

RESOURCES AND CLIMATE



water

energy

minerals

nature



ANNUAL REPORT 2008

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY



Launch

of Geocenter Denmark - new professor to strengthen climate research

The Danish geoscience environment was strengthened further in 2008 with the establishment of Geocenter Denmark with about 600 employees and 1,000 students from the Department of Geography and Geology and the Geological Museum at the University of Copenhagen as well as GEUS and the Department of Earth Sciences at the University of Aarhus.

The objective of Geocenter Denmark is to establish a national centre for geoscience research, education, consulting, innovation and communication at a high international level, and this is stated in the Center's new statute, which entered into force on 1 June 2008.

Geocenter Denmark is a binding collaboration between the independent institutions, and it is to secure a strong international research and education environment for the geoscience field. In a historical perspective, establishment of the Center is an extension of the previous Geocenter Copenhagen to now include the University of Aarhus.

The Center was launched at a personnel day at which external lecturers spoke about the challenges and expectations facing the Center's research, and all the Center's staff and PhD students discussed development opportunities within research, education and communication at workshops.

One of the most important research fields is climate. Never before has the climate been so high on the national and international agenda, and the geosciences are pivotal with regard to describing and responding to the many issues relating to climate change both in the past and in the future. In May, Professor Jörn Thiede took up the position of professor for Geocenter Denmark, and he will help strengthen climate research at the Center.

Together with the researchers at Geocenter Denmark, he will help add even more fuel to climate research. This will include establishing new education programmes within climate and marine geology with focus on polar areas, and

attracting more international and national climate-research projects to the Center. Finally, he is to promote participation by Geocenter Denmark in international research networks within climate research and contribute to consulting services from the Center on climate issues.

Over the past ten years, Jörn Thiede has been a director at the German Alfred Wegener Institute for Polar and Marine Sciences (AWI), and he is a professor in oceanology at the University in Kiel.

Read the Statute and research profile of Geocenter Denmark on the Centre's website at: geocenter.dk.



GEOCENTER
DANMARK

Introduction

The 2008 Annual Review provides a brief insight into a challenging year during which the significance of geoscience for society has received a lot of international attention.

In 2008, GEUS found its place in the new Danish Ministry of Climate and Energy, while also maintaining close cooperation with its primary stakeholders, the Ministry of the Environment, the Greenland Home Rule and the Ministry of Science, Technology and Innovation.

Climate change and its possible effects have impacted both the scientific and political agendas. At GEUS we have focused on the areas in which we can contribute to research-based decisions. We have advised on water, ice, nature and renewable energy, and we have also worked with fossil-fuel resources, as these are still an important part of energy production and security of supply.

Work in Denmark on preventing flooding and securing the groundwater resource has aroused great interest in GEUS' model calculations of the water cycle, while in the energy field there has been focus on the possibilities of geothermal heat and storage of CO₂. Monitoring of Greenland's ice sheet is progressing well and with a great deal of outside interest.

The possibility of oil/gas resources in Greenland and the Arctic has attracted international interest. Therefore, in 2008 GEUS launched a long-term programme in North-East Greenland to reveal the area's hydro-carbon potential.

Interest in minerals in Greenland has also been extensive for most of 2008, but the financial crisis has temporarily toned down activity. Work by GEUS and the Bureau of Minerals and Petroleum to develop areas and arouse interest in mineral exploitation continues, however.

The "yes" from Greenland in the referendum in November 2008 on self governance is expected to lead to new cooperation agreements between GEUS and the Bureau of Minerals and Petroleum which, in line with recommendations from the Self Governance Commission and existing agreements between the Danish government and the Greenland Home Rule, will establish a long-term, continuous and promising collaboration to the benefit of both parties. Mapping the continental shelf in five areas as the

basis for Danish territorial claims has put the work of GEUS into a new international context and attracted overwhelming international interest from the public and many organisations who want information about the project and about the Convention of the Law of the Sea.

In 2008, GEUS expanded its participation in international collaboration. GEUS is now represented on the board of EuroGeoSurveys and it has set up a project unit with four other surveys to form The North Atlantic Geoscience Group which will gather research expertise on the North Sea/North Atlantic. International project work, especially with the Third World has also grown, and new partners have formally applied to work with GEUS, including the China Geological Survey (CGS).

In 2008, the Nordic countries hosted the International Geological Congress in Oslo, with 6,000 delegates. GEUS had a leading role for Denmark in planning the Congress, and the Danish Minister for Climate and Energy, Connie Hedegaard, was a key guest on the climate day.

During its initial year, Geocenter Denmark has developed well, with several joint projects and improving national and international influence. The Center also established a joint professorship in climate research, to which Prof. Jörn Thiede, previous director of the Alfred Wegener Institute, was appointed.

On the financial side, we are pleased to report that in 2008 GEUS was granted access to basic funding from the globalisation pool on an equal footing with universities. We hope that this development will continue.

2008 has been a challenging year, both organisationally and financially, but GEUS has emerged successful from these challenges. We are looking forward to 2009, confident that growing international cooperation and recognition of GEUS as an important research institution with activities of special interest to society will establish a stable financial foundation for the institution.



Per Buch Andreassen
Chairman of the Board



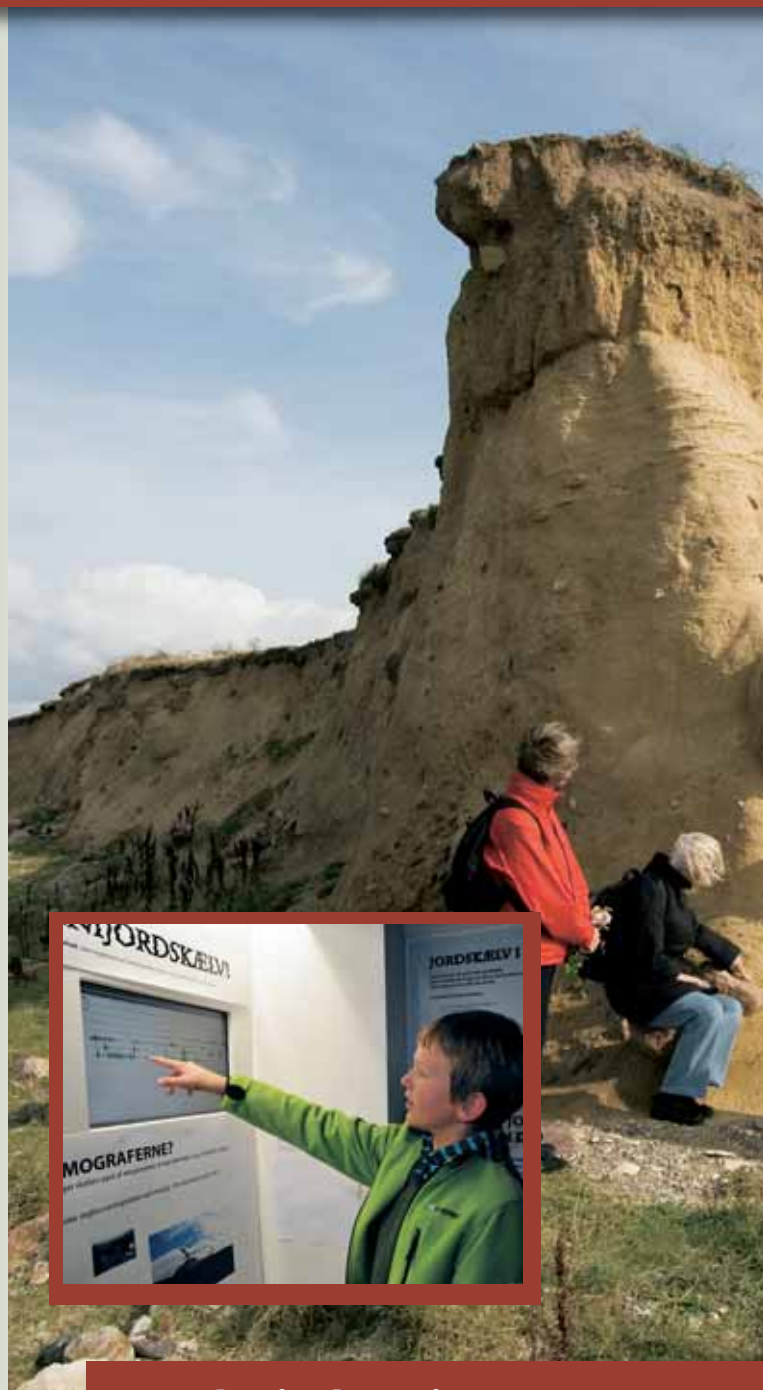
Johnny Fredericia
Managing Director

Popular science about Greenland in English

It has finally been published - the long-awaited book in English about the geology of Greenland *Geological History of Greenland - Four billion years of Earth evolution*. The book is an English translation of the popular-science book in Danish called *Grønlands geologiske udvikling - fra urtid til nutid*, published by GEUS in 2005. The terrain in Greenland reflects the geological history of the Earth over 3,800 million years. This book takes us on the long journey back in time and along the coast of the world's largest island. It is a fascinating story of building and erosion of mountain chains and of roaring volcanoes and tropical coral reefs. The impressive, naked terrain in Greenland makes it possible to read this story. The book summarises the results of more than 60 years of geological surveys of onshore areas and the continental shelf; it explains the geological processes and it illustrates the economic resources lying underground in Greenland. There has been, and still is, great interest in the Danish version, which is now in its second printing, and shortly after publication GEUS received many enquiries about an English version. This is now available.

A look at Mother Earth in her nakedness

One of the main attractions of the 33rd International Geological Congress in August in Oslo was the presentation of the first digital geological map of the entire world. Geologists were able to admire our world in its nakedness; stripped of plants, soil, water and man-made structures. The map is the result of the largest ever geological mapping project, in which geologists from 102 countries worked together to create a global geological foundation for managing the world's nature and resources. Geological maps are an important tool in finding water, oil and minerals, or in averting the consequences of natural disasters such as earthquakes and volcanic eruptions. Data are available on a web portal as a dynamic geological map which is constantly being updated as new data tick in from throughout the world. The map is the result of the OneGeology project and it presents the rocks beneath our feet in the same way as Google™ Earth presents maps of the Earth's surface. GEUS is contributing digital geological map data from Denmark and Greenland. OneGeology is a joint contribution from the geological surveys to the UN International Year of Planet Earth 2008, which has activities running from 2007 to 2009.



Geological stories direct to the Danish public

In 2008, Danes had ample opportunity to become acquainted with the geology of Denmark and meet researchers from GEUS. In the last weekend of September, several thousand people went out into the countryside to experience the 76 tours and events taking place on 'Geology Day'. At coastal cliffs, gravel pits and in the rolling countryside, geology experts from throughout Denmark were ready to talk about the history of Denmark's geological gems. During the Research Day in May and the Natural Science Festival in September, geologists from GEUS visited schools, libraries, enterprises



d information

Storage, quality assurance and presentation of geological knowledge and data



Geodata in a European perspective

Just like the rest of the world, the European community increasingly needs access to nature and environmental data across man-made borders in order to manage resources in the best possible way. Exchange of geodata and environmental data is therefore very important for the EU. During 2008, GEUS worked on several research projects supported by the EU to promote the exchange of geodata across European national borders. The Geomind project developed a data portal for geophysical metadata giving the user an insight into which types of data that are available from nine EU countries and how to obtain the data. Similarly, the eWater project developed a data portal covering hydrogeological data from 14 EU countries, in which it is possible to search for information on groundwater levels and chemistry. Both portals are in several languages. Finally, GEUS is taking part in the OneGeology-Europe project which aims at developing a digital geological map of all of Europe in 1:1 000 000 scale. The geological data will be available via a web portal in which maps and information about the surface geology can be found in many languages. The projects support the EU INSPIRE Directive on establishing a common European infrastructure for spatial information to enable easier exchange of data over national borders.



Extended and more user-friendly access to data on wells and water

GEUS' Jupiter public sector database gives access to nationwide information on wells, groundwater and drinking water. The database is part of the Danish Nature & Environment Portal together with other nationwide databases with nature and environmental information. The database is used every day by employees at municipalities, regions and environment centres who are involved in managing groundwater, the environment and minerals. During 2008, a new user-management system was developed so that employees at municipalities can work with the Jupiter database directly through their own IT systems, and access to the database has been improved, for example for those taking samples in the field. They can now access well data typing in locations and coordinates using mobile equipment such as cell phones or PDAs. The Jupiter database has also been expanded during the year and now it contains water-quality data for water being treated at water works and geochemical data from wells which monitor possible leakage from landfills. Finally a large number of locations and landfill control data have been entered from databases kept by the former Danish counties.

and organisations all over Denmark to talk about climate change, green energy and our vital groundwater. The final large events of the year took place during the Night of Culture in Copenhagen in October at which people could meet geologists from GEUS at events at the Geological Museum and at the Danish Energy Agency to hear about climate, energy, earthquakes and beautiful minerals. The nationwide activities under 'Geology Day' were coordinated by *Den Danske Nationalkomité for Geologi* in collaboration with the Forest and Nature Agency, GEUS, the Geological Museum and the Geological Institute at the University of Aarhus.

New tools for assessing future water resources

Calculations of the effects of climate change on the water cycle in Denmark show that we can expect great changes in the distribution of Danish water resources in the future. Some locations will see more frequent flooding, while others will experience water shortages. A new project, HYACINTS, has started to develop better tools to assess the effects of climate change on Danish water resources, both nationally and locally. Over the next few years, the project will develop a method to couple the climate model directly with the hydrological model, which calculates water flows underground and on the surface. "In the real world, the earth's surface and the atmosphere are constantly influencing each other and this is the effect we want to see built into the calculations of our water resources," said Jens Christian Refsgaard, research professor at GEUS and head of the project. The basic elements are the regional climate model, HIRHAM, from the Danish Meteorological Institute (DMI) and GEUS' national hydrological model - the DK model. The project will also mean that the nationwide DK model can supply better calculations of water resources in small, local areas. Finally, the project will produce comprehensive assessments of the uncertainties in the calculations to ensure the best possible forecasts for future water resources. HYACINTS methods and tools are expected to have export potential for the Danish water sector, and therefore the project will also develop methods to estimate precipitation conditions by using satellite data, especially in the Third World where there is often a lack of data and where the mountainous landscape greatly influences the distribution of precipitation. The project includes participants from the University of Copenhagen, the University of Aarhus, GEUS, DMI, DHI and the consulting firms Alectia Aqua and GRAS, the water companies *Københavns Energi*, *Aarhus Kommune Værker* and *Odense Vandselskab* as well as Environment Centres Roskilde and Odense. HYACINTS (Hydrological Modelling for Assessing Climate Change Impacts at different Scales) is being funded by the Danish Council for Strategic Research.

Water cycle under scrutiny

Hydrological models are important tools used in management of Denmark's water resources, or to forecast the influence of climate change on the water cycle. The quality of calculations using the models depends very much on how well we can describe the processes which control the water cycle. Experience shows that it is often necessary to adjust the model calculations considerably in order to make them fit the values measured. This is partly because we lack sufficient knowledge about the processes controlling the water cycle, such as the distribution of precipitation, evaporation from different surfaces, and the exchange of water between the surface and the groundwater. In the Skjern River basin, researchers from the HOBE research centre are studying the hydrological processes in order to set up more credible models to calculate how water flows in the basin and in what quantities. In 2008, three field stations were built to measure precipitation, evaporation, temperature and groundwater charge in areas which represent the three typical Danish surfaces; meadows, fields and forests. Seismic measurements and borings have been made along the eastern coast of Ringkøbing Fjord in order to draw up a detailed description of the geology of the area as an important factor in calculations of the quantities of groundwater flowing into the sea through the seabed. The work at the centre is being carried out by researchers from the University of Copenhagen, GEUS, the University of Aarhus, the Technical University of Denmark and the Danish Meteorological Institute. HOBE (Center for Hydrology – Hydrological Observatory) is a VKR Centre of Excellence with funding from the Villum Kann Rasmussen Fonden.

Water r



Development of new sensors to monitor drinking water

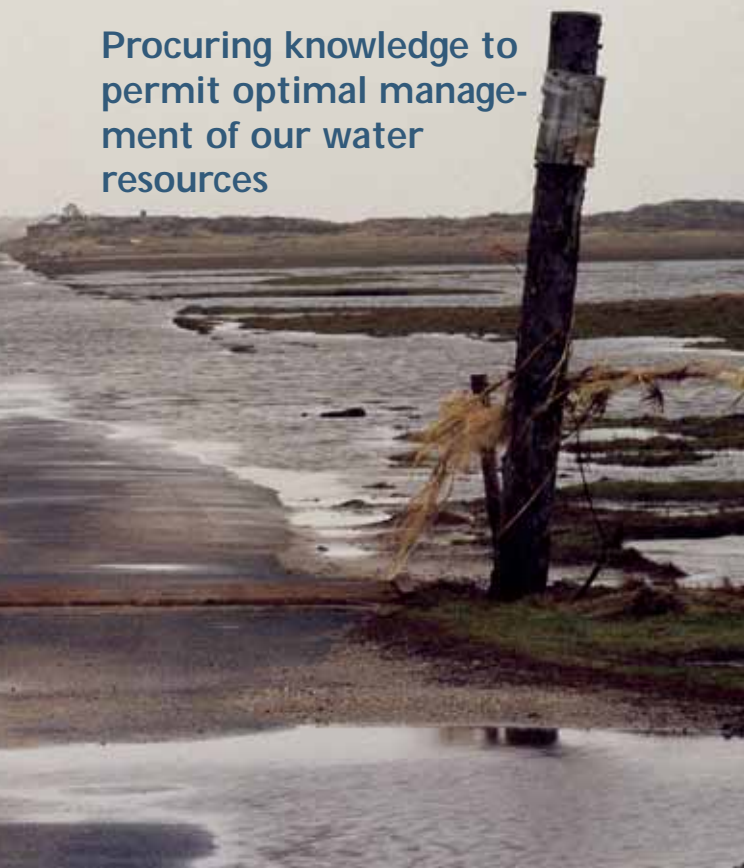
The quality of drinking water is monitored today from monitoring wells drilled by the water works, from which samples are taken regularly and sent for analysis at a laboratory. GEUS is participating in the ENSOWAQ project, which is developing a number of new sensors to give early warning of polluted water. The small sensors will be built into the water intake in monitoring wells and they will continuously measure the presence of undesirable substances in drinking water. The project will develop sensors which can trace chemical substances and sensors which can measure whether there are microbiological organisms such as bacteria in the water. GEUS is heading work to develop a sensor to trace BAM, a degradation product from the pesticide dichlorobenil, which remains a problem for the groundwater despite having been banned for some time. The work is based on GEUS' earlier immunochemical research during which antibodies were developed which can show the presence of the pesticide. The method has been developed to analyse individual samples and work in 2008 aimed at adapting the method to conditions where water is continually flowing past the measuring sensor. Work was carried out in cooperation with DHI, the Technical University of Denmark, *Københavns Energi, Statens Serum Institut* and Mikrolab Århus A/S, with funding from the Danish Council for Strategic Research.

Assessment of the effect of climate on pesticide leaching

Climate change in Denmark may have several undesirable consequences. Climate models tell us that in the future there will be more and heavier rain, and therefore we can expect more leaching of pesticides to the groundwater, lakes and water-courses. Changes in the climate are also expected to influence the choice of crops, and new varieties are expected to be introduced, requiring the use of different pesticides. This may lead to undesirable impacts from spray pesticides on the aquatic environment. In order to put these climate effects into figures, GEUS has launched the PRECIOUS project in cooperation with the Danish Meteorological Institute (DMI) and the Faculty of Agricultural Sciences at the University of Aarhus (DJF). Using scenarios of the future climate, choice of crop and use of pesticides, this project is to calculate changes in pesticide leaching into the aquatic environment. The work involves setting up scenarios of climate development and calculations of the fate of pesticides in the aquatic environment using different modelling tools. The assessment of the expected changes in crop choices and pesticide use will be based on studies of cultivation practices in France, Germany and the Netherlands. Changes in pesticide leaching will be calculated for two upland areas included in the Danish groundwater monitoring system. These are the Odderbæk upland in Himmerland with sandy soil, and the Lillebæk upland on Funen with clayey soil. The PRECIOUS project (Prediction of Climate Impacts on Pesticide Leaching to the Aquatic Environments) is being supported by the pesticide research programme being run by the Danish Environmental Protection Agency.

resources

Procuring knowledge to permit optimal management of our water resources



Climate and water resources in the North Sea region

The year 2008 saw the launch of a new research project, CLIWAT, which is to evaluate the effects of climate change on the hydrological cycle in the North Sea region in order to establish a basis for planning appropriate climate adaptation in the area. Climate models have indicated that in the future we can expect more frequent flooding in the region and increasing problems because of algae growth along coastlines caused by the expected increased leaching of nutrients from the groundwater to the sea. Finally, we can expect more migration of salt water into the groundwater because of increasing sea levels. Using calculations with hydrological models, the project will assess these effects for selected climate scenarios. Work includes collecting new geological and hydrological data along the coast and in the hinterland in selected areas in Belgium, the Netherlands, Germany and Denmark. During the year researchers started setting up a hydrological model across the border between Denmark and Germany as well as collecting field data on the current nitrate load as a basis for estimating future leaching of nutrients. Researchers from GEUS are working on the project with researchers and personnel from municipalities and regions in the four countries along the North Sea. The project is being funded by the European Regional Development Fund.

Procuring of knowledge
for continued exploration
and exploitation of energy
resources in Denmark and
Greenland

Energy resources

CO₂ storage in Europe

Capture and storage of CO₂ underground is one of the methods which can be used to limit emissions of the greenhouse gas to the atmosphere. For several years now, Europe has been focusing on CCS technology (Carbon Capture & Storage) in many EU-funded, international research projects. One of these projects is GeoCapacity, which is headed by GEUS. The project was concluded in 2008 and it has established a solid foundation for assessing CCS as a method of reducing CO₂ emissions for all of Europe. The results include development of a standard for the assessment of the storage capacity of underground reservoirs as well as a GIS database of large CO₂ sources and storage sites in 25 European countries. The database includes information about CO₂ emissions from industry and power plants and infrastructure such as pipelines. Potential geological storage sites are also found here. The results in the database have already been used in connection with preparation of the proposed EU directive on geological storage of CO₂. Like another EU project in which GEUS is also taking part (COACH), GeoCapacity has worked on transferring competences within geological storage of CO₂ from the EU to China. Knowledge from the research projects will be brought into play in international fora in which GEUS is represented. One of these is CO₂GeoNet, a European Network of Excellence which aims at enhancing Europe's scientific and technological position within CO₂ storage by bringing together resources and expertise. At the end of 2008, the network published the brochure *What does CO₂ geological storage really mean?* In the brochure the reader will find answers to questions such as: how does the method work, where is it possible to store the greenhouse gas and how safe is the method? The aim of the brochure is to communicate clear and impartial scientific information to a wide public and to inspire dialogue on important issues related to the technical aspects of the method.



Lots of geothermal energy

Global climate problems call for new energy solutions which can reduce emissions of CO₂ into the atmosphere. Heat from inside the Earth in the form of geothermal energy is one of the energy sources available. In Denmark, geothermal energy is exploited at plants on the island of Amager and in Thisted. Hot water is drawn up from water-bearing sandstone layers 1-3 kilometres down in the subsurface. For many years, GEUS has worked on developing geological models to describe and predict where there are geological layers in the subsurface with hot water in sufficient amounts and which can be pumped up to the surface. In 2008 this work included assessments of four reservoirs in eastern Sealand on behalf of *Hovedstadsområdetets Geotermiske Samarbejde* (HGS). In early 2009 HGS published a new assessment showing that the geothermal reserves in eastern Sealand can satisfy 30-50 per cent of the Greater Copenhagen district heating requirement for several thousand years. The many years of survey work by GEUS has revealed that Denmark has many deep sand layers bearing hot water. In 2009 the Danish Energy Agency and GEUS will prepare a report on the extent of geothermal reservoirs as well as the opportunities and limitations of geothermics in all of Denmark.

D.Sc. in oil-forming coals

The majority of the oil produced around the world has been formed by algae in rocks deposited in the sea. Coal is formed from plants on land which first settle in bogs and then become turf. The chemical composition of this plant material has historically led researchers to believe that coal is a source of gas rather than oil. New research results in a doctoral thesis, defended by Henrik Ingermann Petersen from GEUS at the end of November 2008, contest this belief and show that the age of the coal is extremely significant for its ability to generate oil. His research shows that, due to the differences in the chemical composition of the coal, the oldest coal from the Carboniferous Period primarily forms gas, while the youngest coal from the late Cretaceous Period and from the Tertiary Period can form both oil and gas. The results will have a great impact on exploration for new oil deposits, and the oil industry has already shown interest in the new research. There is a suspicion that the oil in some oilfields in the North Sea originates from coal, and soon after the results were published, GEUS was approached by an oil company which wanted to know if oil-forming coal could be expected to be found in the Norwegian part of the North Sea.



New surveys of the oil geology in North-East Greenland

Recent years have seen growing interest from the oil industry in the high Arctic areas, and in 2007 the USGS published new figures for oil resources in North-East Greenland in connection with the American assessments of the entire Arctic area. The new assessments, which are based on cooperation with GEUS, show that the shelf areas in North-East Greenland have great interest in a hydrocarbon context. The geology of the offshore area has been poorly surveyed, partly because of the difficult conditions, and in 2008 GEUS launched a long-term programme to survey the analogous geological formations on shore in North-East Greenland in order to update and extend understanding of the oil-geological potential of the area. The projects have been part-funded by the oil industry and they will gather existing data in a GIS format as well as acquire new data. In 2008, drilling was carried out at Jameson Land in order to investigate one of the most important types of source rock in the North Atlantic. Stratigraphic and sedimentological surveys of other rock units in a larger area along the coast were also carried out. Finally, geologists have collected information about the uplift history of the onshore areas, and a comprehensive aerial photography campaign has secured a good foundation for later mapping of geological coastal profiles over a large area. The results of the project will help ripen North-East Greenland over the next few years for possible licensing rounds currently on the drawing board at the Bureau of Minerals and Petroleum in Nuuk.

Progress in the Continental Shelf Project

In 2005, Denmark ratified the United Nations Convention on the Law of the Sea, which opens for opportunities to claim subterranean and seabed resources outside the 200 nautical mile limit. A requirement for any claims is that there is a natural extension of the onshore area exceeding 200 nautical miles. Any claims have to be documented, primarily with information about sea depths and seismic data. Since 2004, GEUS has been busy acquiring and interpreting data from the five areas in question. These are one area in the Arctic Ocean, two off North-East Greenland and southern Greenland, and two areas north-east and south-west of the Faeroe Islands. In May and June, seismic data were acquired from the area south-west of the Faeroe Islands and in June and July the final seismic data and information on the depth of the seabed were collected in the area north-east of the Faeroe Islands. Interpretation of data from this area was completed in 2008, and the final documents for submission to the UN in support of claims to the area will be completed in early 2009. Information was collected about the depth of the seabed off southern Greenland, and the assessment of the LOMROG project was completed, which acquired data in the Arctic Ocean north of Greenland in 2007. On the basis of this evaluation, it was decided to plan a new data-acquisition cruise in 2009, with the icebreaker Oden as the platform. The Continental Shelf Project is being funded by the Ministry of Science, Technology and Development, with contributions from the Faeroese government, and work is being carried out as a collaboration between GEUS and other institutions from Denmark, the Faeroe Islands and Greenland.

Geological mapping and new mineral finds

Solid geological knowledge is important for exploration by mining companies, and therefore the industry wants detailed geological maps and maps of mineralisations. In recent years GEUS has been working intensively on geological mapping and assessing the mineral potential of the area around Godthåbsfjorden in West Greenland, while 2008 was the first year for similar efforts in the areas further south between Buksefjorden and Frederikshåb Isblink. Field work in the summer has included geological mapping in the Fiskenæsset area with a view to modernising the existing maps in the scale 1:100 000. In parallel with this mapping, ore geological surveys have been carried out in order to assess the opportunities for finding new mineral deposits. Activities are focusing on the Precambrian supra-crystalline rocks, which may contain mineralisations of precious and base metals. The work over the summer was extremely successful, and geologists found several new gold mineralisations and ruby deposits. The geological mapping has been carried out in a collaboration between GEUS and a number of universities from the UK, Sweden and Canada. The activities have been partly funded by the Bureau of Minerals and Petroleum in Nuuk.



Mineral res

Marketing Greenland's minerals

Targeted marketing of Greenland's minerals is one of the activities initiated to help attract investment to Greenland from the international mining industry. The mineral potential of Greenland is being marketed through direct contact with the industry, dissemination of knowledge via the media, and by giving easy access for the mining sector to publications and geodata. During 2008, in cooperation with the Bureau of Minerals and Petroleum in Nuuk, GEUS took part in two large minerals fairs in Vancouver and Toronto, at which investors and the mining industry met to consider the potential of investments in the exploration and mining sector. In addition, information about exploration activities and the geology of Greenland is also reported through the newsletter 'MINEX' as well as the thematic magazine 'Geology and Ore' and the fact sheet 'Exploration and mining in Greenland'. Service for the industry also includes easy web access to extensive data and publications in databases which are regularly updated as the work in Greenland progresses. This means online access to open company reports and geoscientific publications and data in the DODEX database and presentation of mineral deposits and other geodata via the web facility Greenland Mineral Occurrence Map (GMOM). At the end of 2008, the international mining industry was feeling the effects of the global financial crisis, but there is still considerable interest in Greenland.

Conclusion of successful public diamond surveys

The occurrence of diamonds in Greenland has been known for many decades, but not until the opening of diamond mines in Canada has the mining industry shown serious interest in West Greenland. In the 1990s there was a large-scale search for diamonds and several mining companies have retained their interest. With support from the Bureau of Minerals and Petroleum, in recent years GEUS has followed up on the work of the companies with scientific surveys of kimberlitic rocks in western Greenland and compilations of non-confidential company data. GEUS completed this work in 2008 and the results of the long-term efforts were presented at the 9th International Kimberlite Conference in Frankfurt in August. The extensive results have been included in a new atlas of kimberlites in West Greenland, the first edition of which was completed during the year. The atlas contains information about deposits and the chemistry of kimberlites and kimberlite-like rocks as well as information about the geological conditions in the areas where they are found. Public efforts have helped sharpen interest from the mining industry in diamond exploration in Greenland, and the results of work by both GEUS and the companies have in recent years led to an increasing number of diamond finds in Greenland. 2008 was no exception as in November the Avannaa Resources company could report finds of 1,487 diamonds in the Disko Bay area, including 10 macro diamonds.

Creating the scientific basis for targeted and environment-friendly exploitation of mineral deposits in Greenland and Denmark

ources



New book about the fold mountains of North-East Greenland

A new book about the fold mountains of North-East Greenland entitled *The Greenland Caledonides. Evolution of the North-east Margin of Laurentia* was published in 2008 in the series *Memoirs Geological Society of America*. The book presents a review of the results of the comprehensive mapping by GEUS of the entire northern part of East Greenland. The mapping was carried out between 1968 and 1998 and the results have been published regularly in several hundred scientific reports as well as 16 maps in the scale 1:100 000 and five less detailed maps in 1:500 000. In 14 chapters the book reviews the geological development of the region, which is primarily composed of fold mountains formed during the Caledonian orogeny about 400 million years ago. A geological map of all of North-East Greenland and a CD with the map accompany the book. The 26 authors of the book are employees of GEUS as well as external geologists who have taken part in the mapping. A vital part of the planning, organisation and practical design of the text and illustrations in the book was done by GEUS with funding from the Carlsberg Foundation.

Marine raw materials in Denmark

Denmark is more or less self-sufficient in raw materials for building and construction. Resources such as sand, gravel and clay come primarily from quarries on shore and the increase in extraction in some areas conflicts with the desire to preserve landscapes and nature. Therefore, attention is being directed towards raw materials on the seabed, and in recent years GEUS has been mapping landscapes and sediments on the seabed. In contrast to the Danish coastal waters, the North Sea has been poorly surveyed. This means that very little is known about the mineral resources in this large area, apart from the areas nearest the coast where, on behalf of the Danish Coastal Authority, GEUS has mapped sand deposits for coastal protection. In 2008, GEUS compiled a review of available data on the North Sea in order to prepare and optimise a marine geological survey. At the end of the year, work began in earnest when the EU granted funding for a project to map the landscapes and deposits on the seabed with a view to making a habitats map. As part of the move towards more sustainable exploitation of raw materials, in 2008 GEUS completed a project in the Storstrøm area in cooperation with the Agency for Spatial and Environmental Planning, which aimed at examining how we can best coordinate extraction both offshore and onshore. Finally, as a consultant for minerals companies, GEUS has carried out marine geological surveys north of Funen and in Køge Bugt in order to assess the available data on the areas.



Renewable energy from the ice sheet

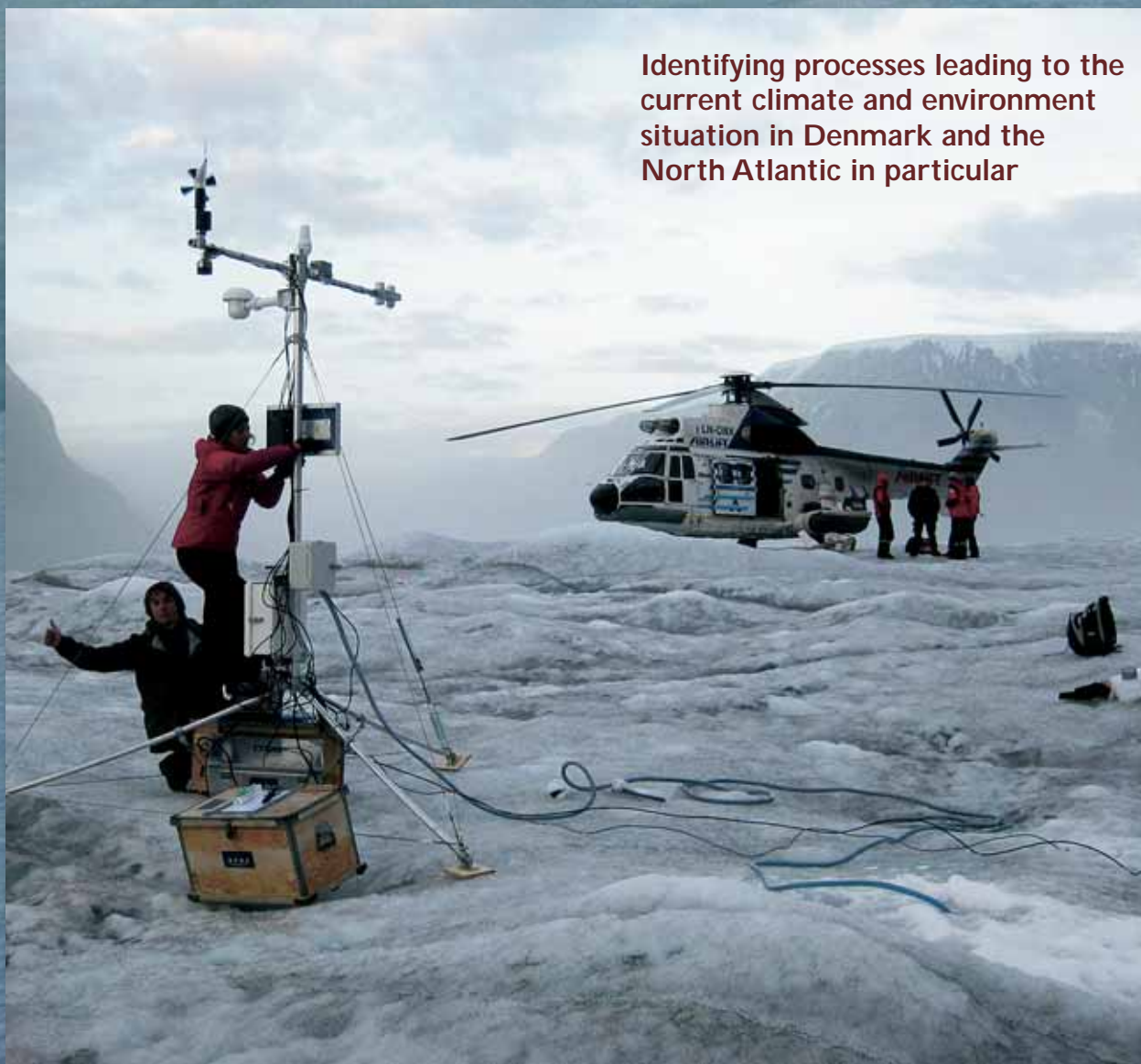
Since 1993, renewable energy from hydro power has been part of energy supply in Greenland. In that year, Greenland's first hydropower plant near Buksefjorden came online to supply Nuuk, and since then another two plants have come into operation to supply the towns of Tasilaq, Narsaq and Qaqortoq. A fourth plant is being built near Sisimiut, and Nukissiorfiit (Greenland's energy utility) is planning yet another plant at Paakitsoq to supply the town of Ilulissat. The majority of the water flowing into the Paakitsoq basin is meltwater from the ice sheet, and during 2008 GEUS, on behalf of Nukissiorfiit, carried out an assessment of the hydropower potential of the basin. The work has included calculations of the drainage patterns of the meltwater and the movement of the ice under selected climate scenarios calculated by the Danish Meteorological Institute. The work concludes that undesirable changes are unlikely to occur in the drainage routes of the meltwater and in the location of the ice margin in the period up to 2080, and that the amount of meltwater for power generation will be stable up to 2035, slightly increasing in the subsequent years up to 2080.

Glacier-induced earthquakes reveal the dynamics of the ice

Since 2003, it has been well known that occasionally a special type of earthquake occurs close to several large glaciers which calve icebergs into the sea from the ice covers in the Antarctica, Alaska and Greenland. The tremors do not resemble ordinary earthquakes, but they can be measured on seismographs throughout the world. The large glaciers originating from the ice sheet in East Greenland have caused many of these glacial earthquakes in recent years. After three years of surveying the Helheim glacier in East Greenland, in 2008 it was possible for an international group of researchers, including researchers from GEUS, to solve the riddle behind these quakes. The tremors arise when large icebergs hit the seabed after breaking free from the glacier. The results have aroused great interest, and researchers now have an extra and cheap tool to monitor the dynamics of the ice in often remote areas. Using seismographs it is possible to measure the tremors from the icebergs breaking off, and thereby monitor whether the large glaciers are suddenly starting to calve ice at a higher rate than previously.

Nature and

Identifying processes leading to the current climate and environment situation in Denmark and the North Atlantic in particular



Reconstruction of the state of the aquatic environment

Lakes and bogs are nature's own archives of the changes in nature and the environment. Studies of lake sediments and their contents of plants and animals provide us with a clear picture of how the environment has changed thousands of years back in time. Danish nature has been heavily impacted by human activity everywhere, and studies of old lake sediments are a good tool to illustrate how far we now are from the natural state. This is important for implementation of the EU Water Framework Directive, for example, which requires a description and definition of the natural background state of the aquatic environment. In recent years, GEUS has examined sediment cores from the lake Sarup Sø in south-western Funen, which covers a period of more than ten thousand years. The results show that the budding agricultural society in the Stone Age was already causing great changes in the landscape and the environment as early as 6,000 years ago. Surprisingly, studies of kisel algae and algae pigments in the lake sediments show that Stone Age agriculture was already causing increased concentrations of phosphorus in the lake. The environmental effects of nutrients have increased significantly since then, and the studies show that the lake was already heavily impacted by nutrients 1,000 years ago. The research project at Sarup Sø is being partly funded by *Forskningsrådet for Kultur og Kommunikation*.



climate

Monitoring earthquakes

GEUS monitors earthquakes in Danish areas. This is done at four permanent seismograph stations in Denmark and at four permanent stations in Greenland as well as a number of temporary stations. Seismologists register large earthquakes around the world and smaller local earthquakes as well as tremors from explosions, traffic and other human disruptions close to the instruments. Fortunately, Denmark and Greenland are not greatly affected by large earthquakes, but on 16 December 2008 at 6:20 a.m. many Danes were awoken by tremors from an earthquake with its epicentre in Skåne, just 50 km east of Copenhagen. Interest in the earthquake, with a strength of 4.8 on the Richter scale, was overwhelming, and in a very short time GEUS received more than 4,000 eye-witness accounts via its website from Danes and Swedes who had experienced the quake. This is important data for seismologists, who use the descriptions to judge the intensity of the earthquake. Measurements from Denmark and Greenland are incorporated in a large international network of stations monitoring earthquakes around the world. These stations are part of an international network of seismographs and other geophysical stations which monitor for violations of the UN Nuclear Test Ban Treaty. Finally, seismologists advise authorities and enterprises in Denmark on the risk of earthquakes in connection with large construction projects such as the bridges over the Great Belt and Øresund.

Monitoring the Greenland ice sheet

The rate of ice melting and icebergs calving from the Greenland ice sheet has increased significantly in recent years and the loss of ice from the large ice sheet has doubled over the past 10 years. This has caused the sea level to rise, arousing concerns around the world in places where many people live in low-lying coastal areas. The Ministry of Climate and Energy has therefore launched a programme to monitor the ice sheet. The new monitoring programme is being headed by GEUS and focuses on what is happening along the margin of the ice sheet where mass loss from melting and calving of icebergs occur. Monitoring is being carried out at fully automatic measuring stations which measure melting, the climate and movements of the ice. Ten stations are already operational and sending data back to GEUS in Copenhagen via satellite. In 2009 the entire measurement network will have been completed with a total of 14 stations, representing seven different climate regions on the ice sheet. Glaciologists are supplementing the measurements on the surface with measurements from aircraft and satellites. In cooperation with the Technical University of Denmark, the edge of the ice is being measured from aircraft all the way around Greenland, and the movement of the ice is being monitored by satellite. Measurements are also being made along 20 of the largest outflow glaciers from the ice sheet from which the majority of icebergs come. Danish monitoring is being supplemented by several foreign stations on the ice. In future, the overall international efforts will provide a more accurate picture of how much ice is melting. The project is called PROMICE – Programme for Monitoring of the Greenland Ice Sheet, and it is being funded by the Danish Cooperation for Environment in the Arctic programme (DANCEA) under the Ministry of Climate and Energy.

Challenges of the Year

INTERNATIONAL CONGRESS
DANISH GEOLOGICAL PRIZE
GROUNDWATER MODELLING
NEW MINERAL
NIELSENITE
COP14
UN CLIMATE CONFERENCE



International Geological Congress

Geologists from far and wide travelled to Oslo in August to take part in the 33rd International Geological Congress (33IGC). More than 6,000 took part in a comprehensive programme with scientific symposia, workshops, and thematic days on issues where geoscience is of great importance to society. Numerous researchers from GEUS attended and they presented the results of their research within geodata, palaeontology and geophysics. GEUS also had an exhibition stand focusing on Arctic resources in cooperation with the Bureau of Minerals and Petroleum in Greenland. The main attraction at the much visited stand was GEUS' new book on the geology and resources of Greenland *Geological History of Greenland*, which was launched during the Congress. Publication of the book is also GEUS' contribution to the International Year of Planet Earth 2008. The objective of declaring 2008 as the Year of Planet Earth was to establish a foundation for allowing the Earth to continue to provide current and future inhabitants with somewhere to live, food to eat, and the raw materials required for their existence and a diverse nature. The International Congress in Oslo was jointly arranged by the Nordic countries and many geoscience institutions, including GEUS, were involved in the extensive preparations for the Congress.

Award of the Danish Geology Prize

In February, GEUS awarded the Danish Geology Prize 2007 to Michael Houmark-Nielsen, an associate professor at the Department of Geography and Geology at the University of Copenhagen. The prize of DKK 25,000 was awarded for his unique work on mapping and understanding the strata from the Quaternary Period in Denmark and his work on the course of the Ice Age. The prize was recommended by the Geological Society of Denmark and presented at a meeting of the Society by Johnny Fredericia, managing director of GEUS. A cornerstone in Michael Houmark-Nielsen's research is systematic use of advanced methods to date when the strata were deposited by ice or meltwater. His many years of work on Ice Age strata in Denmark have been supplemented by studies of Ice Age processes and strata under distant skies in Greenland, Iceland, Svalbard and Russia. When presenting the award, Johnny Fredericia said, "Michael Houmark-Nielsen has been looking at geological conditions in a very large geographical area and he has used many methods in his studies of deposits and processes which have literally formed the foundation of our lives. With his ability to synthesise large amounts of data, he has been able to explain part of our not too distant prehistory. In short, Michael has made his mark on a part of geology we Danes use, experience and are dependent on in our daily lives".



New mineral named after geologist from GEUS

The new mineral, Nielsenite, is only found in one place in the world, namely East Greenland. It has been named after the geologist Troels F.D. Nielsen from GEUS in recognition of his great contribution to exploration of the Skærgaard intrusion where the mineral was discovered. The mineral was discovered by the Russian geologist, Nikolai S. Rudashevsky, in rock samples collected by Troels Nielsen. In addition to being a stratified magma chamber, the Skærgaard intrusion is well known for rare minerals. In 2008, the Canadian geologist A.M. McDonald described the mineral for the first time with Nikolai Rudashevsky and colleagues in the journal *The Canadian Mineralogist*. There is a tradition in the world of mineralogy of calling minerals after important people from the history of geology. New names have to be approved by an international commission in which about 30 members review the scientific documentation for the new mineral and decide whether or not it can be approved. There is a gentleman's agreement preventing mineralogists and geologists from naming minerals after themselves. On the other hand there is ample opportunity to honour other people of direct or indirect importance for mineralogy and geology.



Specialist support for the best possible management of water resources

During the year GEUS has provided specialist support to environment centers and municipalities in connection with the nationwide groundwater mapping and management of Danish water resources. A number of Geo-guidelines were published during the year which will ensure quality and uniformity in the ongoing groundwater mapping, and www.grundvandskortlægning.dk has been launched with information about activities and status as well as downloadable reports. In January, employees from GEUS were amongst the teaching staff on a course in groundwater modelling for employees at municipalities and government environment centers who work with water-resource management, as well as employees at water utilities and consultancy firms. The course was held in cooperation with the Department of Geography and Geology at the University of Copenhagen and Alectia Aqua, and it comprised a mixture of lectures, practical exercises in modelling on computers and exchange of experience.

Participation in the UN Climate Conference COP14

A Danish stand showed examples of climate research, climate adaptation and climate monitoring during the UN COP14 Climate Conference in Poznan in the first two weeks of December 2008. Employees from the Danish Meteorological Institute, the Danish Energy Agency, the coordination unit for climate adaptation research (*Koordineringsenhed for Forskning i Klimatilpasning*) and GEUS presented examples of Denmark's competences within climate research. The 12 000 delegates at the Conference showed great interest in the presentations. GEUS presented three examples of its climate research: a programme to monitor the ice sheet in Greenland, a programme to map the coastal resources in Kenya, as an example of adaptation to a future sea-level rise, as well as research into the effect of climate change on the water cycle in Denmark. On the Danish COP14 blog on the internet, people in Denmark could follow what was happening at the stand.



Building oil expertise in Vietnam

2008 was the final year of the second phase of a cooperation project between the Vietnam Petroleum Institute (VPI) and GEUS to increase oil-geological research capacity in Vietnam. The project is being funded by Danish International Development Assistance (DANIDA) through its ENRECA programme, and it aims at enhancing Vietnamese assessments of the country's oil and gas resources. Training of the Vietnamese researchers continued during the year with teaching and specific research projects focusing on oil-geological issues in the Malay-Tho Chu Basin. Project work has not only aimed at capacity building at the VPI; it has also strengthened cooperation between universities in Vietnam and Denmark. All the project's nine M.Sc. and PhD students continued their courses in 2008 at the Hanoi University of Mining and Geology and the Hanoi University of Science under joint guidance from Vietnamese and Danish senior researchers and university teachers. At the end of the year, two Vietnamese students completed their M.Sc. and PhD courses and the last seven students submitted their final projects which they are to defend in early 2009. In the first half of 2008, the first geological expedition ever to the remote Nam Du Islands in the South China Sea was completed. Vietnamese and Danish PhD students and their tutors carried out geological surveys which have contributed substantially to the understanding of the geological structure of south-western Vietnam. 2008 also saw further consolidation and expansion of the geological and geophysical databases as a result of the new data collections. In December, the final project workshop was held in Hanoi and results of the research programme were presented to researchers, officials and politicians as well as representatives of the oil industry who are active in Vietnam. At the end of the year, the final consolidation phase of the project was approved by ENRECA, running from October 2009 to December 2011.

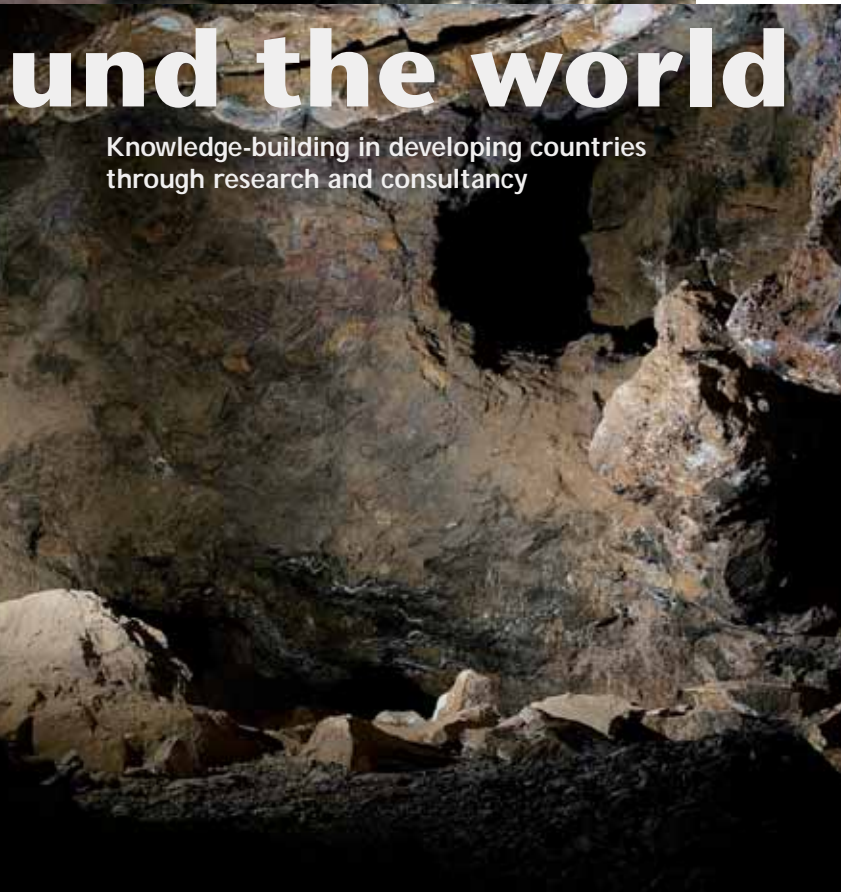
Handbook on sustainable small-scale mining

In recent years, on behalf of the World Bank, GEUS has been working in several developing countries to map the extent of small-scale mining and has provided consulting services for a more environmentally friendly practice in this type of mining. Small-scale mining (SSM) is an important source of income for up to 100 million people throughout the world. Primarily the extraction of gold and precious stones provides many jobs in small communities. Digging for minerals is often done under very poor safety conditions in confined and deep shafts. Mercury is used in gold mining and this causes enormous environmental and health problems if it is not managed properly. In 2008, GEUS worked in Zambia to build knowledge at the Environmental Council of Zambia in order to improve the production and environmental conditions in the SSM sector. One of the results of the project is a *Handbook on small-scale mining* which contains advice for environmental authorities on safer organisation of mines and descriptions of how to prevent mercury from damaging the environment and workers' health. The project is being funded by Danish International Development Assistance through the United Nations Development Programme and it is being carried out in cooperation with Orbicon A/S.

Research into arsenic in the groundwater in Vietnam

The groundwater pumped up from the flood plain around the Red River delta in Vietnam in many places contains high concentrations of arsenic. The highest concentrations are more than 300 times higher than the WHO recommendations for drinking water. Arsenic occurs naturally in the sediments under the flood plain, but natural geochemical processes in the groundwater system mobilise the arsenic and it migrates into the groundwater. Due to the groundwater's good bacteriological quality, all water supplies in the area are based on this source, but arsenic pollution is threatening these supplies. In 2008, the second phase of the research project, VietAs, was started with a mapping of the extent of the pollution and the mechanisms which control releases from the sediment. Surveys have shown that mobilisation of the arsenic is particularly linked to geological layers with a high content of organic material and that the migrating arsenic comes from iron oxides which are dissolved when the organic material is decomposed. The results are a good basis for identifying future well sites with a minimal risk of arsenic pollution, but a number of unanswered questions remains, especially on the large spatial variation in the arsenic content. The project has aimed at both research and capacity building, and during the first phase more than ten Vietnamese students have completed M.Sc. programmes and received tutoring in Denmark. This tutoring will continue in the second phase of the project. VietAs II is being funded by the Danish Research Council for Development Research under DANIDA and is a collaboration project with the Technical University of Denmark as well as Hanoi University of Mining and Geology and the Hanoi University of Science.





Marketing the mineral potential of Yemen

The basis for greater international investment in the Yemen mining sector is there. The country has a promising geology with many mineral deposits, and silver and other metals have been exploited in the past. The Yemen Geological Survey and Mining Resources Board (YGSMRB), under the Ministry of Oil and Minerals, has carried out geological and geochemical mapping of the country, but international marketing of the mineral-exploitation opportunities is lagging behind. With funding from the World Bank, during 2008 GEUS has collaborated with YGSMRB to make Yemen's mineral potential and investment opportunities more visible. Work has included systematising the geoscience data and building up a database, which gives interactive access to information about the geology, mineral deposits, reports and different types of maps via the YGSMRB website. Relaunching the institution's website has also been part of the work and it now contains areas of special interest for the mining industry such as legislation and regulation, investment opportunities, as well as information on geology, minerals and maps. Finally, the project has included preparation of printed marketing material on selected minerals in Yemen as well as conditions for applying for mineral licences. The material is part of YGSMRB's marketing efforts at international minerals trade fairs, and in March 2009, YGSMRB and GEUS are to work together with the presentation of Yemen's minerals potential at the annual PDAC trade show in Toronto.



Key figures 2008

More detailed key figures for GEUS' activities can be found in Årsrapport 2008 (Report and Accounts 2008) and in 'GEUS' virksomhed i 2008 - Faglige resultater' (GEUS activities in 2008 - scientific results), the latter in Danish only, available on request from GEUS or at www.geus.dk

Number of employees: 308

Number of scientific projects: approx. 500

ACCOUNTS 2008

Amounts in million DKK

Revenue:	291.8
Net figure (appropriation):	128.3
Operating income:	163.5
Expenditure:	289.4
Salaries	147.3
Other operating expenditure:	142.1

PRESENTATION ACTIVITIES

Long-term knowledge building

Articles in international scientific journals/publications	117
Articles in GEUS' own scientific series	29
Other scientific publications	8

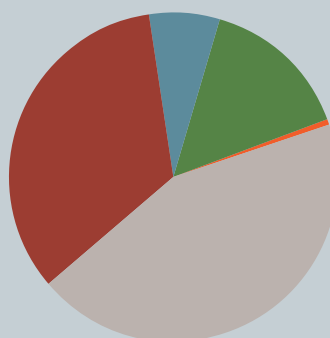
Ongoing scientific task solution
consultancy and presentation

Publicly available reports	73
Confidential reports	47
Memoranda, opinions, expositions, etc.	39
General presentation	
Institution reports (annual report, etc.)	7
General and popular-science presentations	126
- including popular-science lectures	63

Researcher training

Current PhD students with GEUS tutors	61
Completed PhD degrees at GEUS	9

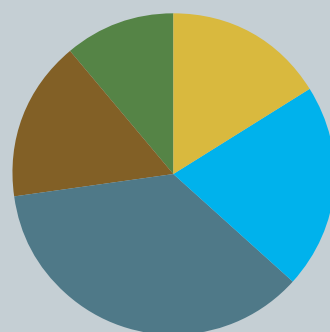
Revenue broken down by source of revenue:



Amounts in million DKK

Budget appropriation:	128.3
Programme and external resources:	99.4
Other co-financed contract research:	20.3
Commercial contracts and sale of data:	42.8
Other revenue:	1.0

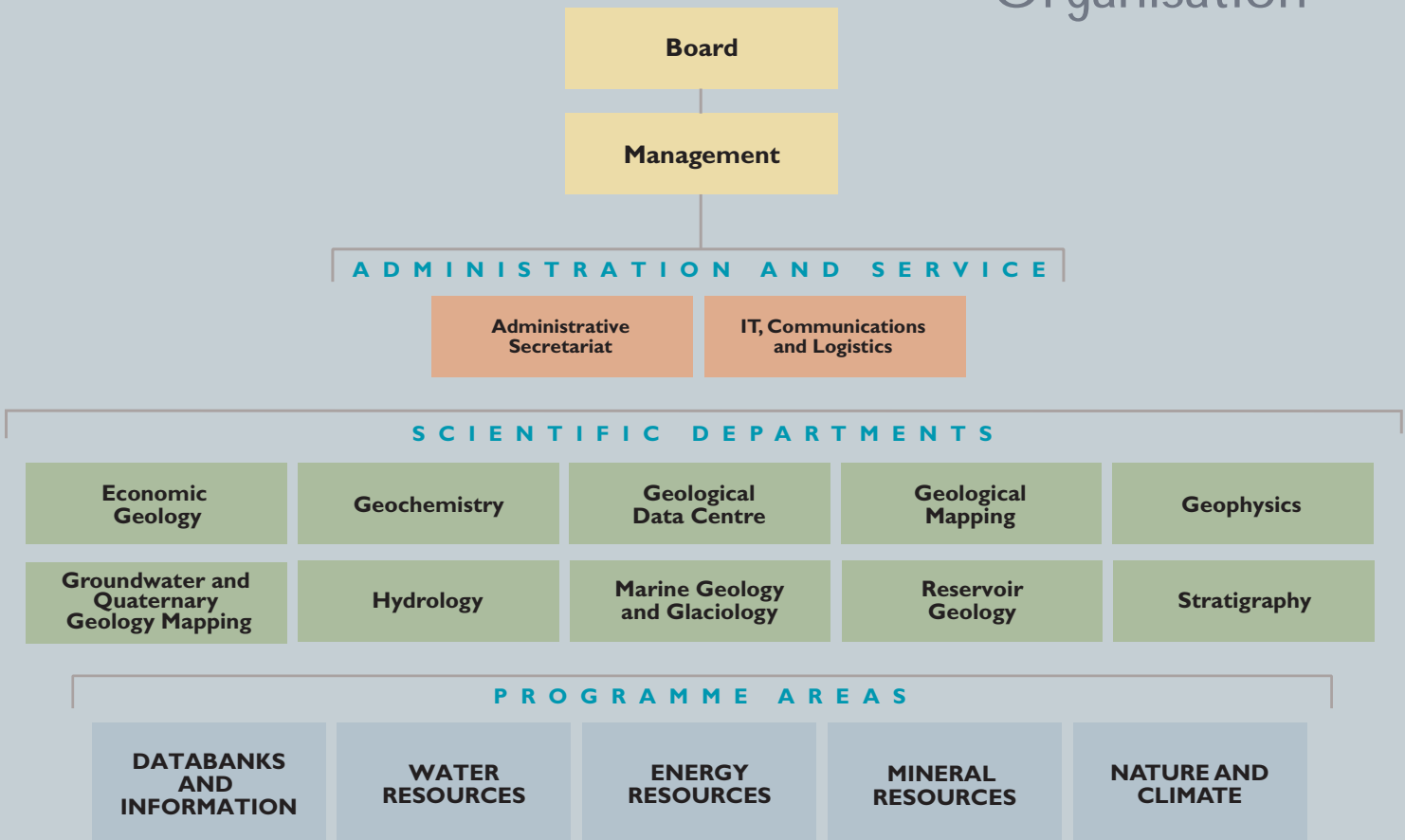
Expenditure broken down by programme area:



Amounts in million DKK

Databanks and information:	46.9
Water resources:	60.0
Energy resources:	104.3
Mineral resources:	46.6
Nature and climate:	31.6

Organisation



During 2008, some minor adjustments were made to the structure of GEUS to make the institution better suited to its tasks and in order to establish a better balance between the size of departments and better utilisation of competences. Therefore, some employees have changed departments and two departments have changed name. The Quaternary Geological Department is now called the Marine Geology and Glaciology Department and the Groundwater Mapping Department is now called the Groundwater and Quaternary Geology Mapping Department. In 2008, there were ten research departments at GEUS and two administrative/service departments. Scientific work is carried out within five programme areas, where tasks are carried out in project groups in a matrix structure.

Programme area: Databanks and information

Archiving and data processing in connection with statutory reporting of geo-data to GEUS. The objective is to ensure that data and sample collections are on a quality level allowing them to be used to implement projects in the areas of monitoring, emergency preparedness, consultancy and research. In addition,

the programme area includes IT projects to develop efficient and modern IT tools for GEUS and presentation of data to the scientific community and the public.

Programme area: Water resources

Procuring the necessary basis on which to manage our water resources. Activities are aimed at water circulation, the volume and quality of water resources, groundwater protection and transportation of substances injurious to the water environment with special emphasis on groundwater. The activities form the basis of consultancy services to government and local authorities.

Programme area: Energy resources

Procuring and contributing the basis for continued exploration and sustainable exploitation of the energy resources of Denmark and Greenland. Activities include own research projects and international cooperation in the areas of oil/gas and alternative energy. The knowledge retrieved forms the basis of GEUS' consultancy services to government and local authorities and to some extent projects carried out for the corporate sector.

Programme area: Mineral resources

Procuring the scientific basis for targeted exploration and environment-friendly exploitation of raw materials and minerals in Greenland and Denmark. Activities include geological mapping and exploration of mineral resources in Greenland and official processing and consultancy services for Greenland Home Rule. In addition, studies are conducted regarding raw materials and construction work in Denmark and internationally.

Programme area: Nature and climate

Identifying the processes in time and space leading to the current climate and environmental situation in Denmark and the North Atlantic region in particular. One objective is to improve the prospect of distinguishing between natural and man-made environmental changes. This programme area also includes mapping of onshore and offshore geological conditions, as well as earthquake research and monitoring.



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