BGR

TERRESTRIAL POLAR RESEARCH

AT THE FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES

PREFACE

The Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR) has been making important contributions to research into the Earth's crust in the polar regions, and thus contributing to a better understanding of the Earth system as a whole, for more than four decades. The BGR cooperates with domestic and foreign institutions in its geoscientific research. As a departmental research institution, it supports the Federal Government in furthering the development of the Antarctic Treaty System and strengthening co-determination rights in economic, environmental and research policy decisions relating to the Arctic regions.

Research work in the polar regions is marked by various political, scientific and logistical challenges. As a common heritage of humankind, Antarctica is protected by international law, and any exploitation of resources is prohibited. Within the framework of its GANOVEX research programme, the BGR conducts basic terrestrial research and studies the structure, composition and geological development of the Antarctic continent. The BGR's GONDWANA summer station at Terra Nova Bay in the Ross Sea serves as the basis for its scientific research, which is carried out in cooperation with international partners.

In contrast to Antarctica, the land masses of the Arctic and parts of the Arctic Ocean are sovereign territories of the neighbouring states. Therefore, the BGR depends on intensive cooperation with these respective states for its research programmes and expeditions on land and at sea. In addition, international cooperation in Arctic research is growing in importance due to increasing financial costs. A good example is the CASE programme, which has been operating under the direction of the BGR since 1992. A number of different partner institutions have already participated in our research work on the geological and plate tectonic development of the entire Arctic region over the past decades. The bilateral research cooperation between Germany and Canada in which the BGR and the Geological Survey of Canada (GSC) work closely together studying the geological structure of the Canadian Arctic, is also exemplary.

More than 40 years of polar research at the BGR – this stands both for high-level scientific expertise and sound policy guidance as well as close partnership and high scientific visibility in research.

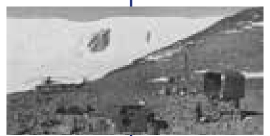
Prof. Dr. Ralph Watzel
President of the Federal Institute
for Geosciences and Natural Resources

1 FACTS IN BRIEF
1.1 HISTORY

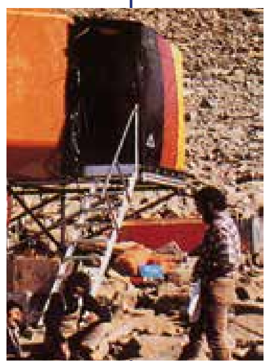
1973
First BGR geophysical research projects in the North Atlantic to explore the hydrocarbon potential of continental margins

1976
BGR's first Antarctic geoscientific research as part of US expeditions

1978
First German marine geophysical expedition in Antarctic waters after World War II by the BGR



1979
Accession of the Federal Republic of Germany to the Antarctic Treaty



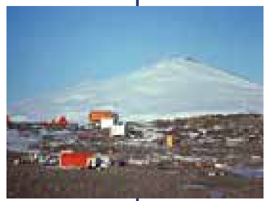
1979/1980
First land expedition (GANOVEX) to northern Victoria Land, marking the start of terrestrial polar research by the BGR

1980
Construction of the Lillie Marleen Hut on Mount Dockery at the Lillie Glacier in northern Victoria Land

1981
Admission of the Federal Republic of Germany to the Round Table of Consultative States of the Antarctic Treaty

1983
Construction of the Gondwana Station at Terra Nova Bay

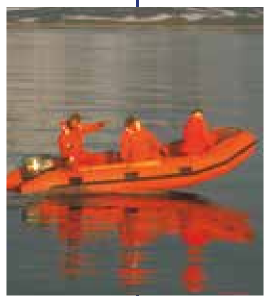
1984/85
With GANOVEX IV, the BGR conducts the first comprehensive, combined geophysical and geological expedition to northern Victoria Land



1987/88
Expansion of Antarctic research to the Shackleton Range (Weddell Sea region) with the GEISHA expedition

1988/89
Expansion of the Gondwana Station to a multi-container building

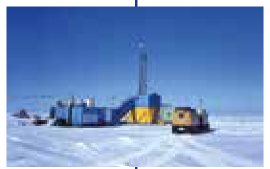
1988 & 1991
First Arctic geoscientific research within the framework of an expedition of the University of Münster in 1988 and the Geoscientific Spitsbergen Expedition SPE'91 to Spitsbergen



1990
Integration of personnel and work priorities from the GDR's geoscientific research in Antarctica into the BGR's polar research

1992 & 1994
Initiation of the CASE programme on Spitsbergen and North Greenland

1995/1996
Expansion of Antarctic research activities from northern Victoria Land (Ross Sea region) and the Shackleton Range (Weddell Sea region) to Dronning Maud Land (GeoMAUD).

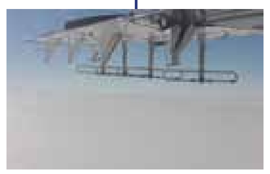


1997-1999
Implementation of the „Cape Roberts Project", an international drilling programme in the Ross Sea, with the participation of the BGR

1998–2003
Expansion of Arctic research activities to the Polar Urals (Russia) and Ellesmere Island (Canada). BGR's first combined terrestrial/marine geoscientific expedition to Nares Strait

2002/2003
Antarctica: Expansion of work to the Lambert Glacier in East Antarctica (PCMEGA)

2006/07
BGR participates in the ANDRILL international drilling programme in the Ross Sea

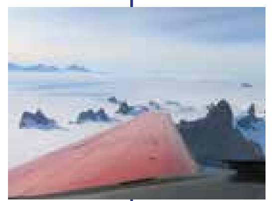


2008/09
BGR participates in AGAP (Gamburtsev Subglacial Mountains) in the High Antarctic as part of the International Polar Year 2007-09

2009/10
BGR starts first high-resolution aeromagnetic survey flights in northern Victoria Land within the framework of GANOVEX X

from 2010
Expansion of CASE Programme research to the New Siberian Islands (Russian Arctic) and Ellef Ringnes Island, Yukon North Slope and Banks Island in the Canadian Arctic

2010/2011
Launch of the GEA research programme in cooperation with the AWI in Dronning Maud Land in East Antarctica



2015–2017
Principal phase of the renovation and environmentally responsible, technical modernisation of Gondwana Station

2017
BGR and AWI start geological and geophysical exploration of potential drilling locations under the Ekström Ice Shelf (Sub-EIS-Obs)

2017
Most extensive terrestrial geoscience expedition to date since the start of BGR's terrestrial Arctic research to the northern shore of Ellesmere Island, Canada (CASE 19)

1.2 BGR POLAR GEOLOGY: SCIENTIFIC EXPERTISE AND SOUND POLICY GUIDANCE

Germany has earned a good reputation in polar research over the past 40+ years. Supported by elaborate programmes at both poles and the work of hundreds of scientists, the country can play an influential role when the futures of the Arctic and Antarctic are negotiated.

After the former German Democratic Republic had already joined the Antarctic Treaty in 1974, the Federal Republic of Germany followed suit in 1979 and launched an ambitious polar research programme. Since then, Germany has continued to expand its involvement in the Antarctic and the Arctic and is now considered a leading research nation. Germany is one of the consultative parties of the Antarctic Treaty and is also an active observer in the Arctic Council in which the states and indigenous peoples of the Arctic are organised. In its „Guidelines for German Arctic Policy" of August 2019, the German government emphasises that it wishes to assume „greater responsibility for the Arctic region". In its 2011 memorandum „German Commitment to the White Continent", the government had already stressed that Germany also remains „committed to the protection of Antarctica in the future".

Heavy snow drift in Helliwell Hills Camp during the Antarctic expedition GANOVEX XI.

Research is one of the means by which Germany gains influence at the poles without having any territorial claims there itself. Through intensive polar research in Antarctica, Germany documents its interest in the region, which, according to the Antarctic Treaty, justifies the consultative status of a state. In the Arctic, a commitment such as this supports the attainment of observer status at the Arctic Council, which, although it does not have a say in decision-making, can participate in discussions and provide advice. Together with the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven, the German Aerospace Centre (DLR) and project funding from the German Research Foundation (DFG), the BGR represents the core of the diversified polar research community in Germany. Its research not only contributes to a better understanding of the polar regions but also secures Germany a say in the bodies that decide on the future of the Arctic or Antarctic. The BGR is also mandated to advise the Federal Government on matters related to geoscience and natural resources and to provide it with first-hand information when it wishes to take a position on relevant international issues.

The German National SCAR-IASC Committee, which embodies the two International Science Councils, SCAR in Antarctica and IASC in the Arctic, at the national level, ensures the integration of German science into the international research agenda. BGR and AWI have the infrastructure and logistical resources needed for research in the remote and hostile polar regions; they also make these resources available to researchers from universities and other institutions. This gives these researchers the opportunity to take part in expeditions to the polar regions.

Research often depends on international networking and collaboration, which is explicitly implemented in Article 2 of the Antarctic Treaty; for this reason, international partners also regularly participate in polar expeditions. The BGR has transferred this concept to its Arctic activities, thereby developing an extensive network of national and international cooperation partners over the past decades. With this network, the BGR team is able to cover all aspects of research into the complex issues that the Federal Institute is working on in the polar regions. These international contacts also make it possible to pool resources and regional and international scientific expertise and thus continue to carry out demanding expeditions despite rising costs.

View from the western margin of the Campbell Glacier towards the Mt. Melbourne stratovolcano in northern Victoria Land.

BGR researchers are regularly drawn to the most scientifically fascinating and often most remote areas of the poles, which are difficult to reach in any case. Since the Federal Republic of Germany joined the Antarctic Treaty in 1979 and the AWI was founded in 1980, there has been a division of labour in polar research between the BGR and the Bremerhaven Helmholtz Centre. The Federal Institute in Hanover uses geoscientific methods to conduct its research in the Antarctic continent and the continents around the Arctic Ocean, while cryospheric, climatic, oceanographic and biological research is the responsibility of the Alfred Wegener Institute in Bremerhaven. The BGR is committed to pursuing two overarching scientific questions at the poles that reach far back into the geological past and still have a major influence on the global Earth system today: the formation, development and disintegration of the landmasses of Rodinia, Gondwana and Pangaea up to today's Antarctic region in the south, and the opening of the Arctic Ocean and the development of its surrounding continents in the northern hemisphere during the disintegration of the ancient supercontinent of Laurasia. The corresponding research programmes, GANOVEX in Antarctica and CASE in the Arctic, have been running for more than four and three decades, respectively, and have contributed significantly to our knowledge of the geological past in the polar regions during this time.

BGR GEOSCIENTIFIC RESEARCH SUPPORTS GERMANY'S POSITION AT THE POLES.

1.3 ANTARCTICA: CONTINENT OF SCIENCE

The territorial claims of individual nation states are suspended in Antarctica. Cooperation is needed in order to conduct research in the region and discover its role in the Earth system. BGR scientists are very active in the bodies that have been created for this purpose.

Antarctica is the only stateless continent on Earth. Far away from the nearest settlements, almost completely covered with ice and therefore absolutely inhospitable, the southern continent has attracted increased interest since the second half of the 19th century. After the race for the discovery of the South Pole between Great Britain's Scott and Norway's Amundsen, seven states gradually announced concrete territorial claims. These claims have been dormant since 1959, however, eliminating the competition for zones of influence. At the height of the Cold War, the two competing political blocs found the diplomatic strength to agree on the international Antarctic Treaty despite all the opposition.

The Antarctic Treaty regulates the peaceful coexistence of nations on the Antarctic continent and in the marine regions south of the 60th parallel. Since then, scientific cooperation for the exploration of Antarctica and its role in the Earth system has been the guiding principle for all human activities at the South Pole. Forbidden activities include military use and, since the Protocol on Environmental Protection (PEPAT) entered into force in 1998, the mining of raw materials. Two conventions, one on the protection of Antarctic seals (CCAS) and the other on the protection of marine living resources (CCAMLR), formalised special protections for Antarctic wildlife. By now, 54 states have joined the Antarctic Treaty. Not all of them have ratified the environmental protection protocol and the conservation agreements, and not all of them have the status of "consultative party". Only such states have the right to vote at the treaty's consultative meetings, which have been held since 1961, when decisions are made about the fate of the fifth-largest continent on Earth in terms of area and the marine regions that surround it. Consultative status depends on scientific commitment, which, according to the Antarctic Treaty, should be substantial enough to show interest in Antarctica.

Twenty-nine signatory states belong to the circle of consultative states; the Federal Republic of Germany has been a member since 1981. The justification for this was provided by the first GANOVEX expedition to northern Victoria Land and the geophysical survey of the Ross Sea carried out by the BGR in the Antarctic summer of 1979/80, among other things. Since then, the BGR and the AWI have established research stations and regularly organised expeditions in which numerous researchers from other institutes and universities have participated, demonstrating the Federal Republic's considerable research interest in Antarctica. The BGR has now conducted 14 expeditions within the framework of the long-term „GANOVEX" research programme alone.

The annual consultative meetings of the Antarctic Treaty are a forum of states. As part of the government delegation, BGR polar scientists advise the Federal Foreign Office on all technical issues. German scientists also sit on numerous specialist committees that draw up the relevant rules. For example, the BGR was involved in the drafting of the PEPAT environmental protection protocol.

In contrast, the Scientific Committee on Antarctic Research (SCAR) is a purely scientific body. It was founded before the conclusion of the Antarctic Treaty as a result of the International Geophysical Year 1957-58 and coordinates worldwide Antarctic research. SCAR is part of the International Science Council whose roots go back to the 1930s. SCAR is made up of scientists from 45 nations. Germany is one of the 34 full members, and its involvement includes two delegates and engagement in several specialist working groups. Based on its observer status, the Committee and its members in turn act as advisers at the consultative meetings of the Antarctic Treaty. Germany is represented in SCAR by the German Research Foundation (DFG).

There has been a national committee subordinate to the DFG in Germany since 1978; this committee maintains contact with the international SCAR and thus anchors German Antarctic research internationally. This task is now carried out by the German National SCAR-IASC Committee in which representatives of the most important polar research institutions, including the BGR, are represented. The committee maintains contact with both SCAR and its counterpart in the Arctic, the IASC (International Arctic Science Committee).

The Sør Rondane Mountains in eastern Dronning Maud Land, East Antarctica.

ANTARCTICA IS RESERVED FOR RESEARCH.

1.4 THE ARCTIC: INTERNATIONAL COOPERATION ACROSS NATIONAL BORDERS

The Arctic mainland is encompassed by the territories of the bordering countries, which also have extensive territorial claims to the Arctic Ocean. The Arctic Council was established as an intergovernmental forum focusing on sustainable development, the interests of indigenous peoples, international research and environmental protection. States without territorial claims, such as Germany, are also heard and have a say in the Council.

Unlike Antarctica, the Arctic is anything but state-free. At present, large parts of the central Arctic Ocean still belong to the high seas and are thus open for research and science. The mainlands and continental shelf areas, on the other hand, belong to bordering states of Russia, Norway, Denmark (Greenland), Canada and the USA. Four of these five states have filed maps of their zones of influence with the competent UN Commission on the Limits of the Continental Shelf (CLCS) and submitted applications through the United Nations Convention on the Law of the Sea (UNCLOS), establishing their territorial claims to the Arctic Ocean far beyond the shelf areas. A glance at the map shows that these zones overlap in places, and most of the competing situations have yet to be resolved. The claims of the five neighbouring states of the Arctic Ocean are largely undisputed, but the areas to which they extend have not yet been finalised. Therefore, access to the Arctic Ocean will be limited in the future. There is a lot at stake; the area around the North Pole is believed to be rich in resources, and new fishing grounds and fast shipping routes between Europe and the Far East could open up as the sea ice melts.

The Arctic Council has been a forum in which the Arctic states have cooperated to promote and regulate sustainable development, environmental protection and the role of indigenous peoples since 1966. In addition to the five states bordering the Arctic Ocean, Iceland, Sweden and Finland, whose territories lie partly within the Arctic but which have no coasts on the Arctic Ocean, also have a seat and a vote. In addition to the states, six umbrella organisations representing the indigenous peoples in the circum-Arctic region participate as permanent members. The Council's mandate was deliberately limited so that it would not be blocked, for example, by the strategic competition between the USA and Russia.

Thirteen states, thirteen governmental organisations and twelve non-governmental organisations are currently admitted as observers to the Arctic Council. They are not permitted to take part in decision-making, but they do participate in the Council's six permanent and four non-permanent task forces. Germany was admitted as an observer to the Arctic Council in 1998. The delegation is headed by the Federal Foreign Office, but it includes numerous scientists who participate in the task forces on behalf of Germany. The intensive activities of the BGR contribute to Germany maintaining its observer status at the Arctic Council; the BGR also advises the Federal Government and its ministries through regular participation in the Arctic dialogue of the departments.

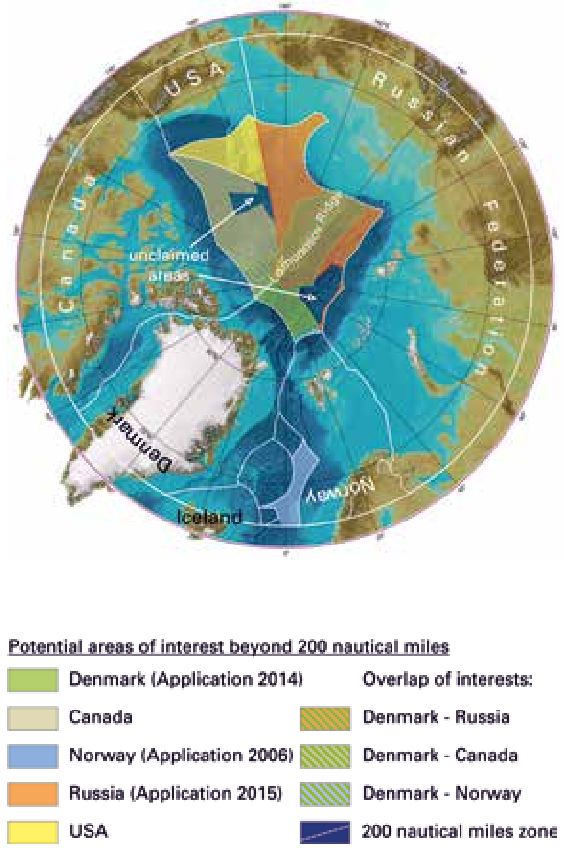
SCIENTIFIC COOPERATION UNITES INTERNATIONAL ARCTIC RESEARCH BEYOND THE NATIONAL BORDERS OF THE ARCTIC NEIGHBOURING COUNTRIES.

Map indicating cooperation partners in the CASE programme worldwide.

Independent of the Arctic Council, scientific organisations from the eight Arctic states founded the International Arctic Science Committee (IASC) in 1990 to promote and coordinate science and research north of the Arctic Circle. The IASC's mission covers all natural science, social science and humanities disciplines and includes the promotion and development of the traditional knowledge of the Arctic indigenous people. Meanwhile, scientific organisations from 15 non-Arctic states belong to the IASC, among them the German Research Foundation (DFG). The IASC has five permanent working groups that cover all aspects of research in the Arctic; in addition, the committee can set up task forces on specific topics. German representatives, including researchers from the BGR, hold seats on all permanent working groups. The National SCAR-IASC Committee serves as the IASC's interface to the German research community.

The political importance of the Arctic has given rise to institutionalised interfaces between science and politics in Germany. The "Arctic Dialogue", a forum for discussions between federal ministries and authorities and scientific institutes and foundations, was launched in 2013. This forum improves the exchange of information between the two sectors and makes the knowledge generated by research and science available to political stakeholders. The German Arctic Office at the AWI coordinates this platform and also serves as an important point of contact for politics and industry on issues of Arctic research.

Map of the United Nations Convention on the Law of the Sea (UNCLOS) in the Arctic. Modified from IBRU (2015).

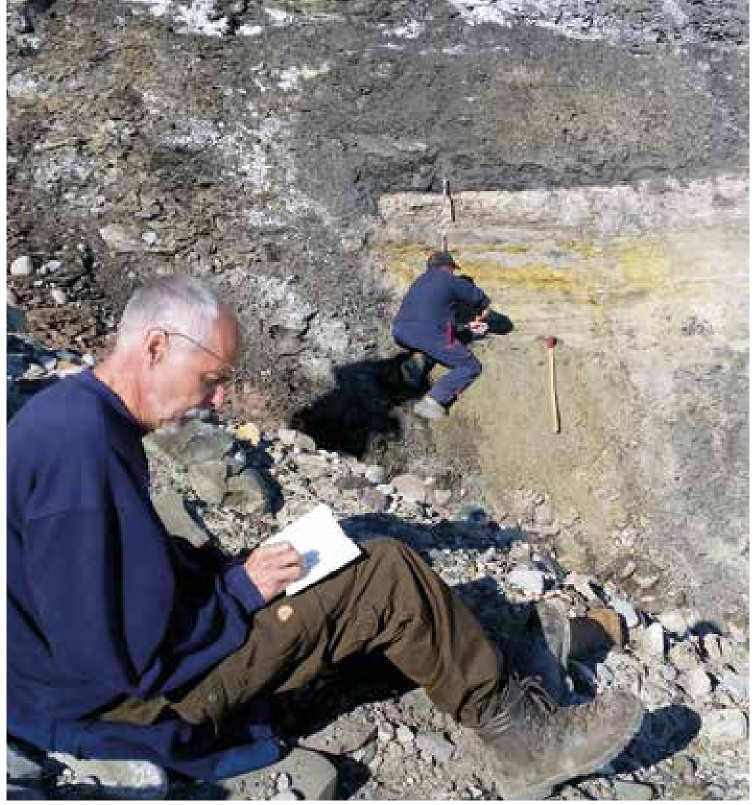


2 METHODS: SUCCESS THROUGH DIVERSITY

Researchers from many disciplines work together to obtain a comprehensive picture of the complex geological processes in the polar regions. The BGR team covers a number of methods itself and seeks external support to complement its research work.

Geoscientific work in the polar regions is interdisciplinary and includes a variety of methods to interpret and reconstruct geological processes over the course of Earth's history. The BGR Polar Geology team has expertise in the disciplines of structural geology, petrology/geochemistry, geophysics, geochronology and sedimentology. Other methods that are used in-house, further developed or adapted to the conditions at the poles, include remote sensing and marine geophysics. In addition, the Polar Geology Unit has a dense network of external cooperation partners at home and abroad to cover disciplines such as palaeontology or methods such as thermochronology.

AN INTERDISCIPLINARY APPROACH AND METHODOLOGICAL DIVERSITY MAXIMISE SCIENTIFIC KNOWLEDGE.



BGR geologists during the CASE 20 expedition taking samples and documenting an outcrop with Eocene sediments at Kap Rigsdagen, Northeast Greenland.

2.1 STRUCTURAL GEOLOGY

Plate tectonics has been shaping the surface of the Earth for billions of years. The processes that move the tectonic plates are slow by human standards, but they leave clearly visible traces in the rocks that have been moved and deformed on a large scale by the collision, lateral displacement and disintegration of continental plates. Structural geology records these movements and thus facilitates the interpretation, understanding and reconstruction of tectonic processes. To this end, the researchers record structural data from planar and linear elements in the field and document indicators of their direction of movement. Another method in structural geology is the examination of thin sections of samples from the deformation zones to identify the microscopic structures that were caused by the movements.

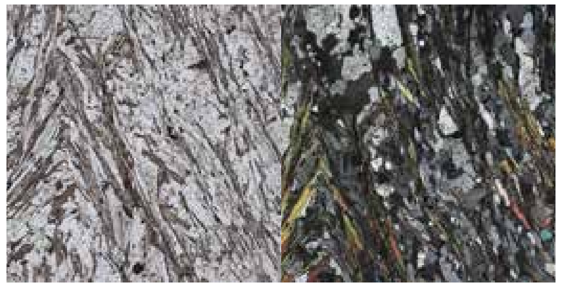
Measuring the lineation of a gneiss with a geological compass in Dronning Maud Land, East Antarctica.

2.2 PETROLOGY/GEOCHEMISTRY

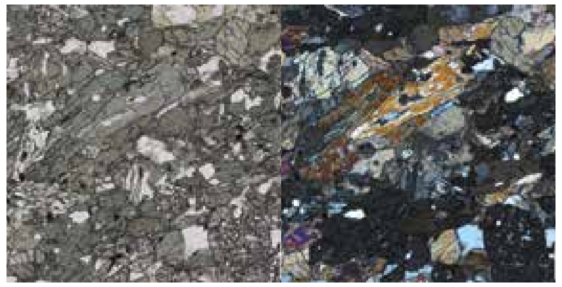
The mineralogical and geochemical composition of rocks is essential to understanding when and where they formed and what processes they underwent in their continued existence. To obtain this information, numerous samples are taken in the field; the samples are later processed into thin sections or crushed into powder and/or mineral separates in the BGR's laboratories. These are then analysed using various devices and measurement methods such as polarisation microscopy, X-ray fluorescence analysis, X-ray diffraction or mass spectrometry.

2.3 GEOCHRONOLOGY

Time is an essential aspect for reconstructing the movements that shape the surface of the Earth. The history of the formation of large-scale mountain ranges in the Earth's crust and the chronology of continental movements are revealed by the age of their rocks. The samples collected in the field are crushed in the BGR laboratories and minerals suitable for dating, such as zircon, are separated. These are analysed by means of mass spectrometry for certain radioactive isotopes, the decay times of which are known, in order to deduce the age. With this information, the formation and deformation ages of crystalline rocks and the origin of sedimentary rocks can be determined. In addition to zircon, the mineral apatite is also used by external thermochronology laboratories to determine the cooling and uplift history of an area using the fission-track method. This can be used to reconstruct the development of present-day landscapes in the polar regions.

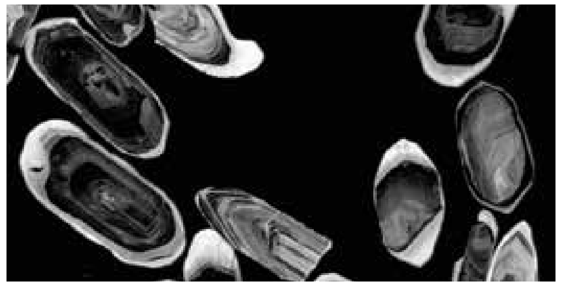


Thin section of a folded mica schist from Spitsbergen consisting of biotite, muscovite and quartz. View in plane-polarised light (left) and with crossed polarisers (right).



Amphibolite rock from Spitsbergen in thin section consisting of amphibole, plagioclase, garnet and chlorite. View in plane-polarised light (left) and with crossed polarisers (right).

Rounded and euhedral zircon grains from a metasandstone from northern Victoria Land.



Cathodoluminescence images of polished zircon grains from a gneiss from Spitsbergen. Differences in brightness are caused by different uranium contents (light = low U content, dark = high U content). The oscillatory zoning forms during the crystallization of the zircon.

2.4 SEDIMENTOLOGY

The study of sedimentary rocks provides information on depositional conditions of past sedimentary basins. For this purpose, the rocks and their sedimentary structures are examined, and their mineralogical and geochemical composition and age of deposition are described. One dating method uses plant and/or animal fossils, which are paleontologically identified and chronologically classified. The environmental conditions at the time of deposition can often be inferred based on their identification as well. For economic geology, this analysis also provides important information regarding possible deposits of coal or oil and gas.

Helicopter shortly before the start of a survey flight from Station Nord, Northeast Greenland.

2.5 AEROGEOPHYSICS (GEOMAGNETICS)

A subfield of aerogeophysics uses magnetic properties in order to be able to track or correlate structures or rock units even under the sea or under the cover of snow and ice. These properties differ according to the composition of the rock units and can thus be recorded with a corresponding measuring system. A probe is flown over the survey area using a helicopter or small aircraft, which can detect this information under snow, ice or water using a magnetometer. It is important here to have good cooperation between the geologists on the ground (structural geology and petrology) and the geophysicists responsible for the airborne investigations in order to correlate the geomagnetic data with the data on the ground.

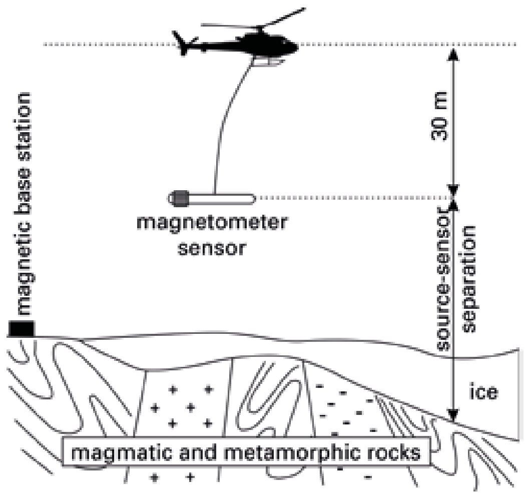


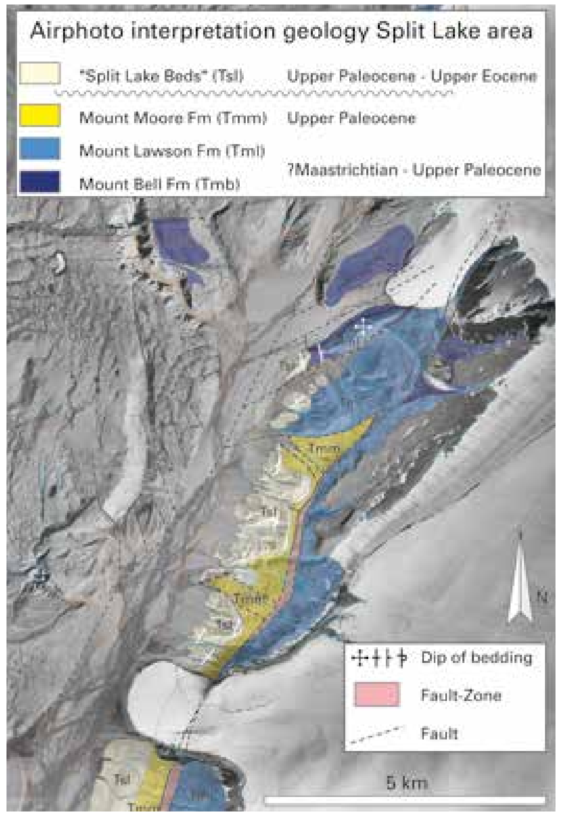
Illustration of an aeromagnetic survey with a helicopter. Variations in the Earth's magnetic field are recorded by a magnetometer, which is towed approx. 30 m beneath the helicopter, and in a fixed ground station. These provide information on the magnetic properties and thus on the composition and structure of the Earth's crust.

2.6 GEOLOGICAL MAPPING

Geological mapping and the creation of geological maps represent the basic work for all further geoscientific research. In addition, they provide important basic data in applied fields such as construction engineering or raw material research. They provide complex information on the occurrence of rock units in a region and their spatial distribution. Today, geological mapping is supported by modern methods such as remote sensing.

2.7 REMOTE SENSING

The exploration of remote areas of the Earth is being increasingly supported by satellites. This technique creates opportunities to identify and determine geological structures, rock formations and possibly mineral resources from space. Intensive cooperation between the Remote Sensing Unit of the BGR or other institutions and the geological field work of the Polar Geology Department serves to refine the methods, for example through the use of new types of sensors.



Aerial view of Split Lake, Ellesmere Island, Canadian Arctic, with interpretation of the distribution of geological units and structures. The interpretation was done in preparation for the fieldwork of CASE 8.

Buoys of air pulsers for seismic measurements off Northeast Greenland.

2.8 MARINE SEISMICS

Polar regions are not limited to continental areas. The continuation of rock units and large structures in the adjacent marine areas are also of great importance. In order to measure these structures, ship-based seismic surveys, which can detect the subsurface below sea level, are conducted in cooperation with the BGR's Marine Seismics Unit and other institutions. Samples are also taken from the seabed and later analysed in the BGR laboratories.

3 ANTARCTICA

3.1 THE HEART OF GONDWANA

The continent of Antarctica is a key factor in the Earth system. Its scientific exploration is crucial to our understanding of the processes that determine change in the global Earth and climate system. Its geological history also plays an important role in this. Therefore, the BGR is conducting research within the frameworks of large-scale programmes such as GANOVEX and GEA, as well as numerous individual projects, on the long period of development that Antarctica underwent while the continents of Rodinia and Gondwana were formed and then disintegrated.

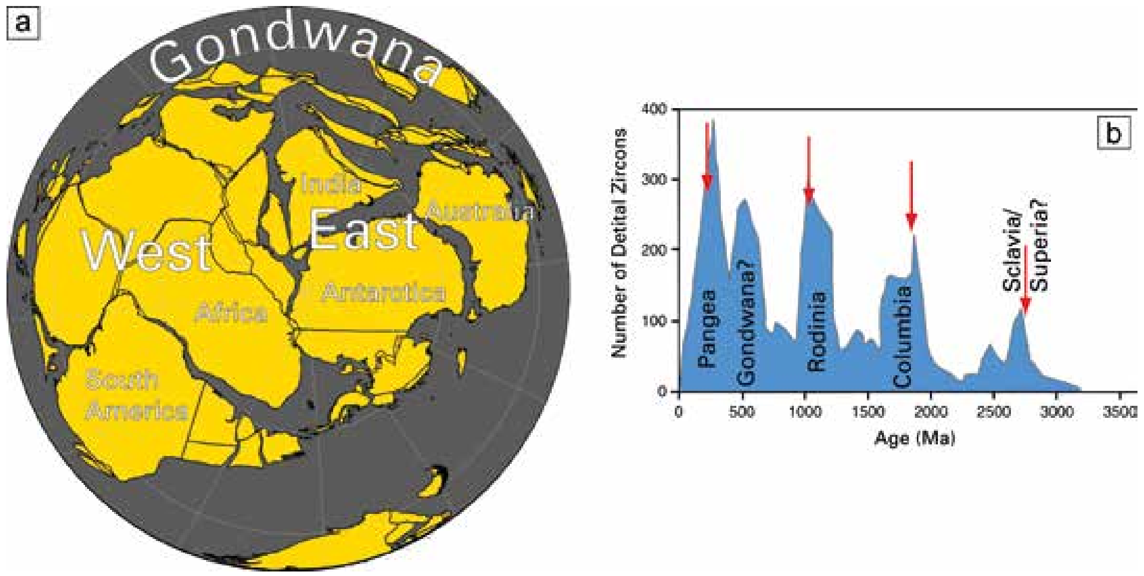
The continent of Antarctica has been in its isolated position at the South Pole for close to 70 million years, an incredibly persistent situation given the dynamics in plate tectonics. The continent was once the heart of Gondwana, a position it had also occupied in its predecessor, the supercontinent of Rodinia. Then, one landmass after another broke off and drifted away, and the circumpolar ocean current set in, isolating Antarctica and causing temperatures to drop and glaciers to form. However, as isolated as its location in the middle of the Southern Ocean may seem, Antarctica, the continent itself and the ocean area surrounding it up to 60 degrees latitude, is a key factor in the Earth system. In terms of human research activities, it is also possible to study processes on the southern continent that are no longer visible, or visible only to a lesser extent, elsewhere.

Deciphering the continent's geological history is of key importance to understanding the dynamic processes that led to the formation of modern Antarctica and its role in the Earth system. Therefore, in 2014, when SCAR drew up its strategic list of the fields whose further exploration should be prioritized in the coming decades, investigation of the geologic past was added to the list. As with the other southern continents, the evolution of Antarctica over the past ca. 550 million years is primarily the story of Gondwana; its formation, which began as early as the Late Proterozoic, its fate as an initially isolated landmass that temporarily merged into the supercontinent Pangaea and survived its breakup virtually unchanged, and finally its disintegration into the now independent components scattered across the Earth's surface.

Almost 98 percent of Antarctica is covered by ice. This means that direct access to the rocks is only possible in a few places; for example, in some parts of the Transantarctic Mountains and where the peaks of other mountain ranges protrude from the ice sheet as nunataks. For this reason, the BGR has relied on a combination of geological and geophysical methods since the early days of its research. All phases of its geological history can be studied on the Antarctic continent, and the BGR is investigating them with its large-scale projects GANOVEX in northern Victoria Land and GEA in Dronning Maud Land. As a cooperation partner, the BGR is also involved in international drilling projects in the Ross Sea (ANDRILL and Cape Roberts Project) and, in cooperation with the AWI, in the Sub-EIS-Obs project. These projects has researchers investigating the tectonic, volcanic and sedimentary development as well as the glaciation history of Antarctica since the break-up of Gondwana.

ANTARCTICA PROVIDES EXTRAORDINARY INSIGHTS INTO THE HISTORY OF THE EARTH.

Large landmasses and supercontinents. a) GPlates reconstruction of Gondwana about 400 Ma ago (Matthews et al., 2016). b) Spectrum of detrital zircon grains (Hawkesworth et al., 2010) in comparison to the main mountain building phases, which are marked with red arrows (Runcorn, 1962).



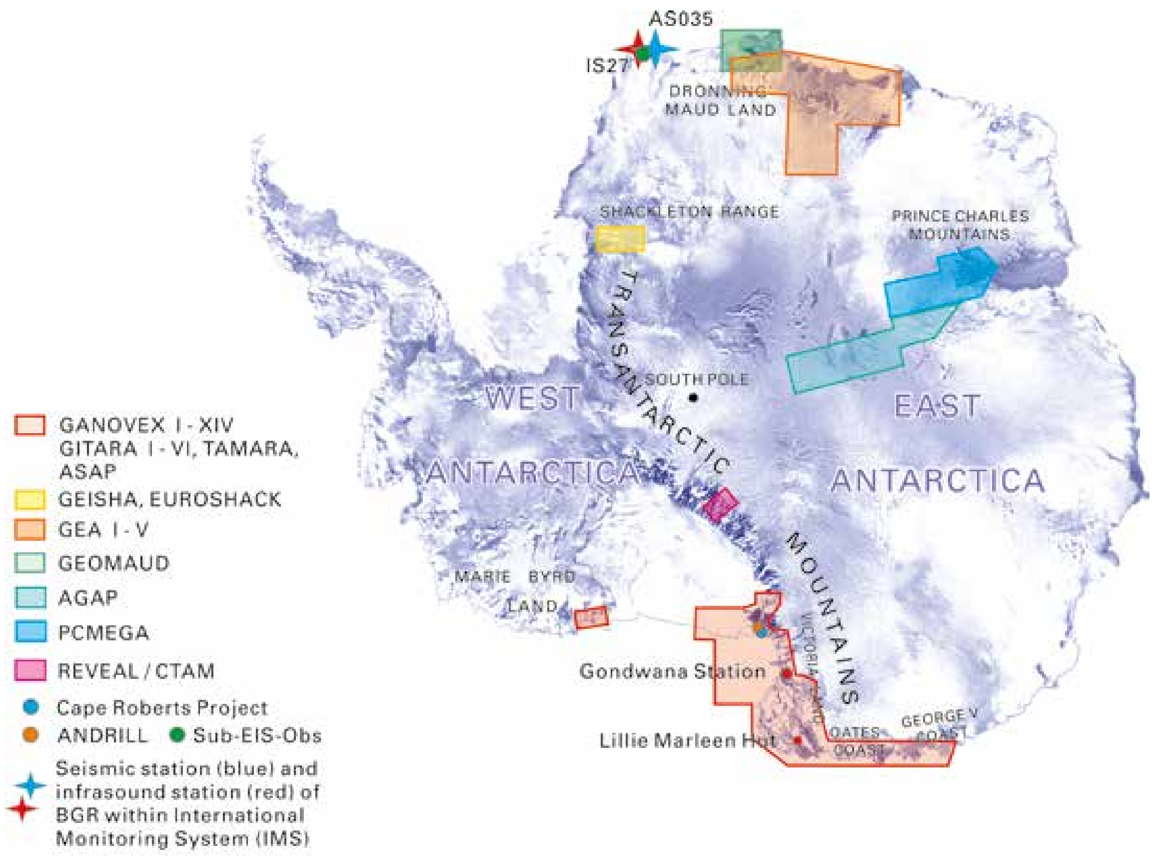
3.2 DIVERSE PROJECTS WITH NUMEROUS PARTNERS: THE BGR PROJECTS IN ANTARCTICA

With its long-standing research programmes and a large number of subprojects, the BGR has been exploring Antarctica for more than 40 years. The focus of the work is on East Antarctica and the Ross Sea region on the border to West Antarctica and their development during the course of the Earth's history.

With its background in the fields of hard rock geology and geophysics, the BGR is investigating geodynamic processes such as the formation and disintegration of the supercontinent Gondwana and its precursor Rodinia, the formation of mountain belts at the margins and in the interior of Antarctica, the development of rift systems and the evolution of the current landforms as a result of the complex interplay of factors such as tectonics, lithology, and climate. To this end, the BGR is active in the Transantarctic Mountains and Dronning Maud Land. Its drilling projects target the Ross Sea and the Ekström Ice Shelf.

Northern Victoria Land in the Pacific part of Antarctica has been the target of BGR research expeditions since the Federal Republic of Germany began conducting research in Antarctica. The area borders on the Ross Sea and includes parts of the Transantarctic Mountains. Thus far, fourteen expeditions have taken place there or in the adjacent areas of the mountain range, all under the programme name GANOVEX (**Ge**rman **A**ntarctic **NO**rth **V**ictoria Land **EX**pedition).

Map of Antarctica with the geological and aeromagnetic working areas of the BGR since 1979. The map also shows the location of the Gondwana Station and Lillie Marleen Hut, the drill sites of the Cape Roberts Project, ANDRILL and Sub-EIS-Obs and the location of the infrasound station IS27 operated by BGR together with AWI at Neumayer Station III as part of the Comprehensive Nuclear Test Ban Treaty.



Northern Victoria Land and the Transantarctic Mountains bear direct and indirect witness to the entirety of Antarctica's history, from the formation and passing of the Gondwana supercontinent to the drifting apart of the East and West Antarctic continental blocks, which can be seen in the formation of the Ross Sea Rift and the uplift of the Transantarctic Mountains during the Cenozoic era.

The BGR cooperated with the Italian National Antarctic Research Programme (PNRA), which operates the Mario Zucchelli Station adjacent to the Gondwana Station, in various expeditions of the GANOVEX programme and aeromagnetic campaigns within the framework of the GITARA programme (**G**erman-**IT**alian **A**eromagnetic **R**esearch in **A**ntarctica). The two partners are working together on a geological map of northern Victoria Land. In 1994, the BGR participated in the international ACRUP programme (**A**ntarctic **CRU**stal **P**rofile), which created a seismic profile across the West Antarctic Rift System in the Ross Sea. Additional cooperation projects in the Transantarctic Mountains included TAMARA (**T**rans**A**ntarctic **M**ountains **A**erogeophysical **R**esearch **A**ctivities) and REVEAL/CTAM (**RE**mote **V**iews and **E**xploration of **A**ntarctic **L**ithosphere/**C**entral **T**rans**A**ntarctic **M**ountains) with the USA.

BGR PROJECTS IN ALL IMPORTANT PARTS OF ANTARCTICA.

The BGR's second major research programme focuses on the other side of East Antarctica, in Dronning Maud Land, which lies in the Atlantic and Indian Ocean sectors of Antarctica. GEA (**G**eodynamic **E**volution of East **A**ntarctica) is a collaborative programme with the Alfred Wegener Institute as co-organiser and various partners from national and international Antarctic research. The aim of the project is to study the evolution and structure of the East Antarctic crust and the formation of present-day Antarctica with its isolated landmass at the Earth's South Pole. GEA builds upon a series of earlier projects that have been carried out in various regions of East Antarctica since the 1990s. Cooperation partners at that time, in addition to the AWI, included the Antarctic research programmes of several states.

These projects targeted various mountain ranges in East Antarctica. GEISHA (**G**eological **E**xpedition **I**n the **SHA**ckleton Range) was conducted in the southern summer of 1987/88 and EUROSHACK (**EURO**pean **SHACK**leton Range Expedition) to the Shackleton Range at the southwestern edge of the Weddell Sea in 1994/95.

View down the Priestley Glacier in northern Victoria Land during GANOVEX XIII.

GeoMAUD (**GEO**scientific Expedition to Dronning **MAUD** Land) visited some regions in central Dronning Maud Land such as Dallmannberge or Wohlthatmassiv in 1995/96. PCMEGA (**P**rince **C**harles **M**ountains **E**xpedition of **G**ermany and **A**ustralia), which was carried out with the Australian Antarctic Division in the early 2000s, targeted the southern Prince Charles Mountains, a mountain range in the vicinity of the Lambert Glacier. AGAP (**A**ntarctica's **GA**mburtsev **P**rovince) was one of the flagship projects of the 2007 to 2009 International Polar Year and used various geophysical methods to conduct the first exploration of the Gamburtsev Subglacial Mountains, which are completely covered by ice.

The BGR was also involved in two international research drilling programmes in the Ross Sea – the Cape Roberts Project and ANDRILL (**AN**tarctic **DRILL**ing Project). Both projects were intended to clarify the tectonic, volcanic and sedimentary development of the Ross Sea in addition to its glacial history. The BGR was a member of the scientific steering committee for the Cape Roberts boreholes. The BGR conducted the ASAP (**A**eromagnetic **S**urveys for the **A**NDRILL **P**rogramme) aeromagnetic survey in cooperation with New Zealand in order to select the ANDRILL drilling sites. In cooperation with the AWI, the BGR is conducting the Sub-EIS-Obs (**Sub**-**E**kström **I**ce **S**helf-**Obs**ervations) project, which uses seismic reflection profiles and the sampling of surface sediments to study the structure and composition of the seabed beneath the Ekström Ice Shelf. The work is intended to establish drilling locations in order to obtain core material, which should yield additional information regarding the history of Gondwana's break-up and the rock composition in the ice-covered Antarctic hinterland, as well as past climate changes.

3.3 EAST ANTARCTICA: PUZZLE UNDER THE ICE

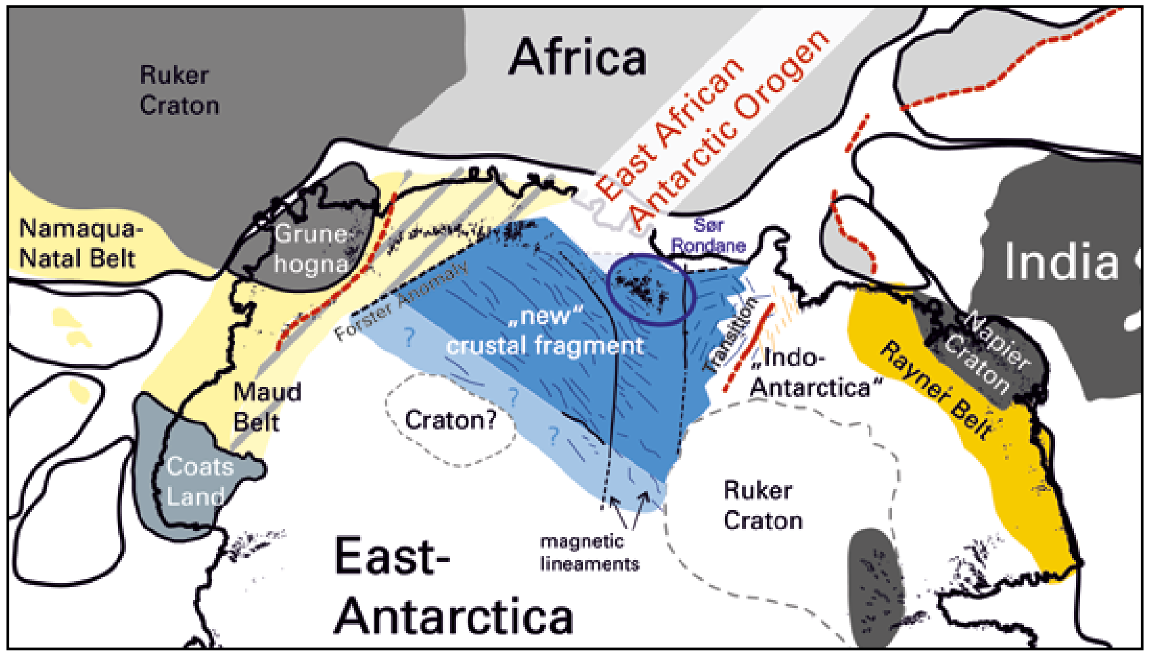
Little is known about the structure or development of the East Antarctic continental block. The thick ice sheet that covers it leaves few opportunities for geological studies. In the GEA research programme, the BGR therefore relies on a combination of geology and geophysics to decipher the history and dynamics of the East Antarctic portion of the continent.

This heavily deformed and transformed rock complex formed about 1,000-900 Ma ago along extensive island arcs and is part of a newly described crustal fragment, the TOAST (Tonian Oceanic Arc Superterrane), which was discovered during the GEA expeditions. Person as scale.

The glaciers of eastern Dronning Maud Land glow brilliant white in the Antarctic sun. From a plane, the contours between the ice and a sky that becomes increasingly milky towards the horizon quickly blur. Craggy, sharp-edged rock spires rise from the smooth surface, indicating that a mountain range is hiding beneath the ice cover. The peaks of the Sør Rondane Mountains rise up to 3,400 metres in elevation, but in a few places, only the top 1,000-1,500 metres of them are visible. The rest is covered by the ice masses of East Antarctica.

The geoscientific view of East Antarctica is scarcely any clearer than the view from an aeroplane. Vast areas of the maps are literally as white as the surface of the glaciers, because no geological expedition has yet reached them. The GEA (**G**eodynamic **E**volution of East **A**ntarctica) research programme, which the BGR is conducting in cooperation with the Alfred Wegener Institute in eastern Dronning Maud Land, is opening up this undiscovered area. The goal is to clarify the structure and formation of the East Antarctic crust and to trace the continent's path to its present position. The programme relies particularly heavily on close cooperation between geologists and geophysicists, for only through this partnership of field work on the ground and large-scale measurements from aircraft can we gain insights into the continent, which is largely

Schematic map of the crustal provinces in East Antarctica with focus on the previously unknown crustal fragment (TOAST), which was discovered by combined geophysical and geological investigations (modified from Ruppel et al., 2018).



BENEATH THE EAST ANTARCTIC ICE SHEET LIES A LANDMASS WITH A COMPLEX GEOLOGICAL HISTORY.

covered by kilometre-thick ice. GEA interweaves research strands that have grown out of a series of international cooperation projects over the past three decades. In addition to universities, other international Antarctic programmes whose stations can be used in the region are also involved as partners.

The five expeditions that have taken place to date have demonstrated that East Antarctica is, by no means, the old stable continental block it was previously thought to be. Instead, the landmass, which makes up about two-thirds of the Antarctic continent, resembles a jigsaw puzzle of individual pieces that first merged to form present East Antarctica during the formation of Gondwana. Geophysics plays a prominent role at GEA, as the exploration area extends into the high plateau of the inland East Antarctic Ice Sheet, some of whose ice is nearly 4,000 meters thick. Only a few rock peaks emerge here to provide clues regarding the geology.

On the GEA IV expedition, geophysicists flew the AWI research aircraft Polar 6 up to 800 kilometres inland to trace a magnetic anomaly pattern in the crust that had already been discovered during flights over the Sør Rondane Mountains during GEA I to III. Geological fieldwork during these expeditions revealed that the anomalies are related to rocks of a previously unknown crustal fragment derived from extensive island arcs from the early Neoproterozoic. Their age was later dated at approximately 1,000 to 900 million years and thus extends into the time of the supercontinent of Rodinia.

Additional aerial surveys of the adjacent ice-covered terrain as part of GEA IV showed that this fragment extends up to 800 kilometres inland. An evaluation of the aerogeophysical measurements showed that the crustal fragment has an area of about 500,000 square kilometres, which is roughly the size of France. This crust from the Neoproterozoic period was apparently compressed by the surrounding continents during the formation of Gondwana around 350 million years later and finally converged with them to form the supercontinent Gondwana. Dating of rock samples and research into the structural geology of the Sør Rondane Mountains demonstrated that this process took about 150 million years there.

The geophysical survey flights with ice radar and a gravimeter on board gave scientists a better picture of the Earth's surface under the ice masses. For example, the coastal area between the Sør Rondane Mountains in the west and the Yamato Mountains in the east exhibited strong indications of erosion, which can be traced back to a short period of alpine glaciation shortly before the complete glaciation of Antarctica and to a distinct river system that had formed during the Jurassic period shortly before and during the disintegration of Gondwana. The mighty glaciers that have been flowing over the region for around 34 million years have not been able to remove the traces of this erosion event.

3.4 GONDWANA: LIFE STORY OF A MAJOR CONTINENT

The Transantarctic Mountain range is the visible boundary between East and West Antarctica. It provides information not only about the more recent part of Antarctic history, characterised by the large-scale West Antarctic Rift System and mountain uplift, but also about the many hundreds of millions of years earlier when the landmasses were part of Gondwana. Expeditions of the GANOVEX programme to northern Victoria Land at the Pacific end of the mountain range cover the complete period since the formation of the supercontinent.

The Transantarctic Mountains stretch for a seemingly endless 3,500 kilometres across the entire continent, and their peaks mark the morphological border between East and West Antarctica. Large sections of the mountain range are buried under glacial ice, which flows from the East Antarctic Ice Sheet over and through the mountain range to the ice shelves of West Antarctica. However, several four-thousand-metre peaks protrude from the ice, the highest being Mount Kirkpatrick on the Ross Ice Shelf at 4,528 metres. If geologists wish to explore the history of the continent lying over the South Pole, the Transantarctic Mountains probably offer the best opportunity to do so, because there are few other places where rocks from the deep geological past are so exposed. Moreover, the mountain range is one of the two shoulders of the West Antarctic Rift System, where West and East Antarctica are breaking apart documenting what is probably the last act in the disintegration of the supercontinent of Gondwana.

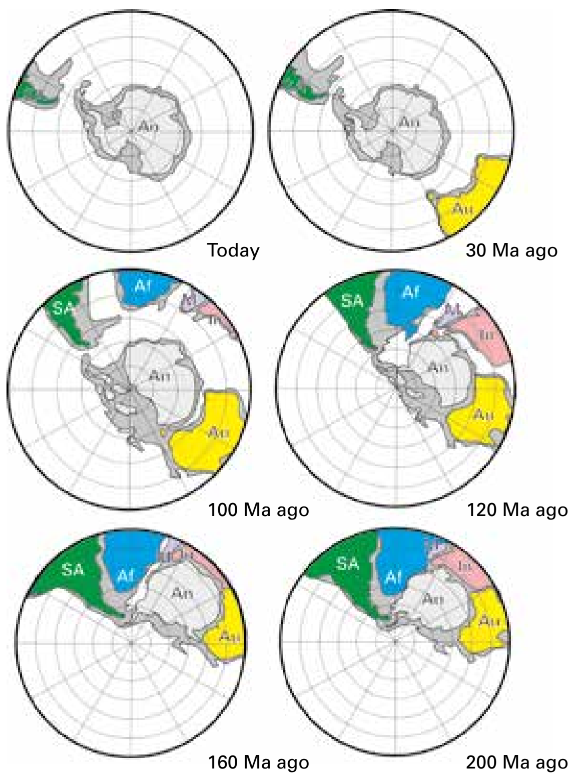
This disintegration has continued for about 180 million years. However, Gondwana is an ancient continent; its formation, existence and disintegration has been the dominant process in the Earth's southern hemisphere over the past 500 million years. After all, the supercontinent lasted for over 300 million years. For approximately 150 million years, from the late Carboniferous to the Jurassic, Gondwana was part of the supercontinent of Pangaea, and Antarctica was always a central part of the action, so to speak. The formation and disintegration of Gondwana is therefore the primary focus of GANOVEX, the Antarctic flagship programme that the BGR has been advancing at the South Pole for more than 40 years.

GANOVEX CAPTURES THE ENTIRE LIFE CYCLE OF A SUPERCONTINENT.

In the meantime, GANOVEX has conducted 14 expeditions to explore northern Victoria Land and the adjacent regions at the Pacific end of the Transantarctic Mountains, an area roughly the size of Germany. In addition to numerous scientific publications, the results include a geological map of all of northern Victoria Land at a scale of 1:500,000 as well as various geological, structural geology and magnetic field maps of sub-areas at a scale of 1:250,000. In cooperation with the Italian National Antarctic Research Programme, several geological map sheets have also been published as part of the GIGAMAP programme (German-Italian Geological Antarctic MAP Programme), which will depict northern Victoria Land and parts of southern Victoria Land at this scale.

Rock fragment with a fossilised footprint of an early Triassic dinosaur from a rock sequence newly discovered during GANOVEX XI in the Helliwell Hills.

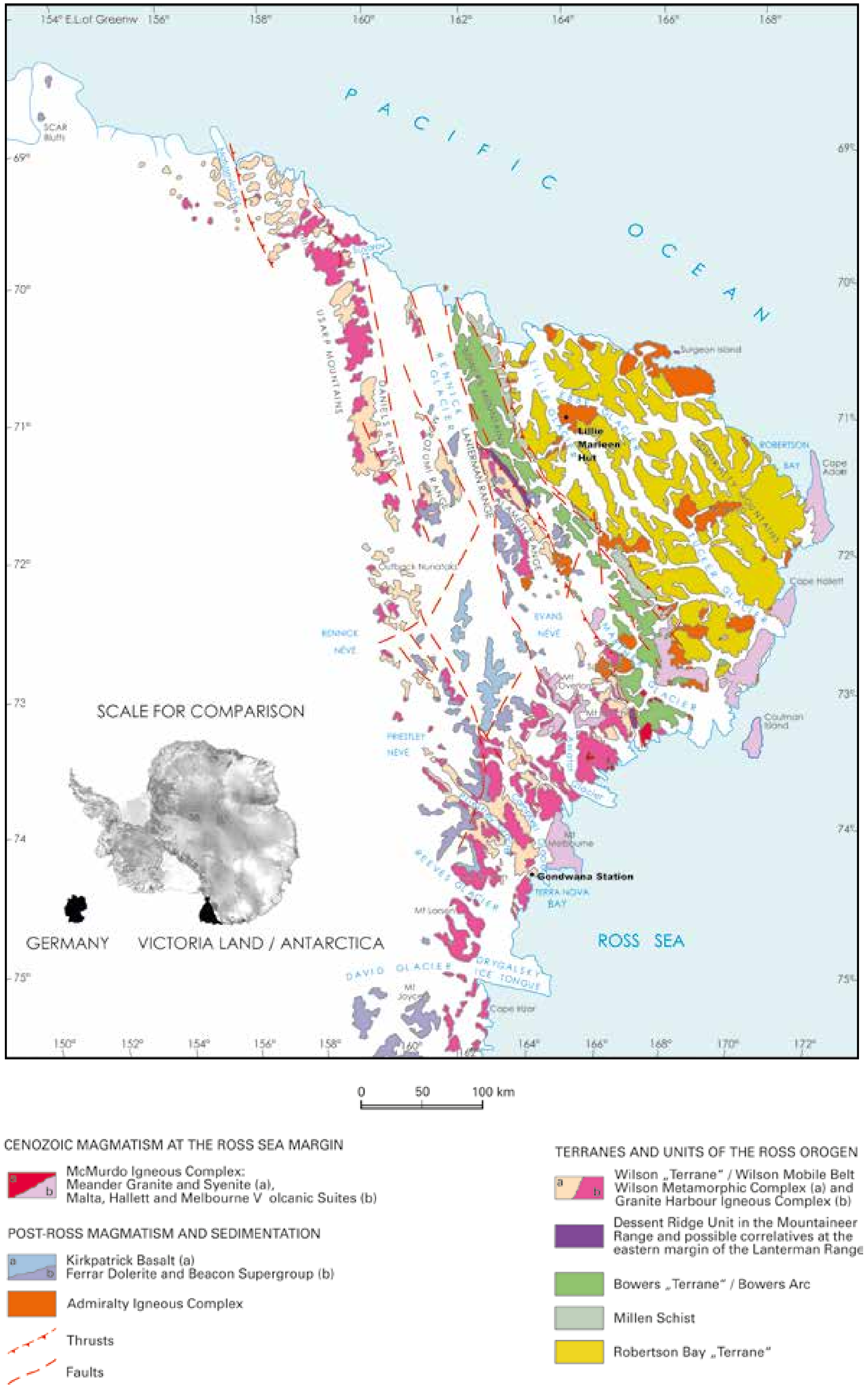
The disintegration of the Gondwana supercontinent.
SA = South America, Af = Africa, M = Madagascar, I = India, Au = Australia, An = Antarctica / Ma = million years (after Walther 1998).



The researchers of the BGR and its partner institutions aim to gain a comprehensive picture of what has happened since the late Proterozoic with their interdisciplinary research expeditions. Geology provides information about the rocks themselves, while structural geology deciphers tectonic development. Geochronology assigns an age to the events, so that the development can be correlated with the history of the Earth, and geophysics provides clues as to the extent of the processes that were studied at individual sites. Geochemistry, in turn, provides information regarding the environmental conditions that prevailed at different times on the Antarctic continent or Gondwana. If there is also a fossil record, palaeontology enriches this picture with information about the prevailing living conditions.

The GANOVEX programme has demonstrated that the Transantarctic Mountains offer an excellent window into the history of Gondwana. According to current findings from the more recent GANOVEX campaigns, its history as a morphologically high mountain range only began around 35 million years ago, i.e. at the time

Geological map of northern Victoria Land, modified from the GIGAMAP series jointly published by PNRA and BGR.

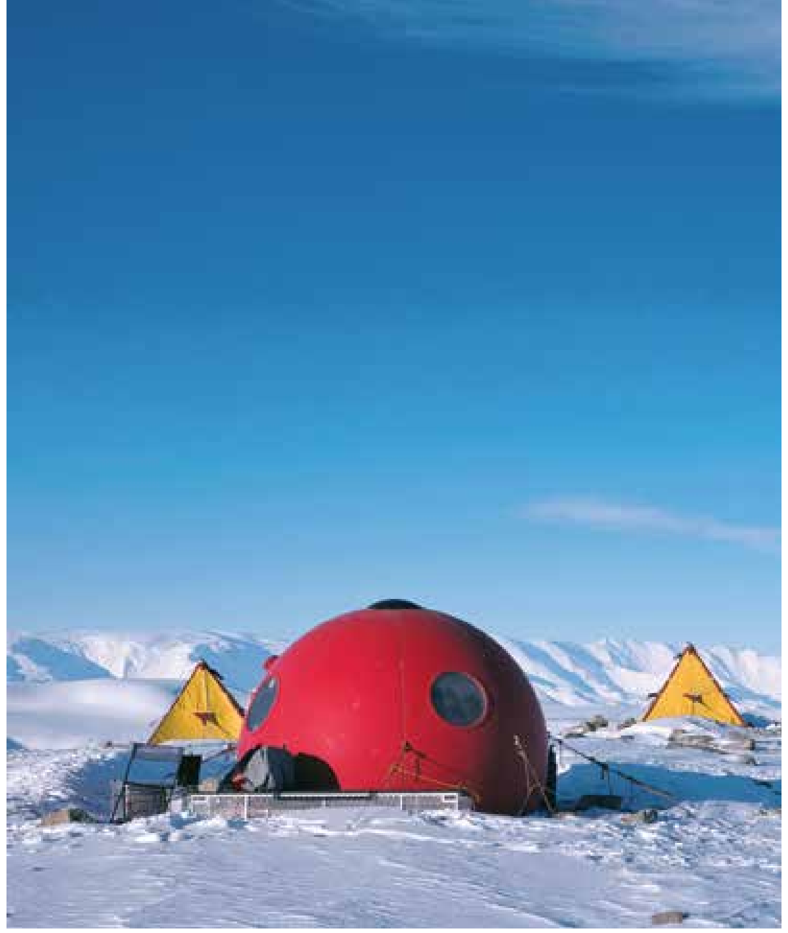


when Tasmania as the last part of Australia separated from Antarctica. The bedrock on which it is built, however, is from the Ross Orogeny, which took place at the time of Gondwana's formation. This mountain range was of the same type as the present-day Andes. It was formed when the oceanic plate of the Palaeopacific was subducted beneath the margin of the East Antarctic continental plate, raising this plate margin like the folds of a tablecloth and forming a deep oceanic trench. Similar to the west coast of South America, parts of the Earth's mantle were melted, and the rising magma further lifted the continental margin and fed several volcanoes during the development of the Ross Orogen. This geomorphological feature resumes beyond East Antarctica in what is now Australia, as both continents were immediate neighbours at the time. There, however, it is called the Delamerian Orogen.

Many detailed questions remain unanswered; for example, when the orogeny began and how long it lasted. Up to now, scientists have assumed that mountain building began around 530 million years ago and lasted for approximately fifty million years. However, results from the more recent GANOVEX expeditions now suggest that mountain building lasted twice as long and began correspondingly earlier, specifically 580 to 590 million years ago. What these findings mean for the tectonic models that simulate the formation of Gondwana remains to be seen.

On one of these expeditions, intensive geophysical survey flights were conducted over an area of the Lanterman suture zone near the Rennick Glacier. Aeromagnetic measurements with a helicopter yielded a high-resolution image of the magnetic anomaly in this contact zone between two ancient crustal blocks. Earlier measurements had revealed a large-scale anomaly there, but this flight was now able to better define its structure for a narrow area of the suture.

Relatively few geological traces are known from the time between the Ross Orogeny during the formation of Gondwana and the formation of the



The remote campsite Marinella on the Mariner Glacier during GANOVEX XIII/2. The "apple", a small fiberglass hut, served as a kitchen, office and lounge at the same time for the geophysics team.

Transantarctic Mountains during the course of its disintegration. This period spans 300 million years during which a supercontinent rose and fell, ice caps grew and disappeared again, dinosaurs appeared and abruptly disappeared, and Gondwana itself disintegrated into its now familiar components in a slow process lasting more than 100 million years. It was also the period during which the Antarctic part of the supercontinent moved incrementally from a position over the equator towards the South Pole until, during the more recent Cretaceous period, Antarctica finally arrived at its position over the South Pole, where it remains to this day.

It is hardly conceivable that such a period would be completely calm and without upheavals, and current research shows that the Earth's crust was in fact very active during this time. In many cases, old fractures from the time of the Ross mountain-building event were reactivated at later times, and the mountains themselves went through the usual erosional process and were completely eroded until a hilly river and lake landscape determined the appearance of the Victoria Land in the era of Gondwana. At the same time, however, additional folding, rifting and intense volcanic eruptions occurred elsewhere, for example at the Pacific margin of ancient Antarctica, which continued to be active and characterised by ongoing subduction. These processes lasted until the Early Cretaceous, when most of Gondwana had long since begun to disintegrate. In northern Victoria Land, the collision of the Palaeopacific plate with the East Antarctic continent was superseded by large-scale extension and huge lateral displacements. Results of the GANOVEX expeditions show that an extensive basin formed within the Gondwana supercontinent at this margin of East Antarctica and Australia, during the Late Triassic at the latest, and lasted until the Early Cenozoic. The slow drifting apart of the two continental blocks and the formation of the West Antarctic Rift System, which finally led to the rise of the present-day Transantarctic Mountains, ended the existence of this intercontinental basin relatively late, shortly before the final separation of the last fragments of Gondwana and the isolation of Antarctica.

A highlight of the recent expeditions of the GANOVEX programme, were the numerous signs of a diverse ecosystem from the Late Triassic that the researchers found. They discovered the remains of a 200-million-year-old petrified forest in whose fossilised wood the burrows of maggots and insect droppings were still preserved. At that time, northern Victoria Land was no longer a rugged mountainous landscape, but a flat terrain over which rivers meandered and which was covered by extensive lakes. Apparently, reptiles and probably other vertebrates also lived there because the fossilised footprint of a Triassic dinosaur was found during the expedition. Precise classification is difficult, but it probably belongs to a rather rare group that has been demonstrated to have lived from the Late Permian to the Late Triassic and has been found on several continents. The find was the first indication of their existence in northern Victoria Land.

Gondwana began to break apart with a series of violent volcanic eruptions 180 million years ago. In the Transantarctic Mountains and throughout Antarctica, except for the Antarctic Peninsula, there is no direct evidence after this time other than young volcanic rocks and deposits from the most recent glaciation periods. What is certain is that the present-day southern continents, Madagascar and India, detached from Antarctica one after the other. As one of the last crustal blocks, Australia began to separate starting about 95 million years before present. A system of hitherto unknown faults, presumably from that time, was discovered during the more recent GANOVEX expeditions; these can more plausibly explain the concrete separation process of the two continents. The sediments of the former vast basin of the Mesozoic and Early Cenozoic have since been eroded and removed as a result of the intensive uplift of the Transantarctic Mountains and were finally deposited as sediments more than ten kilometres thick in the rift basins of the Ross Sea.

Crevasses in the Campbell Glacier at Gerlache Inlet.

Sampling with a gravity corer during the Sub-EIS-Obs II expedition on the Ekström Ice Shelf.

3.5 DRILLING IN ANTARCTICA: GEOLOGICAL FINDINGS FROM THE DEPTHS

Glaciation greatly complicates the search for geological traces in Antarctica. The glaciers have transported copious amounts of sediment into the shelf seas and buried the rest under ice whose thickness can be measured in kilometres. The only way to obtain information specifically from the period after the advance of the glaciers is through drilling projects. The BGR has been involved in two major international projects and is working on a third in collaboration with the AWI.

Antarctica's role as one of the coldest regions on Earth has been comparatively recent. It has been around 34 million years, barely more than the blink of an eye in terms of Earth history, since the glaciers extended over most of the continent and turned it into an inhospitable icy landscape. Today, the continent is covered by continental ice whose thickness reaches up to 4,000 metres, but it is not as eternal as it seems. The West Antarctic Ice Sheet, for example, has apparently shrunk at comparatively regular intervals until it broke down completely, only to grow again to its current size.

The international community of researchers is gaining insights into the recent past of Antarctica primarily by drilling into the layers of sediment on the continental shelves. The BGR has been involved in two international drilling projects. Between 1997 and 1999, the Cape Roberts Project drilled to a depth of almost 1,000 metres into the seabed near Cape Roberts in the Ross Sea, thus obtaining an almost complete sedimentation history of West Antarctica during the period from about 34 to 17 million years ago. The sequence obtained from a total of three boreholes extended to approximately the beginning of the Antarctic glaciation. A conventional drilling rig was erected on the sea ice, in order to drill through the two-metre-thick ice and water depths of between 150 and 300 metres into the subsurface.

The ANDRILL project also took place in the western Ross Sea during 2006 and 2007 and was able to obtain cores totalling 1,200 metres in length at two locations between Ross Island and the mainland, reflecting the past 20 million years in unprecedented resolution. The core sequences of both drilling projects document both the glaciation history of the region at the interface between East and West Antarctica and the more recent development of the West Antarctic Rift System. From the Late Eocene onwards, coinciding with the beginning of glaciation around 34 million years ago, the intensive activity of the system in this part is evident. The oldest sediments date from this time, but the rift system in the Ross Sea is assumed to have already been active during the Cretaceous. However, earlier sediments that could have documented the beginning of the rifting have not been found, at least at the drilling sites of the two projects.

Nevertheless, the development of the region since the uplift of the Transantarctic Mountains in the Cenozoic is clearly visible. The intense extension resulted in the subsidence of the Victoria Land Basin during the Oligocene. However, massive deposits containing erosional debris from the Transantarctic Mountains quickly filled the rift basin, and the tectonic activity of the region is also evident in these sediments; numerous natural fractures can be discerned from the Neogene into the Quaternary.

ANDRILL rig and working environment on the McMurdo Ice Shelf, Ross Sea.

Looking at the paleoclimate, the cores demonstrate that the region was surprisingly variable in terms of climate. A core section from the bottom of the stratigraphic column, and another section dating from the Middle Pleistocene to the present, document the coldest periods in the entire core. In contrast, 15.7 million years ago, during the Middle Miocene, the mean air temperature was +10 degrees Celsius, and the landscape was tundra with low-growing vegetation and freshwater lakes. After another colder period, warm conditions prevailed again during the Pliocene and Early Pleistocene, when the carbon dioxide content in the atmosphere was at times as high as it is today, but eventually tipped over into today's icy climate, when the CO2 content dropped to far below current levels. The cores also reveal the influence of the Milankovitch cycles, in particular the eccentricity of the Earth's orbit around the Sun, which fluctuates in a 400,000-year rhythm, on the stability of the West Antarctic Ice Sheet.

The BGR is currently playing a key role in the preparation of a borehole in the Ross Sea (SWAIS-2C), with New Zealand as the primary responsible party supported by international cooperation. In addition, BGR and AWI are pushing ahead with a drilling project on the opposite Ekström Ice Shelf off Dronning Maud Land in East Antarctica. This project will involve drilling through a sedimentary column similar to that drilled through in the Ross Sea. In preparation for this, three campaigns have taken place so far for the preliminary investigation of the area within the framework of the Sub-EIS-Obs project. Initial geophysical surveys have shown that the sediments on the Ekström Ice Shelf rest on a basalt layer called the Explora Wedge. This apparently dates from the first phase of the break-up of Gondwana 180 million years ago and continues into South Africa. At that time, Africa was the first to break away from Antarctica, a process that was accompanied by intense volcanic eruptions. The periods documented by the sediment deposited on this basalt will only be known through the drilling, but the hope is that they will close the gap in the geological record after the initial break-up of Gondwana.

BOREHOLES PROVIDE INSIGHTS INTO RECENT ANTARCTIC HISTORY.

4 THE ARCTIC

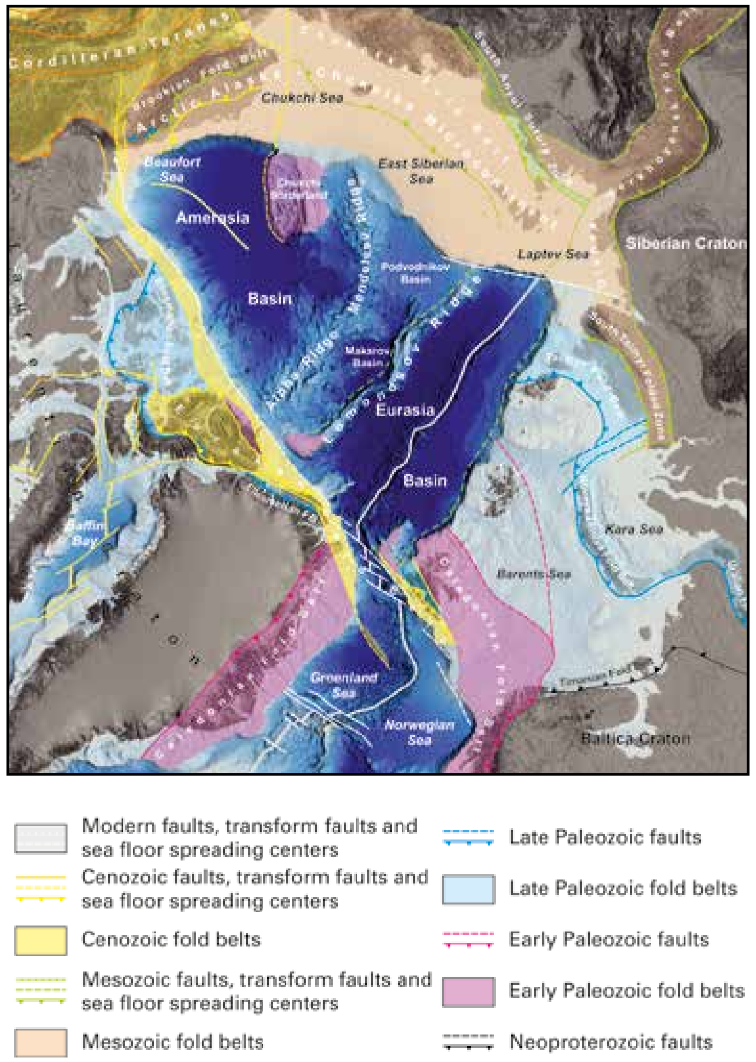
4.1 KEY TO THE EARTH SYSTEM: THE CONTINENTS ON THE PERIMETERS OF THE ARCTIC OCEAN

The Arctic Ocean plays an important role in the Earth system and is currently the scene of dramatic variations due to climate change. Geological research on the formation and development of the Arctic also serves to further our understanding of these processes and provides support with policy issues.

The formation of the Arctic Ocean began 145 million years ago, when the northern continent of Laurasia ruptured along the suture between the present-day continents of North America and Asia, opening up the Amerasian Basin. It was only during the more recent geological past that what began as an inland sea surrounded by land at the North Pole gained a deep-sea connection to the young Atlantic Ocean with the development of the Fram Strait.

Its location at the North Pole and its connection to the Atlantic Ocean make the Arctic Ocean an important factor in the Earth system, and it is the part of the Earth where global climate change is currently exhibiting its most dramatic consequences. Neither its role in the Earth system nor the ongoing and future changes in the region can be reliably assessed without careful research into the geological conditions. This includes the question of the genesis of the Arctic Ocean, which is being actively addressed by the BGR and international cooperation partners. During the course of its now long-standing research activities in the Arctic, large parts of the European and North American Arctic between Spitsbergen and the Mackenzie Delta, as well as areas in the Siberian Arctic, have been studied for this purpose.

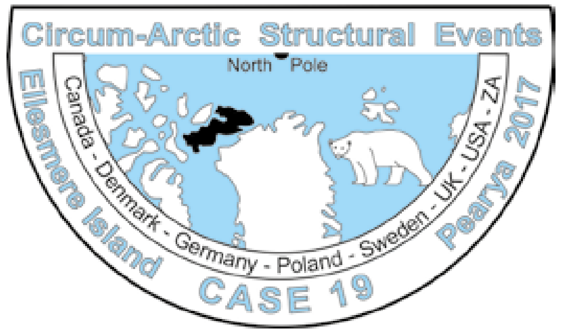
Bathymetric map of the Arctic with the distribution of the circum-Arctic fold belts and mountain ranges.



Geoscientific research on land and on the ocean not only serves to improve knowledge of the formation and development of the Arctic Ocean basin, but also plays a role in the expansion of their exclusive economic zones to 200 nautical miles in accordance with UNCLOS for which all littoral states are striving. As a country with no territorial interests of its own, Germany maintains good relations with all stakeholders, particularly because of its intensive research commitment, and can contribute to the peaceful balancing of interests with factual research results. This includes the sustainable development of trade and tourism via the shipping routes through the Northeast and Northwest Passages, which are opening up due to climate change. It also includes extracting the mineral resources believed to exist in the Arctic as carefully as possible.

RESEARCH WITH A FOCUS ON GEOSCIENCE AND POLICY.

4.2 EXPLORING THE LANDMASSES AROUND THE ARCTIC OCEAN: BGR PROJECTS IN THE ARCTIC

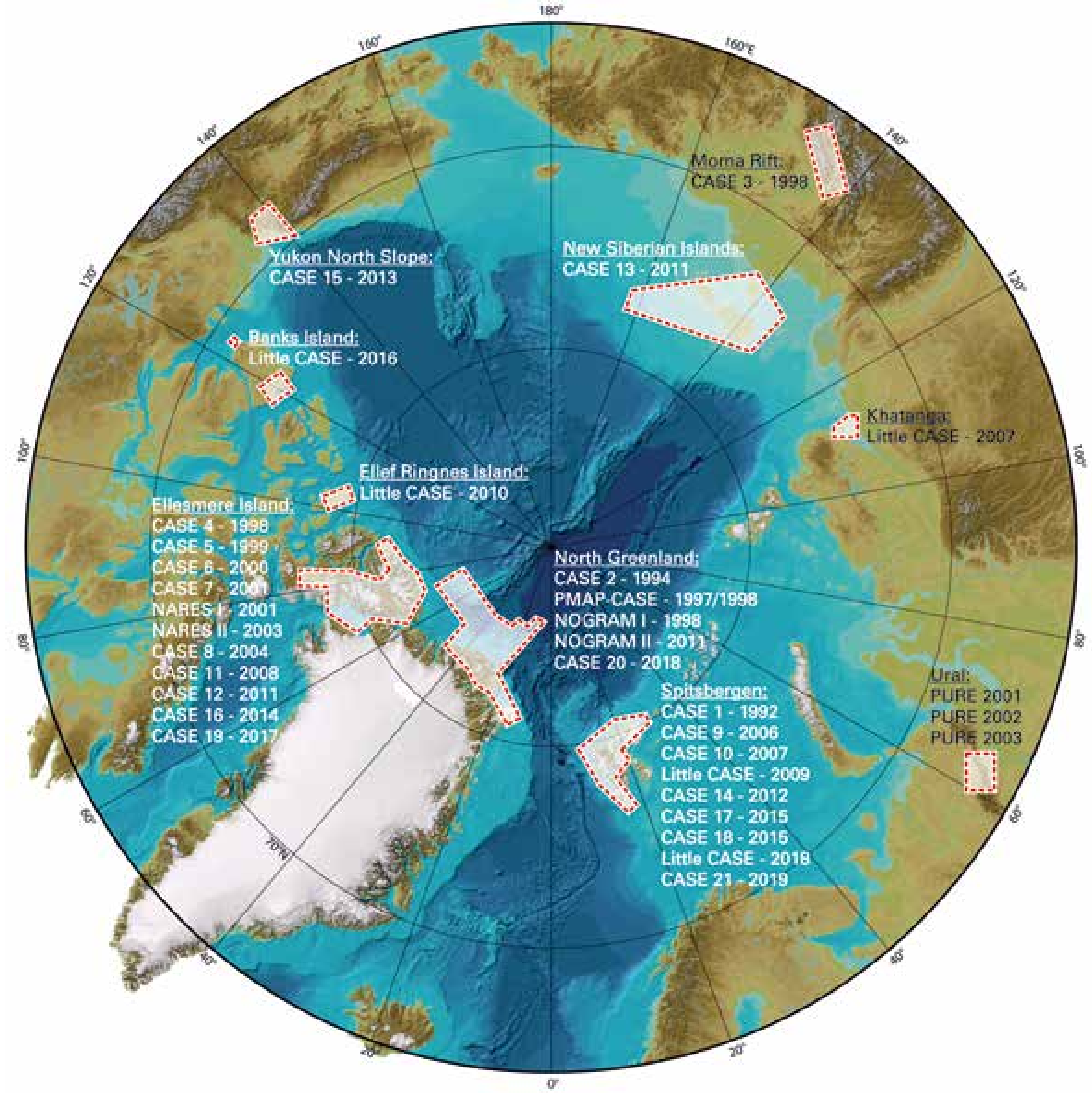


The formation of the Arctic Ocean and the development of its adjacent mainland areas still pose great mysteries to science, which is why BGR researchers are actively seeking geological clues to these questions in many places around the Arctic.

The BGR is active throughout the Arctic region. The 22nd expedition has now been conducted as part of the CASE research programme, which has been running since 1992. The "**C**ircum-**A**rctic **S**tructural **E**vents" programme aims to reconstruct the plate tectonic evolution of the Arctic Ocean as a result of the opening of the Amerasian and Eurasian basins using terrestrial data from the surrounding continental margins. The scientific question of the CASE programme is as simple as it is complex: How did the Arctic Ocean, this large basin between the Eurasian and North American continental plates, develop? There are still no conclusive answers to this question in terms of plate tectonics. In contrast to the marine expeditions of geophysicists in the Arctic Ocean, geologists on land along the various coastal areas of the Arctic Ocean can directly touch, examine and map rocks, structures, folds and fault zones and determine the respective ages of the movements. This makes it possible to directly compare rock units and deformation zones on different plates and thus also to reconstruct when continental plates collided, how long they remained next to each other and when and how they separated again. Since the inception of BGR's Arctic research, the primary focus and research areas have been along the continental margins between Spitsbergen and the Canadian Arctic Archipelago via Greenland, to the Yukon North Slope on the border with Alaska. On the opposite side of the Arctic Ocean, there have been expeditions to Yakutia, the mainland areas near the Laptev Sea and the New Siberian Islands with Russian partners.

Thematically linked to the CASE programme are aeromagnetic surveys conducted under the within the framework of PMAP-CASE (**P**olar **M**argins **A**eromagnetic **P**rogram), NARES I and II (Nares Strait) and NOGRAM (**NO**rthern Greenland **GR**avity and **A**ero**M**agnetics) as German-Canadian cooperation projects. The aim of the AWI-BGR cooperation project NOGRAM was to obtain high-resolution magnetic and gravimetric data in order to perform detailed mapping of geological/tectonic structures in selected areas in and around North Greenland. As a result, maps from remote areas that are difficult or impossible to reach by other means have been published. The mostly ice-covered Nares Strait between Greenland and Ellesmere Island in northern Canada forms the connection from the Arctic Ocean to Baffin Bay and the Labrador Sea. A plate boundary between the North American and Eurasian plates, called the Wegener Fault, which is closely linked to the opening of the North Atlantic and the Arctic Ocean, is believed to exist here. The exploration of the Wegener Fault and the young sedimentary basins coupled to this fault was the goal of the NARES projects, which the BGR conducted in cooperation with the Geological Surveys of Canada and Denmark in 2001 and 2003.

Research related to natural resources was conducted in cooperation with partners from geological institutes of the Russian Academy of Sciences in Moscow and Syktyvkar in the Polar Urals as part of PURE (**P**olar **UR**als **E**xpedition). During the summer months of 2001 to 2003, the partners studied structural geology and mineral deposits in the target area to clarify the genesis of chromite and platinum group elements in ophiolites.



Map of the Arctic with the geological and aeromagnetic working areas of the BGR since 1992.

As in Antarctica, geological mapping remains one of the fundamental tasks for understanding the geological and plate-tectonic processes of the past. A large number of official geological maps have been produced on Svalbard and Ellesmere Island in cooperation with the Norwegian Polar Institute and the Canadian Geological Survey. The highlight of the geoscientific maps is the BGR's contribution to the international tectonic map „Tectonic MAp of the Arctic (TeMAr)" at a scale of 1:5,000,000, published under the leadership of Russia and France.

THE BGR WORKS CIRCUM-ARCTIC.

View on the icebergs and the frozen sea at the coast of Waldemar Glückstadt Land in Northeast Greenland.

Rootstock of a 55 million year old tree at Stenkul Fiord on Ellesmere Island, Canadian Arctic, see hammer as a scale.

4.3 ROLLER COASTER CLIMATE

Sediments are archives of the Earth's history. Wherever the layers have been preserved, geologists can reconstruct the life, climate and landscapes of past epochs.

The contrast with the present could hardly be greater. Around 54 million years ago, dense deciduous forests grew in Canada's Arctic north. Oaks, elms, hornbeams and various species of walnut stood where only the most frugal birches, willows, conifers and low shrubs can now endure. Poplars and alders lined the streams and rivers that now wind through permafrost. On the coast were extensive mangrove swamps like those found today on the coast of Mexico at the southern end of the continent. Traces of this once lush, subtropical ecosystem were found in soil samples taken during the BGR's CASE 15 expedition in the Caribou Hills in the Arctic Mackenzie Delta in cooperation with French specialists. French researchers had already found traces of a similar ecosystem on the opposite Siberian Arctic margin in samples from the CASE 13 expedition to the New Siberian Islands.

Many aspects of the Arctic region's evolution are still unexplored over long periods of time. Above all, geologists often lack the time frame in which the findings from the field can be related to. In order to establish this chronological sequence for the tectonic events that shaped the formation of the Arctic, geologists at the BGR rely on sediments, which have been deposited chronologically, and if they have remained undisturbed, their stratigraphy reflects the development of the region over geological periods. The mangroves in the present-day Mackenzie Delta, for example, were dated to the Early Eocene due to a layer of volcanic ash that ran through the middle of the pollen-bearing strata.

Outcrop in the Caribou Hills with the Mackenzie Delta in the background. The volcanic ash layer can be recognized by its orange-red weathering colour. Person as scale.

Careful analysis of ash layers such as this often leads to the discovery of datable minerals, for example zircons. Through precise geochronological dating, the minerals provide important anchor points at which the sequence of sediments at the site can be hooked into the absolute chronology of the Earth's history. Zircons, for example, very reliably store the moment of their formation during an eruption. Once the tiny crystals have been formed the clock of radioactive decay runs inexorably inside them, which allows the specialised laboratories to determine their age with a high degree of precision.

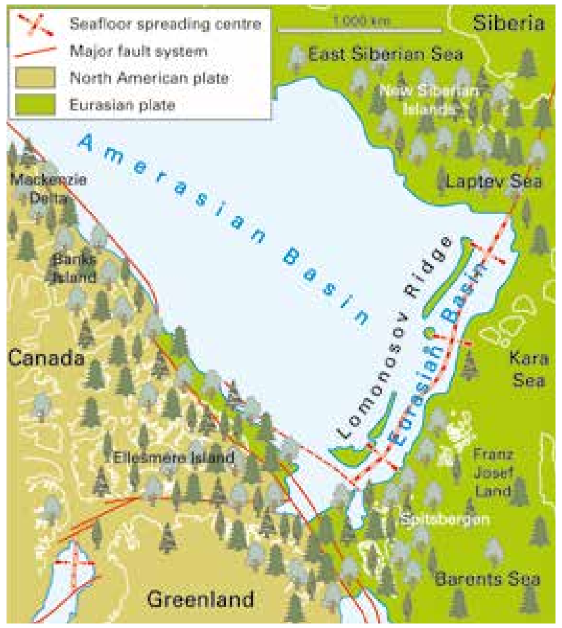
Another method for the chronological classification of sediments is based on the ratio between carbon isotopes of different weights. This ratio has fluctuated through the course of the Earth's history with intermittent sharp, singular peaks and valleys, which are reflected in isotope curves covering many tens of millions of years and, moreover, are calibrated with astronomical cycles. If both volcanic ash and carbon-rich layers are present in a sedimentary sequence, the two methods can be combined. This yields highly accurate determinations of the age of the sediments. The sharp fluctuations in the isotope curves are caused by disturbances in the global carbon cycle, which have repeatedly led to extreme warming events (hyperthermal events) throughout the world. Warming events such as these also facilitated the growth of such lush forests in high latitudes, as found in the Caribou Hills or on the New Siberian Islands.

GEOLOGY AS A TIME MACHINE – WHEN THE ARCTIC WAS STILL DENSELY FORESTED.

At Stenkul Fiord and Split Lake in the south of Canada's Ellesmere Island sedimentologists from the BGR were able to obtain sample material for both methods on several expeditions and thus also gain a time frame for the events of the Cenozoic Eurekan deformation, a tectonically very active phase in the Arctic, which are documented there in the strongly folded and deformed rocks. This demonstrates that tectonic activity due to contraction of the Earth's crust occurred shortly after the second Eocene Thermal Maximum (ETM-2). At that time, at the beginning of the Cenozoic or about 66 to 40 million years ago, the highest temperatures in the world were last reached, before it subsequently became increasingly cooler.

Coals that have been identified as being from the time of the Paleocene-Eocene Thermal Maximum (PETM) on the basis of their strong negative deflection in the isotope curve were found a few metres below the ash layer, separated by a stratigraphic break caused by previous tectonic movements. These coals mark the beginning of the Eocene, and are therefore about two million years younger than the sediments above. The stratigraphy makes it clear that tectonic movements on the fault zones were very dynamic during the Eurekan deformation and occurred over a geologically short period of about two million years between the end of the Paleocene at the PETM and ETM-2. However, these two extreme hyperthermal events are much more than simply very precise stratigraphic time markers. As an expression of massive natural disturbances of the global carbon cycle during the Eocene, they also offer the opportunity to conduct in-depth studies on the climatic conditions at that time, for example on the mean annual temperature and precipitation, at such high latitudes. Climate researchers can then draw comparisons with the expected effects of the current global warming phenomenon, which is also caused by the release of large amounts of carbon into the Earth's ocean-atmosphere system.

Reconstruction of the Arctic Ocean (Amerasian Basin) with the distribution of vast forests at the end of the Paleocene 56 million years ago.



4.4 THE NORTH AMERICAN CONTINENTAL MARGIN - AN ARCTIC SAN ANDREAS FAULT

The formation of the Arctic Ocean was much more complex than current models suggest. This is demonstrated by the field discoveries along the North American continental margin, which the BGR has compiled over the course of more than 20 CASE programme expeditions.

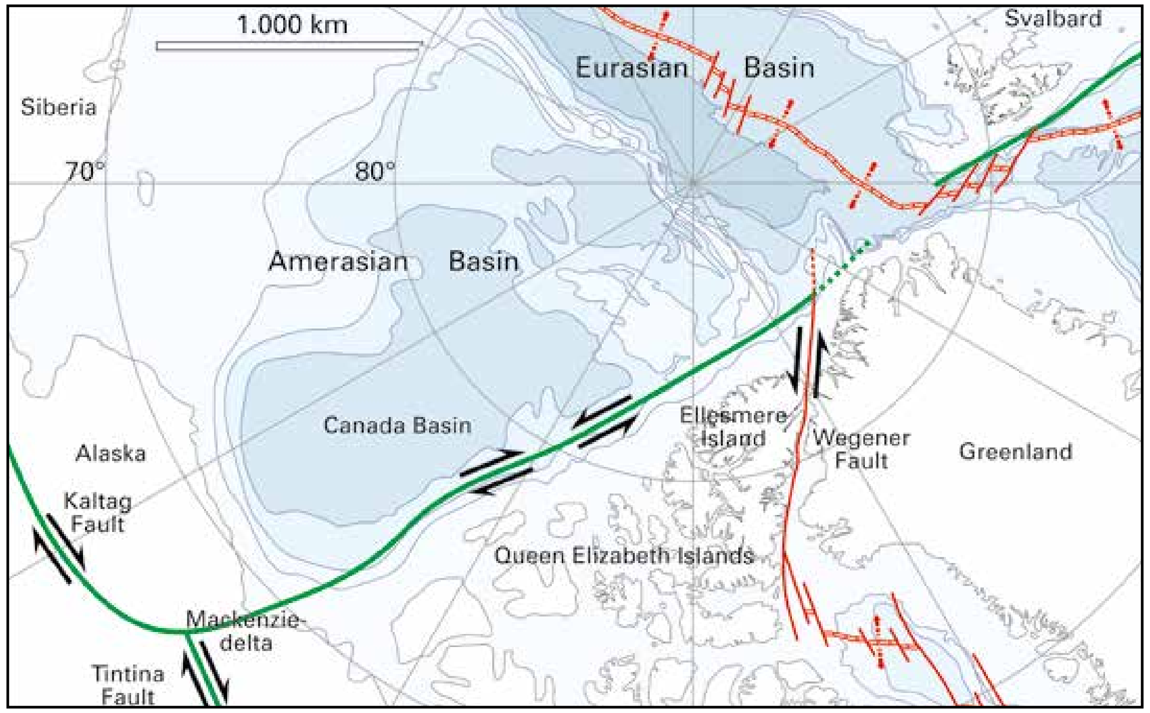
At Cape Lawrence in the northeast of Ellesmere Island, conditions are wintery by our standards, even in midsummer. Snow often still lies on the glacier-covered mountain ranges that line the Nares Strait, the wind drives ice floes together on the water and pushes them towards the coast, and temperatures rarely rise above mid-single digits. From a geoscientific point of view, however, the 1,000-metre-high cliffs are a paradise, because Arctic geological history can be read with the naked eye on its steep walls. Clearly visible strata run along the mountain slopes and show that an enormously turbulent period has been recorded here. The strata belong to the time of the Eurekan deformation of the Paleogene, when the Mesozoic supercontinent Laurasia broke apart, Baffin Bay and the Labrador

Meadow of flowers in the Aulavik National Park west of Thompson River in the north of Banks Island, Canadian Arctic.

Front of a glacier and icebergs in the frozen south end of Yelverton Inlet on the north coast of Ellesmere Island, Canadian Arctic.

Sea opened up in northeastern North America and the second, younger part of the Arctic Ocean took shape with the Eurasian Basin.

The formation of the Arctic Ocean at today's North Pole is still one of the great questions of geoscience. The beginning and the provisional end point of this development are clear; what originally began as an inland sea during the Cretaceous is now connected to the world ocean via the Fram Strait. Research into the plate tectonic processes that led to the present-day Arctic is still a challenge, due largely to the Arctic wilderness and the remoteness of the expedition areas that researchers must confront in their search for clues. Research cruises to most Arctic countries are still possible only with the greatest effort, so that very little is known about the geological situation there. Land expeditions are also very demanding and must cover an enormous and, as is gradually becoming clear, very heterogeneous area around the central ocean.



Location of the large fault zone on the northern edge of the North American continent between Alaska and Greenland.

Despite all logistical hurdles, there has nevertheless been intense exploration activity by the international Arctic research community over the past decades. Field work during the nearly two dozen land expeditions of the CASE programme in numerous areas, particularly along the North American-European Arctic margin, has shown that many structures and movements exposed at the Arctic continental margins are not accounted for in previous models of Arctic Ocean formation.

Researchers at the BGR were previously able to demonstrate this in the most detail on the faults from the time of the Cenozoic Eurekan deformation. This event is a complex sequence of extensions, compressions, lateral displacements and collisions that are exposed along a chain of deformation or crumple zones up to 250 km wide. But above all, like the famous San Andreas Fault in California, it is a massive transform fault where two plates are moving laterally past each other. It is also striking that the continental margin between the Mackenzie Delta and the north coast of Greenland runs as if drawn with a ruler. This 2500-kilometre-long fault system runs from Canada's Yukon Territory on the Alaskan border along the Arctic edge of the Canadian Arctic Archipelago across northern Greenland to Spitsbergen. Many of the CASE expeditions have taken the BGR to these key areas, where it has explored the Eurekan deformation in detail, adding more pieces to the puzzle of the recent tectonic history of the Arctic at these points. The fault may thus represent the suture where the break-up of the northern Laurasia supercontinent began with the separation of Siberia and North America and the opening of the Amerasian Ocean basin. In any case, the occurrence of recent earthquakes on the north coast of Ellesmere Island shows that the faults parallel to the North American continental margin are still active today.

Field observations from Ellesmere Island to Spitsbergen via Greenland indicate a complex event during the Eocene. The deformations took place in two phases that extended over practically the entire period between 53 and 34 million years before the present. They began simultaneously with the activation of oceanic ridges in the Labrador Sea and Baffin Bay, in the North Atlantic and in the Eurasian Basin of the Arctic Ocean, which temporarily turned Greenland into a self-contained continental plate. There is much to suggest that this simultaneous formation of the ocean basins is also the cause of the complex deformation in the three areas.

OPENING OF AN OCEAN IN SEVERAL PHASES.

Until the Eocene, the Canadian-Arctic Archipelago, Greenland and Spitsbergen were not islands lined up like pearls on a string and separated by straits and basins as they are today, but adjoining parts of a single, large landmass that only slowly broke up under the pressure of rift valleys on land and spreading ridges in the sea. In the centre was Greenland, which was connected to the Eurasian and the North American plates prior to the Eocene. In the Eocene, the present island was separated from the North American Plate by the left-lateral transform fault known as the Wegener Fault and the incipient spreading ridge in the Labrador Sea. They apparently followed pre-existing extensional structures in the Earth's crust. As a result, a third, smaller, Greenlandic plate was temporarily formed between the North American and Eurasian plates.

This tectonic plate moved northeast towards the Eurasian Plate on which Spitsbergen lies, during the first phase of the Eurekan deformation. During this phase, the spreading ridges west and east of the Greenland plate propagated towards the north. Baffin Bay was formed in the west, and the Greenland Sea opened in the east. In the contact zone between Greenland and Spitsbergen, contraction with folding and thrusting affected the west coast of Spitsbergen, while the Wegener Fault remained a transform fault. In the second phase of deformation, the Greenland plate turned counter-clockwise and transformed the character of the Wegener Fault. As had previously occurred in Spitsbergen, Ellesmere Island and northwest Greenland were pushed against each other creating a broad collision zone on Ellesmere Island parallel to the Wegener Fault, while the boundary between Spitsbergen and Greenland became a right-lateral transform fault. To the west and east of Greenland, the ocean basins continued to open.

The end of the Eurekan deformation came when the spreading ridge in the Labrador Sea and Baffin Bay became inactive, and the Greenland Plate subsequently became part of the North American Plate. In the North Atlantic and the Eurasian Basin of the Arctic Ocean, however, seafloor spreading continued, so that the North American Plate and the Eurasian Plate were eventually completely separated, and a passage between the oceans, the Fram Strait, was formed.

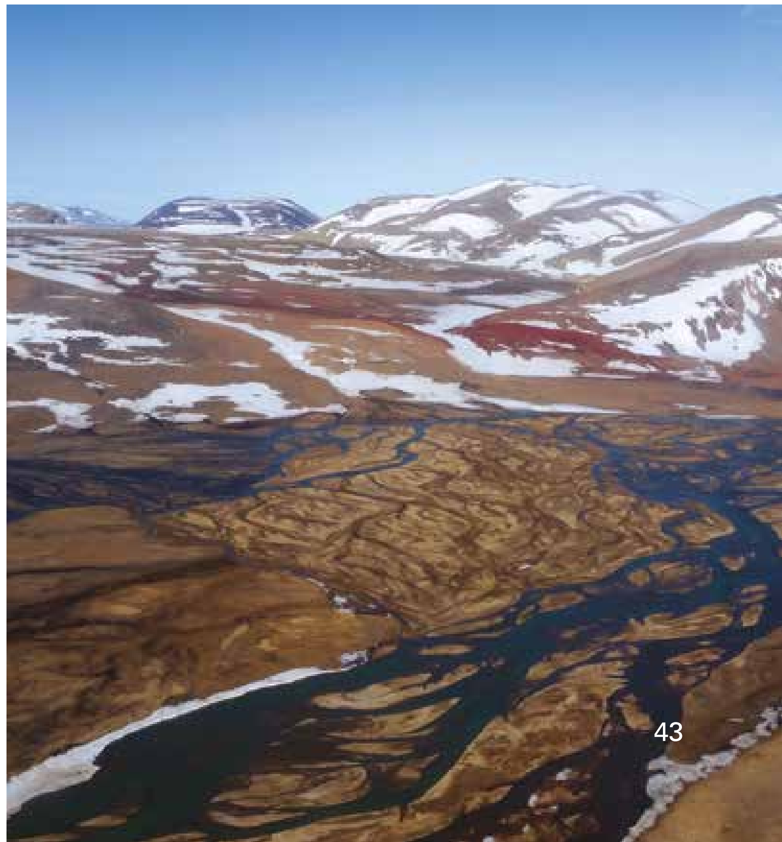
However, these findings are nothing more than an initial clue, as the details of how the continental movements took place at that time remain unclear. According to the current model, the separation of Laurasia began around 145 million years ago. Starting in the region of the present-day Mackenzie Delta, the continental margins of North America and Siberia opened up like the blades of a pair of scissors, thus spanning the Amerasian Basin. The formation of the basin was probably driven by a spreading ridge, the inactive remains of which can still be found today in the substrata of this basin. The role that the transform fault of the Eurekan deformation played in the resulting reorganisation of the plates in the Far North remains to be demonstrated by further research in marine geophysics and terrestrial structural geology.

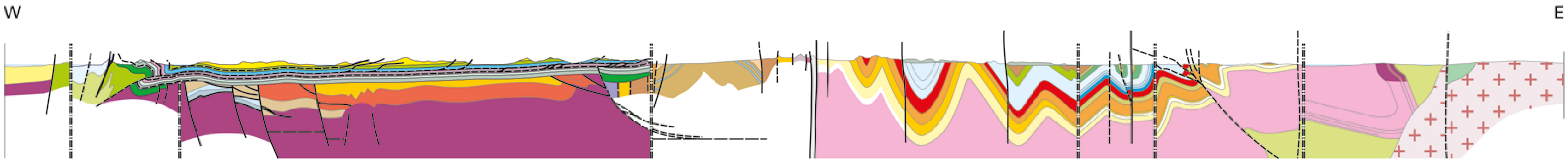
Initially, however, the disintegration of Laurasia was abruptly interrupted about 110 million years ago, and the first phase of ocean formation in the Arctic ended because the Alaskan Chukchi microcontinent collided with the margin of Siberia, ending the opening of the Amerasian Basin. The second phase of Laurasia's disintegration began 65 million years ago, when the spreading ridge developed in the early Atlantic Ocean between North America and Greenland, leading to the Labrador Sea and later to Baffin Bay.

Ten million years later, a new phase of plate tectonics set in, forming the North Atlantic and the younger Eurasian Basin of the Arctic Ocean. This caused the Lomonosov Ridge to detach from the Eurasian continental margin and drift into its present position. The Eurasian Basin that rifted in the process is still growing today, as the Gakkel Ridge in its centre remains active, forming oceanic crust at a rate of about one centimetre per year. This makes the Gakkel Ridge the slowest spreading ridge on the surface of the Earth.

Due to the size and inaccessibility of the Arctic, a direct comparison of the structures and geological developments of the Siberian and North American continental margins is still a challenge today. The BGR jointly conducted the first marine geophysical surveys in the Laptev Sea with Russian colleagues during the late 1990s. In 2011, the work was continued in collaboration with an international team of researchers with geological studies on the New Siberian Islands, an uninhabited archipelago in the Laptev Sea. According to the model that is currently still prevailing, the islands, along with the Siberian continental margin, should have been in the immediate vicinity of the North American continental margin during the Mesozoic. However, initial evaluations of the rock samples from the New Siberian Islands show that this was probably not the case.

Summer landscape in the mountains of Trolle Land, Northeast Greenland.

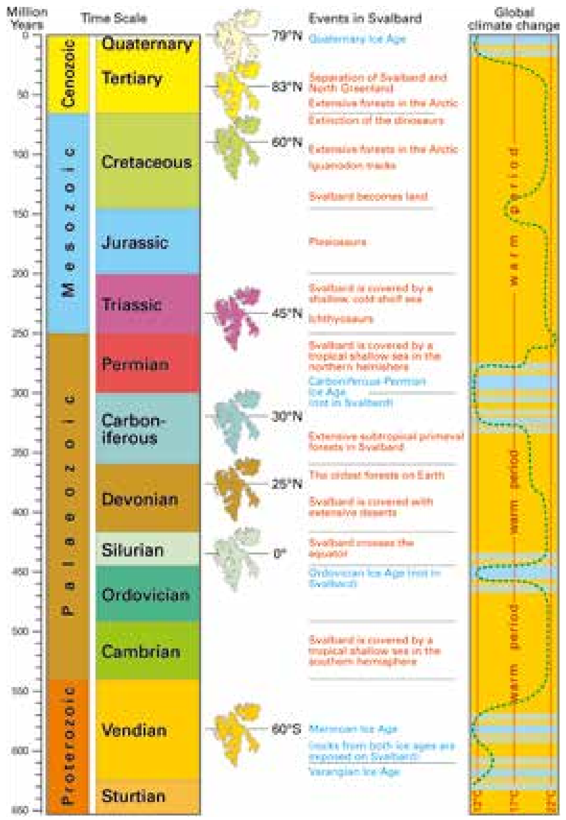




250 kilometres long west-east profile indicating the geological structure of the Earth's crust of Spitsbergen.

4.5 SPITSBERGEN: AN ARCHIPELAGO ON A JOURNEY

Present-day Spitsbergen is almost vegetation-free. This makes it possible to look deep into the geological record without much difficulty. Over the last 600 million years, the archipelago has experienced everything from deep glaciation to tropical climates – and has drifted some 12,000 kilometres from the southern to the northern hemisphere in the process.



Geological table illustrating the northward drift of Spitsbergen from the southern to the northern hemisphere with the most important events and the climate curve over the last 600 million years (Piepjohn et al., 2012).

Studying continental drift over the course of the Earth's history is like working on a gigantic puzzle that cannot be solved by a single group of researchers. A great number of geologists and palaeontologists must examine countless rocks and fossils in order to be able to reconstruct the journey of a small continental plate like Spitsbergen through space and time. On Spitsbergen and the surrounding islands, there are outcrops of rock series almost 30 kilometres thick, spanning a period of about 2 billion years from the Palaeoproterozoic to the present. During the CASE expeditions the almost uninterrupted geological record contained in these rock units and numerous discoveries of sedimentary structures and fossils offered scientists in the field a rare opportunity to follow the transformation of a specific site through the geological past, and at the same time, its migration across the Earth's surface, completing the puzzle of Spitsbergen's journey through time.

The development of Spitsbergen through space and time since the Neoproterozoic period around 650 million years ago is easily comprehensible. At that time, the archipelago began its 12,000 km long journey from the south through all the climate zones of the globe to its current position at the North Pole. The starting point was at about 60 degrees south latitude. Spitsbergen was then firmly in the grip of the great glaciation phases and ice ages of the Cryogenian, which covered the Earth's surface at that time with large-scale glaciers. This is evidenced by thick moraines deposited by the ice streams and the drop stones that were released due to the melting of drifting icebergs, fell into clay deposits off the coast at that time, and have survived in this matrix until today.

SPITSBERGEN OFFERS A RARE GLIMPSE INTO EARTH'S EVOLUTION THROUGH TIME AND SPACE.

In the 200 million years that followed, Spitsbergen and North America (Laurentia) drifted northwards and crossed the equator during the Ordovician, 490 to 450 million years ago. Massive limestone deposits from the subsequent Silurian Period demonstrate two things: the northern edge of Laurentia was then in the tropics and lay at the bottom of a shallow sea that was apparently covered with reefs. In the mountains of northern Greenland and on Ellesmere Island, their remains can still be seen today over a length of 800 kilometres. Palaeotectonic models also indicate that the continents of North America and Baltica drifted towards each other on their journey northwards. This convergence is clearly visible in the mountains that were formed during the Caledonian Orogeny in Scandinavia, on the British Isles, on the east coast of Greenland and in Spitsbergen.

During the Devonian, the once isolated cratons of North America and Baltica were united in the „Old Red" continent, which remained at equatorial latitudes. Spitsbergen had risen above the water surface again and was part of a vast desert. The fossil imprints of a rainstorm that fell on the area of the present-day Woodfjord on the north coast of the island of Spitsbergen 400 million years ago still bear witness to this today. Fossilised mud cracks also bear witness to muddy layers of drying waters. The first forests appeared during the Late Devonian. By a lucky coincidence, individual trees in central Spitsbergen were preserved in their upright living position. It remained tropical during the Carboniferous Period that followed, which, on Spitsbergen as in many other parts of the world (including Germany), produced lush forests that provided the basis for thick coal seams.

During the Late Carboniferous, Spitsbergen, along with large areas of the present-day Arctic, was flooded by a shallow sea; in the meantime, we had arrived in the subtropical climate belt of the Northern Hemisphere. The corresponding layers show a diverse, colourful and rich living world with corals, mussels, brachiopods, sea urchins, fish, squid and other living organisms. With the Permian and the formation of the supercontinent of Pangaea, Spitsbergen, along with northern Greenland and the Canadian Arctic, had reached the mid-latitudes of the Northern Hemisphere. Its shallow seas became cooler and were populated by marine reptiles during the Triassic and Jurassic. The archipelago did not rise above the surface of the water to form islands again until the beginning of the Cretaceous. Located in the central part of the ancient continent of Laurasia, it had a mild climate and dense forests, although it had already reached its present northern latitude. Footprints of herbivorous dinosaurs and remains of carnivorous dinosaurs attest to a diverse fauna. Unlike the dinosaurs, the dense forests survived the transition to the Cenozoic. The climate also remained very warm despite the fact that it was now close to the poles. The rupture of the North Atlantic and the formation of the Arctic Ocean separated the connection between the American continental plate and Spitsbergen. The archipelago moved southeast together with the Eurasian continent by the formation of the Fram Strait. Two million years ago, the temperate climate also ended, beginning another glaciation phase in Spitsbergen's history.

5 THE NATIONAL POLAR SAMPLE ARCHIVE: THE MATERIAL BASIS OF POLAR RESEARCH

In Berlin, the BGR operates the National Polar Sample Archive, where rock samples from the German research community in the Arctic and Antarctic are collected, catalogued and made available for further research.

The administrative building of the former train barracks in Berlin's Spandau district presents a representative front to Wilhelmstrasse. It is one of the few buildings of the complex, formerly built in magnificent Gothic brick, that has survived from the 19th to the 21st century. After its military use came to an end, civilian users moved in during the 1990s. One of them is the BGR, which maintains its Berlin branch in Wilhelmstrasse. At the request of the National SCAR-IASC Committee, the **NA**tional **P**olar Sample **A**rchive (NAPA) was set up here in 2005. Rock samples collected from the Arctic and Antarctic by German polar researchers are housed here and recorded in digital catalogues. The archive moved into the garages in the courtyard behind the Gothic brick building on Wilhelmstrasse, which had housed British battle tanks until 1994.

View into the rock cabinets of the NAPA with samples from the Geological Expedition to the Shackleton Range (GEISHA).

There, neatly catalogued rock samples from over 40 years of German polar research are now stored, the oldest from the first expedition of the GANOVEX programme in 1979/80. Rock samples from the polar regions are particularly valuable, because they are obtained from very remote areas, with great logistical effort and considerable financial expense. NAPA was founded to store samples obtained by scientists from universities and other research institutions over a long period of time, as storage space is often very limited, particularly at universities. Both regions are represented with numerous samples. Kamchatka, the Siberian Arctic, Spitsbergen, Greenland and the Canadian-Arctic Archipelago account for part of the samples. However, there is also an extensive inventory from the Antarctic northern Victoria Land, the Shackleton Range and Dronning Maud Land.

The spectrum is likely to broaden over time, as the archive is designed and founded for the very purpose of taking in sample collections from universities and other research institutions when they can no longer hold them. The fears in the German polar research community regarding a loss of valuable and expensively acquired sample material were so great, that the „Geology and Geophysics of the Polar Regions“ working group in the German Society for Polar Research (DGP) formulated a request to this effect, which was brought to the BGR by the German National SCAR-IASC Committee. NAPA takes over the sample collections and archives them. All of the sample metadata are recorded in a database, and the samples are photographed and can be looked up online in geoinformation systems.

To date, the archive comprises close to 10,000 samples in around 50 collection cabinets, ranging from kilogram-sized chunks of crystalline rock that give an impression of the forces to which the rocks have been subjected during the course of the Earth's history, to small samples like mineral separates whose true origin is no longer visible but have been prepared for analysis. The archive also contains some fossilised wood, which clearly shows that the polar regions also knew climate zones other than the present ones. As an absolute minimum for documentation, the BGR requires as exact an indication of origin as possible and, of course, a label on the sample that clearly links it to the documentation. Often, however, the information is much more detailed.

Within the framework of the BGR's joint collection database, „GewiS“, the rock samples are entered into a searchable online database and can be borrowed. The archive is not a museum collection, so the archival materials are explicitly available for further research. The idea is that the valuable samples should be comprehensively available to science and contribute to as many findings as possible. In this way, researchers who cannot get to the desired area to collect rock samples will also have the opportunity to analyse material from the working area. In order to be able to take in more sample material in the coming years, the archive in Berlin is constantly being adapted to meet the demands.

TREASURES FROM PAST POLAR EXPEDITIONS ARE MADE AVAILABLE FOR FUTURE KNOWLEDGE.

6 LOGISTICS

6.1 INDISPENSABLE BASIS FOR POLAR RESEARCH

Harsh conditions and poor access to the working areas pose immense logistical challenges for expeditions to the polar regions. BGR scientists and their guests from other polar research institutions benefit from well-established procedures and contacts that the Polar Geology logistics has built up over decades.

A wide valley, framed by steeply sloping mountain ranges, snow-covered at best, but with virtually no vegetation. On the grey valley floor, however, the summer sun has brought out countless pink flowers. A flagpole with the flags of the eight participating nations, a good two dozen yellow-orange single-person tents, a handful of larger tents, red and white fuel drums and storage and waste containers. Across a small river, a makeshift airstrip marked with red boxes. For two months during the summer of 2017, this was home to 30 members of the CASE 19 expedition.

The largest research trip of the terrestrial BGR Arctic programme to date led to the north of Ellesmere Island between Kulutingwak Fiord and Yelverton Inlet, just under 900 kilometres from the North Pole. This was right in the middle of the intricate evolutionary history of the Arctic Ocean, which has been at the centre of the CASE programme since the beginning.

CASE 19 was one of the BGR's most logistically complex land expeditions in the northern polar region. Tents, instruments, material and provisions for 30 participants and some guests, and last but not least, fuel for planes and helicopters, had to be flown over some 950 kilometres from the northernmost regular airport at Resolute Bay on Cornwallis Island. This was done in two stages, because the larger Basler BT-67 transport planes could not land at Yelverton Inlet. On an airstrip at Tanquary Fiord in Quttinirpaaq National Park, they switched to smaller Twin Otter planes, which covered the remaining 110 kilometres to the base camp over the snow-covered mountains of North Ellesmere Island.

This amount of effort is common in the North American Arctic, Greenland and Siberia. Human settlements there are located far away from the geologically interesting areas. In Antarctica, the effort required is even greater, because the continent is even less developed, but the BGR has its own summer base there, the Gondwana Station. A logistician in the BGR's Polar Geology Unit is therefore responsible for organising the expeditions. Expeditions to the Arctic require at least a year of preparation, while those to Antarctica usually have a lead time of around two years.

Because the BGR does not have its own ships, planes or helicopters in the polar regions that it could use for its expeditions on land and occasionally on water, these are chartered locally. Expeditions to the working areas are usually not possible without air support, because the distances are enormous, and land transport through undeveloped areas is impossible.

For other equipment, too, logistics is increasingly relying on local service providers who rent material for the expedition season. Although the BGR keeps equipment stocked in Hanover, support from local providers is becoming increasingly important. This not only frees the budget from transport and storage costs, but also ensures good contacts in the partner countries. However, such connections are an indispensable part of the cooperation with which the BGR conducts its polar research. The partnerships with the research programmes and institutes of other countries in Antarctica or with the specialist authorities in the Arctic states, some of which have been tried and tested for many years, allow resources to be pooled, for example, by coordinating research trips and sharing transport capacities. The Federal Institute has earned a reputation as a reliable contractual partner at both poles. The networks then also help to solve unavoidable logistical problems that regularly arise on site. A solution is often found quickly and without bureaucratic hurdles in a direct exchange between long-standing partners.

The benefits of the logistical support are not limited to the BGR researchers. As a departmental research institution under the auspices of the Federal Ministry for Economic Affairs and Energy, the BGR is also tasked with paving the way for access to the polar regions, especially for German universities and institutions without own logistics. Many stakeholders in the German polar research community use the assistance of institutional stakeholders such as the BGR, because financing and organising their own expedition is often very costly for them. To achieve the research goals of its expeditions, the BGR supplements its geoscientific methods, if necessary, by inviting external scientists from Germany and abroad. This is often the only way to tackle the complex issues in the Arctic and Antarctic. From an easily accessible starting point, BGR logistics takes care of onward transport and the organisation of work and accommodation on site.

Base camp of the CASE 19 expedition at Yelverton Inlet on the north coast of Ellesmere Island at 82° latitude north.

The fuel depot of the CASE 19 expedition and a starting Basler-BT 67 at the entrance of the Quttinirpaaq National Park in Tanquary Fiord, north of Ellesmere Island.

LOGISTICS FACES SPECIAL CHALLENGES IN THE POLAR REGIONS.

6.2 LOGISTICS IN ANTARCTICA: A RESEARCH STATION WITH A SMALL ECOLOGICAL FOOTPRINT

Historically, the focus of BGR Antarctic research was and still is in the Victoria Land of the Ross Sea sector. The Gondwana Station there is the logistical starting point for the expeditions of the GANOVEX programme. This programme is being conducted in cooperation with other national Antarctic programmes.

In the area of the Ross Sea facing the Pacific Ocean, BGR logistics relies on its own Gondwana Station at Gerlache Inlet in Terra Nova Bay, which has been available as a summer station since 1983. The Gondwana Station is the starting point for most expeditions into Victoria Land and the neighbouring areas. Close cooperation exists, above all, with the Italian National Antarctic Programme PNRA, whose Mario Zucchelli Station is located on the opposite side of the bay, as well as with the Korea Polar Research Institute (KOPRI), which operates the directly neighbouring Jang Bogo Station all year round. This means that the BGR can often use the supply runs of these Antarctic programmes for its own logistics. German scientists have also used aircraft, operated by Italy, which can still use the ice runway on Terra Nova Bay at the beginning of the Antarctic summer.

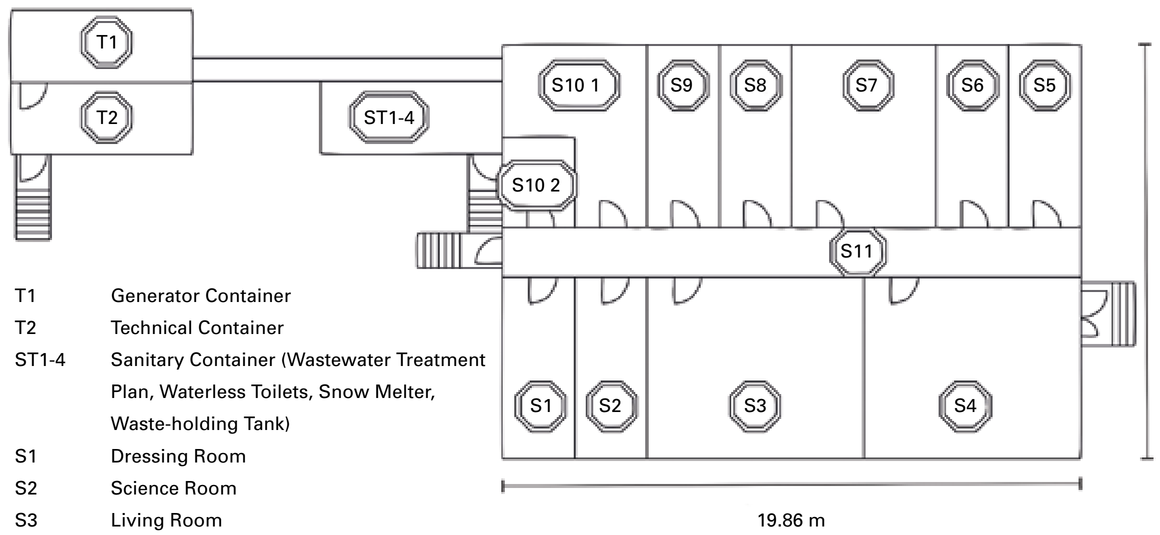
The BGR charters the required ships, helicopters or aircraft on its own or participates in the chartering of these vehicles. The necessary off-road polar equipment, such as snowmobiles (skidoos), Nansen sledges, and tents for accommodation, kitchen and work, as well as radio equipment are mostly kept in stock but otherwise rented at the Antarctic entry gates. In its second focal point of activity in Dronning Maud Land on the opposite side of Antarctica, the BGR also relies on intensive cooperation with other partners from Germany and abroad. First and foremost is the Alfred Wegener Institute, which operates the German Neumayer Station III there. There are also good contacts with the Belgian Antarctic Programme, which operates the Princess Elisabeth Station at the foot of the Sør Rondane Mountains in Dronning Maud Land.

Gondwana Station

Since Germany began its Antarctic research, northern Victoria Land and the adjacent areas have been the focus of BGR studies. The Gondwana Station was therefore set up as early as 1983 during the GANOVEX III expedition at Terra Nova Bay in the form of a bivouac hut. It was the first research station to be built at Terra Nova Bay. In the Antarctic summer of 1988/89, the hut was converted into a containerised summer station. Situated on the ice-free Cape Möbius 20 metres above Terra Nova Bay, the station offers repair, recreation and work rooms, a kitchen and sanitary facilities. Today, people sleep in tents on the few flat sites around the station just as they did 40 years ago. There is space for up to 30 scientists in total.

THE BGR HAS A LOGISTICAL BASE IN VICTORIA LAND AND RELIES ON COOPERATION.

Front view and floor plan of the Gondwana Station.



T1	Generator Container
T2	Technical Container
ST1-4	Sanitary Container (Wastewater Treatment Plan, Waterless Toilets, Snow Melter, Waste-holding Tank)
S1	Dressing Room
S2	Science Room
S3	Living Room
S4	Storage and Working Room
S5	Station Manager / Radio Room
S6	Science Room (Multi-use)
S7	Dining Hall
S8	Kitchen
S9	Food Storage
S10 1	Shower, Washing and Laundry Room
S10 2	Water Technology Room
S11	Main Hallway

Between 2015 and 2017, the station was modernised at great expense and brought up to the latest environmental standards. In addition to a fundamental renovation of the almost 30-year-old station building, the focus was on overhauling the energy and drinking water supply and the wastewater treatment system. Gondwana Station is now among those Antarctic research stations that have a very small ecological footprint. The modernised station is thus available for the BGR's use for at least another 25 years.

An additional technical building was constructed for the newly installed systems. A 6.7-kilowatt photovoltaic system and two redundant 35 kW generators provide the energy supply. Four battery blocks can store a total of 38.4 kilowatt hours of electricity. During the Antarctic high summer in December and January, 60 per cent of the station's power can be supplied by solar energy. The waste heat from the technical systems is used to heat the station. In addition, heat is also extracted from the station's ambient air by air collectors.

These sources can cover a good 40 per cent of the heating needs, with electric heating panels and a solid fuel stove providing the rest. An intelligent energy management system ensures the optimal configuration.

The fresh water is primarily obtained with a snow melter and a seawater desalination plant and is disinfected by means of UV filters. The wastewater is treated with biological drip filter systems and the installation of dry toilets with solids separation reduces the station's water demand to a minimum.

Lillie Marleen Hut

The first accommodation facility for Federal German Antarctic research was the Lillie Marleen Hut in a hollow of Mount Dockery, which is located at the Lillie Glacier in the Everett Range in northern Victoria Land. It was built in January 1980 during the GANOVEX I expedition as a base for geoscientific investigations in the Transantarctic Mountains. It is a bivouac hut insulated against the cold and made of fibreglass material. The hut has been included in the list of „Historic Sites and Monuments in Antarctica“ since the XXVIII Antarctic Treaty Consultative Meeting (ATCM) in Stockholm in 2005. Part of the monument is the memorial stone commemorating the sinking of the supply vessel „Gotland II“ in the Antarctic summer of 1981/82.

Lillie Marleen Hut on Mount Dockery in the Everett Range of the Transantarctic Mountains.

6.3 LOGISTICS IN THE ARCTIC: STRONG PARTNERS FOR RESEARCH UNDER CHALLENGING CIRCUMSTANCES

Research in the Arctic always takes place under the conditions and according to the rules of the states on whose territory the scientists are visiting. This makes things easier in terms of logistics, because there are usually local contacts who facilitate the organisation.

Apart from the logistical aspects, another special challenge of organising Arctic expeditions involves the bureaucratic and administrative arrangements. As the BGR is always the guest of a state when performing its field activities, it is required to submit numerous applications to the authorities of the respective host country in order to obtain the permits for conducting our planned field activities. The subjects of the applications include environmental protection, avoiding the disturbance of animals, storage of fuel, use of water and the involvement of the local indigenous population and settlements.

Except for the glacier-covered areas of Greenland, Spitsbergen, Ellesmere Island and Alaska, the vast tundra and mountain regions of the Arctic are largely ice-free, unlike Antarctica. Therefore, in order to conduct expeditions, it is necessary to set up a logistics chain that must cover two important points: the transport of equipment and personnel from the northernmost regional airfield to the expedition area up to 900 km further north and back, and the construction of a base camp where the expedition participants can live and work largely self-sufficiently for up to eight weeks. In order to cope with work in an

Aerial photograph of the CASE 19 base camp with kitchen, lounge tent, sleeping tents and helicopter landing area.

area of up to 500 km^2 around the base camp, helicopters are stationed at the base camp; this considerably increases the logistical effort due to the additional provision of fuel. At the end of the expedition, all the equipment must be cleaned up and flown back. Ideally, there should be no visible remains of a base camp after the completion of the field work.

Under these circumstances, organising the logistics for a stay of several weeks for a group of between ten and thirty people with the appropriate equipment and aircraft is a challenge, particularly when this must be done from Hanover, which is several thousand kilometres away. One of the partners who have proven helpful in such cases is the Polar Continental Shelf Programme (PCSP) in Canada. This agency supports all visitors to Canada's far north, if they come on a scientific or governmental mission. It does not matter whether they are Canadian or foreign researchers. Assistance ranges from the provision of aircraft or helicopters to the rental of necessary equipment, to communication links from expedition camps via radio or satellite. The programme even provides a laboratory with basic facilities for the cryopreservation of samples at its Resolute Bay logistics base.

Disembarkment of geologists in a rubber boat at Crozierpynten, Lomfjorden, Spitsbergen.

Since the BGR first visited Ellesmere Island in 1998 as part of the CASE programme, it has been a regular customer of the Canadian logistics service provider. The contacts between the Polar Geology Unit in Hanover and the on-site partners in Resolute Bay are close and built on trust, to the extent that the PCSP staff sometimes take over the preliminary reconnaissance for a BGR expedition and look for suitable landing sites for aircraft or helicopters.

In other Arctic regions as well, the BGR works closely with the respective national partners to obtain permits and additional support for expeditions and to facilitate the conduct of the field work. In addition to the Geological Survey of Canada (GSC) and the Yukon Geological Survey (YGS) for the Canadian Arctic including Banks Island and the Yukon North Slope, these partners include the Geological Survey of Denmark and Greenland (GEUS) as well as the Villum Research Station of Aarhus University for North Greenland, the Norwegian Polar Institute (NPI), and the University Centre of Svalbard (UNIS) for Spitsbergen. For the sites located in the Russian Arctic, the BGR cooperates intensively with the Russian Geological Research Institute (VSEGEI) in St. Petersburg, which, in addition to organising the expeditions to Siberia (e.g. ship charters), has above all, taken on the work of submitting complicated and extensive applications for permits to enter partially restricted areas.

Starting helicopter, flagpole and tent in the base camp of the CASE 19 expedition.

Geologists disembarking with a barge from the Russian supply icebreaker „Michail Somov“ on the east coast of Bennett Island (New Siberian Islands) during the CASE 13 expedition.

Such „outsourcing“ of logistics via cooperation with the competent local authorities is obvious for terrestrial geology in the Arctic, as the mainland is always under the jurisdiction of one of five Arctic states anyway. For the logistics of the BGR‘s Polar Geology Unit, a strong, experienced local partner also makes the work much easier. This is the principal reason why the planning time for an Arctic expedition is only half as long as that for a research trip to Antarctica. The logistics institutions active on the ground have local knowledge from which the researchers from abroad can benefit. They also know the local regulations very well, because depending on the host country, the regulations for the protection of the sensitive Arctic environment are highly extensive.

Local partners also usually have the best contacts in the local community. Relying on local support wherever possible and using local sources for procurement is also a maxim of logistics in the Arctic. This means that material bought or rented locally does not have to be transported between continents and back again at the end of the expedition. This is easy on the budget and the environment. At the same time, the scientists in the mostly very small local Arctic communities are a significant economic factor, so it is a win-win situation for everyone.

Exchange of scientists and equipment on the „airfield“ of the CASE 19 expedition with the base camp in the background.

IN THE ARCTIC, BGR LOGISTICS CAN RELY ON COOPERATION PARTNERS WITH EXTENSIVE EXPERIENCE.

THE BGR IS AN ESTABLISHED PARTNER IN INTERNATIONAL POLAR RESEARCH.

7 LINKED UP AT HOME AND ABROAD

The BGR is one of several German scientific institutions with extensive research programmes and efficient logistics in the polar regions. It can offer its cooperation partners at home and abroad comprehensive cooperation.

Polar research is large-scale, interdisciplinary, organisationally demanding and financially costly. The BGR therefore consciously relies on cooperation with scientists from universities and research institutions in Germany and abroad for its programmes in the polar regions. This cooperation has developed fruitfully since its beginnings more than 40 years ago and has led to a dense network of contacts in the national and international scientific community. The Federal Foreign Office and the German embassies also play an important role by supporting our work in the polar regions in many ways through their contacts.

The German polar research community is diverse and strong in research. In addition to the BGR, AWI and DLR, which have a presence at both poles with large-scale programmes, there are numerous scientists at universities and non-university institutions who make valuable contributions. In particular, the German Research Foundation (DFG) supports university scientists in the Arctic and Antarctic with the „Infrastructure – Antarctic Research with Comparative Studies in Arctic Ice Regions“ Special Priority Programme (SPP 1158). The „Geology and Geophysics of the Polar Regions“ working group in the German Society for Polar Research (DGP) meets regularly and has been acting as an informal planning and information forum for years.

Many of the terrestrial geology projects and schemes carried out within this framework rely on BGR logistics. This supports access to geologically attractive but difficult-to-reach field sites and participation in thematically challenging research programmes that are highly regarded in the international community.

At the same time, this cooperation also results in a transfer of knowledge to the BGR. In return, participants invited to the expeditions make important contributions to the topics tackled in the BGR programmes on the basis of their expertise. An important aspect of this cooperation is the promotion of young scientists. Master’s and doctoral students are given intensive insight into practical geoscientific work in the polar regions, and contact with the next generation of polar researchers is promoted.

A Twin Otter taking-off on the Antarctic plateau during AGAP, one of the flagship projects of the International Polar Year 2007 to 2009.

International cooperation in the two polar regions differs greatly. The landmasses surrounding the Arctic Ocean are divided into the territories of five states; therefore, scientific work there is based on functioning cooperation with the corresponding national institutions. The BGR maintains good relations with all countries bordering the Arctic Ocean, which has made research in all these countries possible. Cooperation with Canada is particularly intensive. A framework agreement concluded between the geological services of both countries in 2015 at the German embassy in Ottawa places a focus on the research work in the Canadian Arctic. In addition to basic geoscientific research on the development of the Arctic Ocean, the formation of sedimentary basins in which oil and natural gas deposits are suspected is also being studied. The upcoming investigations will assess the resource potential. In addition, there is work on researching climate changes in the geological past, which can also be incorporated into models of present and future climate change.

In Antarctica, international cooperation based on the Antarctic Treaty between countries and institutions is extremely fruitful. The BGR works particularly intensively with the Italian National Antarctic Research Programme PNRA, which operates a station in northern Victoria Land in the immediate vicinity of the Gondwana Station. Italy has been the most important scientific and logistical partner for many expeditions of the GANOVEX programme. The BGR has also participated in international scientific drilling campaigns, and additional drillings are about to be implemented or are in the planning stage.

The BGR has initiated cooperation programmes to pool geoscientific research efforts, such as LIRA (Lithospheric Investigation in the Ross Sea Area) with countries active in the Ross Sea sector (besides Germany, the USA, Italy and New Zealand). The goals of this cooperation are joint research planning and coordination as well as the exchange of information. To this end, workshops and other working meetings have been and are being held.

8 GLOSSAR

ACRUP	Antarctic Crustal Profile
ACRUP	Antarctic Crustal Profile
AGAP	Antarctica's Gamburtsev Province
ANDRILL	Antarctic Drilling Project
ASAP	Aeromagnetic Surveys for the ANDRILL Programme
ATCM	Antarctic Treaty Consultative Meeting
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (= Federal Institute for Geosciences and Natural Resources)
CASE	Circum-Arctic Structural Events
CCAS	Convention for the Conservation of Antarctic Seals
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
DFG	Deutsche Forschungsgemeinschaft (= German Research Foundation)
DGP	Deutsche Gesellschaft für Polarforschung (= German Society of Polar Research)
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (= German Aerospace Center)
DDR	Deutsche Demokratische Republik (= German Democratic Republic)
ETM	Eocene Thermal Maximum
EUROSHACK	European Expedition to the Shackleton Range
GANOVEX	German Antarctic North Victoria Land Expedition
GEISHA	Geologische Expedition in die Shackleton Range (=Geological Expedition to the Shackleton Range)
GEA	Geodynamic Evolution of East Antarctica
GeoMAUD	Geoscientific Expedition to Dronning Maud Land
GEUS	De Nationale Geologiske Undersøgelser for Danmark og Grønland (= Geological Survey of Denmark and Greenland)
GewiS	Geowissenschaftliche Sammlungen (= Geoscientific Collection)
GIGAMAP	German-Italian Geological Antarctic Map Program
GITARA	German-Italian Aeromagnetic Research in Antarctica
GSC	Geological Survey of Canada
IASC	International Arctic Science Committee
KOPRI	Korea Polar Research Institute
LIRA	Lithospheric Investigations in the Ross Sea Area
NAPA	Nationales Polarprobenarchiv (= National Polar Sample Repository)
NARES STRAIT	"Nares Strait" Arctic Expeditions
NOGRAM	Northern Greenland Gravity and Aeromagnetics
NPI	Norsk Polarinstitutt (= Norwegian Polar Institute)
PCMEGA	Prince Charles Mountains Expedition of Germany and Australia
PCSP	Polar Continental Shelf Program
PEPAT	Protocol on Environmental Protection to the Antarctic Treaty
PETM	Paleocene-Eocene Thermal Maximum
PMAP	Polar Margins Aeromagnetic Program
PNRA	Programma Nazionale di Ricerche in Antartide (= National Antarctic Research Program)
PURE	Polar Urals Expedition
REVEAL/CTAM	Remote Views and Exploration of Antarctic Lithosphere / Central Transantarctic Mountains
SCAR	Scientific Committee on Antarctic Research
SPE´91	Geowissenschaftliche Spitzbergen Expedition 1991 (= Geoscientific Spitsbergen Expedition 1991)
SPP	Schwerpunktprogramm (= Priority Programme)
Sub-EIS-Obs	Sub-Ekström Ice Shelf-Observations
SWAIS-2C	Sensitivity of the West Antarctic Ice Sheet to 2 Degrees Celsius
TAMARA	Transantarctic Mountains Aerogeophysical Research Activities
TeMAr	Tectonic Map of the Arctic
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNIS	The University Centre in Svalbard
USA	United States of America
VSEGEI	A. P. Karpinsky Russian Geological Research Institute
YGS	Yukon Geological Survey

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Cover photograph
View from Helm Point at Edisto Inlet to Mt. Herschel in the Transantarctic Mountains of northern Victoria Land.

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