Knowledge about our resources

ANNUAL REPORT 2016
GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF ENERGY, UTILITIES AND CLIMATE

GEUS

New senior management and organisational change

During the year, the Geological Survey of Denmark and Greenland (GEUS) welcomed a new management team. In April, Flemming Larsen took up his position as Director General, and later it was announced that Flemming Getreuer Christiansen would take up position as Deputy Director General and Anne Merete Koefoed as Administration Manager, in early 2017.

Moreover, 2016 saw minor changes to the organisation. Administrative and service functions were gathered into four units: (1) Management Secretariat, (2) Finances, Legal Affairs and HR, (3) Press and Communications and (4) Logistics and Infrastructure. The IT department was transferred to a new department: Data and IT, and a new Marine Geology department was established in Aarhus at the Aarhus University campus, together with the existing Groundwater and Quaternary Geological Mapping department. Finally, employees from ice and climate were merged into a new Glaciology and Climate department.

In late 2016, the Minister for Energy, Utilities and Climate, Lars Christian Lilleholt, appointed a new Board of Directors for GEUS. Professor Minik Rosing was re-appointed as Chairman of the Board. On the occasion of his appointment, the Minister said: "GEUS plays a pivotal role as a consultancy and research institution for our geological knowledge about Denmark as well as Greenland. I'm extremely pleased that the new Board of Directors, with Minik Rosing as Chairman, will enable us to ensure that GEUS can continue its important work."

New Management

Flemming Larsen, Director General

Flemming Larsen has a master's degree in geology and a PhD. He began his career at GEUS in 1986 but left two years later. From 1988 to 2007, he worked in the consultancy sector as well as at the Technical University of Denmark (DTU). In 2007, he returned to GEUS. From 2012 and up to this appointment, Flemming Larsen worked as head of department of geochemistry at GEUS.

Flemming Getreuer Christiansen, Deputy Director General

Flemming Getreuer Christiansen has a master's degree in geology and a PhD. In 1984, he began his career at GEUS, where he has been Deputy Director General since 2008 and responsible for coordinating work within energy resources and mineral resources. From 1992 to 2008, he worked as head of the oil-geological department in the then Geological Survey of Greenland (GGU), and later he became head of the department of stratigraphy at GEUS.

Anne Merete Koefoed, Administration Manager

Anne Merete Koefoed is a qualified lawyer. She has been employed at GEUS since 2007 and came to GEUS from a position as a human resource manager at the trade union HK/Danmark. Before that, she worked as a human resource manager for the Danish Business Authority and as the deputy head of the personnel and organisation department at the Ministry of the Environment.

Foreword

Implementation of the GEUS strategy 2016, which is running over 8 years, was begun in 2016 and we are off to a good start. Significant results have been achieved within all the defined strategic themes.

Within the area of *digital data and knowledge services*, GEUS is focusing on making digital geological data available and more user-friendly for professional users and the public. In Denmark, this development of services targeted at user needs for compiling basic data is done within the framework of the Danish Natural Environmental Portal. Under the auspices of EuroGeoSurveys (EGS) and with GEUS as one of the leading institutions, the work was performed through the launch of the European Geological Data Infrastructure portal (EGDI) in the spring of 2016. The EGDI portal makes it possible to store and present pan-European data on geological mineral resources.

GEUS has contributed to the completion of groundwater surveying in Denmark, which mapped 40% of the country's land area with special drinking water interests. We have contributed with systematic storage of data for posterity, as well as knowledge on the occurrence of groundwater in the deep Miocene deposits in Jutland.

In the geological world, the green transition of the energy sector means development of *geothermal energy and underground storage*. In spring 2016, GEUS launched the Dyb Geotermi WebGis portal which makes it possible for public authorities and stakeholders in the geothermal sector to access knowledge about the potential exploitation of warm, deep-lying water in the subsurface for heating.

Under the strategic topic titled *oil and gas as the foundation for supply and conversion*, GEUS assisted the Government of Greenland's Ministry of Mineral Resources (MMR) in 2016 with the major project of preparing material on the extraction of oil and gas in the onshore areas around Disko and Nuussuaq in West Greenland.

Knowledge about *minerals – basic and critical resources* is a cornerstone of GEUS' collaboration with the MMR. As part of the targeted marketing of Greenland's mineral resources, GEUS carried out geological mapping in the field in 2016, and the results have been presented in publications and at industry conferences. As a special initiative and under the Center for Minerals and Materials (MiMa), GEUS prepared an account of Danish mineral resources and the needs of the industrial sector. The aim of this was to evaluate the security of supply in the future.

Since 2007, the PROMICE project has carried out systematic monitoring of the ice melt of the Greenland ice sheet. Monitoring is performed by 25 fully automatic monitoring stations, and data are sent via satellite to GEUS in Copenhagen. The reported ice melt of the Greenland ice sheet in 2016 was the largest since 2012, when the largest ice melt was reported in the now ten-year-long monitoring programme. Data from PROMICE are part of a joint EU project (INTAROS) to establish improved monitoring of climate conditions in the Arctic area.

In 2016, GEUS and a number of other European organisations in the EGS began a collaboration with 54 African nations on the sustainable exploitation of their mineral resources. The project will run for the next four years, and will focus on capacity building in the participating countries.

Due to increasing media interest in GEUS' activities, a Press and Communications unit was established in 2016 headed by an experienced journalist.

The Annual Report 2016 presents a small selection of the almost 700 projects which are carried out annually by GEUS. Key figures for the year are included at the end of this report and show a slight decrease in revenues, primarily due to a downturn in the energy sector. In 2016, just as in 2015, GEUS had to carry out minor adjustments in staff and operations. This had the intended effect as the annual financial result was satisfactory. In the coming years, it is expected that sufficient revenues will be generated to maintain the current professional capacity.

Minik Rosing
Chairman of the Board

Flemming Larsen
Director General

Databanks

Storage, quality assurance and presentation of geological knowledge and data

European data worth billions now accessible

In June, EuroGeoSurveys (EGS), of which GEUS is part, launched the first version of a joint European infrastructure for geological data with an associated portal: European Geological Data Infrastructure (EGDI). The database provides information about geology and resources across borders throughout Europe. Just like the rest of the world, European society increasingly needs access to data about nature, the environment and mineral resources across national borders in order to manage the resources in the best possible way. Exchange of geodata and environmental data has high priority in the EU.

The EGDI portal provides access to geological data and services from a large number of European research projects, which have gathered and harmonised various types of geological data. These include geological data and mineral resources data from the OneGeologyEurope EGS project and the EU project: Minerals4EU. The core of the EGDI is a central database that stores common European data, and using the portal, data can be found on a number of topics such as minerals, energy, soil, groundwater or marine geology. Moreover, the EGDI also contains a metadatabase with information about a multitude of common European, regional and national sets of geodata.

The EGDI provides the framework for the results of many previous, ongoing and future EU geodata projects, and it will ensure that data are not lost. Much has been invested in geoscientific projects, after which data have not been easily accessible. However, the launch of the EGDI will remedy this. The development of the EGDI is at the hub of the EuroGeoSurvey strategy to establish a European Geological Service to support EU strategies and policies within areas relying on geological data and information, such as mineral resources, energy and water supply as well as environmental and natural disasters.

Gathering knowledge about mineral resources for European decision makers

Growth and development in Europe rely on a sufficient and sustainable supply of mineral resources. This calls for knowledge about needs for mineral resources and their accessibility, as well as legislation to support the needs of European society in the mineral-resources area. The MICA (Mineral Intelligence Capacity Analysis) EU project headed by GEUS is working on identifying the needs of European stakeholders for knowledge related to mineral resources and on developing tools to gain easy access to the required knowledge. This is knowledge about primary mineral resources to be mined or excavated, and secondary mineral resources from reusing materials. The goal is to provide consultants and decision makers both at EU level and national level as well as stakeholders from industry and the research community with a tool to get easy access to knowledge, for example about the demand for copper and accessibility to the metal in Europe, and the measures necessary to ensure sufficient and sustainable supply. In February, GEUS hosted the project start-up meeting, and during the year, GEUS has worked on developing a common project database with associated web interfaces for the various tools in the project. The MICA project is a partnership between a large number of European research institutions, universities and geological surveys and is funded by the EU Research and Innovation programme, Horizon 2020.

Increasing use of GEUS map and data services

The Jupiter database, run by GEUS, is a common database with nationwide information on wells, groundwater and drinking water. The database contains information from more than 295 000 boreholes and it has been incorporated in the Danish Natural Environment Portal with other nationwide Danish databases containing nature and environment information. The database is used every day by employees in municipalities, regions, agencies and companies working on the groundwater, the environment and mineral resources. During the year, electronic reporting by waterworks of the status of use of drinking water boreholes for the Jupiter database was simplified and made more user-friendly.

GEUS has developed so-called WMS and WFS services for the Jupiter database and other national databases run by the institution so that users can view directly on their own IT systems different themes compiled from the geographic information system, GIS. For example, there is information on wells, availability of geophysical data, or the presence of various chemical substances in the groundwater. The services are very popular, and the number of searches with WMS map services on the GEUS website increased from 1.3 million in 2014 to 4.6 million in 2016. Most of this data extraction is for information on wells, water utilities and water extraction sites from Jupiter, but many users have also searched in GERDA, the geophysical database, and in MARTA, the marine mineral resources database, to find information about where geophysical measurements have been made and what type of data has been collected.

Groundwater mapping completed

At the end of 2015, groundwater mapping in areas with special drinking water interests (OSD) was completed by the Danish Nature Agency – now the Danish Environmental Protection Agency (EPA) – after 17 years' work. A total of 40% of Denmark's subsurface is included in the mapping. These are areas in which drinking water is currently being abstracted or in which there is a desire to protect the groundwater, so that we can continue to abstract clean drinking water in the future.

As a specialist data centre, over the years GEUS has assisted the Danish EPA with coordination and consulting services to complete the national groundwater mapping as uniformly as possible. A wealth of data has been harvested, and GEUS has ensured that all data and mapping results have been processed and stored in the nationwide databases for wells and water chemistry, geophysics, reports and geological models, so that data will be accessible to public authorities, consultants and waterworks etc. Part of the work by GEUS has been to examine, describe and document the geological layers from the Miocene epoch and the buried valleys.

Comprehensive geological surveys have shown that large parts of the subsoil in Jutland have thick layers of sand from the Miocene epoch 5–23 million years ago. These layers of sand contain large quantities of high-quality drinking water. They are often found under thick protective layers of clay that prevent pollution from the surface from leaching into the groundwater. GEUS has compiled a good picture of the location of these valuable layers of sand and how they are linked. This knowledge has now been compiled in a spatial model of the geological layers; a so-called 3D model. The model is available in the GEUS digital model database together with other geological models resulting from the groundwater mapping.

The many years of geological surveys by GEUS have also revealed pronounced valleys buried in the subsurface throughout Denmark. The valleys are filled with geological layers containing important groundwater resources. The valleys are deep-lying and therefore well protected against pollution from the surface. However, as the valleys are formed as trenches in the subsurface, they may cause pollution from the surface to penetrate without obstruction down to the deeper-lying layers. So far, 5600 km of buried valleys in the subsurface, distributed over more than 250 locations have been mapped, and the results of the mapping have been made available at: http://begravededale.dk/english_version.htm.

"We've gathered our knowledge about the Miocene strata in a 3D geological model, which shows how the geological layers relate in 3D. And data from the mapping of the buried valleys have been gathered on a website. Both sets of data can be updated when new knowledge is generated, and these are some of the tools made available by GEUS to manage groundwater resources," says Thomas Vangkilde-Pedersen, head of groundwater and quaternary geological mapping at GEUS.

New method of treating drinking water

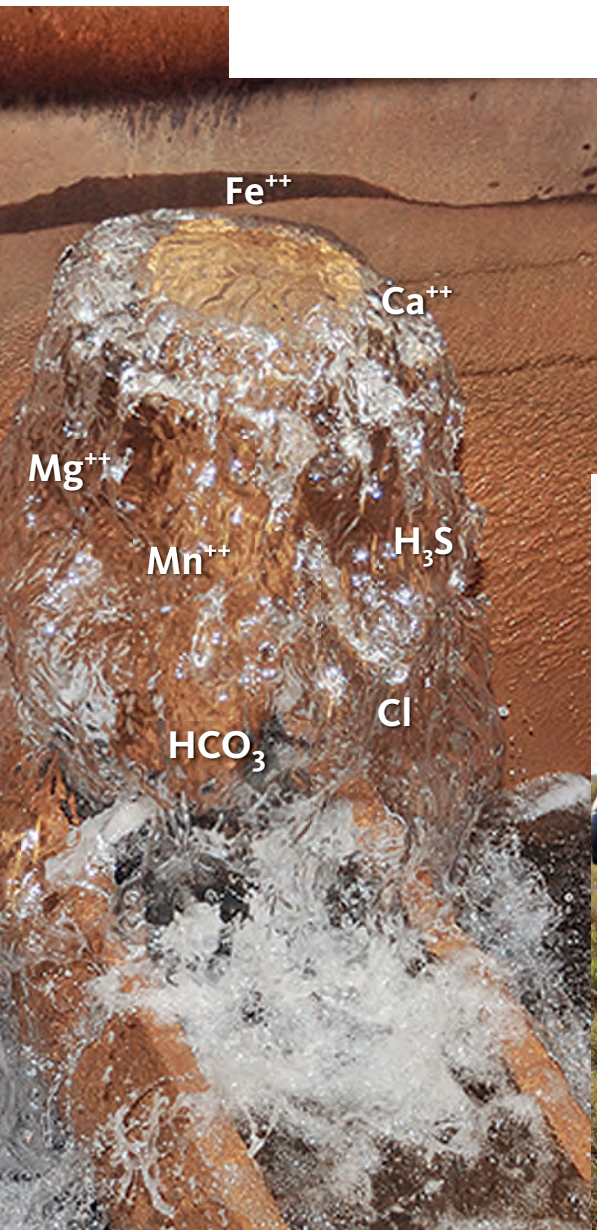
In some places, the groundwater is under threat of contamination from pesticides and chlorinated solvents. Some drinking-water wells have to be closed down because of excessive concentrations of these chemicals. A new research project, headed by GEUS and called MEM2BIO, is underway to develop cost-effective and environmentally sustainable technologies to treat drinking water contaminated by pesticides and chlorinated solvents, without forming undesirable degradation products. Researchers on the project are using advanced membranes and pesticide-degrading bacteria in combination to treat polluted drinking water. The membranes filter the pesticides from the water, and the bacteria then degrade the pesticides into natural, non-toxic substances. The MEM2BIO project is receiving financial support from Innovation Fund Denmark. The project is an inter-disciplinary collaboration between research institutions, enterprises and waterworks, with participation from Aalborg University, Aarhus University and Silhorko-Eurowater A/S, who are supplying equipment for water treatment, Applied Biomimetic A/S, who are supplying the membranes, as well as TREFOR Vand A/S and DIN Forsyning.

Photo: Lasse Gudmundsson, GEUS.

New test field in the Pesticide Leaching Assessment Programme

The Danish Pesticide Leaching Assessment Programme (VAP) is a comprehensive monitoring project to investigate whether approved pesticides leach into young groundwater in concentrations above the limit value. The findings from VAP enable rapid assessment and, if relevant, removal of approved pesticides from the market, if they leach into the groundwater in excessive concentrations. The system was established in 1999 and today it comprises five test fields in ordinary agriculture that are being treated with pesticides in approved dosages. The fields represent the different soil and climate conditions in Denmark. They have been instrumented to monitor pesticides and their degradation products from the surface through the soil column and until they possibly end in drains and groundwater. Two of the fields are on sand deposits near Tylstrup in Nordjylland and near Jyndevad in Sønderjylland, while the three others are on fractured clay deposits near Silstrup and Estrup in Jylland and near Fårdrup on Sjælland. The results from VAP show that there are more pesticide residues in the groundwater under fractured clay soil than under sandy soil. About 40 per cent of the surface of Denmark is covered by fractured clay soil, and VAP will therefore be expanded in 2017 with yet another test field on this type of soil. Establishment of the new field started in summer 2016. The field is situated near Lund on Stevns. In VAP, researchers have investigated 101 pesticides or their degradation products. Many of the pesticides tested have not given rise to changes in the approval, but on the basis of the results of VAP and other projects, the Danish Environmental Protection Agency (EPA) has banned these substances: metribuzin, terbuthylazin, rimsulfuron, metalaxyl-M and bifenox. VAP is a partnership between Aarhus University, GEUS and EPA.

Photo: Lasse Gudmundsson, GEUS



Claim to extend the Greenlandic continental shelf

The United Nations Convention on the Law of the Sea opens for opportunities to claim subsurface and seabed resources outside the 200-nautical-mile limit. Claims have to be documented with data on sea depths and sediment thickness. In August, in New York, a delegation from Greenland and Denmark, including researchers from GEUS, presented Denmark's claim to the continental shelf off the coast of Greenland to the UN Commission on the Limits of the Continental Shelf (CLCS). The claim covers three areas: An approx. 895 000 km^2 area outside 200 nautical miles from the coast of North Greenland in the Arctic Ocean, for which written documentation for the claim was submitted to the CLCS in 2014, an area off North-East Greenland for which a claim was submitted in 2012, and an area off South Greenland for which a claim was submitted in 2012 and 2013. Documentation for the claims was completed by a partnership between GEUS and several institutions from Denmark, the Faroe Islands and Greenland and was based on data from the Danish Continental Shelf Project.

In December 2016, GEUS hosted the 8th workshop on the Arctic Ocean. More than 65 people took part, including scientists and managers from the Continental Shelf Project from the five Arctic countries as well as senior officials from the countries' foreign ministries. Since the first workshop in St. Petersburg in 2007, the focus of these regular events has gradually changed from planning data collection and interpretation to using data and results for claims to the CLCS. The results of previous and current collaborative projects were also presented during the workshop, as well as plans for long-term preparedness-response work and visions for new research.

GEUS' Deputy Director General, Flemming Getreuer Christiansen, said that he was extremely pleased with the good attendance at the workshop, the many excellent presentations and the lively debate: "This reflects the importance of cooperation and it demonstrates the good technical and scientific cooperation between the countries that has prevailed for such a long time. There's every reason to believe that this cooperation will continue for many years to come, probably until all the countries have had their claims processed by the CLCS".

Photo: Energistyrelsen.

Launch of geothermal energy portal

The Danish subsurface contains an enormous green energy resource in geothermal energy, which could help reduce Danish carbon emissions. In the spring, GEUS opened a new website to gather all our knowledge about geothermal energy and present a number of geological maps that are highly relevant for geothermal energy. The website is in Danish and is called Dyb Geotermi WebGIS-portalen. The site provides an overview for stakeholders in the geothermal-energy sector and the authorities of the characteristics of the subsurface, the geological uncertainties, and the density and quality of the geological data in Danish land and coastal areas. The site means that exploration for geothermal energy can concentrate on the most promising areas and thus secure a higher success rate.

The website was presented at two well-attended geothermal-energy seminars in Copenhagen and in Kolding organised by the Danish Energy Agency and GEUS. The Minister for Energy, Utilities and Climate, Lars Chr. Lilleholt, launched the site at the event in Copenhagen with the words: "Given our target to remove all fossil fuels from the energy supply by 2050, an obvious way forward is to exploit the energy lying right beneath our feet. I myself was a strong proponent for having geothermal energy included in the 2012 Energy Agreement, which established a financial pool to promote geothermal energy, among other things, and I'm very pleased that these funds have been invested so successfully. Now there are indications of very exciting prospects for geothermal energy as an important part of the energy supply of the future".

Mapping geological heat storage

The Danish heat and energy sector is currently undergoing an extensive transition to renewables. This entails drastic expansion of plants utilising solar and wind power and, to a certain extent, geothermal energy plants. As wind and solar production does not always follow in line with society's energy needs over the year, it is necessary to store the energy. GEUS is heading a project to chart the possibilities of storing heat in the subsurface and to examine possible technical solutions, risks and investment costs of underground heat-storage systems. Research in recent years has shown that not all geological storage options are equally suitable for storing heat, and in some areas the establishment of underground heat-storage systems could conflict with other uses of the subsurface. Therefore, geologists are screening the subsurface for geological strata that are suitable for heat storage and that are located close to existing district-heating plants and other heat-producing enterprises. The results are also coupled with information about other relevant land uses such as areas with special drinking-water interests. The project is supported by the Energy Technology Development and Demonstration Programme (EUDP) under the Danish Energy Agency and includes collaboration partners VIA University College, Brædstrup Fjernvarme, Planenergi and Aarhus University.

Oil/gas licensing rounds in Greenland

The licensing round for onshore areas at Disko and Nuussuaq in West Greenland was launched at the end of the year. In this connection, GEUS completed two activities for the Ministry of Mineral Resources (MMR) under the Government of Greenland with a view to marketing the area. The activities entailed completion of a GIS compilation of all oil-geological data from research projects and exploration activities to describe the structural development of the Disko–Nuussuaq area. In June–July, GEUS completed a field trip in the area for employees from industry and from the MMR. The Greenland Government has also announced a licensing round for oil and gas exploration in 2017 for the offshore area in Baffin Bay off North-West Greenland and a licensing round in 2018 for offshore areas off South-West Greenland. In preparation for these rounds, GEUS completed a comprehensive mapping for the MMR of the geological conditions in the eastern part of Baffin Bay and GEUS is compiling oil-geological data relevant for oil and gas exploration in the marine area off South-West Greenland.

Accessibility of Danish mineral resources

The Danish subsurface contains a number of important mineral resources: sand, gravel, stone, clay, chalk/limestone, salt and granite. Of these, sand, gravel and stone are extracted onshore and from the seabed. Most of Danish mineral resources are used for various purposes within the Danish building and construction sector; some are exported. The Center for Minerals and Materials (MiMa) under GEUS published two reports during the year on Danish mineral resources, and together with an account of Danish mineral resources published in 2015, these provide an overview of the accessibility of mineral resources in Denmark. One of the reports provides a geographic summary of mineral-resources extraction in Denmark. On national and regional maps, the report shows where mineral-resources extraction is taking place, as well as the quality and volumes of the resources extracted.

The second report analyses the access to aggregate (sand and stone) for the Danish concrete industry in order to assess whether the industry will be able to obtain the mineral resources it needs in the short term and in the long term. Concrete is an important material for the Danish building and construction sector, employing around 150 000 people and with revenues of around DKK 200 bn. Furthermore, the minerals extraction and concrete sectors employ 5000 and 1000 people, respectively, and they have annual revenues of DKK 6 bn. and DKK 2 bn., respectively. The report reviews the organisation of the three sectors within the concrete industry: factory-made concrete, precast concrete elements and other concrete products, with focus on the needs for sand, gravel and stone. The report also examines the requirements of producers regarding mineral resources as well as the challenges facing the industry. Finally, the report contains a review of the business structure of Danish companies extracting mineral resources.

Greenland's mineral resources

A large team of geologists from GEUS completed field surveys in the area north of and around Karrat Fjord in West Greenland. The objective of the project was to carry out geological mapping and identify the mineral-resources potential in the area, in particular zinc and lead sedimentary deposits. The work included detailed geological surveys to elucidate the geological development of the area and a large number of samples were taken for ore-geological and geochemical analyses and to determine the age of the rocks. Finally, stereo photographs were taken by helicopter and hyperspectral data were collected from steep mountainsides for later photo-geological and hyperspectral interpretation of the geology in the laboratory. The project is co-funded by GEUS and the Ministry of Mineral Resources (MMR) under the Government of Greenland.

In November, GEUS and the MMR held a workshop at which the uranium potential in Greenland was evaluated by a panel of experts from the research community and from industry. The workshop followed a standardised procedure in which a panel of experts debated and appraised possible undiscovered uranium deposits within delineated areas following a review of all available data, maps and literature from previous work. A report on the conclusions of the panel of experts is expected to be published in mid-2017.

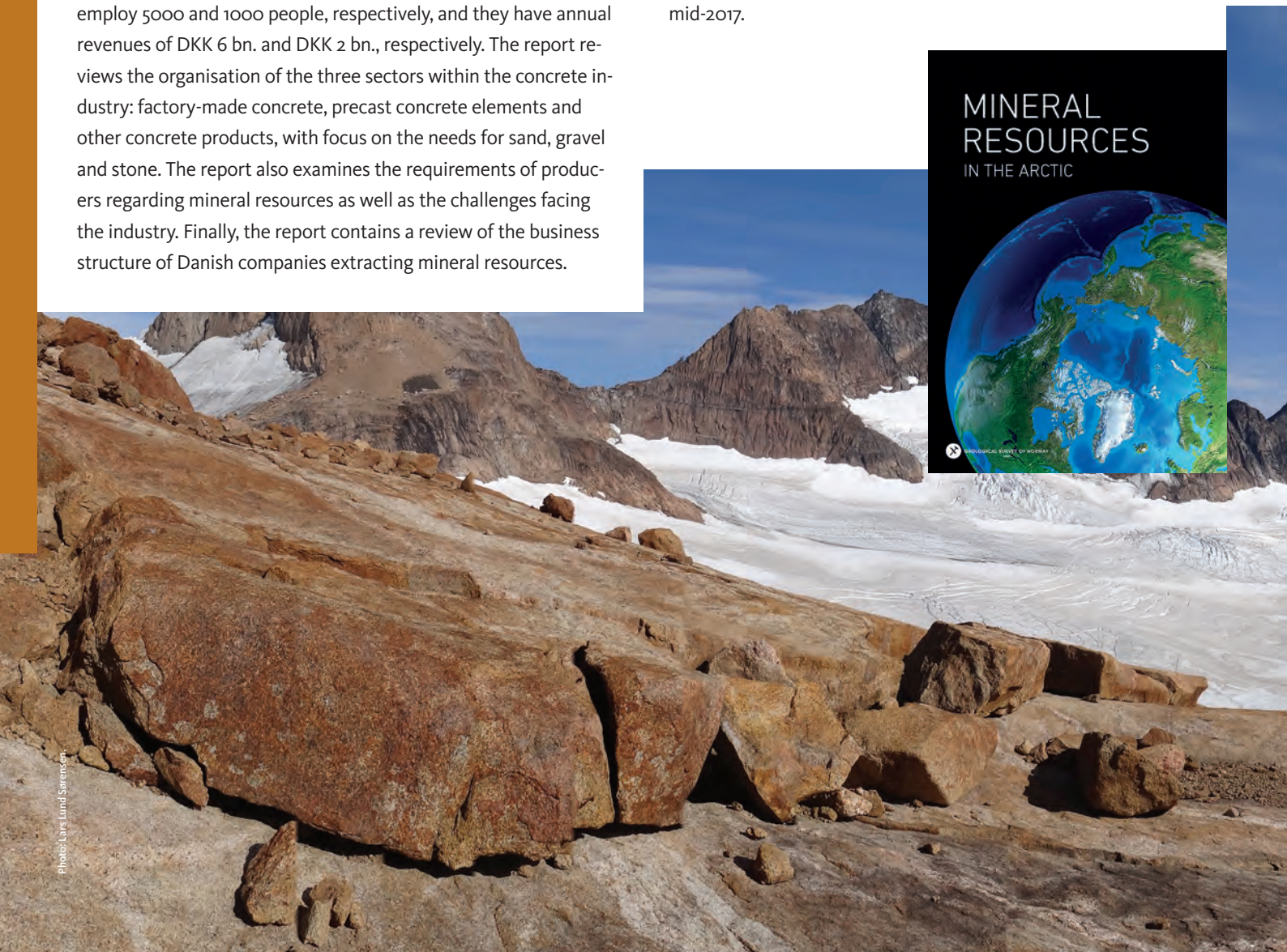


Photo: Lars Lund Sørensen.

Mineral resources

Scientific basis for targeted and environmentally sound exploitation of mineral deposits in Greenland and Denmark

Two publications reviewing mineral resources in Greenland

Geologists from GEUS have contributed to two major publications issued in 2016 summarising the minerals potential in Greenland. One of the publications is an article entitled 'Metallogeny of Greenland', which was published in the Ore Geology Reviews journal. This provides a comprehensive overview of the geological environment and finds of mineral deposits in Greenland. The second publication is a book entitled 'Mineral resources in the Arctic' containing all available information on the most important metal and diamond deposits in the Arctic north of 60°N. The book has information on the 28 diamond deposits and 207 large, very large and potentially large metal deposits in Alaska, Canada, Greenland, Iceland, Norway, Sweden, Finland and Russia as well as information on massive deposits of sulphides on the seabed. GEUS contributed to the chapter on mineral resources in Greenland. This includes descriptions of provinces with mining potential, as well as the history of mining in Greenland. The most well-known ore deposits are also described. The book can be downloaded free of charge from www.ngu.no.

Increasing investment in exploration and mining

Targeted marketing of Greenland's mineral resources is one of the activities that will help attract investment to Greenland from the international mining industry. The mineral potential of Greenland is being marketed through direct contact with the industry and provision of knowledge through various media. In 2016, GEUS worked on this marketing with the Ministry of Mineral Resources (MMR) under the Government of Greenland, and in March GEUS took part in the annual PDAC mining congress in Canada. Contributions from GEUS included a lecture on the MMR Greenland Day presenting exploration opportunities and minerals potentials in Greenland to the exploration and mining industry.

GEUS' goal is to work with the mining industry on research and consultancy that can generate incentives for further investment in exploration and mining operations. In this context, over the summer GEUS conducted geological surveys for FinnAust Mining Plc at the abandoned settlement of Moriusaq near Thule in North-West Greenland. There is heavy-mineral sand in the area with the titanium-containing mineral, ilmenite. The sand can be found in the current coastal zone, in raised beach ridges, and on the seabed off the coast. In August, geologists from GEUS surveyed the area more closely to map the amounts of ilmenite in the area. The work included geo-radar measurements and sampling onshore, and at sea, measurements were taken using an echo sounder, while sampling was performed using vibration corer. The project is being funded by FinnAust Mining Plc.

Coordinated monitoring of the Arctic

The Arctic is currently in focus more than ever, in part due to climate change, which is having a dramatic effect on the area. Changes in the Arctic nature are being tracked in monitoring programmes by several countries, and there is a need to coordinate data and activities to improve this monitoring. The EU INTAROS (Integrated Arctic Observation System) project will develop better monitoring of the Arctic by expanding, improving and coordinating existing monitoring systems in different Arctic regions. GEUS is taking part in the project, which has a strong inter-disciplinary focus and which will combine data from the atmosphere and sea as well as ice and land areas collected by many research institutions in Europe, North America and Asia.

There is a particular lack of field measurements in the Arctic, and one of the goals of the project is to assess the strengths and weaknesses of the existing observation systems and to find solutions for how best to fill in some of these critical gaps in the network of field measurements. This may include setting up more instruments to collect field data or developing new instruments to gather the data assessed as necessary to obtain a better picture of the changes in Arctic nature. One of the goals of the project is to increase and strengthen local involvement in the measurements, so several measurements in the Arctic are being performed in collaboration with the local community. Together with the increasing amount of satellite data, many of the coordinated field measurements will be made available in one, consolidated database system that will be developed and implemented during the project period from 2016 to 2021. Finally, through demonstration projects, INTAROS will highlight the value of the consolidated project dataset for selected stakeholders, e.g. the value for the fishing industry to combine ice and marine data to describe the marine ecosystem.

GEUS is an important partner in the INTAROS project because of the institution's two comprehensive monitoring programmes in Greenland. These are the PROMICE programme, in which a network of automatic measuring stations monitors the Greenland ice sheet, and secondly earthquake monitoring in Greenland through operation of a number of seismic monitoring stations. The INTAROS project has 37 European partners from 14 countries and 12 partners from six other countries and it is funded by the EU Horizon 2020 research and innovation programme. The project is headed by Nansen Environmental and Remote Sensing Center (NERSC) in Norway.

Monitoring of the Greenland ice sheet

Ice melt from the Greenland ice sheet has increased considerably since the turn of the millennium, and although 2016 was no record year, large melts from the ice surface were recorded. The measurements come from the Programme for Monitoring the Greenland Ice Sheet (PROMICE), which is monitoring the mass loss from the ice sheet using 25 fully automatic monitoring stations to measure the ice melt, the climate and ice movement, and then transmit the data to GEUS in Copenhagen via satellite. 2016 was influenced by early ice melt due to record-high temperatures

in Greenland, low reflection of solar radiation from the Greenland ice sheet and a long, but not record-breaking melt season.

PROMICE also keeps an eye on ice loss from the large calving glaciers in Greenland using data from satellites and aerial measurements. Among other things, GEUS surveys the size of 45 of the widest glaciers in Greenland every year. In 2016, 22 of these glaciers retreated and lost an area of 101 km², 11 advanced and became 41 km² larger, and 12 remained unchanged. The net loss of 60 km² is the largest loss since the record ice loss in 2012.

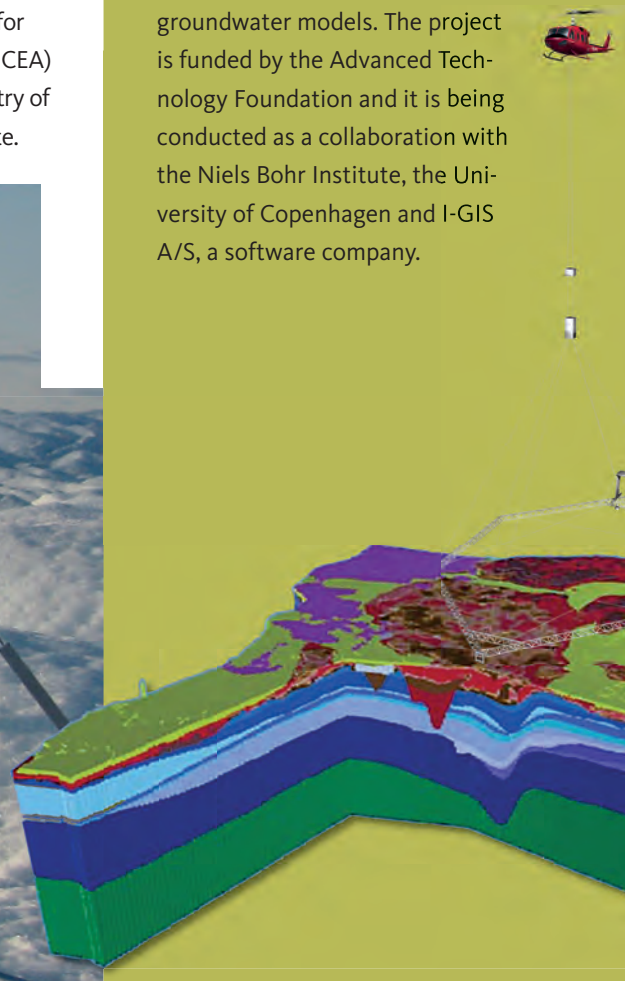
Data from PROMICE are distributed free of charge to the international research community via www.promice.dk, and the public is informed through www.polarportal.dk, operated in cooperation with the Danish Meteorological Institute (DMI) and the Technical University of Denmark (DTU). Danish monitoring activities are supplemented with measurements from several foreign stations on the ice. In upcoming years, overall international efforts will provide a more accurate picture of the degree to which the ice sheet is melting, and thus how much this is contributing to the rise of the global sea level.

PROMICE is headed by GEUS in collaboration with DTU and Asiaq, Greenland Survey; it is funded by the Danish Cooperation for Environment in the Arctic (DANCEA) programme under the Ministry of Energy, Utilities and Climate.

Effective methods for 3D geological modelling

In recent years, large quantities of geophysical data have been collected in Denmark in connection with the now completed national groundwater mapping. In particular, these data stem from the SkyTEM measurements taken from helicopter, which are being used to map the geological strata. It is difficult and time-consuming to translate the large amounts of geophysical data into useful geological models for mapping groundwater aquifers. GEUS is taking part in the ERGO (Effective high-resolution Geological Modelling) project to develop effective methods for use in 3D geological modelling of large sets of data. The aim is to develop a user-friendly software system which, using automated methods, can help researchers interpret data and design useful geological models. Work includes developing software that can 'learn' how researchers interpret data in one area and enable the program to automatically roll-out this knowledge in another area.

Groundwater surveying is high on the agenda in several developing countries in which there is only limited knowledge available to interpret and translate the large amounts of data into geological models. In the long term, the ERGO project will provide opportunities to export Danish know-how, which will enable local geologists with less experience to build high-quality geological groundwater models. The project is funded by the Advanced Technology Foundation and it is being conducted as a collaboration with the Niels Bohr Institute, the University of Copenhagen and I-GIS A/S, a software company.



GEUS around the world

Knowledge-building in developing countries through research and consultancy

New European–African geoscientific collaboration

In partnership with several European sister organisations, GEUS is enhancing geological knowledge in a number of surveys on the African continent so that the countries can exploit their natural resources better. Africa is rich in minerals and unique landscapes that can generate growth and welfare for the continent. However, many countries lack the knowledge required to exploit these resources.

In this new collaboration project (PanAfGeo) GEUS is teaching Africans about managing and organising geodata, and GEUS is heading a training programme to improve the living conditions and earnings for the large numbers of Africans who make their livings from exploiting minerals in the subsurface. Artisanal and small-scale mining (ASM) is a type of low-technology mining which provides a living for millions of people in developing countries. In Africa alone, about 10 million people are directly engaged in mining operations and even more are indirectly involved in ASM for their living. There is a rapidly increasing number of small-scale miners in Africa.

Minerals are most often dug up under very poor safety conditions in confined and deep shafts, and when workers are mining for gold, for example, mercury is often used in the process and this causes enormous environmental and health problems if not managed properly. Miners also lack geological knowledge about where best to dig, and how to organise digging and excavation to ensure the best yield. When there are profits, miners do not always get the full returns from their efforts because they lack business skills as well as knowledge about, and access to, the markets in which they can sell their minerals.

The ASM part of the PanAfGeo project will train miners and personnel at the relevant authorities in improved working methods and earnings potentials to establish a more sustainable industry in terms of finances, health and the environment. So far, collaboration has been agreed with seven African countries: Burkina Faso, Cameroon, Ghana, Kenya, Malawi, Mozambique and Zambia. In addition to the training programme, the project will also prepare an easy-to-read and well-illustrated 'Handbook for small-scale mining', which will contain advice for miners so that they can increase their earnings and improve their working conditions.

"There is a strongly increasing number of small-scale miners in Africa, as this is the only way to make a living in many areas and the only alternative to unemployment or emigration," says John Tychsen, a chief advisor at GEUS and head of the ASM project.

PanAfGeo is funded by the EU and it is part of the African Union Support Programme. The ASM project is also supported by funds from the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF), funded by Global Affairs Canada.

Photo: Peter Apple.

Sustainable small-scale mining in Ethiopia

GEUS has been working with the Ethiopian Ministry of Mines, Petroleum and Natural Gas (MoMPNG) for six years to improve living conditions and earnings for the many Ethiopians making their living from small-scale mining. The MoMPNG estimates that one million people work in this type of low-technology mining, in which minerals are often dug up under very poor safety and health conditions in confined and deep shafts and tunnels.

In 2016, GEUS completed a similar project with sharp focus on how to involve women in the working processes in small-scale mines. Work included training women in six provinces in selected work processes in gold, gems and salt mining. One of the goals has been to involve women in cutting, polishing and other processes of opals in order to increase the value of the product supplied to the market. Activities have been in collaboration with the British company Estelle Levin Ltd. and the Ethiopian firm SuDCA Development Consultants. The project is funded by the World Bank based on funds from the Japan Social Development Fund (JSDF).

Building hydrological expertise in Ghana

In the GhanAqua project, GEUS is strengthening research capacity in Ghana within hydrogeology so that Ghana can manage its water resources better. The project is focusing on assessing the groundwater resources in the White Volta Basin in northern Ghana, where there is a need to establish large-scale, sustainable irrigation plans for agriculture. Work will include developing a hydrogeological model and a numerical groundwater model to assess groundwater recharge and variation in the size of the resource as a consequence of climate change and large-scale irrigation. The project will primarily use knowledge and historical data that are available from local stakeholders as well as geophysical data collected from aircraft under the comprehensive EU Mining Sector Support Programme. Finally, activities will include training Ghanaian PhD students in hydrogeological disciplines through classroom teaching and participation in specific research activities.

During 2016, geologists have processed and interpreted geophysical data from the White Volta Basin with a view to setting up a geological model of the area. Subsequently, work on developing a numerical groundwater model for the Nasia basin has commenced. On the teaching side, three Ghanaian PhD students have received five months' training at GEUS in Denmark and at the University of Copenhagen. The project is led by the University of Ghana and it is a collaboration between three Ghanaian institutions; the Water Research Institute, Hydronomics Ltd, and the Center for Savanna Ecosystem Research, as well as GEUS, Aarhus University and the University of Copenhagen. GhanAqua is a South-Driven Development Research Project funded by Danida.

Glimpses of the year

Photo: Signe Jacobi Larsen, GEUS

International Geological Congress

In August/September, geologists from around the world gathered in Cape Town in South Africa to take part in the 35th International Geological Congress. More than 4000 people from 117 countries took part in the extensive programme of scientific symposia and workshops in which the social and economic significance of the geosciences was presented and debated in particular. More than 120 institutions and companies displayed their geological expertise from stands. Geologists from GEUS co-organised several symposia dealing with, among other issues, geological development of the Arctic and the minerals potential of the area, and GEUS focused on the following themes: Greenland's mineral resources and capacity building within water and climate in Africa on the joint Nordic stand 'Resources for Society', which was run with our sister organisations GTK from Finland, NGU from Norway and SGU from Sweden.

Lecture on recycling mineral resources

Increasing global consumption of mineral resources means that it is vital to consider how we can reduce consumption of primary resources and instead increase recycling in a materials cycle. This requires cooperation between geologists, engineers, materials technologists and behaviour researchers, and the materials cycle also requires more knowledge about houses, cars, mobile phones and other items from which materials can be reused to obtain a better idea about the potential for recycling. Center for Minerals and Materials (MiMa) at GEUS examines and disseminates information about the mineral resources value chain; from exploration and extraction to consumption and on to recycling and development of new technologies. During the spring, MiMa focused on reusing mineral resources through a series of meetings about circular materials consumption at which internationally recognised researchers and other experts shared their knowledge about the possibilities and challenges linked to recycling mineral resources. Lectures on reusing metals and the minerals potential in existing buildings and about what is required to go all the way towards a society with no waste were on the agenda.

Photo: Morten Johansen.
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Europa Nostra Prize 2016 for Danish-led heritage project

The seas around Europe are a treasure chest of heritage. Shipwrecks, flooded towns and sunken landscapes lie waiting to be discovered and investigated. UNESCO has estimated that more than 3 000 000 shipwrecks on the seabed worldwide have yet to be explored. However, using the seabed for offshore wind farms, pipelines and undersea cables threatens to damage this undersea cultural heritage. This makes it important to develop new methods to manage and protect Europe's historical undersea monuments. An international research project named SASMAP, in which GEUS is taking part, has been working for three years on developing a method to map and protect Europe's undersea cultural heritage. In May, in Madrid, the SASMAP project was awarded the EU Prize for Cultural Heritage – Europa Nostra Award 2016. GEUS was responsible for the marine geological part of the project, which has produced geological models of the seabed to reveal the likely location of undersea cultural treasures, and marine geologists have also used satellite pictures to scan the shape and depth of the nearshore seabed.

Successful soapstone workshop in the Nuuk area

Soapstone can be found in various places in the Nuuk area, but it is only used to a very limited extent for handicraft products. Some of the deposits have been used historically by ancient Inuit cultures or Northern civilisations and therefore they have great archaeological value and value as a tourist attraction. In June, GEUS invited people in Nuuk to a soapstone workshop at Ikkattut on the island of Storø near Nuuk, on which there are several deposits of soapstones. The workshop was part of a project to encourage locals to use the soapstone deposits, either for handicraft or as a tourist attraction. Several artists who work with soapstone as well as other locals took part in the workshop, at which there was an opportunity to see the soapstone deposits and hear about both the geology and archaeology associated with the deposits as well as about the rules for exploiting the deposits.

Key figures for 2016

More detailed key figures for the activities of GEUS are available in Årsrapport – Regnskabsåret 2016 (Report and Accounts 2016), and in Faglige resultater 2016 (the latter in Danish only). Both of these are available at www.geus.dk – publikationer – institutionsrapporter.

Number of employees: **289**
Number of scientific projects: approx. **700**

ACCOUNTS 2016

Amounts in million DKK	
Revenue	**273.1**
Net figure (appropriation)	139.3
Operating income	133.8
Expenditure	**273.1**
Salaries	162.7
Other operating expenditure	110.4

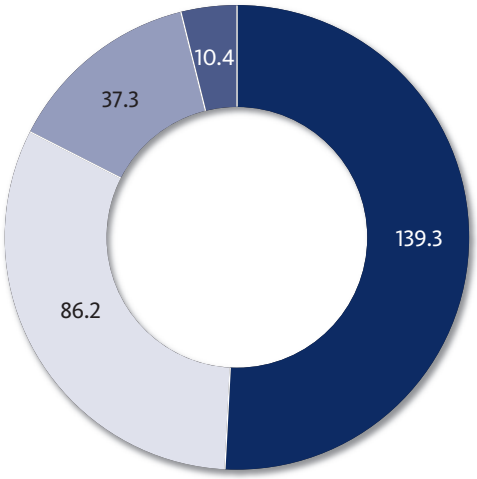
INFORMATION ACTIVITIES

Long-term knowledge building	
Articles in international scientific journals/publications	128
Other scientific publications	8
Conference contributions with abstracts or posters	152
On-going scientific tasks, consultancy and presentation	
Publicly available reports	52
Confidential reports	29
Memoranda, opinions, expositions etc	32
General information	
Institution reports (annual report etc.)	5
General and popular-science presentations	76
- including popular-science lectures	37
Use of GEUS web	
Visits to www.geus.dk	626 000
Use of GEUS' web map services	8.4 mio.

RESEARCHER TRAINING WITH GEUS TUTORS

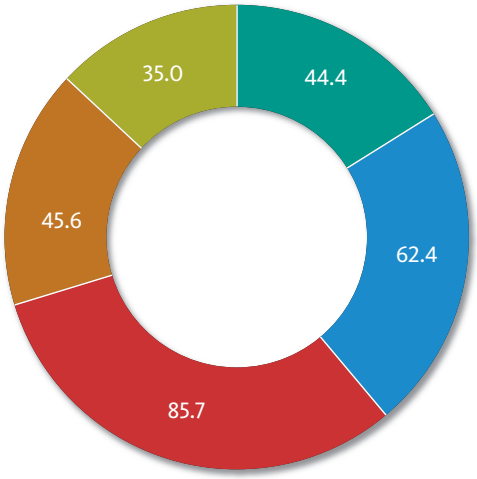
Current PhD students	47
Completed PhD degrees	12

Revenue broken down by sources of revenue in million DKK



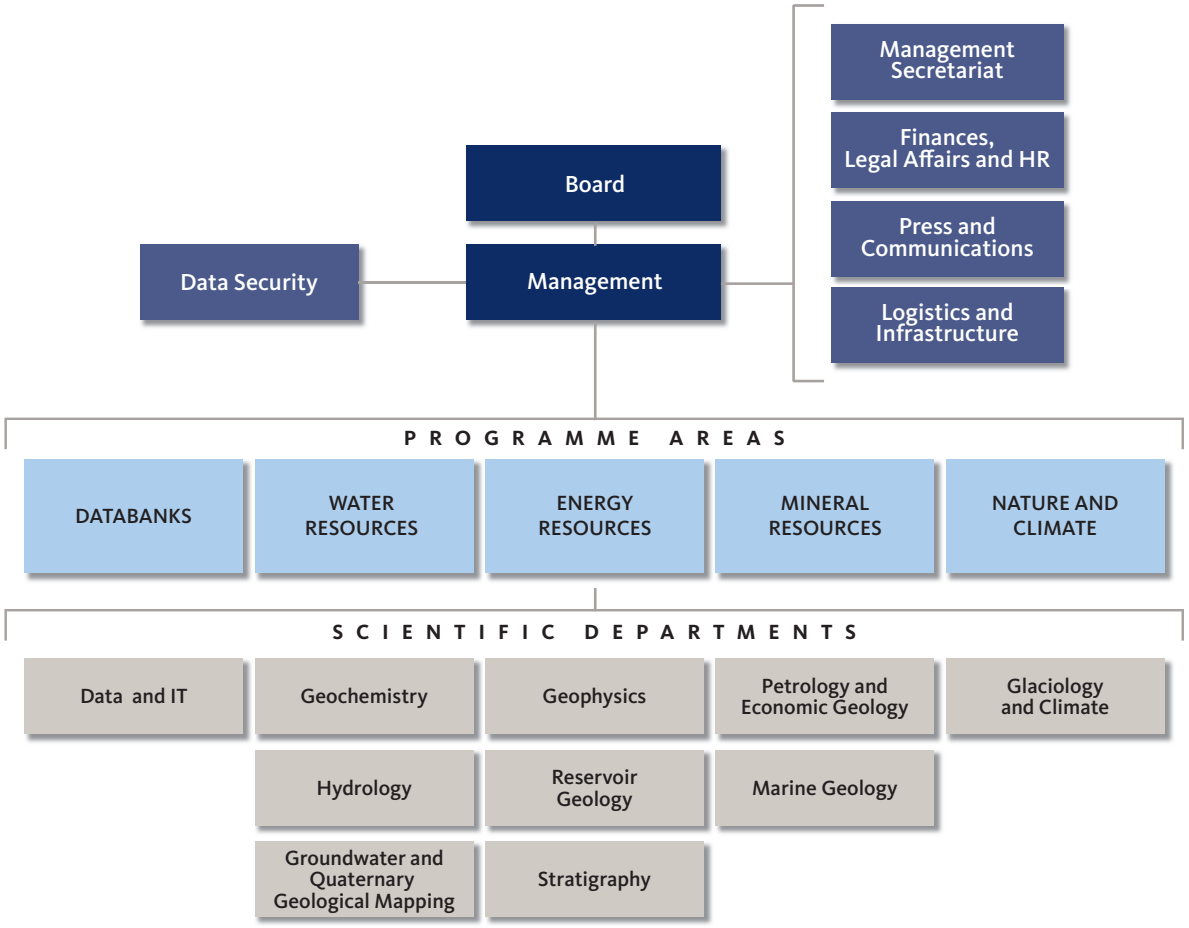
National budget and supplementary government appropriations:	139.3
Programme and external resources:	86.2
Other co-financed contract research:	37.3
Commercial contracts and sales of data:	10.4

Expenditure broken down by programme area in million DKK



Databanks and information:	44.4
Water resources:	62.4
Energy resources:	85.7
Mineral resources:	45.6
Nature and climate:	35.0

Organisation



In 2016 there were ten research departments at GEUS and four administrative/service units. Scientific work is being done in five programme areas, where tasks are carried out in project groups in a matrix structure.

Programme areas

Databanks

Storage, quality assurance and presentation of geological knowledge and data. The aim is to establish a level of quality of data and sample collections which helps work on monitoring, emergency management, advisory service and research. In addition, the programme area comprises IT projects, which ensure efficient and modern IT tools at GEUS.

Water resources

Knowledge to optimise the management of Danish water resources. Activities are directed at the water cycle, the extent and quality of water resources, and transport and decomposition of xenobiotic substances in the aquatic environment, focusing mainly on the groundwater. The activities also form the basis for advisory services to authorities, regions and municipalities in Denmark and abroad.

Energy resources

Knowledge for exploration and exploitation of energy resources in Denmark and Greenland. This work comprises own research projects and international cooperation with oil/gas and renewable energy. The collected knowledge forms the basis for GEUS' advisory services to authorities in Denmark and Greenland, and also for projects carried out for the industry.

Mineral resources

Scientific basis for targeted and environmentally sound exploitation of mineral deposits in Greenland and Denmark. This work includes geological mapping and mineral exploration in Greenland, as well as official processing and advisory services for the Government of Greenland. In addition, surveys are carried out in connection with raw materials and construction work in Denmark and internationally.

Nature and climate

Knowledge about the past and present climate and environment in Denmark and the North Atlantic area. The objective is to improve the prospects of distinguishing between natural and human-induced environment and climate changes. The programme area also includes a mapping of onshore and offshore geological conditions, as well as earthquake research and monitoring.

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Geological Survey of Denmark
and Greenland (GEUS)

Øster Voldgade 10
DK-1350 Copenhagen K
Denmark

Telephone: 38 14 20 00
Telefax: 38 14 20 50
geus@geus.dk
www.geus.dk