sailed to Spitsbergen in August 1912 to obtain polar experience for his planned Northeast Passage crossing. But on Spitsbergen, or more precisely on Nordostland, the second largest island, on the northeast side of the archipelago, he and three of his companions disappeared when they tried to cross the island by dog sledge. A few days later Schröder-Stranz's ship was surrounded by pack ice in the Sorge Bay, and some crew members decided to set off on foot towards the next settlement. This decision also turned out to be a tragic mistake. In the end only seven of the original 15 expedition members survived.

The race to the South Pole, as played out by the Norwegian Roald Amundsen and the British Robert Falcon Scott, also ended tragically. Amundsen, who had sailed to Antarctica on Fridtjof Nansen's ship, the *Fram*, won the race. He and four of his men, all experienced skiers, made their way into the interior of the icy continent on dog sledges and became the first men to reach the South Pole on 14 December 1911 – 34 days ahead of their rivals. They then returned home safely. Their adversaries, on the other hand, were not so lucky. Due to bad weather, Scott and his four companions were not able to make it to their emergency food depot on the way back across the Ross Ice Shelf. The Antarctic winter had overtaken them and the men died of cold and exhaustion.

In Germany, the success or failure of German polar expeditions was analysed in detail in scientific circles. The experts concluded that future expeditions to the Arctic or Antarctic regions would have to meet certain basic requirements. They should be backed by a well-established organization that, in cooperation with institutions and authorities, would raise the necessary funds and develop guidelines for expedition equipment. In addition, the scientists called for a regularly published scientific journal for polar research. Until then most of the papers on Arctic and Antarctic research had appeared in a variety of different periodicals, making it difficult for many interested readers to access the widely scattered articles and reports.

Some of these wishes were fulfilled by new societies established after the First World War. They included the International Society for the Study of the Arctic by Means of Airship, which later became the Aeroarctic Society, as well as the Archive for Polar Research, now called the German Society for Polar Research. Both of these institutions published professional journals. In the Archive, furthermore, material was collected to assist in the preparations for expeditions.

1.29 > A propeller sledge built by the Finnish State Aircraft Factory. The German polar researcher Alfred Wegener had two of these built for his Greenland expedition, but the two vehicles *Schneespatz* (Snow Sparrow) and *Eisbär* (Polar Bear) failed to operate properly during the mission.

Into the ice with Zeppelin and airplane

After the First World War, many forms of modern technology in the fields of communication and transport, such as radiosondes, radios, airships, planes and snowmobiles, were adopted for use in polar research. One of the first to take advantage of these innovations was the discoverer of the South Pole, Roald Amundsen. He had earlier been trained as an aircraft pilot in Norway in 1914, and in May 1925 he departed from Spitsbergen with his crew and two Dornier seaplanes towards the North Pole. However, the adventurer did not reach his goal. When they landed the two aircraft on the sea ice at 88 degrees North so that Amundsen could determine their exact position with a sextant, one of the planes was damaged. Getting the remaining machine airborne again became a struggle for survival for the six expedition members. About three weeks passed before they were able to construct a runway on a large, stable ice floe. They had to spend four days flattening the new snow with their feet. When they were finally successful on their sixth take-off attempt, the expedition team were able to return to Spitsbergen.

But this near catastrophe was no reason for Amundsen to abandon his plan to fly to the North Pole. Just one year later he succeeded in creating a sensation, together with his financial backer Lincoln Ellsworth and the Italian general and aviation pioneer Umberto Nobile. In the airship *Norge*, they not only flew to the North Pole, but also became the first to completely cross the Arctic Ocean, landing in Alaska after a flight time of 70 hours.

Two years later, Umberto Nobile again piloted a self-built airship towards the North Pole in order to carry out extensive scientific investigations on the way. But the *Italia* crashed – an accident that had far-reaching ramifications. During the subsequent search for survivors of the crash, Roald Amundsen, among others, also lost his life.

1.30 > The airship *Norge*, in which Roald Amundsen and his team flew from Spitsbergen over the North Pole in May 1926. It was 109 metres long and achieved a top speed of 85 kilometres per hour.

Not all of the technical innovations of the time would prove to be useful in the polar regions. The propeller sledges that the German polar researcher Alfred Wegener (1880–1930) planned to use for transporting loads on his Greenland expedition (1930–1931) are one example of this. In the freshly fallen snow the heavy vehicles failed, which, due to a tragic chain of events, ultimately led to Wegener's death on the Greenland Ice Sheet.

However, during this period of technological advances, an additional cornerstone was laid for modern polar research. Wegener's Greenland expedition was exemplary in this regard. For it, the scientists had combined three expedition plans into one comprehensive plan, so that all of the participants of the expedition worked on an overarching topic – in this case the inland ice and the weather on the Greenland Ice Sheet – from different scientific perspectives.

As airships began to make more frequent long-distance flights, it became obvious that more reliable weather data from the Arctic region were needed, for example, for transatlantic flights from Europe to North America. At the time, however, these data were only being collected at a few stations and were not sufficient to accurately predict local weather phenomena over the large Arctic islands and over the Greenland Ice Sheet. Scientists and industry therefore called for an expansion of the weather-observatory network, as well as measurements in the higher atmospheric layers of the Arctic.

This demand was addressed during the Second International Polar Year (August 1932 to August 1933), which saw the establishment of a denser measuring network in the Arctic. The scientists launched towed weather balloons with radiosondes attached. Along with these, measurements of the upper atmospheric layers were made by airplanes, whose findings were intended to help understand the influences of polar weather on processes at the middle latitudes.

Over time, the new technological possibilities and improvements in weather prediction made polar research increasingly successful. Expeditions to both polar regions were subsequently well equipped, as technology and participants were tested on preparatory expeditions and thoroughly prepared for operations in the polar regions. The use of aircraft made it possible to leave the ice or land surfaces and investigate large areas from the air. Experience had shown that it was preferable to publish the findings of expeditions through government agencies or similar higher-level institutions. In addition, researchers began to conduct their field research in the polar regions from one or more base stations, for example, from Spitsbergen or the Antarctic Peninsula.

A continent for research

After the Second World War, however, as the number of research stations and the number of winters spent in Antarctica increased, so did the claims to ownership of areas in the region. Bordering and neighbouring countries such as Argentina, Chile, Australia and New Zealand filed claims for certain regions, while Norway, Great Britain and France also wanted pieces of the pie.

Under the politically tense conditions prevalent during the Cold War, Norwegian, British and Swedish scientists carried out joint seismic surveys between 1949 and 1952 in Queen Maud Land, east of the Weddell Sea, to measure the thickness of the Antarctic Ice Sheet in this margin area. To this day, this expedition is regarded as a model for international cooperation in polar research.

Soon thereafter, the international scientific community succeeded in organizing an International Geophysical Year from 1957 to 1958, which historically became the Third International Polar Year. It was the largest meteorological and geophysical experiment that had been carried out up to that time. Twelve nations installed a total of 55 stations in Antarctica – not only on the fringes of the continent, but also directly at the South Pole and on other parts of the ice sheet. With the help of the most modern methods of that time, including the early Russian and American satellites, Antarctica and its overlying atmosphere were extensively studied.

These scientists thus provided the impetus for a peaceful and purely scientific perception of the continent and laid the groundwork for the Antarctic Treaty, which was signed by twelve states in 1959 and entered into force in 1961. The signatories to the treaty not only relinquished their ownership claims, they also agreed that:

- The Antarctic is to be used only for peaceful purposes;
- They support international cooperation in research with the free exchange of information;
- Military activities in the Antarctic are prohibited;
- Radioactive waste may neither be introduced or disposed of here.

To date, 53 states have signed the Antarctic Treaty and committed themselves to permanently protecting Antarctica and using the area south of the 60th parallel exclusively for peaceful purposes. The participating countries include 29 Consultative Parties. These nations actively conduct research in Antarctica and are entitled to vote at the Antarctic Treaty Consultative Meetings, which the other signatories are also invited to attend. At the annual conferences, the principles and objectives of the Treaty are amended and supplemented according to the rule of unanimity.

Since the enactment of the Antarctic Treaty, research activities in the Antarctic region have been coordinated by the Scientific Committee on Antarctic Research (SCAR), which was established at that time. The International Arctic Science Committee (IASC) plays a similar role in the Arctic region. It relies, however, on the voluntary cooperation of all nations conducting research in the Arctic. There are no regulations for the Arctic similar to those laid out in the Antarctic Treaty. The political and economic interests are too divergent for that.

In contrast to the early days of polar research, scientific expeditions today are no longer adventurous journeys into the unknown. Satellite data include the extent of sea-ice cover, enabling the long-range planning of routes. Weather services generally warn of approaching storms well in advance, and automated measuring systems such as ARGO gliders, moorings below the ice, weather stations, and sea-ice buoys transmit data directly to research institutions via radio from many scientifically fascinating regions.

Despite all of the technological advancements, however, the ice cover, extreme climate, and geographical remoteness of many polar regions still represent significant obstacles to scientific work, so that polar research is only possible through international cooperation.

Conclusion

The Arctic and Antarctic – two fundamentally different polar regions

The north and south polar regions are among the most remote and extreme environments for life on Earth. In both regions freezing temperatures, ice, snow and the darkness of the long polar nights make it difficult for plants, animals and humans to survive. Yet the two regions are also fundamentally different from one another. In the south, Antarctica is a vast continent surrounded completely by the Southern Ocean. In the north, the exact opposite applies to the Arctic. Here, the land masses of three continents effectively surround an ocean located in the centre. The only ice sheet in the Arctic covers a large portion of Greenland. But this is still significantly smaller than the Antarctic Ice Sheet, which covers 98 per cent of the continent. On the other hand, the Arctic Ocean possesses a permanent sea-ice cover. Its surface area grows and shrinks in response to the rhythm of the seasons, never diminishing as much as the sea-ice surface in the Southern Ocean, which melts almost completely in summer.

In the geological history of Earth, extensive ice cover over both polar regions at the same time is an exceptional situation. There have only been a few times in the past when the drifting continents have been arranged such that climatic conditions in both the northern and southern hemispheres favoured the icing of the poles. While the climate history of Antarctica is now quite well understood, many open questions remain about the history of ice formation in the Arctic land and marine regions.

The geographical differences between the two polar regions account for their different human settlement histories. Most land areas of the Arctic have been accessible to humans on foot. Coming out of North Africa, they settled in Siberia about 45,000 years ago, and later trekked from there over a land bridge into North America. However, people were only able to settle in Greenland and the northernmost reaches of Europe after the ice sheets of the most recent glacial period had melted. Until then, massive ice had blocked the northward routes in North America and Europe for the hunters and gatherers. Today around four million people live in the Arctic.

In order to reach the more remote Antarctic, it took seaworthy ships and brave seafarers who dared to sail far to the south. The southern continent thus was not discovered until the 19th century and was initially seen only as a seal and whale hunting ground. From the 20th century onward, adventurers and polar researchers explored the icy continent directly, yet in the public eye advances into unknown regions were often more interesting than scientifically relevant data and observations.

After the First World War, modern technology was increasingly applied in polar research. Both the Arctic and Antarctic regions began to be explored from the air. With the establishment of research stations, it became possible to carry out long-term surveys, which improved the ability to predict weather in the polar regions. Furthermore, the significance of the two regions for the Earth's climate was recognized. International scientific cooperation then laid the foundations for the Antarctic Treaty System, which entered into force in 1961 and to this day ensures the protection and peaceful, purely scientific use of the continent. There is no comparable contractual framework for the Arctic region. Despite divergent political interests, researchers from a variety of nations are working hand in hand in both polar regions. The extreme climate and isolated conditions in the two regions present humankind with special logistical and technical challenges that can often only be overcome by working together.