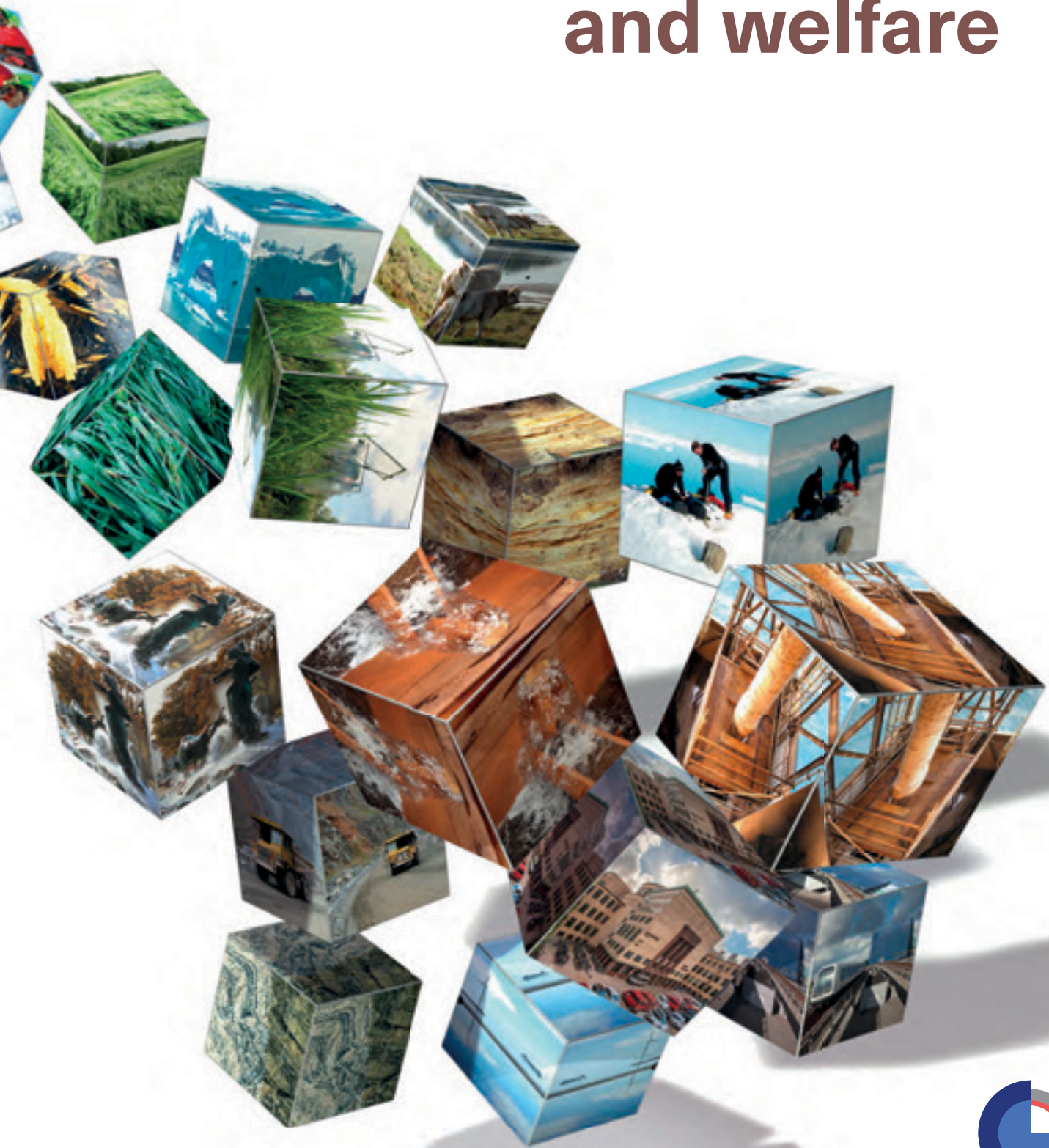


Resources for growth and welfare



ANNUAL REPORT 2015
GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF ENERGY, UTILITIES AND CLIMATE



G E U S

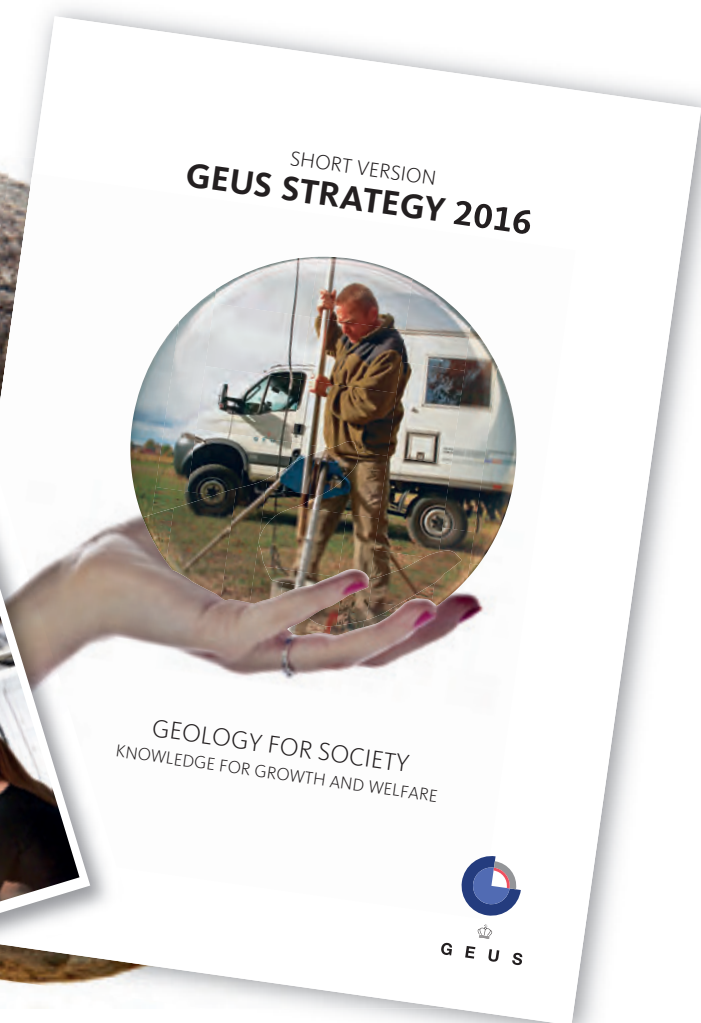
New strategy

Under the heading *Geology for society – knowledge for growth and welfare*, GEUS launched its new updated strategy in 2015. The strategy was prepared by the Board and management of GEUS during the period September 2014 to September 2015. The strategy has an eight-year span and comprises the strategic foundation for GEUS' performance contract with the Ministry for Energy, Utilities and Climate for the period 2016–2019.

The strategy reflects development trends in Denmark and abroad as well as the driving forces that will be decisive for GEUS' choices and priority setting in the future. The driving forces include: the need to convert the energy supply, to adapt to future climate changes, and to keep water resources in check, as well as fiercer competition for minerals and other raw materials. Moreover, human health will be in focus, and access to nature and recreational areas will have great importance for the well-being of the population.

The strategy consists of a number of targets and scientific topics as well as structural initiatives to support GEUS in its tasks. The strategic targets are long-term, general and functional targets, which GEUS will follow so as to best complete its mission, while the topics are scientific, dealing with the subjects and overall objectives at which GEUS will direct its activities strategically for the benefit of society.

A printed version of the strategy is available from GEUS or electronically at www.geus.dk in a short as well as an extended version in Danish and a short version in English.



Foreword

The year 2015 was characterised by increasing internationalisation. GEUS' objective to expand its international work and play a more prominent role in international research, not least within the EU, was brought to fruition as GEUS participated in a number of high-profile initiatives and projects.

As the only institution from Denmark, GEUS is participating in a Knowledge and Innovation Community (KIC) for mineral resources – a European super consortium with more than a hundred participants from industry, research and education. This consortium, which is called EIT Raw Materials, includes all the major players in the field and aims to help develop the mineral resources sector in Europe with support from both EU and national funding. GEUS' membership offers a portal to project participation and is already leading to invitations to join other innovation projects. GEUS' work in KIC is partly based in the Center for Minerals and Materials (MiMa), which delivered a comprehensive vulnerability analysis of the mineral resources supply for Danish industry.

European collaboration continued to evolve through EuroGeoSurveys (EGS), and GEUS is currently the EGS institution taking part in the second largest number of EU projects in Europe, comprising projects within all of GEUS' core areas. Furthermore, GEUS ranked among the top research organisations in Europe in a survey of publications on European groundwater research and the impact of such research. This ranking was further confirmed in a recent international evaluation of GEUS' research in the water area. Similarly, GEUS assisted in the development of urban geology in Europe together with partnership cities. This is an area which is expected to see much more interest in the future.

New databases and data services in Greenland, Denmark and at EU level were launched in 2015 bringing into play GEUS' data across many sectors, within administration, consultancy, planning and industry, and helping to save society and users considerable costs and attract new investment.

Several research projects were completed in 2015 with significance for oil and gas production in the North Sea and for the green energy sector, i.e. projects on deep and shallow geothermal energy and heat storage. The geothermal potential was mapped and will be presented in 2016 as a part of a GIS platform to help plan geothermal wells. Furthermore, together with its partners, GEUS developed a GIS platform for use when establishing shallow geothermal installations.

GEUS' monitoring of the Greenland ice sheet was part of the scientific basis for the climate summit in Paris and it served to document that the loss of mass from the ice sheet is increasing and will influence future sea-level rise significantly.

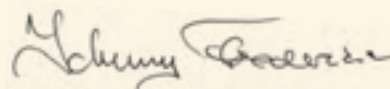
In 2015, GEUS earned its share of media and political attention due to its work on and knowledge about subjects such as shale gas, radioactive waste, nitrate leaching due to new fertilisation standards, and the discovery of pesticides in groundwater. The media's interest in 'conflict over content' placed new demands on GEUS' external communication skills – demands which will grow more pertinent in the future.

The positive results aside, there is no escaping the fact that the market situation meant that winning new projects, especially within the area of energy, was difficult for GEUS in 2015. Furthermore, less funding and fiercer competition meant that GEUS had to adapt its budget and make a number of employees redundant.

However, with a new strategy, a new performance contract and increasing internationalisation, GEUS is entering an exciting and challenging 2016. GEUS is well prepared for the tasks ahead, although stable funding and the ability to win externally funded projects will be an important prerequisite.



Minik Rosing
Chairman of the Board



Johnny Fredericia
Managing director

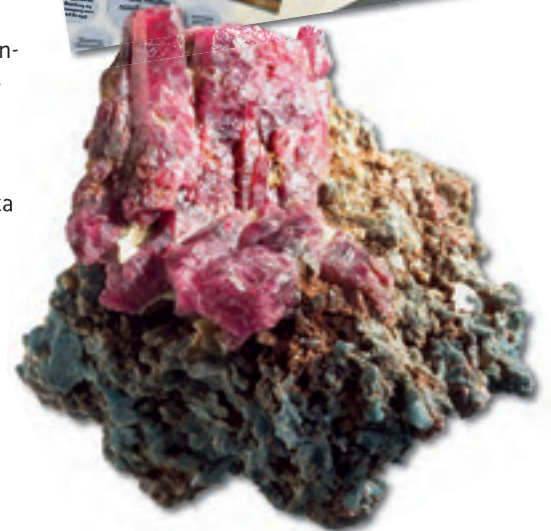
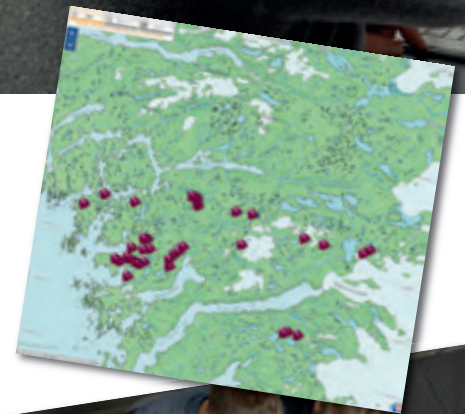
Online data on the geology and mineral resources of Greenland

The Government of Greenland and GEUS collectively administrate the *Greenland Mineral Resources Portal*, which provides access to a wealth of information about geology and mineral resources in Greenland. During the year, the portal was developed further and new topics and features were introduced. The portal provides access to different scale geological maps, geophysical and geochemical data, aerial photos, field observation data and information about geological environments. Searches for data are done via an interactive GIS map, and users can also access publicly available reports made by companies, GEUS publications, mineral deposit descriptions and analyses of samples from the popular mineral resources hunt, Ujarassiorit, in Greenland. The portal gives access to searches in several underlying databases and users can study search results via metadata and PDF files. Much of the data can be downloaded via the webshop linked to the portal.

During the year, GEUS also launched a data portal on ruby occurrences in West Greenland. This portal provides information about 87 ruby-sapphirine occurrences in the area around Qeqertarsuaat south of Nuuk, as well as eight occurrences near Nuuk and Maniitsoq. These data include descriptions of the geology and mineralogy of the occurrences, geological locations as well as references to geological maps, scientific publications, journals and reports.

3D seismic data available via online shop for the oil industry

In 2015, GEUS expanded access to data in the *FRISBEE* online shop where users can search for and buy data on oil and gas exploration and other surveys in the deep subsurface in Denmark. The database contains reports, logs, merged logs and digital core photographs from deep boreholes released in Denmark. The data available are primarily from the Danish sector of the North Sea, however there are also data from onshore drilling operations and drilling operations in Danish coastal waters. Via *FRISBEE*, users can search for data and pay for data via credit card or invoice. *FRISBEE* now also contains reports and data from publicly available 3D seismic surveys. Most of these data are from the North Sea, however there are also data sets from 3D seismic surveys on land, e.g. at Stenlille on Sjælland and at Feldsted and Tønder in Sønderjylland. The data available in *FRISBEE* are data from original 3D processing and only end products are available in the database, e.g. 'final migration' and/or 'final stack'.





Common European minerals databases

In recent years, GEUS has participated in several EU-funded research projects to promote the exchange of geodata across European borders. These projects support the EU INSPIRE Directive on the establishment of a common European infrastructure for spatial information to enable easier exchange of data across national borders. In 2015, GEUS took part in three research projects aimed at collecting and harmonising knowledge and data on mineral resources in the EU with a view to securing the supply and sustainable use of mineral resources. The Minerals4EU project was completed and involved development of a portal with information about mining operations and mineral deposits, as well as with access to the *European Minerals Yearbook*, which contains country-specific information about minerals, production, and imports and exports of mineral resources. Furthermore, work was carried out under the EURARE project, which is developing the foundation for an industry that can secure the future supply of REE and REE-related products to important European sectors, e.g. the automotive, electronics and chemicals industries. One of the objectives is to develop a database with information on EU REE resources and knowledge about eco-friendly and effective extraction and refining technologies.

Finally, GEUS is part of the ProSUM project to develop databases and a portal with information about opportunities for recycling and secondary sources of critical raw materials in the EU. This is knowledge about volumes and flows of e.g. waste products from industry, waste electronic equipment, batteries, end-of-life vehicles, and waste from mining operations where there is a potential to reuse raw materials.

New book on geological exploration in Greenland

In 2005 GEUS published the book entitled: *Grønlands geologi udforskes – glimt af geologernes arbejde* (Exploring the geology of Greenland – glimpses of the geologists' work). This book recounts how geologists worked on their many expeditions to all parts of Greenland over the course of almost 70 summers. For many years, geologists have been trudging the mountains, traversed the country by aeroplane and sailed the coastline of Greenland in order to map the geology. This book tells the story of their work and provides glimpses into how they lived, what they ate, and what ships, aeroplanes and helicopters they used to cross this vast country with its harsh nature. The book is aimed at readers with an interest in Greenland, geological exploration, expeditions and adventure. It focuses on the state's exploration activities. Since 1946, these activities have been carried out under the auspices of GEUS, involving many Danish and foreign researchers. The richly photo-illustrated book contains fact boxes on the geologists' work during their expeditions to all parts of Greenland and it contains over 70 profile descriptions of geologists and other explorers in Greenland. The author, Niels Henriksen, worked at GEUS from 1963 to 2000, and, in his capacity as head of department, he lead geological mapping for many years. He took part in exploration from early on as a student and has participated in field work in Greenland for 35 summers, and many of these expeditions are described in the book.



International research evaluation

The Board of GEUS continuously evaluates the quality of the institution's scientific work. In 2015, an international panel recommended by the Danish Council for Independent Research probed the quality of GEUS' research on water resources. In its assessment, the panel reported that GEUS' research is of high quality. Furthermore, the panel emphasised as an important strength that GEUS successfully applies its hydrological model as a tool to integrate and work across research topics such as groundwater monitoring, groundwater mapping, the water cycle, water quality, water and environmental technology, and management of water resources. The Board has subsequently expressed its satisfaction with the results of the assessment and stressed that GEUS has a strong portfolio of research projects in the water resources area, and that these are extremely visible internationally. The Board was also pleased with the panel's assessment of employee motivation and GEUS' research facilities. GEUS has subsequently prepared an action plan following up on the recommendations in the assessment report. The plan has been endorsed by the Board.

The Minister for Energy, Utilities and Climate, Lars Christian Lilleholt, has noted the report and said: *It is extremely satisfactory that GEUS has received such a positive assessment in an area of such significance for the Ministry, GEUS and society in general.*

National nitrogen model

GEUS, the Danish Centre for Food and Agriculture (DCA) and the Danish Centre for Environment and Energy (DCE) at Aarhus University developed a national nitrogen model in 2015 which can calculate in more detail and more accurately the amount of nitrogen being leached into coastal waters in Denmark each year and how much is being removed before it ends up in the sea. Nitrogen leaching from the root zone of farmland and other areas is transported via drainage systems and groundwater to watercourses, lakes and wetlands, from where it flows onward to the fjords and coastline. During this transport, some of the nitrogen is removed from and retained in the root zone, subsurface or in surface waters. This retention of nitrogen depends on the natural conditions between the farmland and the coast and, therefore, varies from place to place.

The model divides Denmark into small areas of just 15 km² from where the transport and retention of nitrogen from the farmland to the coast are calculated. Three sub models have been coupled to achieve this: A sub model for nitrogen leaching from the root zone developed by DCA, a sub model for water flows and nitrogen retention in the groundwater zone developed by GEUS, as well as a sub model for contributions of organic nitrogen and nitrogen retention in surface waters, i.e. lakes, watercourses and wetlands, developed by DCE. Development of the model applies the greatest possible national measurement data basis, which includes data from more than 300 watercourse stations, e.g. collected under the national programme for monitoring the aquatic environment and nature (NO-VANA). Furthermore, the model-calculated leaching is based on measurements of leaching from a large number of farmland trials and monitoring under the LOOP land-monitoring programme. Development of the model was commissioned by the Danish Environmental Protection Agency, the Danish Nature Agency and the Danish Agri-Fish Agency.



Large-scale modelling of saltwater intrusion in groundwater

Saltwater intrusion in groundwater reservoirs along coasts is a growing problem which is threatening drinking water supply in many places. The problem could grow worse with expected rising sea levels in the future. Together with its partners from Aarhus University and the University of Copenhagen in Geocenter Denmark, GEUS is carrying out a project studying how past and future sea levels have and will affect the intrusion of seawater in low-lying coastal areas. The studies are focussing on the westernmost part of Sønderjylland towards the Wadden Sea, an area which is sensitive to saltwater intrusion and where Denmark is likely to experience the largest sea-level increase in the future.

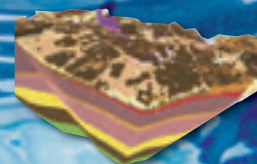
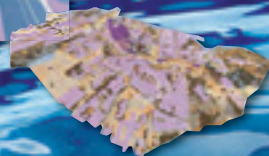
Researchers want to estimate the saltwater intrusion using 3D geological and hydrogeological modelling. Saltwater intrusion depends on the relative increase in sea level and on the geology of the coastal area. However, it also depends on prehistoric groundwater flow, and researchers therefore want to include palaeoglaciological parameters such as the history and thickness of Ice Age ice sheets, subglacial groundwater flow, and groundwater age in their modelling. Finally, the researchers will estimate future saltwater intrusion based on scenarios for relative sea-level change.

In 2015, a 3D geological model was developed for Sønderjylland to serve as the basis for the calculations in the hydrogeological model, being developed. Furthermore, samples from wells in the area were collected for chemical surveys and age-determination of the groundwater. Preliminary results suggest that the deep groundwater in the central part of Sønderjylland is very old. The project is the first in Denmark to examine saltwater intrusion in coastal groundwater reservoirs on a large scale and within a multidisciplinary framework which combines geophysics, geology, groundwater dating and 3D geological and hydrogeological modelling. The project is receiving financial support from Geocenter Denmark.

Better assessment of spatial patterns from hydrological models

Water scarcity, over-exploitation and pollution have increased pressure on the world's water resources. This threatens the living conditions of people, animals and plants and limits agricultural production. Water resources management has primarily been based on knowledge from hydrological models which produce calculations on catchment-area scale and there is an urgent need to develop these models further so that they can meet the demands in modern water resources management about knowledge of water flows and substance transport in small areas within a hydrological catchment area. GEUS is developing new methods which use satellite data to improve calculations in high spatial resolution with advanced hydrological models.

This is taking place under the SPACE project aimed at developing methods for spatial calibration and validation of grid-based hydrological models. This work covers mapping hydrological parameters on the basis of satellite data, such as water content in the soil and evaporation, as well as developing new statistical evaluation criteria to handle spatial patterns. For the methodology development, data from the two hydrological test areas in the Skjern River catchment area and Wüstebach in Germany are used. Researchers have been collecting large quantities of hydrological field data from these areas for several years. Finally, the SPACE project will use satellite data to evaluate the results of the hydrological calculations performed using GEUS' national hydrological model. The SPACE project is financed by the VILLUM FONDEN Young Investigator Programme.



Knowledge to optimise management of Danish water resources

Water resources

Energy resources

Knowledge for exploration and exploitation of energy resources in Denmark and Greenland

More knowledge about the oil and gas potential in the North Sea

Although the Central Graben in the North Sea is a mature oil province, knowledge about the hydrocarbon potential of its Cretaceous strata is inadequate. GEUS is working to procure this knowledge under the CRETSYS project (The Cretaceous Petroleum System in the Danish Central Graben). The CRETSYS project emerged from the PETSYS project and is funded by oil companies active in oil and gas exploration in Denmark. Work includes new interpretations and comparison of 3D seismic and stratigraphic data from wells, and it will result in a coherent framework for the complex geological Cretaceous strata and a description of basin development. Furthermore, the geologists on the project are working on a list of reservoir properties, e.g. porosity and permeability, and they are preparing an outline of the regional variation in oil migration routes from the Jurassic source rocks into the chalk beds. During 2015, two workshops were held at which the results were presented, and a GIS-based website is under development from which companies can retrieve data and survey results.

Preparation of oil and gas licensing rounds in Greenland

The Government of Greenland has announced two licensing rounds for oil and gas exploration, one in 2016 for onshore areas on Disko and Nuussuaq in West Greenland and one in 2017 for offshore areas in Baffin Bay offshore North-West Greenland. Occasioned by the Greenland Ministry of Mineral Resources, GEUS updated a GIS compilation with petroleum geology from scientific surveys and exploration in the Disko-Nuussuaq area. The compilation includes sedimentological and stratigraphical data from the onshore areas and seismic data from the Vaigat strait between Disko and Nuussuaq. Furthermore, in 2015 GEUS completed an extensive survey for the Ministry of Mineral Resources of the geological properties of an area of around 200,000 km² in the easternmost part of Baffin Bay. This area has been subject to oil exploration activities following licensing rounds in 2007–2008 and 2010, and extensive geophysical and geological data have been collected. GEUS updated the existing survey with new data so that there is now an improved and up-to-date basis for appraising the geological development and hydrocarbon potential of the area.

Compilation of knowledge on shale gas

In August, Total E&P Denmark completed the first shale gas test well at Dybvad in Nordjylland following three months of drilling. Total and the state-owned oil and gas company Nord-søfonden have discovered gas in the alum shale in the Danish subsurface. However, the shale layer examined turned out to be considerably thinner than expected and, therefore, gas production from the shale is not feasible. While the surveys in Denmark were ongoing, GEUS also continued work on surveying shale gas at European level.

The estimation of shale-gas resources in Europe is still very uncertain, e.g. due to limited exploration and lack of actual production experience. Working with the Joint Research Centre (JRC) of the European Commission, EuroGeoSurveys (EGS) has launched the EUOGA project, which is currently compiling existing knowledge about the European shale-gas potential from EU and ESG member states. The project is managed by GEUS. In our own backyard, GEUS contributed to a scientific study commissioned by the Ministry of Environment and Food which aimed at putting existing international knowledge about the extraction of shale gas into a Danish context. This work was headed by the Technical University of Denmark and also counted contributors from the Danish Centre for Environment and Energy at Aarhus University.



Deep and shallow geothermal energy

Climate change calls for new energy solutions which can reduce emissions of CO₂ into the atmosphere. The Danish government is aiming for a fossil-fuel-free Denmark by 2050. The Danish subsurface contains a large green energy resource of geothermal heat in reservoirs at around 1–3 km depth, as well as a resource of shallow geothermal energy which involves exploiting the temperatures in the top 100–200 m in geothermal boreholes. Furthermore, there are possibilities to exploit the heat or to store it seasonally in geological strata at depths of 0.2–1 km.

In 2015, GEUS completed a seismic survey of a series of key geological horizons with geothermal potential. This means there is now a survey basis for the required detailed appraisals of the depth conditions, quality, thickness and size of the reservoirs. Furthermore, GEUS finalised the first version of a GIS web application for the Danish Energy Agency with knowledge and data on geothermal energy. The web application contains a number of 3D depth maps of the geothermal reservoirs as well as thematic maps showing geological key parameters and parameters of significance for geothermal production properties. Finally, the application contains a geological screening of the subsoil beneath 28 areas, mainly urban areas, selected in consultation with the Danish Energy Agency.

In the area of shallow geothermal energy, there has been demand from the industry to expand a web tool developed by GEUS for planning new geothermal boreholes with data on geology and thermal properties of soil. In 2015, this tool was further developed to include an interface to an energy calculation program developed by the Danish Technological Institute, so that geological information can be included directly when planning new geothermal boreholes. GEUS also finalised its contribution to the EU REGEOCITIES project on identification and removal of administrative barriers to establish geothermal installations. In this connection, in collaboration with ENVINA, GEUS held a course for municipal employees and published a guide on how to establish closed-loop geothermal boreholes.

Minerals for Danish industry – economics and supply

In 2015, the Center for Minerals and Materials (MiMa) at GEUS published an analysis of the demand for mineral resources by Danish industry sectors. This is the first analysis ever carried out of the socio-economic significance of mineral resources and of the vulnerability of the sectors to possible scarcity. Danish industry exported goods totalling DKK 250 billion in 2011 and more than 50% of raw materials used by industry are mineral resources extracted through mining activities. The study shows that minerals account for around 16% (around DKK 42 billion) of total exports. With a relatively large consumption of minerals, the metals and machinery sectors have the highest export values compared to raw material consumption. The study also showed that the use of mineral resources in Danish industry contributes about 57,000 jobs, or 20% of total employment in the industries.

On the basis of assessments by the European Commission of the risk of raw materials supply disruption, the analysis estimates that this risk is minimal for Danish industry with regard to iron, aluminium, nickel and copper. Danish industry also produces goods which contain raw materials for which the risk of supply disruption is considerable, such as boron, chromium, magnesium, phosphorous, the platinum-group metals and silicon. Several of these elements are constituents in steel alloys which are in wide use in Danish industry, and steel can therefore be considered as a critical raw material. Finally, the analysis reveals an increased risk of supply disruption for some of the raw materials used in the wind turbine industry, e.g. rare-earth elements (REE).

New Danish mineral resources statistics

Sand and gravel are basic raw materials in modern society. They are primarily used in building and construction works and the demand for these materials is set to grow with increasing population and buying power. Despite the large quantities of these mineral resources available in Denmark, securing their supply in the future poses a great challenge, because extraction activities often have to compete with other land interests. In Denmark, a total of around 32 million m³ sand, gravel, rock, chalk, clay and salt are extracted annually. In 2015, the Center for Minerals and Materials (MiMa) at GEUS published a new statistical survey of Danish mineral resources which provides an idea of the size and location of mineral resources in Denmark. These are the first complete statistics of mineral resources in the Danish subsurface onshore and in the seabed in Danish waters. The publication is intended to help in efforts to secure sustainable use and future supplies.

The statistics include sand, gravel, rock, granite, clay, expansive clay, diatomite clay, limestone/chalk and salt, and are based on existing geological and geophysical data. The statistics estimate the mineral resources in 98 municipalities and 41 marine areas. Resources have moreover been classified as either measured, indicated or inferred depending on the level of certainty about their individual occurrence. Many of the resources are in areas where extraction is impossible or undesirable, such as urban areas, roads, listed sites, farmland, forestry areas, recreational areas, shallow marine areas and special nature conservation sites.



Greenland's mineral resources

In 2015, GEUS carried out several activities to assess the mineral resources of Greenland. In July, a new perennial project was launched in Karrat Fjord in West Greenland. The objective of the project is to examine the area's base-metal potential, especially zinc. In 2015, the project, which is a collaboration between the Ministry of Mineral Resources and GEUS, included aerial photographs of steep mountain sides to be used in 3D photogeological interpretations as well as surveys of a number of areas where previous surveys have revealed potential mineralisations. Geologists compared and published geological and mineralogical data from South-East Greenland collected in the field in the period from 2012 to 2014. In July and August, there was a minor follow-up project on the ruby potential south-west of Sermilik Fjord and on the island of Kulusuk.

In August, geologists from GEUS and the Korea Institute of Geoscience and Mineral Resources (KIGAM) examined designated parts of the Motzfeldt intrusion in South Greenland to find out how mineralisations of niobium, tantalum and rare-earth element metals (REE) formed. This study will continue in 2016. Finally, in November GEUS hosted an international workshop at which a panel of experts from research and industry assessed the titanium-vanadium potential in Greenland.

New EU super consortium to secure Europe's raw materials supply

In 2015, the European Institute for Innovation and Technology (EIT) allocated funds for a new Knowledge Innovation Community (KIC) on raw materials – EIT Raw Materials. The KIC consortium, which consists of more than 100 leading partners from industry, research and education, has been tasked with securing the future supply of mineral resources in Europe as well as creating growth and jobs. Promoting innovation throughout the mineral resources value chain is one of the items on the consortium's programme, and this will introduce new solutions, products and services for sustainable exploration, extraction, minerals processing, recycling/circular economy and materials substitution.

The KIC consortium is organised in six regional offices with different focus areas, and GEUS is a partner in the Nordic branch, where the primary area of work is mineral exploration, mining operation and minerals processing and refining. The primary competences of GEUS in this value chain are within mineral exploration, material characterisation, risk management and environmental monitoring. Furthermore, GEUS is contributing with competences within value chain analysis and aspects relating to scarcity, vulnerability and sustainability in minerals production and consumption, as well as with its special expertise on Greenland and the Arctic region in general.



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

Mineral resources



3D municipal model for administration and handling of water in large cities

With growing interest in using the subsurface for storm-water infiltration and other climate-related solutions or for heat-storage systems, groundwater cooling, water extraction or for infrastructure such as tunnels and buildings, there is a strong demand for knowledge about the subsurface below our cities.

In 2015, GEUS finalised a project to develop a 3D geological/hydrogeological model of the subsurface under Odense Municipality. The project was carried out with Odense Municipality, VandCenter Syd, I-GIS and Alectia A/S with support from the Foundation for Development of Technology in the Danish Water Sector. The project worked intensively to couple the model of the natural geology of the deeper layers with the model of the surface layers which includes large man-made infill areas.

The model and the modelling tools developed are important for Odense Municipality and Vandcenter Syd related to manage and handle water. This includes tasks related to infiltration and diversion of water to reduce the risk of flooding or related to protecting drinking water supply. The project also produced a number of recommendations for developing 3D geological/hydrogeological models below the city which may serve as inspiration to others.

Faster meltwater release from the Greenland ice sheet

In 2015, *Nature Climate Change* published the results of a study by glaciologists from GEUS and the Cooperative Institute for Research in Environmental Sciences (CIRES) in Boulder, USA. The results revealed that meltwater from the Greenland ice sheet may be released faster than expected because of massive ice layers in the surface-near layers of snow and firn. Researchers have examined the effect of the very high temperatures observed in recent years on the structure of the surface-near layers of snow and ice, called firn, in the ice sheet near Kangerlussuaq in West Greenland. During the three expeditions in 2012, 2013 and 2015, researchers examined several hundred kilometres of the ice-sheet surface, mapping the structure in the firn layers with radar equipment and by drilling numerous firn cores. The studies showed that large quantities of meltwater have infiltrated the snow and firn during the very warm periods observed in recent years. The meltwater freezes again and forms massive ice layers which function as a lid, preventing infiltration of additional water. The meltwater therefore does not seep down into the firn, but is led away from the ice in streams along the surface of the ice. Researchers first discovered this phenomenon in 2012, when large rivers of meltwater suddenly formed on the surface of the ice in areas where the water had previously remained in the firn, where it refroze. The 2015 studies received financial support from the Danish Council for Independent Research (Natural Sciences).



Robustness to flooding

GEUS is taking part in a common Nordic research project, NORDRESS, which is generating knowledge about how to better protect society against natural disasters and how best to secure and help society recover after a disaster event. Recent years' extensive flooding in Denmark as a consequence of cloudbursts etc. have demonstrated a need for this type of knowledge. GEUS is heading efforts to develop monitoring systems which can give early warning and information about the extent of a flood event through public and stakeholder involvement. Researchers are drawing on experience from a previous GEUS pilot project, which examined the possibilities for real-time warning with GEUS' national hydrological model, so that the model can continuously calculate developments in the surface water and groundwater throughout Denmark. Part of this work involved a user survey among municipalities, water utility companies, farmers and other stakeholders to identify the types of hydrological data in demand and the format in which to deliver them.

The NORDRESS project involves developing methods for how to utilise the real-time experiences of the public before, during and after a flood event, so that these experiences can be included in a real-time warning system or help in mapping the extent of flood events and prioritising response measures. For example, this could be through photos or reports submitted directly by individuals via apps and the social media. NORDRESS is receiving funding from Finland, Iceland, Norway, Sweden and NordForsk.

Mapping the sea ice and marine primary production

Arctic sea ice has been dwindling over the past decades. This affects marine primary producers such as diatoms and blue-green algae, which are the basis for the marine ecosystem in the Arctic, and this, in turn, has repercussions for marine food chains, the carbon cycle and the fishing industry. In April and May, researchers from GEUS gathered sediment cores from the sea floor under the frozen Wandel Sea at Station Nord in North-East Greenland to reconstruct long-term changes in the marine primary production caused by changes in sea-ice cover. Sediment cores from the sea floor contain information about climate and environment conditions going back thousands of years, and important parameters such as temperature, salinity, sea-ice cover and productivity can be reconstructed using a combination of geochemical, sedimentological and micropalaeontological indicators. The new data will make it possible to develop more reliable forecasts of developments in the Arctic using sea-ice and ecosystem models. The project is financed by the VILLUM FONDEN Young Investigator Programme and the fieldwork was organised by the Arctic Science Partnership jointly with the Arctic Research Center at Aarhus University.



GEUS around the world

Knowledge-building in developing countries through research and consultancy



Research and capacity building in Zambia

In 2015, GEUS finalised a Danida water sector programme in Zambia which was to promote effective and sustainable exploitation of the country's water resources. GEUS headed a sub-project in the programme, which aimed at supporting and developing teaching and research competences in the water sector. During the project, two Zambians earned their PhD, while eight Zambians obtained MSc degrees. Part of the programme involved participation in a research project which examined occurrences of saline groundwater in the western part of Zambia. Through airborne, geophysical surveys and drilling, this project mapped the extent of the saline groundwater. The results show that the source of the salt is deposits in the subsurface originating from an large, old salt lake, which used to cover part of the current northern Botswana as well as the south-western part of Zambia. The work took place as a collaboration between GEUS, the University of Zambia, the Technical University of Denmark and Aarhus University.

Clean drinking water in Vietnam

In some places, the groundwater pumped up from the flood plain around the Red River in Vietnam contains high concentrations of arsenic. Arsenic occurs naturally in the sediments under the flood plain, but natural geochemical processes in the groundwater system mean that the arsenic is mobilised and migrates into the groundwater. As the groundwater is of good bacteriological quality, all drinking water in the area is extracted from these aquifers, however contamination with arsenic is now threatening the supply. For several years, with funding from Danida, GEUS has been working to procure new knowledge about the mechanisms that are causing the presence of the arsenic in the groundwater aquifers. This work has revealed that the contamination with arsenic is linked to areas of the flood plain with the youngest sediments. Backed by funding from the European Research Council, GEUS is now working to procure new knowledge about the age of the sediments in the flood plain. The objective is to identify areas where drinking water without arsenic can be pumped up. This

work includes dating sediments and groundwater, and in 2015 GEUS and researchers from the University of Copenhagen used satellite data to map the sediment pattern in the flood plain, both spatially and temporally.



Sustainable small-scale mining in Cameroon

The Government of Cameroon wants to promote mining in the country through research and development within mineral resources. The ultimate goals are economic growth and job creation. The mining sector in Cameroon is still very young, and although there are several signed mining operation contracts between the Government and mining companies, there are still no ongoing mining operations. However, small-scale mining (SSM) has long been a source of income for many people, especially in southern and eastern parts of the country where many people dig for gold and diamonds. The economic and social situation for the SSM industry is very uncertain because of insufficient organisation and access to markets where miners can sell their minerals. Furthermore, gold and diamond diggers have difficulties financing their activity through e.g. micro loans and many of them suffer under poor working conditions and from tropical diseases.

GEUS is participating in a project in Cameroon to give the Government better opportunities to improve conditions for the SSM industry. This project includes an analysis of working methods, organisation and socio-economic and environmental issues, and it will investigate opportunities and barriers to recruiting more women to the industry. Finally, workers will be trained to use better working methods and focus their attention on creating a sustainable industry in terms of finances, health and the environment. GEUS is a sub-contractor in the project, which is being headed by La Fundación Alianza por la Minería Responsable (ARM) of Columbia and is financed by the World Bank.

Collaborative petroleum geology work in Vietnam

Since 1995, GEUS has been working on capacity building in Vietnam in order to enhance the country's ability to assess its oil and gas resources. GEUS' research and training activities, which were completed in 2015 and were funded under Danida's ENRECA programme, have gradually transformed into collaboration. Together with the national oil company PetroVietnam, the Vietnam Petroleum Institute (VPI) and an international oil company, GEUS concluded a project in 2015, which analysed possibilities for discovering oil-generating source rocks in Vietnam. Furthermore, with financial backing from an international oil company, GEUS is studying large-scale geological development to understand the hydrocarbon potential in south-east Asia. Finally, GEUS is exploring opportunities to utilise its extensive experience with capacity building in Vietnam within the areas of energy and water to assist with similar knowledge and competence building in Myanmar, where Denmark opened a new embassy in 2014. In 2014 and 2015, this work included establishing local networks and contacts.

Glimpses from the year



Dissemination of knowledge about mineral resources

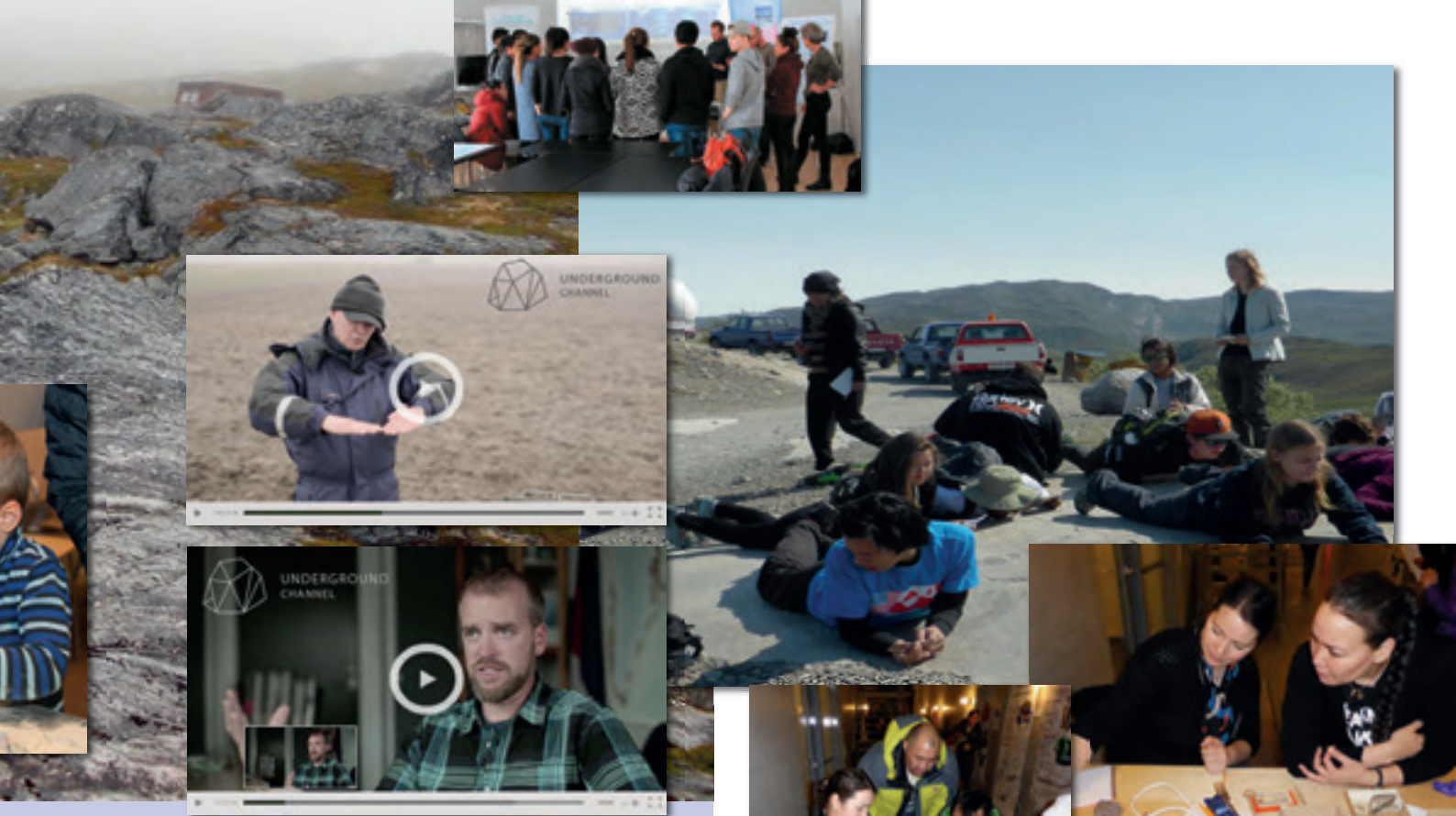
The Center for Minerals and Materials (MiMa) at GEUS examines and disseminates information about the mineral resources value chain; from exploration and extraction over consumption to recycling and development of new technologies. For example, MiMa publishes fact sheets with descriptions of occurrences, uses, production conditions and supply risks for a number of the world's most important mineral resources. In 2015 MiMa published six fact sheets and the centre's website at mima.geus.dk contains information about aluminium, graphite, gold, chromium, the platinum-group metals, silver, tin, uranium and wolfram. MiMa also examined the significance of mineral resources for Danish industry, jobs and the economy and published a report on the subject. This and other reports on surveys of Danish mineral resources and selected Greenlandic mineral resources are available on the MiMa website. MiMa Meetings are events at which important issues related to the socio-economic significance of mineral resources are discussed by some of the most experienced experts in the world.



New video channel launched

A new geoscientific video channel was launched in 2015. Through the video media, the new *Underground Channel* provides viewers with answers to complex questions about the challenges facing the Earth, such as climate change, mineral resources exploitation, drinking water protection and dramatic phenomena such as earthquakes, volcanic eruptions and tsunamis. The *Underground Channel* is targeted at students in primary and lower-secondary schools and high schools as well as people who care about our common future and are keen to learn about the state of the Earth: the powerful forces of nature, the scarcity of resources and possible future scenarios.

During 2015, more than 30 videos were produced on topics allowing viewers to follow researchers at work in the field, join lectures by international experts, and gain insight into the work of individual researchers in the field of geoscience. *Time travel for groundwater* and *Hunting for mass extinction* are two examples of a series of videos where viewers can follow in the footsteps of GEUS researchers in their search for groundwater aquifers and for an explanation of a previous mass extinction event on Earth. Geocenter Denmark is behind the channel, which is a formalised collaboration between: The Natural History Museum of Denmark and the Department of Geosciences and Natural Resource Management (University of Copenhagen), as well as the Department of Geoscience (Aarhus University) and GEUS.



Geology on the curriculum in Greenland

Geologists from the Nuuk office of GEUS were busy teaching students geology over the summer of 2015. In July at Kangerlussuaq, a group of high school students from Denmark, Greenland and the USA were given a tour of the area and were taught about geology and mineral resources. The event was part of the natural science summer school in Greenland under the Joint Science Education Project, which is a collaborative effort between Greenland, the USA and Denmark. Also in August a group of Danish high school students visited Nuuk as part of a Master Class to learn about Greenland and to gain insight into current conditions in Greenland. The Danish students could see and learn about Greenland's nature first-hand on a field trip to Kobbefjord and during a session at Nuuk Gymnasium, they were taught both geology and biology by researchers from GEUS and the Greenland Institute of Natural Resources.

In November, geologists from GEUS participated in Science Day at the Greenland Institute of Natural Resources. Around 150 16–18-year-old students from Nuuk Gymnasium visited the event to get a taste of the biological and geological sciences. Finally, GEUS was also present at an education/career day at Nuuk Gymnasium in November which focussed on education paths and companies. Students heard about various geography and geology programmes and about working at GEUS and Asiaq – Greenland Survey, the Greenland Ministry of Mineral Resources and the Greenland oil company Nunaoil, which were also present.

Culture nights prove popular

As many as 1550 Copenhageners stopped by at GEUS on Øster Voldgade in Copenhagen in October when the Ministry of Energy, Utilities and Climate opened its doors to the public during the Polar Bazar culture-night event. Employees from the Danish Meteorological Institute, the Danish Energy Agency, the Danish Geodata Agency and GEUS welcomed visitors with an exciting programme about the Arctic. Visitors could experience life in a polar camp, see the ice melt, dig for fossils, navigate a boat in the Arctic waters and test their strength against the cold katabatic wind in Greenland (the Piteraq). Gold washing was a popular activity, set up in a 'mine tunnel' in the basement under GEUS. Many visitors also seized the opportunity to hear about the many alluring Greenlandic rocks and even take some home. Furthermore, in January GEUS in Nuuk and the Greenland Institute of Natural Resources opened their doors to the public during the annual Culture Night. The event, which spanned three hours, had 963 visitors, who heard about and saw examples of Greenland's ore deposits and oil-bearing rocks, and rock collectors could have their rocks determined by experts.

Key figures for 2015

More detailed key figures for the activities of GEUS are available in *Årsrapport – Regnskabsåret 2015 (Report and Accounts 2015)*, and in *Faglige resultater 2015 (the latter in Danish only)*. Both of these are available at www.geus.dk – publikationer – institutionsrapporter.

Number of employees: **313**

Number of scientific projects: approx. **650**

ACCOUNTS 2015

Amounts in million DKK

Revenue	284.3
Net figure (appropriation)	138.2
Operating income	146.2
Expenditure	285.0
Salaries	172.4
Other operating expenditure	112.5

INFORMATION ACTIVITIES

Long-term knowledge building

Articles in international scientific journals/publications	179
Other scientific publications	13
Conference contributions with abstracts or posters	187

On-going scientific tasks, consultancy and presentation

Publicly available reports	103
Confidential reports	25
Memoranda, opinions, expositions etc.	44

General information

Institution reports (annual report etc.)	4
General and popular-science presentations - including popular-science lectures	114
	63

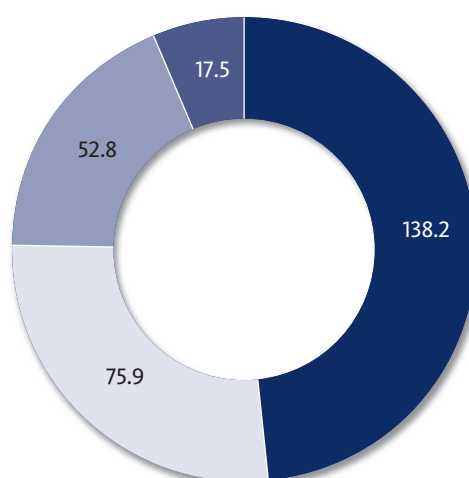
Use of GEUS web

Visits to www.geus.dk	519,000
Use of GEUS' web map services	2.8 mio.

RESEARCHER TRAINING WITH GEUS TUTORS

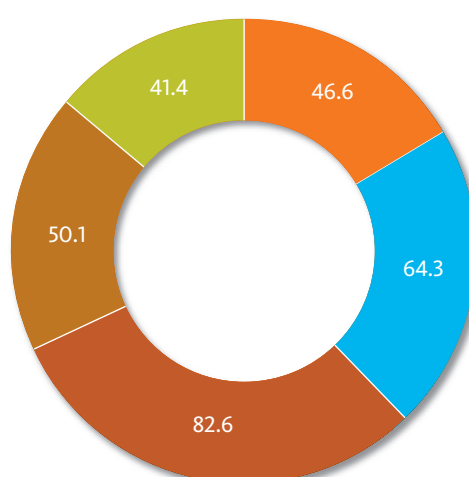
Current PhD students	52
Completed PhD degrees	17

Revenue broken down by sources of revenue in million DKK



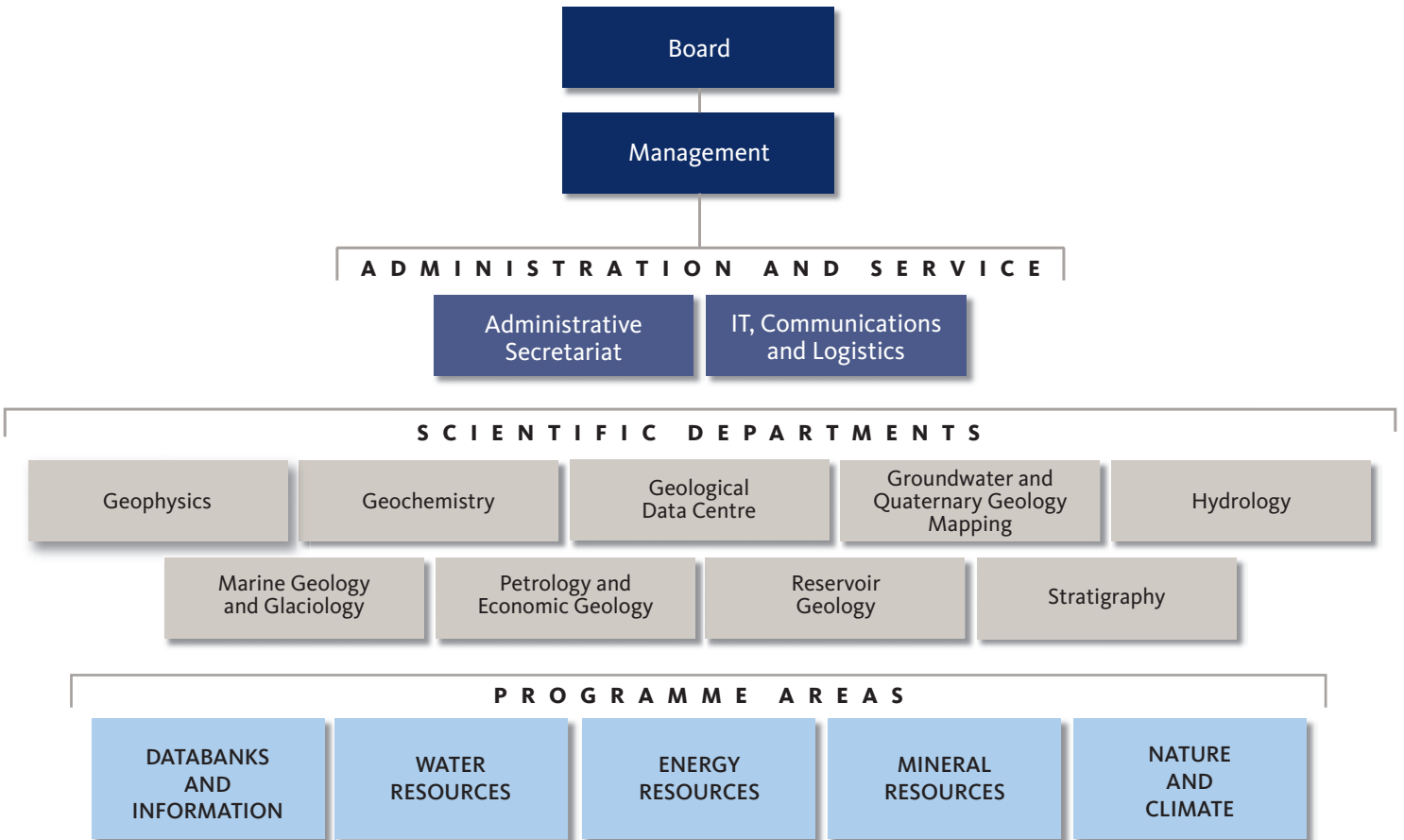
■ National budget and supplementary government appropriations:	138.2
■ Programme and external resources:	75.9
■ Other co-financed contract research:	52.8
■ Commercial contracts and sales of data:	17.5

Expenditure broken down by programme area in million DKK



■ Databanks and information:	46.6
■ Water resources:	64.3
■ Energy resources:	82.6
■ Mineral resources:	50.1
■ Nature and climate:	41.4

Organisation



In 2015 there were nine research departments at GEUS and two administrative/service departments. Scientific work is being done in five programme areas, where tasks are carried out in project groups in a matrix structure.

Programme areas:

Databanks and information

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 operation and development of GEUS' IT infrastructure as well as communication to the scientific community and the public.

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 abroad.

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.



Danish Ministry
of Energy, Utilities
and Climate

ISBN: 978-87-7871-436-7



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Energy
Minerals
Nature
Climate

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Layout and cover: Carsten E. Thuesen, GEUS. Photos: Peter Warne-Moors, Jakob Laurrup and others.
Reprographic work: Benny Schark, GEUS. Print: Rosendahl - Schultz Grafisk A/S.
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