FIGURE 1. Geologic map of Bornholm from 1819 prepared by H.C. Ørsted at the request of King Frederik VI. The map is the first geologic map of a region of Denmark and reflects society's increasing need for raw materials and energy. The purpose of Ørsted's expedition to Bornholm was to map the island's coal deposits. Plate in Ørsted & Esmarch 1819.

The geosciences

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Geology

Historical background

1. Lars Stemmerik is the author of the paragraph on geology, Henrik Breuning-Madsen of the paragraph on geography, though Bo Elberling has written the section on Henrik Breuning-Madsen's research, pp. 196s.

Geological research is essentially place-bound and reflects the conditions in a specific area or time period. As a consequence, observations from a particular region do not necessarily attract broad scientific interest, and internationalization progressed relatively slowly. Geological investigations and research have always been closely linked to society's need for raw materials and knowledge about the underground. Thus the first geological investigations in Denmark were performed by H.C. Ørsted, who was sent to the island of Bornholm by King Frederik VI in order to map the coal reserves, and based on this work he prepared the first geological map of Bornholm (published by the Royal Danish Academy of Sciences and Letters in 1819).

Ørsted was accompanied by Johan Georg Forchhammer, and together they were later responsible for involving the Academy in a major project to identify water-bearing layers in the subsurface. As was typical for the time, the objectives of this artesian drilling project, which took place on the site of the Holmen navel base in Copenhagen in the period from 1831 to 1845, were both of a practical and scientific nature. The quality of the drinking water was abysmal, and it was hoped that groundwater could be used as a supply for the city. At the same time there was an interest in exploring the geology of the area.

Forchhammer later became the first professor to have geology as his primary subject at the University of Copenhagen (1831-1865), and is thus considered the founder of modern geology in Denmark. Forchhammer and his immediate successors as professors at the Mineralogical-Geological Museum at the University of Copenhagen, Johannes Frederik Johnstrup (professor 1866-1894) and Niels Viggo Ussing (professor 1895-1911) were all trained as mineralogists, and their broader knowledge of geology was acquired through travels abroad. In 1835, Forchhammer published the first comprehensive description of Denmark's geognostic conditions, but because he was an opponent of the 'Ice Age hypothesis', this first more detailed description of Denmark's geology lacks this important component. Ultimately it was Johannes Johnstrup who introduced the Ice Age theory in Denmark, for example in a lecture at the Academy, but only after Forchhammer's death.

Johnstrup was instrumental for the establishment of a new Mineralogical Museum on Øster Voldgade in Copenhagen, as well as the establishment of Kommissionen for Geologiske og Geografiske Undersøgelser i Grønland (the Commission for geological and geographical surveys in Greenland) in 1876 and Danmarks Geologiske Undersøgelse (the Geological Survey of Denmark (DGU) in 1888. In this way he established the foundation for geological research in Denmark during the 1900s. His successor, Niels Viggo Ussing, was responsible for staffing the new museum, and among others Jesper Peter Johansen Ravn, the first paleontologist at the University of Copenhagen, and the mineralogist Ove Balthasar Bøggild (professor 1912-1942) were employed. He also participated in the establishment of the Geological Society of Denmark in 1893 and was instrumental in the separation of DGU from the university and its establishment as an independent institution. In 1899, he wrote the first popular description of Denmark's geology, and in the early 1900s, he published *Om jyllands Hedesletter og Teorierne for deres dannelse* (On the moorland plains of Jutland and the theories of their formation) (1903) and *Om floddale og randmoræner i Jylland* (On river valleys and terminal moraines in Jutland) (1907), two major contributions to our understanding of the landscape of Jutland. They include the first map of the maximum extend of the last ice cap in Jutland.

From its establishment in 1888 until the early 1950s, DGU was staffed with seven to eight geologists carrying out systematic survey of the near surface strata using hand drills. The institution also assisted farmers with studies of the chalk content of the soil, mapped out brown coal deposits in Jutland, archived data on groundwater, and was from the mid-1930s involved in the first deep exploration wells in Denmark. Internationally, DGU was known for its research on the history of vegetation in Denmark. Analyses of pollen

from bogs and later drill cores from lakes were used to unravel the changes in vegetation and climate since the last Ice Age, and made Copenhagen a centre for this type of research. The field was initially founded by Knud Jessen, and later refined by his successor Johannes Iversen. The research tradition has been developed up to the present by Svend Thorkild Andersen, Nanna Noe-Nygaard, Bent Odgaard (Aarhus University), and Peter Rasmussen (National Museum of Denmark), among others.

Recent time

After the war, the landscape of Danish geological research was transformed quite rapidly - at least compared to the geologic time scale. In 1946 the Geological Survey of Greenland (GGU) was established on the initiative of Arne Noe-Nygaard, who had succeeded Bøggild as professor in 1942. The number of professors increased in order to accomodate the ongoing specialization, and in 1961, the Department of Geology at Aarhus University was established, with Asger Berthelsen as its first professor. As a consequence of increased enrollment and teaching load, the geology programme at the University of Copenhagen was in 1967 divided into four departments with teaching responsibilities and with the Geological Museum they formed a central geology institute (Geologisk Centralinstitut) - a structure which survived until the early 2000s. The need for geological knowledge increased significantly after World War II, resulting in significant expansion both at the universities and the two geological surveys, and as a consequence it became necessary to hire a large number of foreign geologists, most significantly at GGU. This resulted in increased internationalization, particularly in the field of bedrock geology.

Over the last 25 years, geoscience research has undergone major changes. In Denmark the research landscape has been dramatically reshaped, beginning with the merger of GGU and DGU in 1995. The merger of the two geological surveys into one institution, now known as GEUS resulted in a reevaluation of the geological research landscape in Denmark, in which the Academy was represented by Henning Sørensen. It resulted in the establisment of Geocenter Copenhagen, and concentration of the geoscience research environments in Copenhagen at two addresses on Øster Voldgade. The university reform of 2007 resulted in the integration of most sector research institutions into the universities. GEUS remained an independent institution, and the geocenter was expanded to included Geology at Aarhus University; Geocenter Denmark is now the framework of a formalized collaboration between the geology research programmes in Denmark.

In geology, as in other natural science disciplines, research groups have become more prevalent in recent years, as opposed to one-man research, which dominated the field in earlier times. Still the research environment is dominated - to a high degree - by men! There are two female geologists (domestic) being members of the Academy, and less than ten percent of the geology professors and associate professors at the University of Copenhagen and Aarhus University are women.

Development in the field is often driven by the need to integrate widely disparate specializations into a coherent whole, access to larger and more advanced instruments, increased computing power, participation in international consortiums and the general trend in university research towards fewer permanent employees and more PhD students and postdocs. Like the large experimental facilities needed by physics, such as CERN and ESO (read more on p. 205), a number of international geological projects have been established, several of which with Danish involvement. The Ocean Drilling Programme (ODP) and its successor the Integrated Ocean Drilling Program (IODP) have contributed to our fundamental understanding of the geology of the oceans. The establishment of the basic research center Dansk Lithosfærecenter (DLC) in 1994 headed by Hans Christian Larsen was important for Danish involvement in the drilling programs, and a series of boreholes drilled off the east coast of Greenland in the mid-1990s have contributed to our understanding of the early phases of ocean floor formation in the North Atlantic. Another large program with considerable Danish involvement is the European Plate Observatory System (EPOS), in which Hans Thybo has played an active role. Similarly GEUS' mapping expeditions had an international dimension, and provided the basis for studies of the sedimentary basins of North and East Greenland by Finn Surlyk and Lars Stemmerik.

Over the past decades, instrument developments and access to increased computing power have been key drivers for many research areas in geology. The development of methods for the analysis of fossil DNA has contributed to new insights into Holocene animal and plant life. Within geophysics digital data have re-

FIGURE 2. Unique geologic outcrop areas are found on Greenland; pictured here is the transition from the Proterozoic to the Paleozoic in the northernmost region of Greenland.

placed analog data, three-dimensional seismic data have replaced two-dimensional seismic data, and satellite data are now an integrated aspect of regional geological and geophysical surveys. It is possible to study rocks in increasingly greater details, the number of stable isotopes which can be analysed routinely has increased dramatically, and the sample sizes have been reduced correspondingly. Within geochemistry the development of new instruments has been absolutely essential for precise dating of the birth of the solar system and for understanding the early phases of earth's history. Two basic research centres are devoted to these questions: the Centre for Star and Planet Formation (StarPlan) headed by Martin Bizzaro (Natural History Museum of Denmark), and the Nordic Center for Earth Evolution (NordCEE), under Donald Canfield, which is based at the Department of Biology at the University of Southern Denmark and also has divisions at the Natural History Museum of Denmark, headed by Minik Rosing, at the Department of Geosciences and Natural Resource Management, University of Copenhagen, headed by Robert Frei, as well as at the Swedish Museum of Natural History in Stockholm.

Greenland - an important source of Danish geological research

The establishment of the Geological Survey of Greenland (GGU) in 1946 and the close ties which have traditionally existed between GGU (now GEUS) and the Danish universities mean that Greenland has long been - and remains - an important source to research at Danish institutions. This research has contributed to our present understanding of the geological evolution of Greenland and the Quaternary climate history. In the 1960s and 1970s, the vast majority of Danish geology students worked as field assistants for GGU in Greenland, and the unique research opportunities in Greenland have been a motivating factor for most of the foreign geologists working in Denmark. Many of the results achieved in the past 25 years are closely associated to Greenland, and build on research initiated back in the 1900-1990s. Significant contributions have been made by Henning Sørensen, Minik Rosing, Lotte Melchior Larsen, Kent Brooks, and Robert Frei in the fields of petrology and geochemistry, by Finn Surlyk, Nanna Noe-Nygaard and Lars Stemmerik in the area of sedimentary basin analysis, David Harper

in palaeontology, Dorthe Dahl-Jensen in climate history, and Hans Thybo in geophysics.

The investigations in Greenland began at about the same time as the geological mapping of Denmark with the German mineral collector Karl Ludwig Giesecke's seven-year-long exploration of Greenland's west coast as an envoy for the royal Danish Greenland trade commission (1806-1813). In the early phases, the developments in Greenland and Denmark were highly similar, as the same group of people worked in both areas, and because the motivation behind the research was the same: the hunt for resources. Hinrich Johannes Rink, who had participated in the first Galathea expedition from 1845 to 1847 (read more p. 33), undertook the first geological mapping of areas of Western Greenland from 1848 to 1851. However, it was not until Johnstrup took initiative to establish the commission for scientific geological and geographical studies in Greenland (Kommissionen for de Videnskabelige Geologiske og Geografiske Undersøgelser i Grønland) and the associated publication series *Meddelelser om Greenland* (Communications on Greenland) in 1876 that the institutional framework for geological research in Greenland was established.

Ussing was a central person, and his survey and analysis of the Ilimaussaq Intrusion at Narsaq in Southwest Greenland in the early 1900s mark the beginning of a long, vibrant Danish research tradition which can be traced to the contemporary debate on uranium mining in Greenland. Ussing discovered a number of extremely unusual rock types, and realized that the intrusion contained several unique chemical elements, including thorium. Later surveys have demonstrated the presence of uranium and a wide variety of rare metals and alkaline earth metals.

The next phase was linked to the exploitation of nuclear power as an energy source in Denmark in the 1950s. The Ilimausasaq Intrusion was considered a potential source which could make Denmark self-sufficient in uranium, and in 1956, a highly radioactive area around Kvanefjeld was discovered. Henning Sørensen participated in the investigations from the beginning in 1955, and has since published a number of monographs on the mineralogy and petrology, summarized in *Geology of Greenland Survey Bulletin* 190 (2001), which also contains a complete list of minerals in the intrusion. The renewed interest in Greenland for exploitation of the mineral deposits has led to resumption of these research activities.

The exploration of eastern and northern Greenland began in the late 1920s and continued under the leadership of Lauge Koch until the 1950s. Due to an internal strife in the Danish research community, most recently described by Christopher Jacob Ries in his 2003 book *Retten, magten og æren* (The right, the power, and the glory), the research was primarily carried out by foreign geologists. GGU did not start working in East Greenland until the late 1960s, when the area between Scoresby Sund fjord and Mestersvig was mapped in collaboration with the University of Copenhagen. Until the turn of the millennium, GGU/GEUS organized numerous mapping expeditions in the area from Scoresby Sund in the southeast to Washington Land in the northwest, thereby opening up for new research opportunities. Initially, focus was on paleontological studies of the Mesozoic fauna headed by Tove Birkelund, but during the 1970s modern sedimentological studies and basin analysis of the sedimentary basins in East Greenland and, later North Greenland began, with Finn Surlyk as a central figure, later in collaboration with Lars Stemmerik, among others. Today, the sedimentary basins in East Greenland are classic areas for the understanding the early phases of the separation of Greenland from Norway.

With the establishment of the Danish Lithosphere Centre in 1994, a targeted research effort was initiated with focus on the lithospheric conditions in the southern part of Greenland. The center included both groups interested in the study of the 2-3 billion year old basement areas, and groups focussing on the opening of the North Atlantic Ocean and the formation of oceanic floor. Both research areas are dependent on large-scale geochemical data sets in addition to field surveys and deep sea drilling. The lithosphere centre contributed to the acquisition of two advanced ICP-MS (Inductively Coupled Plasma Mass Spectrometry) instruments, used for trace element analysis and isotope analysis of a new suite of chemical elements in 1999-2000. This strengthened geochemical research in Denmark and paved the ground for both StarPlan and NordCee.

Mineralogy, petrology and geochemistry

As described above, geological research developed out of mineralogy and paleontology, and as a consequence of Denmark's historical access to Greenland, mineralogy and petrology have constituted a natural component of the research activities at the universities in Copenhagen and Aarhus as well as at GEUS. In recent years, mineralogy has been assigned a lower priority at the universities, and the last professor in mineralogy

retired in 2014. In Denmark focus has shifted towards geochemistry and petrography, with vital research environments at the University of Copenhagen, Aarhus University, and GEUS. Research is primarily conducted within three clearly defined areas, described in more detail below: volcanism related to the opening of the North Atlantic Ocean; the basement of Greenland and formation of the oldest lithosphere; and the evolution of the oceans and the atmosphere.

The volcanic rocks formed during the opening of the North Atlantic Ocean for approx. 55-56 million years ago are a central research area at all three institutions. The geographically extensive plateau basalts in East Greenland and on the Faroe Islands constitute a considerable part of a so-called LIP (Large Igneous Province) which formed during the opening of the Atlantic Ocean. The basalts in West Greenland are slightly older (61-62 million years old) and formed during the opening of the Labrador Sea between Greenland and Canada. Studies of the plateau basalts in West Greenland and the Faroe Islands were initiated in the 1940s by Arne Noe-Nygaard, and expanded in the 1970s to include East Greenland. The work has primarily taken place at GGU/GEUS by Lotte Melchior Larsen, in collaboration with Asger Ken Pedersen, University of Copenhagen, among others. Together they have developed a method to combine petrographic/geochemical analysis of the individual lava flows with photographic mapping, which makes it possible to study the stratigraphy and morphology in great detail. This method has greatly improved our understanding of the interaction between vulcanism and sedimentation in the basins of West Greenland.

Another important traditional branch of research on Tertiary volcanic activity is aimed at understanding the formation of the Skaergaard Intrusion in southeast Greenland. The intrusion is stratified and constitutes a natural laboratory to study the processes involved in cooling of magma chambers. Danish involvement in this research started with Kent Brooks' longstanding interest for this area, supplemented by significant contributions by Troels F. Nielsen (GEUS), and more recently Christian Tegner (Aarhus University).

From the early 1990s to the early 2000s, the Danish Lithosphere Centre was a natural center for petrological and geochemical research of basement rocks in Greenland to better understand the formation of the

FIGURE 3. Fossil – approx. 650 million-year- old seabed covered by stromatolites about a square meter in size. Stromatolites are layered structures shaped by the growth of microbial mats which have stabilized the sediment, and their form reflects the depositional environment. The relatively large size of the stromatolites in the photograph indicate that they were formed under calm depositional conditions under the wave base. Stromatolites represent the oldest form of life on earth, but have a very limited distribution today.

oldest lithosphere. Studies of the basement rocks in western and southern Greenland have been a central activity for GGU/GEUS since its establishment in 1946, and the resumption of these activities has resulted in more precise dating of the continental collisions which led to their formation. The basement rocks west of Nuuk contain evidence of the oldest known biological activity on earth, as demonstrated by Minik Rosing. Basement rocks have played an important role in his attempts to better understand the structure and development of the continents since the early Archaic Period. Particularly how metabolism of living organisms has affected the oxygenation and differentiation of the lithosphere.

The exploration of the interaction between biological evolution and the chemistry of the atmosphere, oceans and earth's crust has continued at the basic research center NordCee (Nordic Center for Earth Evolution). The research focus of NordCee is to understand how evolution of life has affected the chemical environment- and vice versa. New instruments allow us to analyze the isotope systems of molybdynum, uranium and chromium. The results have been used to trace metabolic processes in the ocean in order to date the oxygenation of the oceans and the atmosphere. Knowledge about ancient levels of oxygen in atmosphere is based on chrome isotopes, and NordCee has documented that a massive increase in the amount of oxygen occurred at the Precambrian-Cambrian boundary - simultaneously with the emergence of larger animals. The center also investigates the evolution from microorganisms to the first multicellular organisms. Finally, the group studies the nitrogen cycle in order to understand the role of biological productivity in the history of the oceans.

In recent years isotope geochemistry has found applications outside geology, for example for determination of the provenance of paint from the Antiquity and - most recently - to trace the last travels of the Egtved Girl. Strontium is extremely useful to determine prehistoric migration patterns. Karin Frei (National Museum of Denmark) heads a research group which has developed to analyze strontium isotopes in hair. By comparing the results from the Egtved Girl's hair with strontium isotope maps of Denmark and Northern Europe, it was possible to map her movements and residences the last few months before her death. The revelation of her wide-ranging movements was a huge sensation in the Danish press.

Meteorites

In Denmark, research on meteorites began with Ove Balthasar Bøggild's study of the Cape York iron meteorites from Northeast Greenland in the late 1920s. It was continued by Vagn Buchwald after he found the Agpalilik meteorite in the same area in 1963. The collection of meteorites at the Geological Museum (part of the Natural History Museum of Denmark) provided the basis for the establishment of the Centre for Star and Planet Formation (StarPlan) at the University of Copenhagen in 2009. Based on advanced isotope geochemical studies of meteorites, the center has been able to determine the age of the solar system with unheard-of precision: 4.5673 billion years with an uncertainty of just ± 160,000 years. The first continental crust has been dated to be 4.3 billion years old. The center integrates isotope chemical studies of meteorites with theoretical studies of the evolution of stars, astrophysical models and astronomical observations, in an attempt to understand the formation of earth-like planets throughout the universe.

The geology of sedimentary basins

Until the end of the 1960s research on sedimentary basins was primarily focussed on paleontological studies of fossil animals and plants. Our understanding of sedimentary rocks was limited and only allowed broad distinctions like marine vs. continental or deep vs. shallow water, based on grain size and fossils. Modern studies of dynamic sedimentology began in the late 1960s, and were introduced to Denmark in the mid-1970s by Finn Surlyk. Since then, sedimentological studies have has been instrumental to understand the evolution of the sedimentary basins of Greenland and Denmark. Surlyk has played a crucial role in this development, both through his own research and as a supervisor for more than 100 MSc and PhD students at the University of Copenhagen.

From the mid-1970s to the end of the 1980s the research was primarily based on vertical data sets, sedimentological profiles. These were collected either from outcrops or drill cores. The focus was on depositional processes. During the 1980s, stratigraphic concepts were integrated into the sedimentological studies. The methods were originally developed for analysis of seismic data; their introduction led to a shift of focus towards sequence stratigraphy and large-scale depositional models. In Greenland, data collection is based on classical fieldwork supplemented by data from scat-

FIGURE 4. The white limestone cliff Stevns Klint was added to the UNESCO World Heritage List in 2014. The cliff is one of the best exposed Cretaceous-Tertiary (K/T) boundaries in the world, which makes it possible to study the Cretaceous-Tertiary mass extinction in great detail here. Over half of all animal species, including the dinosaurs, became extinct at this boundary, which is marked by a thin layer of fish clay right under the large limestone projection on the middle of the cliff. Chalk and limestone have been used as raw materials since the Middle Ages, and there are clearly visible saw marks in the upper regions of the cliff to the left of the landslide debris (and the lighthouse). They were made when building stone was quarried here in the late 1800s.

tered shallow cores drilled by GEUS in connection with petroleum geological investigations. In Denmark the focus was initially on sedimentary outcrops on Bornholm, and it was not until the late 1980s that studies of the North Sea basin began based on cores from hydrocarbon exploration wells, later supplemented by ever increasing amounts of high-quality seismic data.

Since the late 1960s, Surlyk and collaborators and students have been working with sedimentological, stratigraphic and paleontological studies of the Mesozoic sediments in East Greenland and Denmark. In 2003 he edited a monographic work on the Jurassic basins in Denmark and Eastern Greenland together with Jon R. Ineson (GEUS). It summarizes the results of the preceding 30 years of research, *Geological Survey of Denmark and Greenland* Bulletin 1. Surlyk has developed new conceptual depositional models on the background of fieldwork in East Greenland and synthesized the evolution of the Jurassic rift basin by integrating sedimentological, biostratigraphic and sequence stratigraphic data. Lars Stemmerik has worked on somewhat older deposits, from the Carboniferous and Permian periods, in the sedimentary basins of East and North Greenland, as well as on Svalbard and in the Barents Sea. This work has resulted in models for the interplay between climate and sedimentation, as well as detailed paleogeographic reconstructions of the central region of the Arctic, illustrating the movements from a location near the equator to 50° N during the Late Paleozoic. Over the last 10 to 15 years, Surlyk and Stemmerik have collaborated on studies of chalk sediments in Denmark and Skåne in southern Sweden, integrating classical field studies with the acquisition of seismic data and drilling of up to 450 m long chalk cores. This collaboration has led to a revitalization of chalk research in Denmark, with a focus on sedimentology, nannostratigraphy and isotope stratigraphy, as well as paleoclimatology and oceanographic modelling.

Paleontology

The conditions for paleontological research in Denmark have been difficult over the past few decades. Results are often published in monographs rather than articles, and this results in few citations. David Harper, the last professor of invertebrate paleontology, left the country in 2011, and since then research has proceeded

in a decentralized fashion at the universities, GEUS, and a number of smaller museums. Until 2011 Harper headed a group focusing on the earliest phases of animal evolution, particularly the Cambrian explosion, the subsequent Ordovician diversification, and finally, a major mass extinction event in the Late Ordovician. A central location is Siriuspasset, the Sirius Pass, in northern Greenland, where a so-called Lagerstätte contains a unique early Cambrian invertebrate fauna, which makes it possible to study rare ancient forms of life. Harper's work is based on a statistical approach to large data sets, in particular on brachiopod faunas from most of the world, including Greenland. He has contributed to the development of the widely used statistical technique PAST.

In recent years, the Danish tradition within Cretaceous-Danian paleontology has experienced a revival. This has resulted in a number of ecological, stratigraphic and monographics works which together contribute to a better understanding of the Cretaceous and Danian ecosystems.

Quaternary geology and climate history

Research in Quaternary geology and climate history has gained increasing awareness over the last decades as the consequences of changes in earth's climate have become evident. The research has benefited from technological developments and major international data collection programs, including drilling of ice cores and the deep sea drilling programs. Denmark has a leading role in ice core drilling (read more p. 214s.). Climate history studies based on marine sediment samples are a central research area at Aarhus University, where Karen Louise Knudsen and Marit-Solveig Seidenkrantz have worked on changes in the marine system based on analyses of foraminifera supplemented by geochemical proxy data.

Over the past few decades, the classical research on vegetation history based on pollen analysis of cores from lakes has been supplemented by geochemical analysis. Nanna Noe-Nygaard, Bent Odgaard, and Peter Rasmussen have contributed to advance our understanding of the vegetation and climate history of Denmark since the last Ice Age. A central work is Noe-Nygaard's higher doctoral dissertation *Ecological, Sedimentary and Geochemical Evolution of the Late-glacial to Post-glacial Åmose Lacustrine Basin, Denmark* from 1995, an interdisciplinary study combining climate history and ecology with prehistoric archaeology.

The development of methods for extraction and analysis of DNA from sediment cores has opened for better understanding of environmental changes of the landscape and lakes, because the genetic data provide information about organisms rarely preserved in the cores. The basic research center GeoGenetics headed by Eske Willerslev and Kurt Kjær (University of Copenhagen) combines classical analysis of landscape formation, sedimentology and glacial dynamics with stratigraphy and environmental DNA data from core material from lakes in Greenland. More recently the DNA analyses are used to link genetics, archaeology, and environmental history.

Integration of the huge amounts of data from lake, deep sea, and ice cores provides basis for comparing temperature and temperature changes on a regional scale with the formation of the local landscape. This improves the correlation between ice core data and changes observed along the ice margin. Recently the study of the historical changes of the Greenland ice sheet has intensified, based on use of aerial photos and satellite data in a collaboration between the Technical University of Denmark, the University of Copenhagen and Aarhus University.

Seismology and geophysics

The collection of seismic data and other types of geophysical data has exploded in the last few decades, primarily driven by the search for oil and gas reservoirs in the underground. The first reflection seismic data from the Northeast Greenland continental shelf were collected in 1991. They provided the foundation for a preliminary and fragmentary understanding of the geology of an area 3-4 times the size of Denmark. Since then, tens of thousands of kilometers of seismic data have been collected from the area, and our understanding of the geology has improved accordingly.

The oil industry is primarily interested in the upper 6 to 7 km of the sedimentary basins, and for example their data have contributed to the understanding of the geological evolution of the North Sea. Studies of the deeper structures of the lithosphere have primarily been carried out as large basic research projects. The first of these coordinated projects was the European Geotraverse Project, whose goal was to improve our understanding of the deep structure of lithosphere in Europe. The project was launched with funding from the European Science Foundation in 1981, with the participation of Asger Berthelsen, among others. The integration of geological and geophysical data resulted in a better understanding of the deep structures

in a corridor from North Cape in Norway to North Africa, and marks the beginning of a significant Danish engagement in scientific studies of the lithosphere. Hans Thybo has participated in a number of international working groups with a focus on gathering reflection and refraction seismic data from the deep lithosphere. In particular, he has been involved in refraction seismic experiments using a controlled source, most often dynamite. The earliest results were one-dimensional or two-dimensional based on analog methods. Today digitization and increased computing power make it possible to produce three-dimensional tomographic models. Thybo's work led to the discovery of a low-velocity layer at a depth of about 100 kilometers, interpreted as a partially melted zone at the base of the lithosphere.

Within the last ten to fifteen years, there has been considerable progress in shallow geophysical methods for studying near surface layers, typically the upper few hundred meters of the lithosphere. This type of data is included in the TOPO Europe program, which aims to understand the relationship between near surface processes and the deep lithosphere. Currently, there is an intense debate between groups from Aarhus University, the University of Copenhagen, and GEUS about the origin and age of the mountain chains along the west coast of Norway and the east coast of Greenland.

In Denmark, shallow geophysical data are primarily used in studies of groundwater and postglacial deposit systems, and to a lesser extent tectonism. In particular the youngest coastal sediments and their morphology have been studied, using an interdisciplinary suite of methods combining shallow geophysics with physical geography, sedimentology, and new methods of dating.

Geography

Danish geographical studies can be divided into several epochs. In the period before geography became a university subject, mapping (cartography) and climatology were important disciplines. The Royal Danish Academy of Sciences and Letters was active in both areas (read more pp. 26-30 and 64-65). In 1883, geography became a university subject at the University of Copenhagen, with only a small staff and a single professor until 1929. Geography research and teaching have taken place in an interdisciplinary context along with closely related subjects such as ethnography, anthropology, archaeology, and biology. In the 1950s, enrollments in the program began to increase significantly, and the staff of the Department of Geography grew considerably, while similar departments of geography were established elsewhere in Denmark, first in Aarhus and later in Roskilde and Aalborg. The 1970s were a turbulent period, with power struggles between physical geography and human geography which at some institutions resulted in the demise of the subject. Since the 1980s, the various branches of geography have been developing strongly in our increasingly globalized world.

Early geography

In the 1700s and 1800s, a considerable number of geographical surveys were carried out, for example in connection in with voyages of discovery and expeditions. One early pioneer in the field of geography was Hans Egede, who mapped parts of Western Greenland in the 1720s, including the area around the Island of Hope at the entrance to Godthaab Fjord. Egede settled here on his arrival in Greenland, later moving farther up the fiord with his family to the site where Gothaab (now Nuuk) was established. As a missionary, he searched for and found traces of the Christian Norse inhabitants at the Western Settlement and the Eastern Settlement. He carried out a number of expeditions from the Godthaab Fjord, for example towards the northeast all the way to the Greenland Ice Sheet, and he found many traces of the early Norse settlements. He lived in Greenland as a missionary until 1736 and acquired a deep familiarity with the Inuit and their way of life. His most important contribution to geography is *The Old Greenland's New Perlustration* (1741), in which he provides an extraordinary account of the distinctive natural history of the island and the harsh conditions under which the Inuit had created a sophisticated hunting culture. The Inuit way of life and cultural traits are described in detail. The work is the first contribution to a geographical description of Greenland and its inhabitants, and was a groundbreaking work in Danish geography. Hans Egede's work was translated to English and French, and put Greenland on the world map.

Hans Egede's work predates the establishment of the Academy. The same applies to the Danish naval officer Frederik Ludvig Norden's travels in Egypt and Nubia in 1737-1738. In this case, however, the Academy did come to play an important role, as the King asked the Academy to publish Norden's account of his journey, which took place between 1751 and 1755 (read

more p. 62-63). At the same time, the Academy itself was responsible for planning and carrying out a scientific expedition, Eggert Ólafsson's og Bjarni Pálsson's travels in Iceland from 1752 to 1757 (read more p. 30-32).

A few generations after Egede, another Danish geography achieved international recognition: Malthe Conrad Bruun. His geographical work took place outside Denmark, in Paris, on account of his political involvement as a young man in Copenhagen in the 1790s. He had criticized the absolute monarchy in writing, most effectively in the satirical *Aristokraternes Catechismus* (The aristocrats' catechism) from 1796. His publications cost him several lawsuits, which culminated in his banishment in 1800. Before the sentence was served, Bruun had figured out which way the wind was blowing and left the country. He settled in Paris and never returned to Denmark, as the banishment was not retracted until shortly before his death in 1826.

In Paris, he made a living writing for leading newspapers and critical periodicals, but it was as a geographer that he was a pioneering person.

He believed that geography was an empirical science in which it is necessary to distinguish sharply between assumptions and proven facts. His major work is *Précis de la Géographie universelle* in eight volumes, published between 1810 and 1829. The work contains a geographical description of the entire known world at the time. He also founded the important geographical journal *Annales des voyages,* which he edited from 1808 to 1815 and from 1819 to his death. This publication is considered one of the first geographical journals in the world, and about 70 years should pass before a similar Danish journal was published by the Royal Danish Geographical Society. Bruun was one of the major figures in the establishment of the world's first geographical society, Société de Géographie in 1821; he was the society's *secrétaire perpétuel* until his death. In short, Bruun was an extremely gifted person of wide-ranging interests, from poetry to politics to science. He became one of his times acknowledged masters in the field of geography. Unfortunately, Denmark was too small and politically conservative to make room for him, and as a consequence of his banishment, he never became a member of the Academy, which he should have been, judging on the basis of his merits.

In the period before geography became a university subject, its field of study was incorporated into other subjects when relevant. A good example is the Danish botanist Joachim Frederik Schouw, who was the first member of the Academy who systematically studied geography. He was one of the founders of regional and ecological plant geography. In relation to geography, his major work is *Grundtræk til en almindelig Plantegeographie* (Fundamentals of general plant geography (1822). Schouw saw climate as the most important factor behind the geographical distribution of plants, and he produced several papers on climatology, both in Danish and in Latin. One of his works in Danish is *Skildring af Vejrligets Tilstand i Danmark* (Description of the climate of Denmark) (1826), a work submitted in a prize essay contest on a Danish meteorology sponsored by the Academy in 1823. Schouw's entry won, and the Academy financed its publication on the condition that its sponsorship should be named in the book. It was - on the title page in fact: *Et Priisskrift, belønnet af det Kongl. danske Vidsk. Selsk. og udgivet med Sammes Understøttelse* (A prize thesis rewarded by the Royal Danish Academy of Science and Letters, published with the support of the same). His brief work in Latin *Specimen geographiae physicae comparativae* (1828) drew attention abroad. One hundred years later, Schouw's conception of the interplay between climate and plant growth was taken up by the Danish geographer Martin Vahl, who made maps of climate and vegetation belts. These maps have been used in geography lessons in schools in Denmark and abroad.

FIGURE 5. Illustration from Egede 1741 which illustrates different forms of seal hunting in West Greenland. Fine details include the use of dogs, clothing, and sleds. The Royal Library.

FIGURE 6. Malthe Conrad Bruun. Satirical engraving of his flight to Hven, which is indicated at the far left of the image. On the cliff to the right are the scales of justice and the whip of misfortune. Denmark's 'Generalfiskal', the national public prosecutor, pursues Bruun with shackles in one hand and Bruun's book *Aristokraterne Catechismus* (The aristocrats' catechismus) in the other. Copperplate engraving by Gerhard Ludvig Lahde. The Royal Library.

Early university geography

In the second half of the 1800s, geography was established as a subject at many universities in Europe. This took place in recognition of the importance of understanding foreign countries - not least in a military-strategic context, for example in connection with the colonization of the other continents. The geography programme at the University of Copenhagen was established in 1883, when Ernst Løffler was engaged to give lectures on geography. To begin with, the position was not full-time, and there were no physical facilities for a geography laboratory or department before 1901, when the subject was given an auditorium on the second floor of the university at Frue Plads. In 1888, Løffler was appointed professor at the University of Copenhagen, a position he held until 1910. He viewed geography as a university science subject which describes nature as the foundation for human activity in specific regions based on a holistic approach. His works include *Lærebog i Geografien* (A geography textbook) (1884) and *Omrids af Geografien* (Outline of geography) (1893), both intended for use in connection with lectures. His regional descriptions of different peoples are typical of their time; different peoples are compared and evaluated on the background of their material level and the set of values which were dominant in Western Europe at the time. For example, he writes: "The character of the African natural environment is thoroughly inimical to culture, and therefore it can by no means be considered accidental that Africa remains so backward in civilization and social organization." The scientific level of Løffler's work might be discussed, but he did lay the foundation for university studies in geography in Denmark.

Løffler's student Hans Peder Steensby succeeded him as professor of geography in 1911. Steensby was a social mover; he was born into a family of smallholders on Funen and ended up as a professor at the University of Copenhagen. His research focus was primarily human geography, and as a consequence his work has more of an ethnological and anthropological slant than Løffler's. His work can be divided into three phases: first a period with a focus on eskimo culture, the subject of his doctoral thesis from 1905; then a period with an emphasis on the development of agriculture, with examples from North Africa, which he visited in 1908 and again in 1913; and finally a more historical period, in which he studied the Vineland travels of the Norsemen in particular and developed a hypothesis that Vineland was located at the mouth of the St. Lawrence River. To perform fieldwork on this topic, he travelled to Canada in 1920, and on his return journey, he died suddenly on board the steamer Frederik VIII.

Neither Løffler nor Steensby were elected to the Academy. The first professor of geography to become a member of the Academy was Åge Gudmund Hatt, who was beyond a doubt the most controversial professor in the history of Danish geography. Hatt was born near Herning in western Jutland and travelled to the United States as a young man, where he studied ethnography at Harvard University from 1906 to 1907. This would have a strong influence on his subsequent research, and his interest in ethnography was not lessened by his marriage to the painter and ethnographer Emilie Demant Hansen in 1911, who was extremely interested in the culture of the Laplanders. Hatt and his wife travelled to Lapland for research between 1912 and 1914, and in 1914 he defended his doctoral thesis *Arktiske Skinddragter i Eurasien og Amerika* (Arctic leather clothing in Eurasia and America), a work which must be considered virtually ethnography, like his work on reindeer nomadism. From 1919 to 1929, he was assistant curator at the 1st department of the National Museum of Denmark (Antiquity), and from 1922 to 1923, he headed an archaeological expedition to the West Indies. In the 1920s and 1930s, he participated in innumerable excavations of Iron Age settlements, where he introduced 'shovel scraping', and he found and documented Iron Age field systems (surrounded by earth banks).

Hatt became an associate professor of geography in 1923, and in 1929, he became a professor of human geography. His most substantial contribution to geography was the four-volume work *Jorden og Menneskelivet* (The earth and human life) (1922-1927) which was a ground-breaking geographical reference work which covered both human and physical geography. The work was co-authored with Martin Vahl, who wrote about physical geography, while Hatt covered human geography. Vahl had succeeded Steensby and served as a professor of geography at the University of Copenhagen from 1921 to 1940. In 1904, he got the doctoral degree with the dissertation *Madeiras Vegetation* (The vegetation of Madeira), which reflected his insight into the interactions between vegetation, climate and soil conditions; in other words, a continuation of Schouw's studies in the 1870s. This work was followed by *Zones et biochores géographiques,* which was published by the Academy in 1911, despite the fact that he never achieved membership. Hatt, on the other hand, did become a member, as mentioned above; and as tradition dictated, he learned of his election from the newspaper, on April 2nd 1932.

FIGURE 7. Åge Gudmund Hatt and his wife, the painter Emilie Demant. Private photograph, used as cover illustration in Askgaard & Smedegaard 2016. The Royal Library.

Hatt's research covered a range of geographical topics, such as the development of farming systems, the race question and geopolitics. During the German occupation, he became a member of the Danish-German association, possibly because he considered Germany a natural and unavoidable bulwark against Russian communism, and he also held a series of radio lectures which could be interpreted as sympathetic to the Germans. After the war, he was tried before a disciplinary tribunal, and after an inconclusive trial, he was dismissed from the university, although he was given a pension. When he attempted to defend himself at the Academy, it ended in an argument, and he was expelled from the Academy's premises. He stayed away from the Academy for ten years, and became professionally isolated, although he continued his archaeological studies. After the ten years had passed, he returned to the Academy, published in its Writings and Communications, and participated frequently in meetings. In 1959, he achieved the honour of being presented with a festschrift on the occasion of his 75th birthday. He died three months later.

Niels Nielsen, also known as *Nilaus*, became a professor of geography at the University of Copenhagen in 1939, a position he held until his retirement in 1964. He was elected to the Academy in 1944. Nilaus came from Sdr. Vissing in Jutland, studied biology at the University of Copenhagen and wrote his Master's thesis on zoology. Thereafter he switched to geography,

FIGURE 8. Niels Nielsen, known as Nilaus, was one of the few members of the Academy to have the honour of appearing in the satirical cartoonist Storm P's *Dagbogsblade*. The text in the journal BT November 5th 1936 reads: "Doctor Niels Nielsen has stated in the Royal Danish Geographical Society that we are on our way into a new Ice Age. 'Well, we are also in November'". The Storm P Museum.

and in 1924, he submitted his doctoral thesis "Studier over Jærnproduktionen i Jylland" (Studies of iron production in Jutland). He was a committed and enterprising person who had a major influence on geography from the 1930s to the 1950s, developing a strong tradition for exact field studies. He made his academic reputation with his expeditions to Iceland between 1924 and 1936 together with other scientists, including the geologist Arne Noe-Nygaard, who was also a member of the Academy.

His studies in the Wadden Sea area were also well-received. In 1930, he founded Skalling Laboratory, with support from the Carlsberg Foundation. Two years later, a field laboratory was erected on the Skallingen peninsula, supplemented by another laboratory at Esbjerg Harbour in 1936. During the Second World War, the building on Skallingen was removed in connection with the German construction of the Atlantic defence wall, but after the war, the lab was reconstructed with wooden buildings which were left over from the construction of the Rømø dam. The lab has been subsequently expanded and modernized. Today, Skalling Laboratory is one of the University of Copenhagen's few field stations.

In 1953, Nilaus founded 'The Danish tidal flat and marsh survey' (De danske Vade- og Marskundersøgelser), which provided the basis for a number of doctoral theses, for example by Niels Kingo Jacobsen, Børge Jacobsen, and Jens Thyge Møller, all of whom became professors.

Nilaus was also involved in dissemination of new knowledge for the public; for example, he founded the series *Atlas over Danmark* (Atlas of Denmark), which also resulted in a number of doctoral theses, by Axel Schou, Aage Aagesen, and Viggo Hansen, among others, as well as the monograph series *Folia Geographica Danica*. In 1960, the Geographical Laboratory moved into the Kejsergade complex under his leadership, and in this connection he arranged for the Royal Danish Geographical Society, which was housed at the National Museum of Denmark at the time, to relocate to the same address. The two institutions have shared an address in Copenhagen ever since, from the mid-1960s on Haraldsgade and from the mid-1980s on Øster Voldgade. The Geographical Laboratory changed its name to the Department of Geography when it moved to Kejsergade.

Nilaus was a strong personality who dominated Danish geography for almost three decades, thanks to his industriousness, talent, enthusiasm and flair for organization. He was an excellent communicator and was well-known to the general public. Under his leadership, geography at the University of Copenhagen grew rapidly and gained many highly qualified employees.

The adaptation of geography to the post-World War II mass university

Over the course of the 1950s, 1960s, and 1970s, the nature of Danish universities changed; they were to enroll an increasing number of students. As a consequence, it was necessary to increase the academic staff at the Department of Geography and to establish geography programmes at new universities.

At Aarhus University, Johannes Humlum was appointed professor of geography in 1943. In 1954, geography became part of the newly established natural sciences faculty, and in 1963, it became possible to take a degree in geography. Humlum was a visionary person: a highway through mid-Jutland, an airport on the island of Saltholm, and the diking of the South Funen Archipelago were just a few of his many more and less wild ideas. He was also a combative person who was not good at developing a fruitful research environment. In 1966, the conflicts became so serious that the Ministry of Education was forced to intervene. The solution was a department of human geography which was located outside the university. Humlum was the only academic staff and he headed the department until his retirement in 1981.

In the tumultuous period around 1970, when the universities were full of Marxist and radical tendencies, geography at Aarhus University was divided into two laboratories: physical geography and human geography. In 1971, Jens Thyge Møller, who was a professor of physical geography, decided to have physical geography transferred to geology, which left human geography in a precarious situation, as a humanities subject at the natural sciences faculty. Politically speaking, it turned out to be impossible to transfer human geography to the faculty of humanities, and as a consequence, human geography was phased out at Aarhus University, and the subject was finally closed in 1991.

Roskilde University (RUC) was founded in 1972 with an alternative approach to education with a focus on projects and group work. The university offered a two-year basic course in one of three main areas: humanities, natural sciences, or social sciences, followed by advanced studies. Geography would be included in various departmental constructions through the years, for example together with computer science at the Department of Geography, Social Analysis, and Computer Science. Later, geography would be included in International Development Studies along with the social sciences, history, and English, and in the Department of Environmental, Social and Spatial Change from 2006 to 2015. Both physical and human geography were included in all of these constellations. However, human geography was transferred to the Department of People and Technology when RUC was reorganized in 2016, while physical geography went to the Department of Science and Environment.

Aalborg University Centre, now Aalborg University (AAU) was founded in 1974 through a merging of existing degree programmes in Aalborg, for example the Danish Engineering Academy's programmes in Aalborg. Later the School of Engineering in Esbjerg and the Danish Building Research Institute (SBi) also became part of Aalborg University - with a branch in Copenhagen. AAU offers both BSc and MSc degree programmes in geography which include aspects of both physical and human geography, such as 'population, society, and resources', 'dynamics and processes in the natural landscape', 'society and environment', and 'climate change and natural resources'.

The Department of Geography at the University of Copenhagen grew considerably over the first three decades after World War II, both in terms of staff and student intake. As a consequence, conflicting groups emerged within the staff with major scientific and political differences, particularly around 1970, when the student rebellion was raging and Marxist geography was popular among the students and young geographers. As a result, geography was divided into two physical geography laboratories and three human geography laboratories: 'General physical geography', 'Geomorphology', Cultural ecology and agricultural geography', 'Settlement geography, urban geography and physical planning', and finally 'General human geography', which was in reality Marxist geography. This construction held until the end of the 1980s, when Marxist geography was declining rapidly and new patterns of collaboration had emerged. Today, geography consists of four research groups which work closely together.

Although several strong figures shaped the subject after the Second World War, only four were elected to the Academy, and only three of them have been active within the last 25 years. The four researchers, who were all affiliated with the Department of Geography at the University of Copenhagen, will be described below.

Axel Schou was born in Copenhagen and earned his Master's degree in 1927. In 1953, he was appointed professor of physical geography at the University of Copenhagen, a position he held until his retirement in 1972. He began his career as an upper secondary school teacher, where he revealed himself to be an exceptionally good educator, to the benefit of many geography students later. In 1945, he defended his doctoral thesis *Det marine Forland* (The marine foreland), which was his breakthrough in the field of coastal morphology. His basic studies of coastal formation processes and the complex formation of marine forelands were internationally recognized, which was reflected in his position as chairman of the International Geographical Union's Commission on Coastal Geomorphology from 1952 to 1972. In Denmark, his research was recognized by his election to the Academy in 1960. In addition to his scientific contribution, he will be remembered for his wonderful lectures which spellbound audiences, and for the artistic block diagrams he produced.

In 1941, Schou joined the staff of Nilaus' new series *Atlas over Danmark* (Atlas of Denmark). The first volume, which combined text and maps, was his *Landskabsformerne* (Landscape formations) (1949), which was richly illustrated with his block diagrams. The

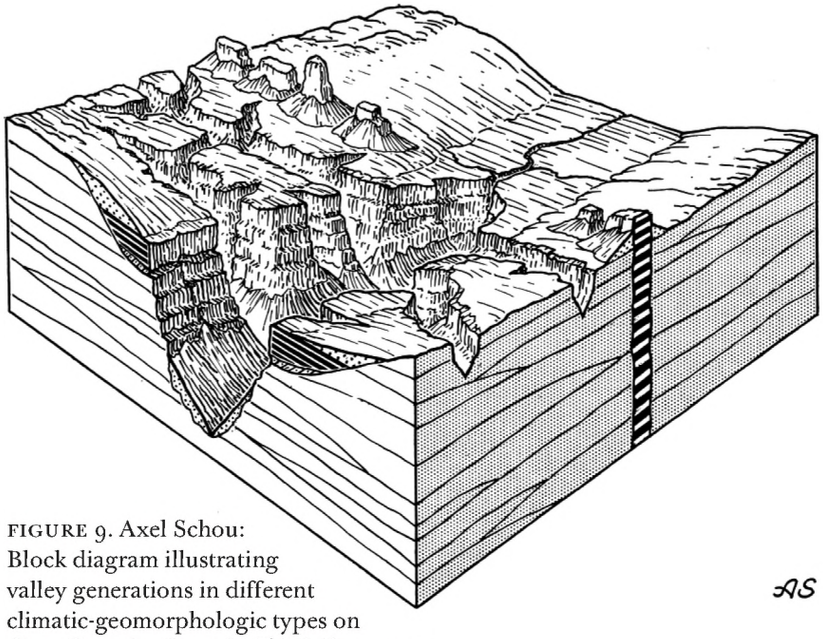

FIGURE 9. Axel Schou: Block diagram illustrating valley generations in different climatic-geomorphologic types on Gran Canaria. *Geografisk Tidsskrift* 72, 1973.

large influx of new students in the 1960s meant that the geography in Copenhagen had to move from Kejsergade to Haraldsgade, where the student rebellion in the in the late 1960's and the 1970's soured Schou's working life; but he took great pleasure in his membership in the Academy. He continued to pursue his research interests after his retirement, and he died in Rome in 1977, enthusiastically involved in exploring the development of the coast at Ostia and the effects of climatic variation on increased coastal erosion.

Sofus Christiansen was born in Dalby on the island of Zealand. He completed his secondary school education in 1949 and got his MSc in geography in 1955. The next year, he was awarded a gold medal for his prize essay "Om det sydfynske øhavs kyster" (On the coasts of the South Funen Archipelago), the topic of which had been set by Schou. At Schou's request, Christiansen participated in the Noona Dan expedition to the Pacific Ocean in 1962, where he studied coral coasts. Like other Danish scientists, he lost his heart to Bellona, a small coral island in the Salomon Islands. He became interested in the islanders' farming system, and he stayed on Bellona several times in the 1960s, on some occasions together with two other members of the Academy, Torben Monberg and Rolf Kuschel.

FIGURE 10. Sofus Christiansen discussing geography with one of his old friends on Bellona in 2006. Photo: Ole Mertz.

Sofus Christiansen's higher doctoral thesis *Subsistence on Bellona Island,* which he defended in 1975, was a concrete result of these research stays. The dissertation describes the functions which are important to maintaining self-sufficiency in isolated areas such as Bellona. The work was a landmark in the branch of human geography which has traditionally focussed on the relationship between environment and culture. Christiansen introduced new quantitative methods and a conceptual model for describing a "shifting cultivation" farming system which resembles the ecosystems described by biology. The methods he described in his dissertation have become a model for the subsequent generation of ecological geographers, with Professor Anette Reenberg and later professor Ole Mertz at the forefront.

In Denmark, Christiansen used the system he had developed on Bellona to study the traditional Danish ådalsbrug (system where the river valley plays an important role) and Faroese spade cultivation system (*reinavelta*), which both traditionally and consciously applied ecological considerations to agriculture. His contribution to our understanding of the Danish *ådalsbrug* was a quantification of the materials transported from the outlying fields and meadows to the inner fields close to the farm. In his studies, he made use of archival material in the form of the diaries of Peder Knudsen, who was a smallholder near the Haderup River in the mid-1800s. He made exact records of his fertilizer consumption and of when and how it was handled. On the basis of this source material, experiments were performed on Hjerl Hede which demonstrated that stabling and manure heap management were crucial in reducing loss of plant nutrients. After retirement, he continued to perform research, and he was extremely pleased that the *Galathea 3* expedition in 2006 included activities on Bellona. He participated himself and he was reunited to old acquaintances from the 1960s. This was a very fine conclusion to a long research career. He died the year after.

His great organizational achievement in the 1970s was to keep the Department of Geography as one unit in the face of a serious crisis caused by the student uprising and the Marxist wave which struck human geography with particular force. In this period, there were strong forces working to split geography into physical geography and human geography, which had already happened in Aarhus and at many other universities in Western Europe. Christiansen, who himself was a generalist with a foot in both the physical and the human geography, fought to prevent this split, which would make it impossible to carry out modern ecological geography research. Although his highly developed diplomatic skills were put to the test, he succeeded bringing geography through the crisis as one unit. Without his diplomacy and the general respect he commanded, geography at the University of Copenhagen would probably have collapsed at some point in the 1970s. He became a member of the Academy in 1979.

Another geographer who became a member of the Academy was Henrik Breuning-Madsen, who was elected in 1992 and who served as general secretary from 2004 to 2009. He was born in 1949 in Copenhagen, got his MSc in physical geography in 1975 and his PhD in 1978 with the dissertation *Jordbundskartering og bonitering belyst ved hjælp af jordens vandretention, bygs rodudvikling og simuleret planteproduktion* (Soil surveying and land evaluation based on soil water retention, the root development of barley and simulated crop production). In 1983, he defended his doctoral thesis *Himmerlands Jordbundsforhold* (The soils of Himmerland – pedology and land evaluation). In the same year, he was appointed associate professor at the University of Copenhagen, after having worked at the Bureau of Land Data in Vejle, an office of the Ministry of Agriculture, and in 1991, he became professor of soil and environmental science at Copenhagen University.

His research career has covered a number of topics. In the second half of the 1970s, his work was based on soil water retention and crop root development, which were used as inputs in models for simulating the soil water availability to plant production in different soil types. In the 1980s, he developed a method of mapping potentially acid sulphate soils which make ochre pollution when drained. This method was used to map this soil type in the entire Jutland peninsula. This survey is now an important aspect of the Danish ochre act. In the 1980s, he headed soil projects along DONG Energy's gas pipelines, and in the nationwide 7 × 7 km

FIGURE 11. Well-preserved 3.3 year-old pork roast in an oak coffin taken out of an experimental barrow at the historical-archaeological experimental center in Lejre (now Land of Legends).

square grid survey performed under the national committee on plant breeding. This material constitutes the backbone of the Danish soil database. Starting in the 1990s, he headed the development of a soil profile database linked to the European soil map at a scale of 1:1.000.000. This comprehensive project involved coordinating the collection and quality control of comparable soil data from the entire European Union and elsewhere.

In 1993, a barrow had to be removed in order to make room for a four-lane highway between the cities of Fredericia and Vejle. Several inexplicable layers of iron were discovered when the barrow was excavated before removal. This led to a long-lasting and fruitful collaboration with the archaeologist Mads Holst, who is now executive director of Moesgaard Museum and member of the Academy. Chemical analyses of samples from several barrows containing layers of iron were performed, and experimental barrows were built at the historical-archaeological experimental center in Lejre (now Land of Legends), in which researchers buried pork roasts and butchered piglets.

On this background, it was concluded that the iron layers surrounding the coffins in Bronze Age barrows had been formed by redox processes. These studies of Bronze Age barrows were concluded in 2002-2004, when a Bronze Age Barrow (Skelhøj) with a blue, oxygen-poor core near the town of Ribe in Jutland was excavated. These studies of barrows also contributed to a new approach to reference soils, when Breuning-Madsen and Bo Elberling (read more p. 197s.) collaborated on exploring Bronze Age soils as archives of the organic carbon and heavy metal contents of pre-industrial soils. This work continued from 2009 to 2013, when Breuning-Madsen investigated by drillings the two barrows at Jelling in the context of the National Museum of Denmark's studies of the Jelling Monuments.

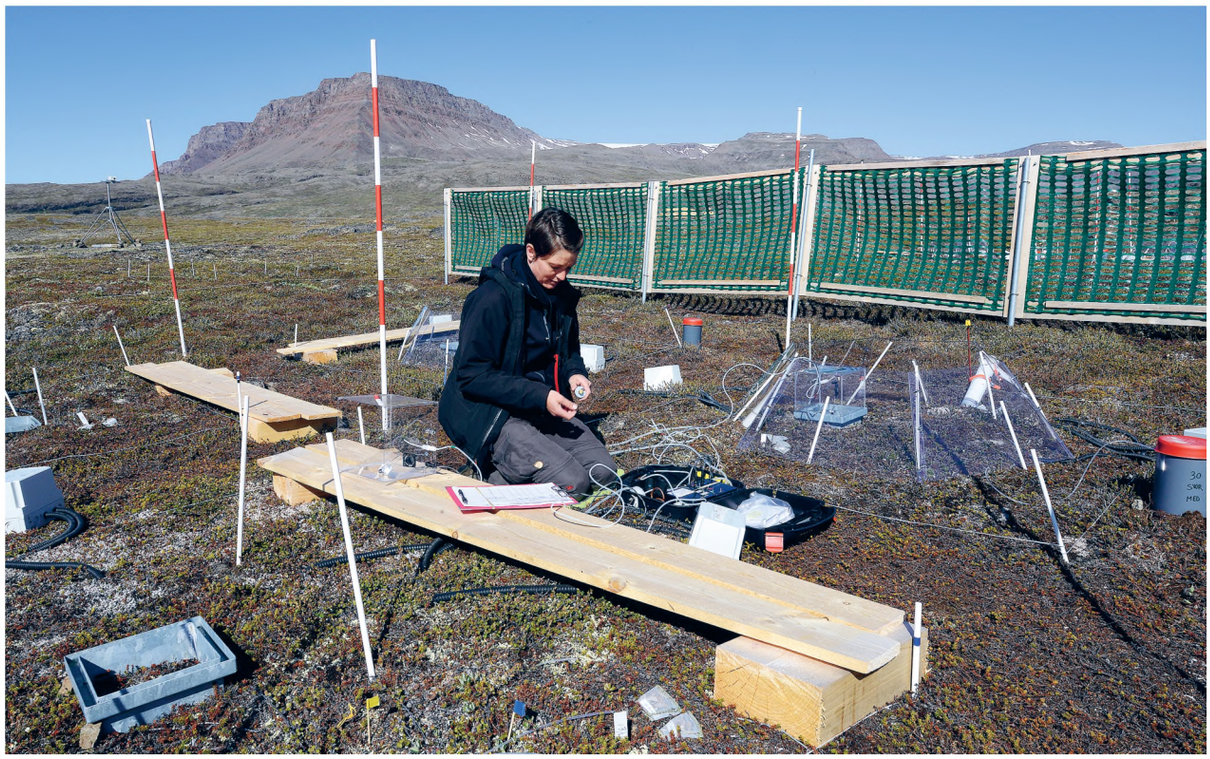

FIGURE 12. The snow fences are part of the experiment setup on Disko in West Greenland, where scientists from the Center for Permafrost (CENPERM) are working to understand the effects of climate change. The center works on changes in the availability of plant nutrients, plant growth, and the release of various greenhouse gasses. CENPERM's research focus is the complex interplay of geological and biological processes.

In the period 1991-2015, Breuning-Madsen was responsible for developing and maintaining a soil-water-plant laboratory at the University of Ghana in Accra. The goal of this project was to ensure that MSc and PhD students could generate empirical data for their projects, and several hundred students have used the laboratory. In order to establish collaborative projects between Ghanaian and Danish researchers, Breuning-Madsen initiated a variety of concrete research projects in Ghana. These projects were important in relation to producing knowledge which is relevant to Ghana, and at the same time had value as basic research. For example, new methods were developed for collecting dust from the Harmattan, a dusty trade wind which blows from the Sahara over West Africa including Ghana. After ten years of dust sample collection, it has been proven that it makes only a very little contribution of plant nutrients to agriculture. In collaboration with Jens Martin Knudsen, who was awarded the Academy's gold medal in 2004, Breuning-Madsen demonstrated that the dust on Mars is more magnetic than dust from the Sahara. Since 2000, the activities in Ghana have financed the publication of a peer-reviewed journal, *West African Journal of Applied Ecology*.

The *Galathea 3* expedition in 2006 united three of the Academy's geographers: Sofus Christiansen, Henrik Breuning-Madsen and Bo Elberling. They participated along with a larger group of scientists from the Department of Geography (University of Copenhagen) in studies of life on selected islands in the Salomon Islands, where Breuning-Madsen and Elberling followed in Christiansen's footsteps and studied the interplay between soil type and farmers' choice of crops on Bellona.

Bo Elberling began his career at the Department of Geography as a research associate professor, and was appointed professor in environmental geochemistry in 2005. He was born in Viborg in 1968 and was educated at the Department of Geology at Aarhus University with a specialization in physical geography. He went on to study at the University of Waterloo in Canada, he focussed on biogeochemical processes in the soil environment. He finished his education with a PhD dissertation at the Department of Geology at Aarhus University in 1996. In 2005, he defended his higher doctoral dissertation on aerobic processes in soil at the Department of Geography at the University of Copenhagen. He has been a member of the Academy since 2012.

Elberling's research has focused on the interplay between soil air, soil water and the soil solid phase. This approach marked a shift from a descriptive to a more quantitative approach in soil geography, with measurements of gas fluxes and sampling of soil water and soil air.

New topics have since become central to his re-

search, including mine waste handling, and new methods to quantify the oxygen consumption rates of mine waste in Canada, Greenland and Svalbard. Another focus has been soil organic matter turnover in connection with land-use change in tropical farming systems; this work has been performed in close collaboration with Breuning-Madsen. His research on farming practices, land-use change, and changes in soil carbon and nutrient pools has at times brought Elberling close to human geography. In Denmark, his research has focussed on the interactions between precipitation, water level variations, greenhouse gas production, and the associated release of greenhouse gasses from Danish forest ecosystems and wetlands.

With his research on mine waste and the turnover of organic matter in soil, he has taken the initiative to combine manipulation experiments in the field with detailed field testing, controlled laboratory experiments, and modelling. The laboratory on Øster Voldgade has thus been the site of thermoblock experiments, growth chambers with living plants, microelectrode studies, and more, in close collaboration with biologists, chemists, and archaeologists.

This interdisciplinary approach has been considerably strengthened by the Center for Permafrost (CENPERM), a basic research center. The center (2012-2022) is directed by Elberling and is affiliated at Institute of Geosciences and Natural Resource Management at the University of Copenhagen. Close collaboration with microbiologists, plant ecologists, and specialists from other fields makes it possible to illuminate the complex interactions between climate, nature and humans in Greenland. The center's research has roots far back in the subject of geography, and is based on the work done in Greenland by Bjarne Holm Jakobsen and Henrik Søgaard from the former Department of Geography, among others, from the mid-1990s.

The Arctic Station on Disko Island in West Greenland is an important focal point for CENPERM's work. This is where Elberling started his Arctic research 25 years ago, and he has been the director of the Arctic Station since 2014. The snow fences and artificially heated sites in this area foreshadow what the future might hold.

Elberling's research on Greenland also combines geography and archaeology. The frozen kitchen middens of Greenland have shown themselves to be a unique source of information about the way of life of the island's past inhabitants. Now they are threatened by climate change: As they thaw, the organic layers decompose more quickly and produce heat, which can accelerates the thawing process independently of future climatic variation.

Generally speaking, Elberling's research is closely linked to teaching and other forms of research communication. The textbook he co-authored with Ole Borggaard, *Pedological Biogeochemistry,* has been reprinted several times since 2004. *Det isfrie Grønland* (Ice-free Greeland) explains CENPERM's work to a general audience in text and images.

It is interesting that this history of the subject of geography in Denmark began in Greenland, and it is also in Greenland that it ends - starting with Hans Egede, ten generations ago.

Source of citation

p. 191 Buciek 1999, p. 48.

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