# On the shoulders of giants - Musings on the history of geoscience in Norway

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The development of geoscience in Norway has been characterized by close contact with the industry from its start to the present day. Five historical periods can be identified: The first period (1600-1760) started with an emerging mining industry based on imported geological knowledge. This led to a need for collecting geological data, an approach that characterised geological studies in the second period (1760-1850). The combined collection of data, detailed fieldwork and analytical work, formed the basis for the growing understanding of natural geological processes with the founding of geochemistry in the third period (1850-1910). In the fourth period (1910-1960) a solid tradition was established which paved the way for proposed fundamental theories that still dominate international geoscience. The fifth period (1960-present) includes the time of rapid adjustment necessary to meet the needs of the petroleum industry in the 1960s.

The fast change of direction of the geosciences as well as the acceleration in development of new technologies that were necessary to meet the demands of the quickly growing oil industry, was only possible because of the existence of a long and solid tradition of geoscience in Norway. An important element in this tradition was the inclusion of new generic knowledge about geological processes and the ability to combine theoretical and academic studies in practical application.

## Introduction

The present contribution has been written at the invitation of the editor of the Norwegian Journal of Geology. Our original intention was to show how Norwegian geoscience has been developing in the light of international cooperation and increased participation in international organizations. However, we soon realized that first we had to explore the basis for this cooperation and to find out what characterized the different time periods. This led us to a retrospective look at our science where we soon came to recognise particular periods that evolved as a direct result of what had been achieved before.

Although we cover almost the entire time span of the development of Norwegian geoscience in the widest sense, it has not been our intention to write the complete history of the geology of Norway. Rather, we have focused on the prevailing conditions at the time, selective highlights, directions of thought and ideas and some of the personalities that characterise the five periods we recognise. It is our hope that readers will find this useful when trying to understand the background for the present state of our science. Our list of personalities is of necessity incomplete, but for those not mentioned, it does not mean that their contributions have not been found worthy of mentioning. For practical reasons we have, with a two exceptions, omitted those scientists who are still alive. The exceptions are Professor Markvard Sellevoll identified for his pioneer geophysical investigations on the Norwegian continental shelf and Professor Knut S. Heier (director of the Geological Survey of Norway between 1974 and 1994) whose research and organisational abilities in the 1960s and later, provided important landmarks in the development of geoscience in Norway.

## The state of the geosciences in Norway

As we celebrate the centenary anniversary of the Norwegian Geological Society (NGF), it is pertinent to remark that our geoscience is more vital, sounder and more prosperous than ever before. This we can state being fully aware of the proud history we outline below, a history in which the country's magnificent landscape and geology have provided the backcloth for ideas and hypotheses for which Norwegian geoscientists have received international recognition (Fig. 1). In Norway today the field of geoscience is considered one of the most solid and highly profiled of the natural sciences thanks, to a large extent, to the development of the petroleum industry since the mid 1960's. This has led to an increased demand for geological expertise based on high quality research funded by the Norwegian government together with the petroleum industry itself. A resultant phenomenal expansion of the numbers of engaged geoscience has thus occurred. In 1950 a total of 60-70 geologists were employed either in academia, at the Geological Survey of Norway or in the mining industry. By 1993, the total number was approximately 1600 and of these over 700 were employed by the (then) national oil companies, Norsk Hydro, Statoil and Saga Petroleum and the Norwegian Petroleum Directorate (Bjørlykke 1995). Today, roughly four out of five geoscientists are engaged in the petroleum industry. Investments related to the petroleum industry are reflected in the 13 Centres of Excellence established from January 1. 2003, of which 4 were awarded to the geosciences. These are the Centre of Integrated Petroleum Research (CIPR; University of Bergen), the Centre of Physics of Geological Processes (PGP; University of Oslo), Centre of Climate Studies (Bjerknes Centre, University of Bergen) and The International Centre for Geohazards (ICG; NGI/UiO/NGU/NTNU/Norsar). This is one of the reasons why publications in the geosciences rank high, both in productivity and in citation lists (Fig. 2) and why the number of graduates with M.Sc. and Ph.D degrees has increased. It is rewarding to see that many of these are entering new fields such as environmental and pollution control, geo-hazards, engineering geology and geo-medicine.

*Fig. 1: The rocks and mountains of Norway have inspired generations of geologists. Photo from Lofoten (Rambergstranda). (Fjellanger-Widerøe Foto AS)*

## The historical perspective

Geology and topography strongly influence where crops can be grown, where roads can be built and where humans can live. This is so today, and was even more important for the people who invaded Scandinavia when the ice finally disappeared from the Scandinavian Peninsula. The inner part of Scandinavia was free from ice approximately 8500 years ago and the first trace of man in Norway dates back to the Boreal period (7000 – 6000 years ago). Indeed, the topography, which is ruled by geological processes, has strongly influenced the history of Norway where demography, economics and politics are concerned, both in peace and war.

The rugged, and in part unfriendly landscape of Norway must have challenged the early Norwegians, but also provided valuable resources in the form of raw material for tools and rocks and minerals for building and trade.

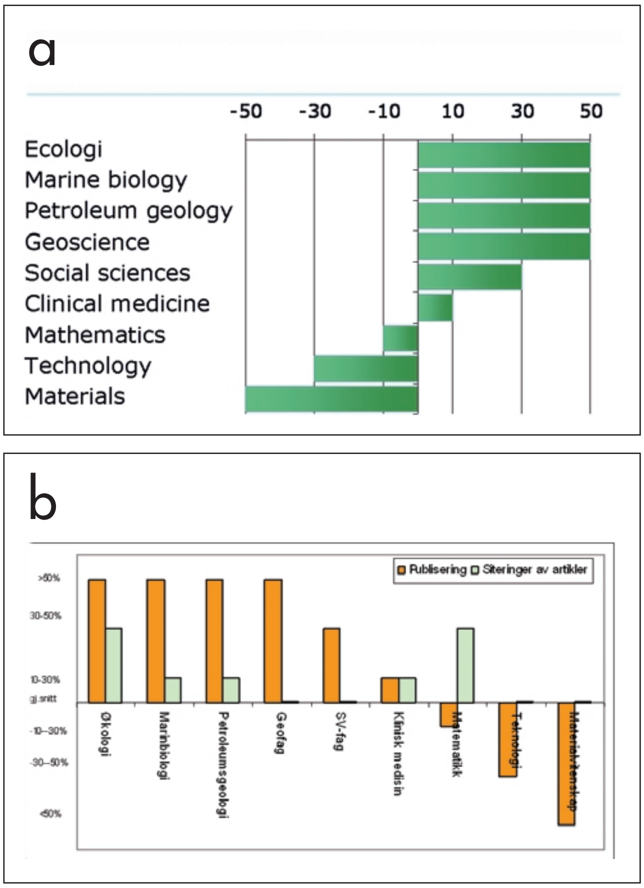


*Fig. 2: a) Numbers of scientific publications produced in Norway and b) citation data for Norwegian geoscience compared to other publications for science in the country. Figures in % of world average. Data from NIFU (2003).*

Nobody living close to nature in this country can neglect the landscape and the geological conditions that formed it. Mineral resources have been and still are, one of the most important elements of the Norwegian economy and contribute strongly to its demographical characteristics.

When considering the development of the geosciences in Norway, it must be acknowledged that the main influence is the general growth of science-based knowledge so typical for the last 400 years of human history. However, the perspective of the natural conditions and the potential of the natural resources of Norway cannot be overlooked. Hence, we have particularly taken these into account in the following description. Based on influential parameters like the international accumulation of geological knowledge, development of new methodologies and technologies and economic influence on the geosciences, we suggest that five periods can be recognised in the development of Norwegian geoscience.

## Period 1: 1600-1760

An emerging and fast-growing mining industry characterises this period (1600-1760). It covers the time span in which silver, iron and copper mining was essential for the economy of the Danish-Norwegian Kingdom and was dominated by the needs related to the mining itself. It was also a period when the first systematic documentation of geological knowledge occurred. With some right, it can be said that the study of geological phenomena in Norway began already in the 16th century with the import of miners from Germany.


*Fig. 3: Norwegian geoscience is founded on a well developed mining industry. Little has changed for the field geologist in the last 500 years. From Agricola (1556).*

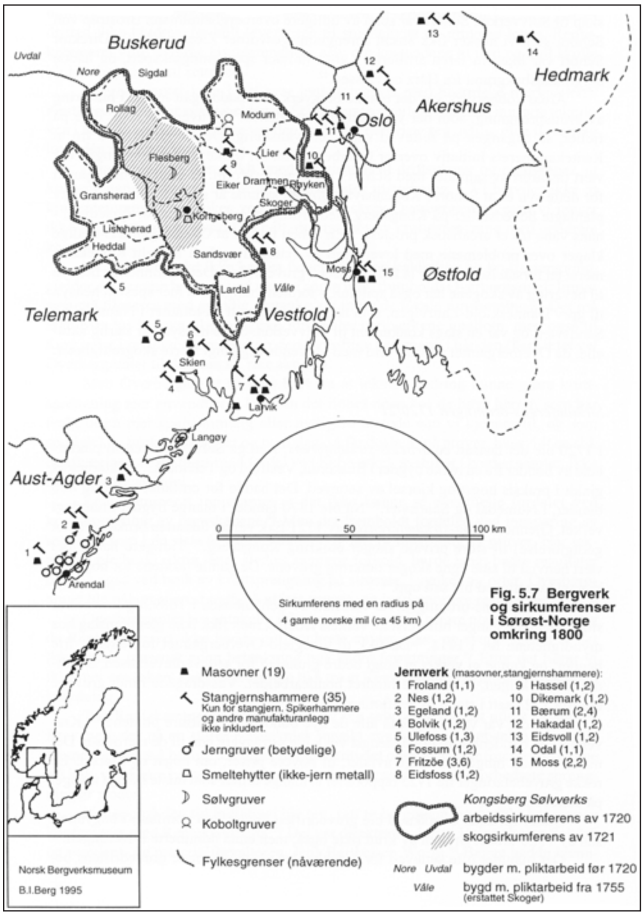


*Fig. 4: Early map of the Kongsberg silver mine district and surrounding mines. From Berg (1998).*

These people promoted a new look at the bedrock and its mineral resources and it may be said that their work was the first step towards the systematic study of geological resources in Norway. To some degree, they also contributed to a tradition that would prepare the ground for what was to become the first Norwegian university.

Larger/-scale professional geological activity in Norway may be considered to have started in 1623, the year the silver mine at Kongsberg opened following the discovery of metallic silver by two shepherd children the same year. This coincided with the exhaustion of traditional silver mines in Europe and America and created considerable optimism for mining in Norway (Berg 1998). Both private organisations and the owner of the Kongsberg mine, the Danish-Norwegian King, were eager to explore and exploit the resources quickly. The German miners not only had the technical ability to run a mine, they were also in possession of contemporary practical geological knowledge perhaps to some extent based on descriptions by the German mineralogist and metallurgist Gregorius Agricola (1494-1555). His main work, "*De re metallica*" (1556) published in Latin, provided an extensive description of geological phenomena as applied to practical mining (Fig. 3).

*Fig.5: Building of the former Bergseminaret in Kongsberg. Photo: Bjørn Ivar Berg, Norsk Bergverksmuseum, Kongsberg.*

The start of mining in Kongsberg coincided with a period of extensive, countrywide exploration for minerals. In addition to the discovery of several new ore bodies in Kongsberg, the 17th century saw the opening of copper mines such as those at Kvikne (opened in 1632), Røros (opened in 1644) and Løkken (opened in 1654), together with a number of iron mines with Arendal, and to some extent Langøy (Kragerø), (Fig. 4) (Berg 1998). The activity of the German miners soon created an environment, which focused upon the systematic and practical use knowledge from the mining activity.

Norwegian natural scientists were also active in this period. Although most had their basic education in theology, an important part of university education at the time, many clerics among them showed a strong interest in nature and an understanding of geological processes. The Danish scholar Steno (Niels Stensen; 1638-1686), realised the implication of fossils (Steno 1669) whilst the cleric Mikkel Pedersen Escholt (ca. 1600-1669) was perhaps the first to apply the term "geology" in the modern sense of the word in descriptions found in his book "*Geologia Norvegica*" published in 1657 (English translation 1662). This book included reports of an earthquake, which was felt over considerable parts of Norway in 1657. Both Steno and Escholt had contacts in the scientific communities of Europe and travelled extensively, bringing back to Norway detailed knowledge relevant to Norwegian geology.

In concluding this period it seems fair to say that the early exploitation of the country's rich mineral resources (Fig. 6), combined with the emerging interest for natural science, formed the basis for the first organisation of geological knowledge, culminating in the establishment of "Bergseminaret" in 1757 (see Period 2). Norwegian miners were quick to absorb knowledge imported from abroad and to develop this for the good of the country, and not so unlike what happened almost 300 years later when Norway became a petroleum producing nation towards the end of the 20th century.

## Period 2: 1760-1850

Although the establishment of "Bergseminaret" at Kongsberg may be said to herald a new development in the geosciences, Period 2 (1760-1850) is likewise characterized by the fact that literature on the topics of natural science in general, and on geology in particular, became more abundant. This opened both for publication of observations and for the promotion of theories and discussion on natural geological processes.

The activity of the German miners soon created an environment, which combined academic achievement with a practical flare. This resulted in the foundation of the Kongsberg "Bergseminar" in 1757, based on an order in Council of King Frederik V (Fig. 5). This institution therefore became one of the oldest seats of technical learning in the world and later developed to provide advanced instruction in technological and academic skills. When the University of Oslo (then the Kongelige Frederik's) was established in 1811, the activities of the "Bergseminar" were transferred to Oslo (then Christiania). Here these activities formed the core of the new university and as many as seven out of the nine professors were appointed in the Faculty of Mathematics and natural science. Their work covered two main fields, those of mineralogy and metallurgy, the latter of which became part of the Technical University of Trondheim (NTH; now NTNU) established in 1910. This explains why the 200th anniversary of higher technical education was celebrated at NTH (NTNU) in 1957.

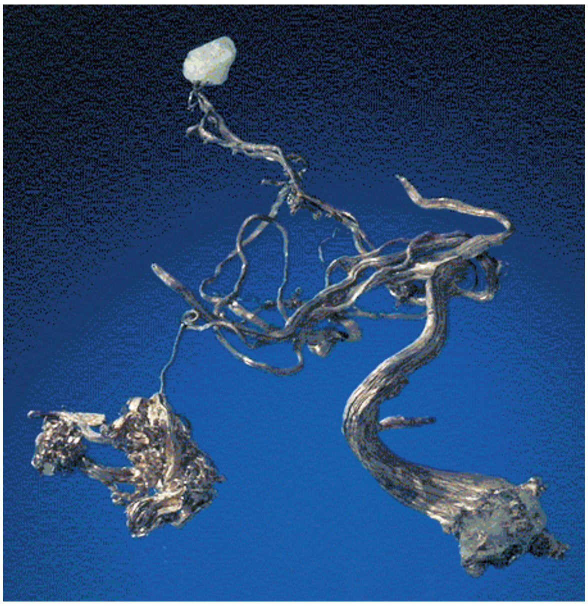

*Fig. 6: A sample of native silver from the Kongsberg mine. The original sample is 24 cm wide and 18 cm high. Photo: Tor Aas-Haug, Norsk Bergverksmuseum, Kongsberg.*

One example of the writers who started to focus on the description of the surrounding natural environment was Erich Pontoppidan (1698-1764). His two-volume monograph of 800 pages (Pontoppidan 1752-1753) describes natural phenomena and landscapes in Norway. Originally from Aarhus in Denmark, he was the bishop of Bergen and travelled widely throughout Norway, collecting information on the nature of Norway. His descriptions, although not always sound, also contain observations on such things as minerals, crystals and fossils (Fig. 7). Most famous is his enigmatic statement that "Oil-Brooks or Streams of Petroleo, Naphta, Brimestone, Pittecoal Fat and other bitominous and oleaginous Juices" expectedly are to be found beneath the North Sea (Gabrielsen & Doré 1995).

The works of Morten Thrane Brünnich (1737-1827) and Jens Esmark (1763-1839) were entirely dedicated to geology. Brünnich (1777) published the first Norwegian book on mineralogy, whilst Esmark, the first professor in geology at the new university in Christiania. Peder P. Hiort (1715 - 1789) assembled collections of geological samples and attempted to develop theories on geological processes based on these. Esmark (1824) was one of the pioneers of the glaciation theory. Based on the study of moraines in Lysefjorden, erratic blocks and striations on rock surfaces, he suggested that the whole of Norway had once been covered by ice.

In this period, the neptunists and plutonists debated furiously and arguments were based on field observations which slowly opened the way to analyse and solve scientific problems according to the hypothetical-deductive method. The debate was fuelled by visits to Oslo by the then neptunists Leopold von Buch (1774-1853) and Johan F. L. Hausmann (1782-1859) in 1806-1808 who observed that magmatic rocks (generally regarded by neptunists to represent older basement) were situated stratigraphically above fossil-bearing sediments

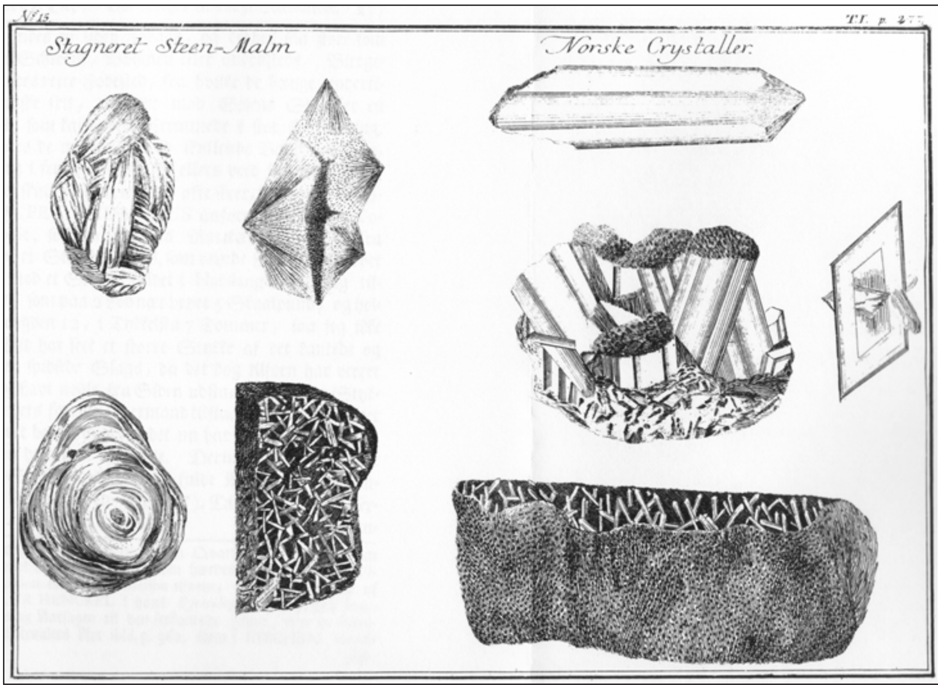


*Fig. 7: Minerals collected by Erich Pontoppidan during his travels in Norway. From Pontoppidan (1753).*

(von Buch 1810). In contrast, Sir Charles Lyell (1797-1875), who visited the same localities together with Keilhau in 1837, was less surprised, because he represented the plutonists (Dons 1978, 1994).

Whilst the above mentioned geologists were active on the international scene, local clerics were being encouraged by Bishop Pontoppidan to observe and describe their own local areas. Among these was Hans Strøm (1726-1797) who published two volumes of observations from the Sunnmøre area, including geology. He also illustrated some of the first fossils from the Oslo Region (Strøm 1784) (Fig. 8).

Palaeontology in this period was gaining ground and fossils from the earliest Palaeozoic rocks of Norway were described by palaeontologists such as Brünnich from Denmark, von Schlotheim in Germany and Dalman in Sweden. In Norway, Boeck (1827), Sars (1835) and Kjerulf (1865) followed soon after. The latter, who became the first director of the Geological Survey of Norway (founded in 1858), knew the value of fossils as a guide to identifying the age of the rock, as he had seen how these had been used to solve geological problems in equivalent rocks in Sweden (see period 3). In fact, Linnarsson in Stockholm had been sent Norwegian specimens, which he identified as being the same as those he had found in the Cambro-Silurian rocks of Vestergötland.

This was a time for sharing knowledge and Norwegian scientists began to travel abroad to learn from a growing international scientific community and also to encourage distinguished foreign geologists, like von Buch and Lyell, to visit Norway. Balthazar Mathias Keilhau (1797-1858) became one of those to enjoy the privilege of extensive travel abroad. In 1821 he became the first candidate to have completed training in geology at the University of Christiania (Oslo), and he was given particular responsibility to perform field studies. One year later he passed his practical examinations in Kongsberg. With this background he was well equipped for study in Berlin and Freiberg. Not long after, in 1834, Keilhau became professor of "mineralogy, geognosi and rock science" at the University of Christiania (Oslo). He travelled extensively and his field studies included the processes of sediment transportation and deposition. His regional study was comprehensive, culminating with the classical work "*Gæa Norvegica*" (1838-1850), where geological descriptions and maps became published for the Oslo region (1838), northern Norway (1844) and southern Norway (1850). In the opinion of many, these contributions earned him the title "Founder of Norwegian Geology".

To summarise the period 1760-1850 we note the transition from mining-based, practical geological knowledge towards systematic observation, based on regional field mapping, correlation and the study of geological processes. The new interest for generating systematic collections led to the development of a

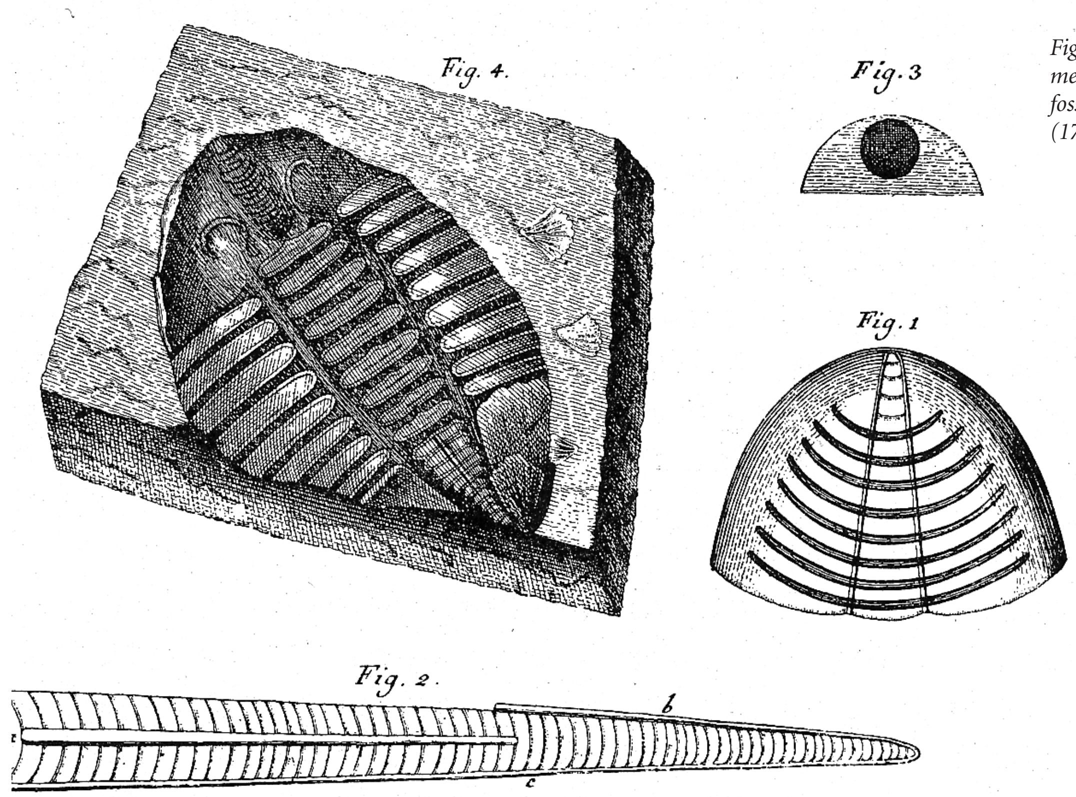


*Fig. 8. The first documented Norwegian fossils. From Strøm (1784).*

strong descriptive tradition which was to influence geology in the century to come. Even today, geoscientists are criticised for being too concerned about systematic observations. This criticism seems to ignore the fact that a solid basis of observation is absolutely necessary for the study of complex, interrelated and sometimes non-linear processes that characterise natural geological systems. The first steps to develop such systematics were taken in this period.

## Period 3 (1850-1910)

In this period the foundation of what we now regard as modern geoscience became established. This implies that academics applied extensive field study to obtain local and regional data for the generic understanding of fundamental geological processes on all scales, from global, tectonic to crystallographic and chemical (Fig. 9).

The period began with a fierce battle between the grand old man of Norwegian geology, Keilhau, and his former student and close colleague, Theodor Kjerulf (1825-1888). In his paper "*Das Christiania Silurbecken*" Kjerulf (1855) refuted the ideas of his mentor on the "transmutation" and genesis of the granitic rocks and advocated strongly for a plutonic e.g. magmatic origin. Later Kjerulf (1879) demonstrated the contrast between his modern view and that of his predecessor (see Hagemann 1963).

Towards the end of the century, differences in opinion also arose between those who believed that large-scale thrusting was an important mechanism in orogens and those who saw the contrasts in such systems in the light of metamorphic processes. It is beyond the scope of the present overview to discuss this in detail, but we note that the battle in Norway was part of a contemporary international scientific debate. More important perhaps is that these discussions reflect an important new situation: The large-scale, mechanistic theories of geological processes were about to be established. For the first time in the history of geology, sufficient data and adequate methods had become available to test these hypotheses against each other and against solid scientific observations.

In the first two periods described above, students of the geological disciplines in Norway had played an important part on the international scene whilst in the third period we recognise, a number of Norwegian geologists who became real leaders who mastered many fields and saw with clarity the complex relationships within geological systems and the processes involved. Thus John H.L. Vogt (1858-1932) performed innovative experimental and theoretical studies in ore geology whilst field geologists such as Hans Reusch (1852-1922), Johan B. Rekstad (1852-1934) and Knut O. Bjørlykke (1860-1946) were involved in debating the processes involved in mountain building. Reusch involved himself with many problems from the study of natural fracture systems to the understanding of the glacial deposits that lay strewn over the entire landscape (Reusch 1852, 1922). In 1882 he described fossils from metamorphic rocks, a sensation that caused the great Sir Archibold Geikie (1851-1924) to visit Norway to see for himself (Yochelson pers. comm. to DLB). Later he found evidence for a much earlier pre-Quaternary glaciation in northernmost Norway (Reusch 1890).

Systematic studies in mineralogy and palaeontology were published by Waldemar Christopher Brøgger (1851-1940) and Johan A. Kiær (1869-1933) whilst Fridjof Nansen (1861–1930) performed innovative studies in marine geology and geophysics. Brøgger first became internationally known through his work as a palaeontologist and stratigrapher, when he mapped and collected fossils for the Geological Survey of Norway in the Trondheim area, in Valdres and in the vicinity of Kongsberg (1878). The significance of the Trondheim fossils became evident much later when their North American affinity was established by Strand (1947) and their significance in early plate tectonic models was outlined by Bruton & Bockelie (1980). Brøgger's Cambrian work was the basis for correlation between Scandinavia and North America and a standard for international biostratigraphy. His greatest contribution to Norwegian palaeontology and stratigraphy was his work *Die silurischen Etagen 2 und 3…* published in 1882 and after he had taken up his position as professor in Stockholm. The work covers the stratigraphy, structural geology and igneous rocks, of the Oslo Region and includes the description of more than 100 fossil species illustrated by the author himself (Fig. 10). Later he contributed substantially to our understanding of the igneous rock province of the Oslo region in a series of books which immediately became international classics. He also described a number of new minerals from the nepheline syenite pegmatites at Langesundfjorden, gave names to several new rock types and was the first to give reliable evidence for the magmatic origin of carbonatites. He was also instrumental in the building of the University museums of natural history at Tøyen, Oslo and was highly successful in raising money for future scientific endeavours.

The development of palaeontology and stratigraphy in Norway is really reflected in the history within the four walls of the University Geological Museum at Tøyen in Oslo to which Brøgger invited Kiær to occupy a part of in 1915 and establish the Paleontological Museum. Kiær, appointed the first Professor in palaeontology in 1909, was responsible for establishing collections of fossils from Norway and elsewhere. Until 1915 these had been housed in the basement of the University Aula in the city centre where they were on public display from 1913.

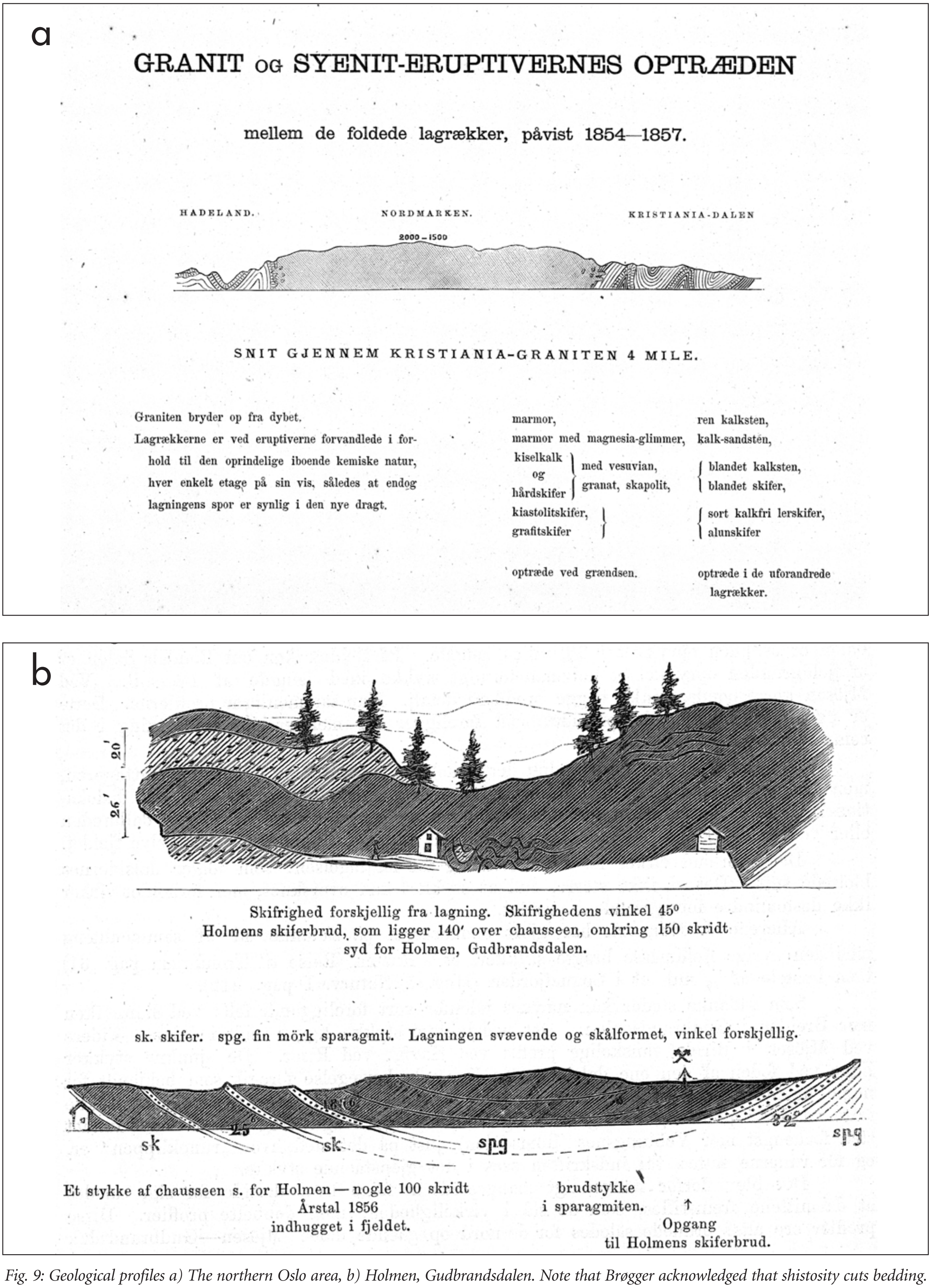


*Fig. 9: Geological profiles a) The northern Oslo area, b) Holmen, Gudbrandsdalen. Note that Brøgger acknowledged that shistosity cuts bedding. From Brøgger (1882).*

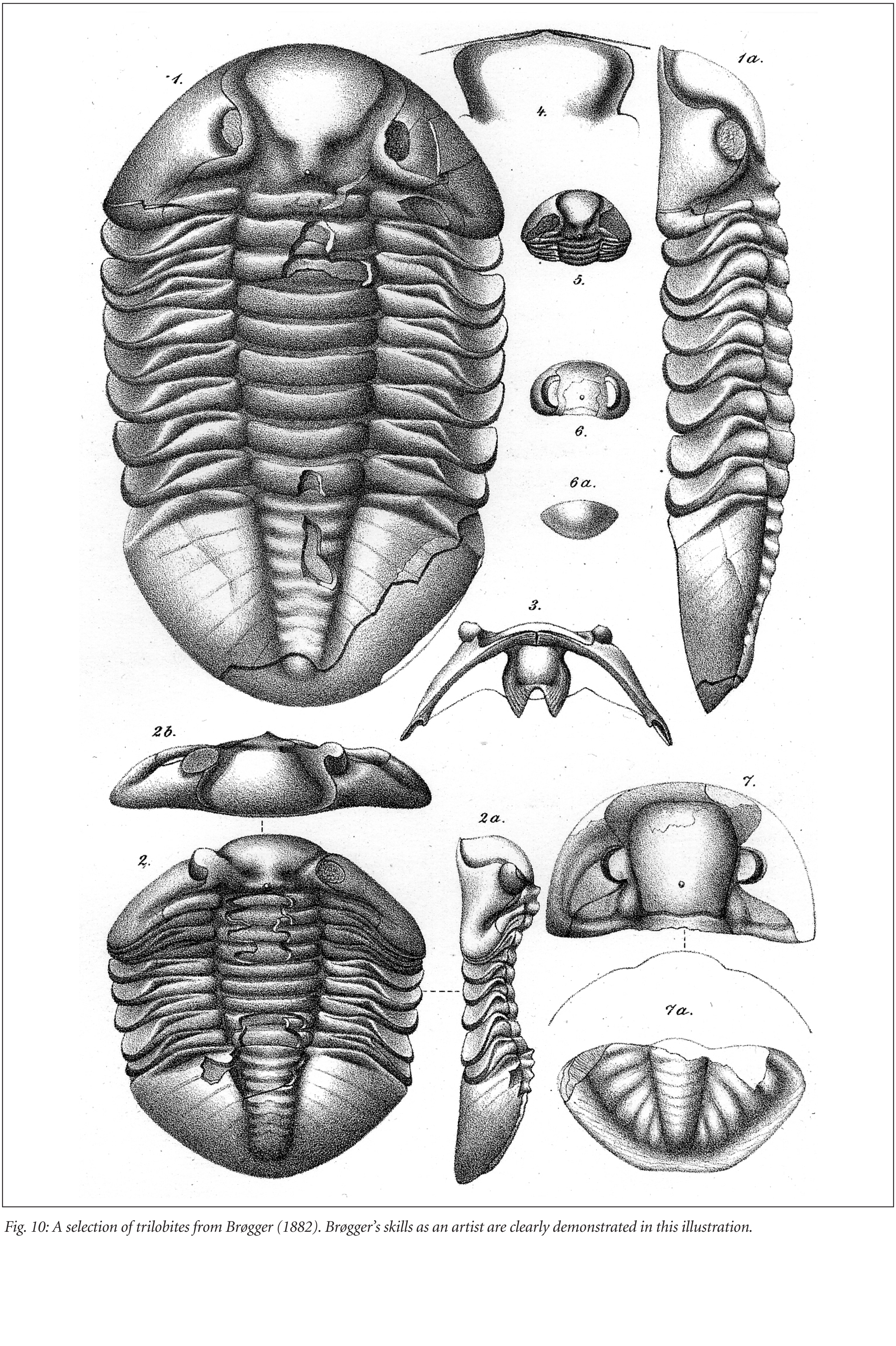


*Fig. 10: A selection of trilobites from Brøgger (1882). Brøgger's skills as an artist are clearly demonstrated in this illustration.*

Kiær's publication *Das Obersilur im Kristianiagebiete* from 1908 is still a valuable reference list for studies of the stratigraphy and palaeontology of the classical Silurian outcrop areas, with detailed coloured maps, reference sections, correlation charts and faunal lists. He was especially interested in faunal associations and the book contains observations on palaeoecology long before this branch of our science became fashion in the 1960's. In 1909, with direct funding from the Norwegian parliament, he made an important discovery of primitive vertebrates and arthropods (Kiær 1924) including Norway's most famous fossil, the eurypterid *Mixopterus kiaeri* from the Ringerike Group at Rudstangen. The combined work of the above mentioned scientists and those around them meant that the geosciences became more structured and thanks to the initiative of Kjerulf and Tellef Dahll (1825-1893).

In 1856, the groundwork for the foundation of the Geological Survey of Norway was laid down and this became a reality in 1858. With Kjerulf as its first leader, the practical work of mapping the country began and soon maps for Christiania (Oslo), Hamar and Christiansand (Kristiansand) appeared between 1858 and 1865. Kjerulf bedrock map of south Norway accompanied by a description (Kjerulf 1877; German translation 1880) and Dahll's map of north Norway (Dahll 1879) laid the foundation for future research. Here one can really admire the fact that geological mapping of the entire country was carried out by such a small group of geologists.

In 1890 Reusch attempted to found a geological society where geologists could meet, but because of opposition from Brøgger, only an informal club was formed on March 2nd 1893. However, the Norwegian Geological Society (Norsk Geologisk Forening: NGF; Fig. 11) was born on February 18th 1905 soon after Norway became a free nation and the first scientific meeting was held on March 25th. Later meetings provided the opportunity for the presentation of a wealth of information of field data collected within all disciplines of geology. These meetings also provided a forum for discussions covering the basic mechanisms and processes involved. However, this period also included the time when continental drift was discussed and rejected (see reviews in Muir Wood 1985; Oreskes 1999). Among those who followed the debates with interest were members of the Society such as Brøgger and Nansen. It is worth noting the important roles played by these two scientists in the negotiations leading up to an independent Norway in 1905 (Hestmark 1999).

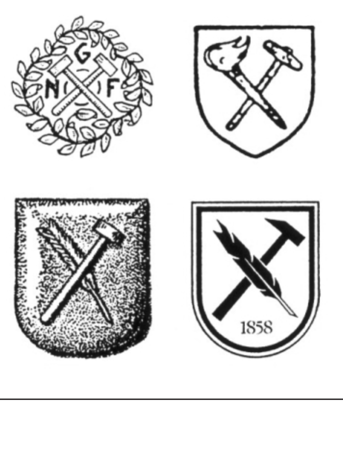


*Fig. 11: Evolution of crests of the Geological Society of Norway from 1918 (top left) and 1946 (top right), and the Geological Survey of Norway from 1891 (lower left) and 1972 (lower right). From Dons (1994).*

It seems indisputable that the period from 1850 to 1910 was an extraordinary one in the history of Norwegian geology. This is not only because the subject was in a stage of rapid development, but also because the talent of geologists in Norway was extraordinary. They generated a firm base for modern geology in that an immense amount of field data of the highest quality was collected within all disciplines. The efforts conducted in the field were almost unbelievable in that most of Norway was mapped by a handful of geologists within the time-span of a few tens of years. On this foundation, great steps forward were made in understanding of basic mechanisms and processes of geology. Furthermore, the scientific talent went hand in hand with a willingness and ability to take the necessary organizational steps. The many roles in the official life of Norway that people like Nansen and Brøgger played, bear proof of this. In contrast to previous periods, however, the mining industry became less of a driving force than before.

## Period 4 (1910-1960)

In this period we see an emphasis on theoretical aspects of geology with the concept of geochemistry and the study of metamorphic reactions becoming increasingly important. Victor M. Goldschmidt (1888-1947; Fig. 12) who had already made a name for himself at an early age of 23 when he published his work on contact metamorphism (Goldschmidt 1911), came to acquire the title "Father of Geochemistry" (Mason 1992) following publication of 9 volumes (*Geochemische Verteilungsgesetze der Elemente*) between 1923 and 1938, on the behaviour of the elements during geologic processes. In these he defined and explained an understanding of the geochemical behaviour of the rare elements and the factors which controlled their distribution in minerals during magma crystallization. He was the first to estimate their ionic sizes and coined the term "Lanthanide Contraction" (Muir 1954).

Goldschmidt was also an initiator when it came to the practical, industrial application of geological knowledge. He was appointed chairman of a governmental commission on the use of raw materials and served as the director of its laboratory ("Råstofflaboratoriet")

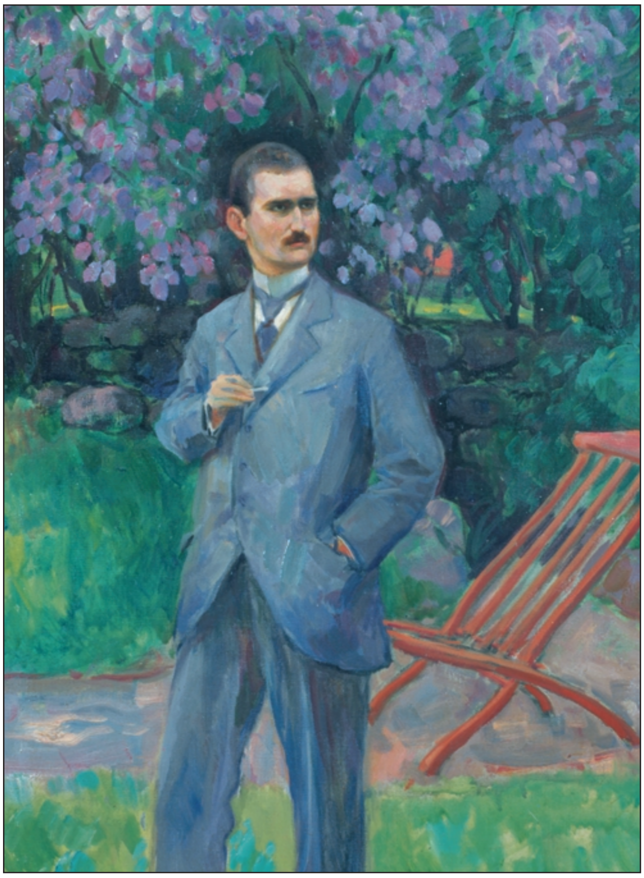

*Fig. 12: Portrait of Victor M. Goldschmidt (1888-1947) painted in 1917 by Thorolf Holmboe (1866-1935). The portrait hangs in the mineralogy display area of the Geological Museum, University of Oslo. Photo by Per Aas.*

whose objective was to develop Norwegian raw materials to replace those whose import was restricted during and after World War I. In 1918 a productive unit was established in the University`s Mineralogical-Geological museum in Oslo (Fig. 13) and research covered a wide field, including methods for the extraction of oil from coal and bituminous shales from Svalbard, the use of native raw materials for production of phosphate and potassium fertilizers, improved methods for extraction of copper from low-grade ore and methods for production of aluminium from orthositic rocks. Goldschmidt and his associates performed experiments on animals to see if replacement of quartz sand by olivine sand in foundries would remove the risk of silicosis. This work led to international patent registration and the industrial production of sources of olivine from 1948 in Sunnmøre and Nordfjord. Goldschmidt's work bridged the gap between geology and chemistry in the same way geology has since evolved in cooperation with other natural sciences. Johan H. L. Vogt also worked in the area where theoretical and applied science come together. He studied ores and natural slags and contributed significantly to our understanding of magmatic differentiation (Vogt 1924-31) and he shared his results with the international community in the textbook Erzlagerstättenlahre, which he wrote together with the German ore geologists Beyschlag and Krusch.

Norwegian palaeontology and stratigraphy were already well known internationally and Johan Kiær's interests in the development of early fossil fish, led him to initiate

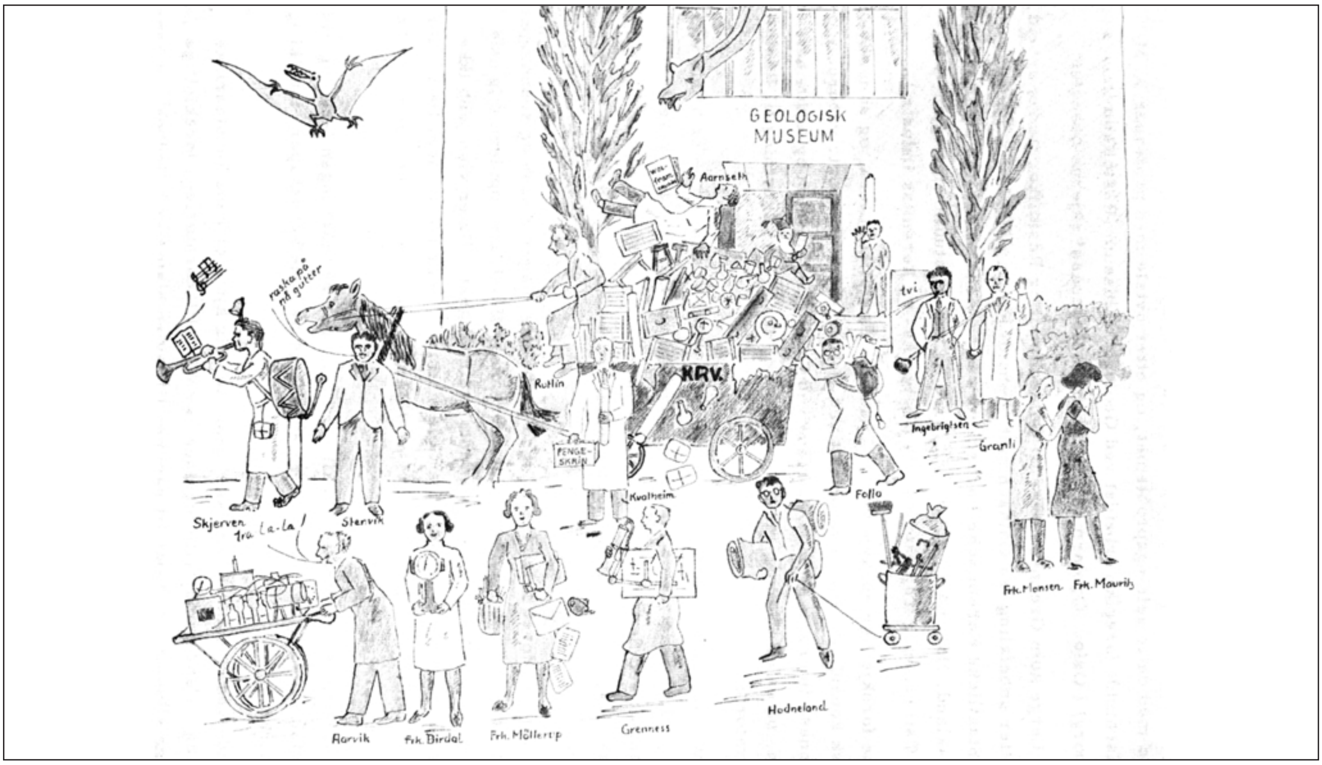


*Fig. 13: In 1952, Statens Råstofflaboratorium with its 11 employees, moves from the Geological Museum in Oslo to Trondheim in the summer of 1952. Drafted by Johs. Grennes. From NGU-Nytt nr. 6 1967.*

expeditions to the Devonian rocks of Svalbard. These included the descriptions of Th. Vogt in 1925 and 1928 and a joint English-Swedish-Norwegian expedition in 1939. His student Leif Størmer (1905-1979) was making a name for himself with detailed studies on trilobites (Størmer 1939, 1942, 1951) including the description of appendages using a method of serial sectioning of specimens. His interest in functional morphology followed a visit to America in 1931 where he studied a variety of arthropods including those from the famous Middle Cambrian Burgess Shale. His ideas on the evolution and relationships of the arthropoda were summarised in a classical paper published during the war (Størmer 1944) after which he became a world authority. Gunnar Henningsmoen (1916-1996) continued this tradition with landmark studies especially on Cambrian trilobite taxonomy and classification (Henningsmoen 1951, 1957) Like Kiær, Størmer and Henningsmoen were stratigraphers who used fossils to solve geological problems as well as those in biology. Størmer's research project: "Studies of the Middle Ordovician in the Oslo Region, Norway" was unique in that a large proportion of grant money covered the costs of supporting numerous palaeontologists from abroad who were invited to work at the Paleontological Museum and describe their specialist group of fossils. All publications appeared in Norsk Geologisk Tidsskrift and 34 titles were produced in the series from 1953 to 1982. Both Størmer and Henningsmoen contributed to an international treatise on invertebrate palaeontology and served respectively as chairman and secretary-general of the International Commission on Stratigraphy (1960-1965).

Discoveries of Devonian plant remains from Norway led Kiær to employ Ove Arbo Høeg (1898-1993) as curator of palaeobotany in 1924, the same year as Høeg joined Adolf Hoel's expedition to Bjørnøya and Spitsbergen. He followed this up by collecting plants in North Spitsbergen while a member of Vogt's expedition in 1928 and results from his own expedition in 1939 appeared soon after (Høeg 1942). This led him to become one of the world's foremost palaeobotanists and an expert on the evolution of early land plants. He retained his interest in the subject after he left Tøyen to become Professor of Botany at the Institute of Pharmacology, University of Oslo in 1947 and later combined this with establishing a section for palaeobotany at the Geological Institute in 1958.

The high standards of geochemistry established at the Geological Museum in Oslo were followed by Tom. Fr. W. Barth (1899-1971) and Knut S. Heier whilst elsewhere the interdisciplinary association of geochemistry, rock mechanics and engineering performed by Laurits Bjerrum (1918-1973) and Ivan Th. Rosenqvist (1916-1994) led to the foundation of the Norwegian Geotechnical Institute in 1953. In particular, Rosenqvist explained why some clays are unstable (so called quick clays) and what is necessary to stabilize them. Also his study of chemical reactions between alum shale and oxygen and the corrosion of iron in clay had important practical applications. These activities were very much in harmony with the tradition of close and successful co-existence between theoretical, basic research and its potential for practical application that has characterized Norwegian geology throughout its entire history. A mathematical insight into geology was provided by Hans Ramberg (1917-1998, to a large extent working in the U.S.A. and Sweden) whose experimental modelling of tectonic processes and rock deformation performed between 1950 and 1990 (Talbot 2001) are elegantly portrayed in his well known text book of 1967 (see also Ramberg 1981).

Also the study of the Quaternary made great progress in period 4, and a rather complete description of its development of Norway was available by the end of the period. This is clearly demonstrated in O. Holtedahl's "Norges geologi" (Holtedahl 1953).

In conclusion, the period leading up to the 1960s was a prosperous one in which geoscience was able to reap the benefits of long term field work, the practical use of theoretical models and the cross fertilisation of geology and chemistry to provide the basis for the industrial exploitation of specific minerals.

## Period 5: 1960 - Present

This period brings us up to the presentday and might well have been named "From "Congress to Congress" with the starting point at the 21st International Geological Congress (IGC), held in Copenhagen in 1960, ending with hectic planning for the 33rd IGC, to be held in Oslo in 2008. Both congresses reflect the globalisation of our science and the importance of Nordic cooperation. In general terms, this period is characterized by an almost explosive expansion of the geosciences, both with regard to tools and technologies, the number of professionals actively involved in industry and academia, as well as the many new areas of challenge. This development has clearly accelerated towards the end of the period, pointing to new opportunities in the years to come.

In Period 5 the geosciences have undergone a major paradigm shift, which has caused dramatic changes involving a larger number of scientists than ever before. These changes have been brought about by:

- *In the 1960s:* The breakthrough of plate tectonics, and its major impact on the understanding of geological phenomena both onshore and offshore.
- *In the 1970s:* The development of North Sea oil and

gas fields; a rapid increase in the demand for geoscientists; geological mapping of the North Sea and subsequently the Norwegian Sea and the Barents Sea.

- *In the 1980s and 1990s:* The introduction of quantitative methods and modelling in all geological disciplines, in particular the development of computers and programmes in collating and interpreting large volumes of data, modelling systems, the presentation of results and scientific communication. Today it is reckoned that in terms of information technology, the petroleum industry is as advanced as the space industry. The power of computers, accelerating towards the end of the period, creat new possibilities.
- *Throughout the period:* The increased and accelerated application of new technology, such as the use of sophisticated mass spectrometers and electron-microscopes, in the study of rocks and minerals, their chemistry and textures and age of formation. In the oil industry, the revolutionary development of seismic tools, like 3D seismic, 4D and 4C, as well as electromagnetic surveying, represent significant quantum leaps
- *Everywhere in this period* there has been an increased participation in international projects, combined with a change from discipline-oriented to thematic and interdisciplinary-oriented approaches to identifying and solving geological problems. At the university level this trend is reflected by the establishment of earth science departments.
- *Finally,* there has been an increased social awareness of the world we live in and the environment around us, including natural resources, pollution, clean water, climate, regional and urban planning, monitoring geo-hazards and waste. This has created new arenas in which geoscientists, both at home and abroad, have taken their share of organisation and responsibility.

Space allows us to alaborate mention only some of the more important highlights of the period. These are:

**Plate Tectonics.** In the late 1960s and early 1970s geologists everywhere were being presented with new data interpreted in the light of plate tectonics. The conception and gradual acceptance of the hypothesis represented a paradigm shift of great consequence for the understanding of large-scale phenomena. Geologists in all branches of geology realised they were part of the same world where results could be integrated; textbooks needed to be rewritten and ingrained beliefs required change. This was a period of enthusiasm and renewal.

In Norway, new interpretations were put forward on the evolution of the Caledonide mountain belt, its constituent nappes, their origin and derivation, the provenance of the volcanic and metamorphic rocks and the meaning of exotic terrains with their individual constituent faunas. The new ideas were essential background for the studies related to the Norwegian "Geotraverse" project and the International Correlation Program. Results were presented during transect-type excursions and at international meetings as in Uppsala in 1981 (Gee & Sturt 1985). Here a new tectonic map of the Scandinavian Caledonides was presented, geologists at the University of Bergen identified slices of ocean crust represented by a string of ophiolite outcrops along the Norwegian west coast (Furnes et al. 1985), and members of the Geological Survey of Norway in Trondheim together with colleagues from the nearby technical university, explained the sulphide mineralization in terms of plate tectonic models (Grenne et al. 1999). Palaeogeographic maps were drawn using data from faunal provinces and sedimentary types as correctives. Inspired by the mechanisms involved in plate tectonics, geologists at the University of Oslo in the early 1970's, reinterpreted the apparently isolated Oslo Graben as a 'failed rift' caused by plate movements that ruptured the crust (Ramberg & Neumann 1978).

Nowhere was the impact of plate tectonics felt more than as in connection with studies of the oceanic regions (Oreskes 2001) with classical works by Norwegian and American scientists, in particular from the Lamont-Doherty Laboratory group (e.g. Talwani & Eldholm 1972, 1977). These cast new light on the evolutionary history of the North Atlantic. This work eventually had implications for our understanding of the Norwegian continental shelf and hence for the future of petroleum exploration (see Gabrielsen & Doré 1995 for summary).

**The adventure of petroleum.** This major 'event' and its associated industry influenced not only the geosciences in Norway, but also the entire nation. This idea that hydrocarbons may occur at the Norwegian shelf was raised in 1956 at an international oil conference in Mexico City (Helle 1984) and was strengthened by the discovery of the Dutch Groningen gas field and by gravimetric data which suggested that sedimentary basins existed in the southern North Sea (Collette 1960; Donovan 1963). That sedimentary basins existed was in fact not new since they had been predicted earlier by Jukes-Browne (1911) based on palinspastic reconstructions and O. Holtedahl (1929) had come to the same conclusion after studying the topography off the Norwegian coast (for summary, see Gabrielsen & Doré 1995 and Sellevoll & Kristoffersen 1995). Nevertheless, it was still widely accepted that the mainland bedrock geology of Norway could be extrapolated offshore and that metamorphic rocks made up the continental shelf (Bjørlykke 1992; Sellevoll & Sundvor 2001).

With this in mind, it is all the more praiseworthy that in 1959, Norwegian geophysicists and geologists, together with German colleagues, took the initiative to plan the so-called Skagerrak project (Sellevoll & Kristoffersen 1995). Work was started in 1962 and resulted in a velocity profile that confirmed the presence of more than 3 km of sediments below the seabed, an observation later supported by gravimetric data (Sellevoll & Aalstad 1971). These pioneer studies heralded a new and successful era of geophysics in Norway, providing remarkable results of great scientific and commercial value (Sellevoll & Sundvor 2001).

Thus in the late 1960s and early 1970s there followed an extensive period of exploration. Major oil companies arrived in Norway in search of oil and for this large numbers of geologists were hired. The establishment of Statoil and Saga Petroleum and subsequently The Norwegian Petroleum Directorate (1972), represented important milestones. Together with Hydro, the three Norwegian companies have since then played important roles in the exploration and exploitation of petroleum resources from the continental shelf, being involved in most of the large discoveries there. In the North Sea, the Ekofisk Field was the first giant to be discovered (in 1969), followed by the Frigg field in 1972, Statfjord in 1974, Troll in 1978 (Fig. 14) and then the giant strikes such as Gullfaks, Oseberg, Snorre, Sleipner, Brage and Grane. In the Norwegian Sea, other giant discoveries include Draugen, Heidrun, Njord, Norne, Åsgard and, finally, Ormen Lange, while in the Barents Sea the Snøhvit field is the only major discovery, so far.

*Fig.14: The development in the North Sea is by some regarded to be a technological wonder, here represented by the Troll platform. Photo: Norsk Hydro*

These and numerous smaller fields, offered, and still offer exciting and challenging jobs to scores of newly graduated students but have also called for great demands on those institutions training them. Universities and technical colleges needed to expand and cooperation between industry and academia was enhanced. Research laboratories within the oil companies worked alongside state funded research groups to increase our knowledge of the newly discovered offshore geology. Norwegian geophysicists have also played a remarkable and important role in developing seismic service companies, at times dominating the global scene. This innovative drive still takes place and new Norwegian companies are showing strength, taking a lead in the development and commercialisation of new surveying techniques, such as sea bed seismic and sea bed logging (Fig. 15).

**Environmental geoscience and natural hazards.** The Norwegian oil industry is now perhaps at is peak, harvesting from the investments in exploration and development of the discoveries in the period 1970- 1990s. Thus the demand for geoscientists on the Norwegian continental shelf may gradually diminish. However it can be partly offset by increased international activities together with a call for geoscientists to play a new role, to meet the challenge raised by remarkable new achievements. Climate change studies and climate modelling are important, as well as the study of geohazards and the growing field of biogeology.

In the last few years attention has been drawn to polar ice changes, the effect on ice-trapped lakes, the possible relationship between climate change and methane release following destabilization of hydrates on the continental shelf, the flow of the Gulf Stream and its control of the climate of Europe, the affect of large scale submarine landslides and the discovery of possible microbial activity in 3.5 Gyr lavas. These and many more open up for a new and exiting development of geoscience in Norway with implications both nationally and internationally.

More than 300 years separate our first period, 1620 –1750 and the last from 1960 to the present yet both share important features such as the demand by industry for geological expertise on the one hand and the willingness to use this in the exploration and exploitation of natural resources on the other. However, there is one major difference now and this applies to the need for the largescale international collaboration and organization which we see already emerging in geoscience at the start of the 1960s.

## The impact of international cooperation on Norwegian geoscience

The influx of international networking on modern science can hardly be overestimated. In fact, high-quality science cannot be imagined without organized cooperation, competition and the sharing of resources across international borders. This is, of course, not to

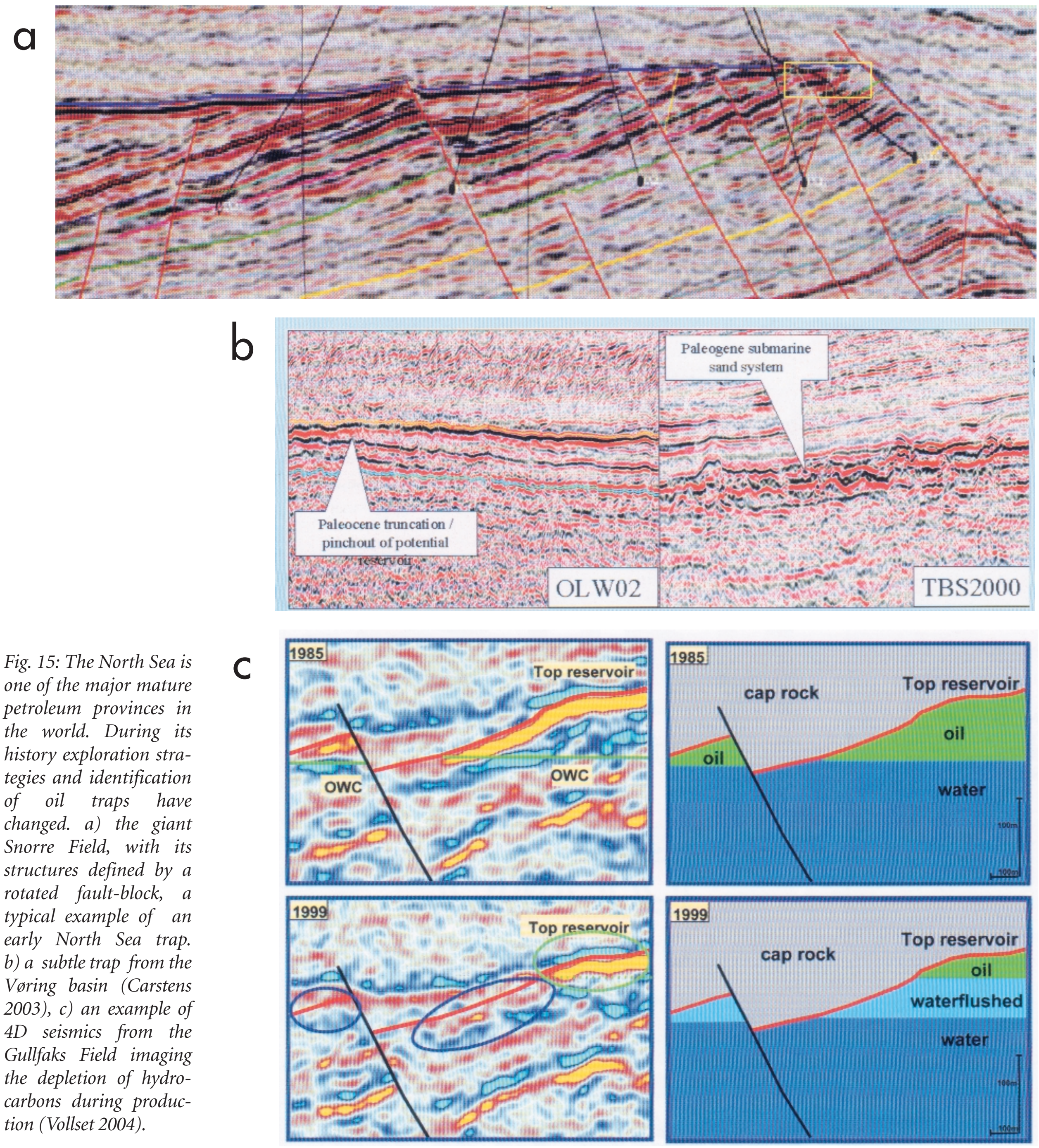


*Fig. 15: The North Sea is one of the major mature petroleum provinces in the world. During its history exploration strategies and identification of oil traps have changed. a) the giant Snorre Field, with its structures defined by a rotated fault-block, a typical example of an early North Sea trap. b) a subtle trap from the Vøring basin (Carstens 2003), c) an example of 4D seismics from the Gullfaks Field imaging the depletion of hydrocarbons during production (Vollset 2004).*

say that international collaboration in geology did not exist before 1960. On the contrary; Norwegian geologists were very much involved in international scientific endeavour. An important new element, however, was that after 1960 such activity became much more coordinated through international organizations. Also, the number of geoscientists participating in international projects increased substantially and the working style turned from that of the individual to that of collaborative groups. Following the International Geological Congress in 1960, a number of large and ambitious international projects and conferences were initiated including the Norwegian Geotraverse Project, the International Geological Correlation Programme (IGCP), ICP, IODP, ICDP and the Paleorift Congress, to name a few of the more important. Ahead of us we will meet the Year of the Planet Earth (2005 – 2007), the International Polar Year (2007 - 08), and the International Geological Congress (IGC) in 2008.

It is impossible to summarize, and describe in detail, all the net-works, organizations and international efforts that have been of importance for the development of geoscience in Norway and we therefore select the following which we believe have been the more important.

**The Deep Sea Drilling Project** (DSDP, 1968 –1984); later Ocean Drilling Programme (ODP 1984-2003) and today the Integrated Ocean Drilling Programme (IODP) is without doubt the world's largest and most successful multinational earth science research effort (European Science Foundation 1997, 2003). Norway became an ODP member through a European 12-nation consortium, in fact the European science office was located in Oslo. Norway's participation has provided the opportunity to influence important decisions concerning geological investigations of the deep oceans and the continental margins and to join international networks of the highest quality. Norwegian scientists have played key roles, particularly in the North Atlantic where the drilling during Leg 104 on the Vøring Plateau, led to a breakthrough in the understanding of rifted volcanic continental margins (Eldholm et al. 1989).

**The Apollo Mission.** In 1967 the first landing on the moon captured the imagination of all those able to watch on television the event as it happened. Later interest in Norway was at its highest when it was announced that K.S. Heier and a team of young researchers at the Geological Museum in Oslo received the first sample of moon rock from the Apollo 12 journey for analysis (Fig. 16). This arrived in March 1970 and in the period following, the team supplemented by one scientist and one technician from the Atomic Energy Institute in Oslo, identified 40 constituent elements using the process of neutron-activation analysis. The project lasted until the end of 1973 during which time other samples were analysed including those from the Apollo 17 journey where the American astronaut H. Schmitt, a former post-doctoral student at the Geological Museum in the 1960s, took part.

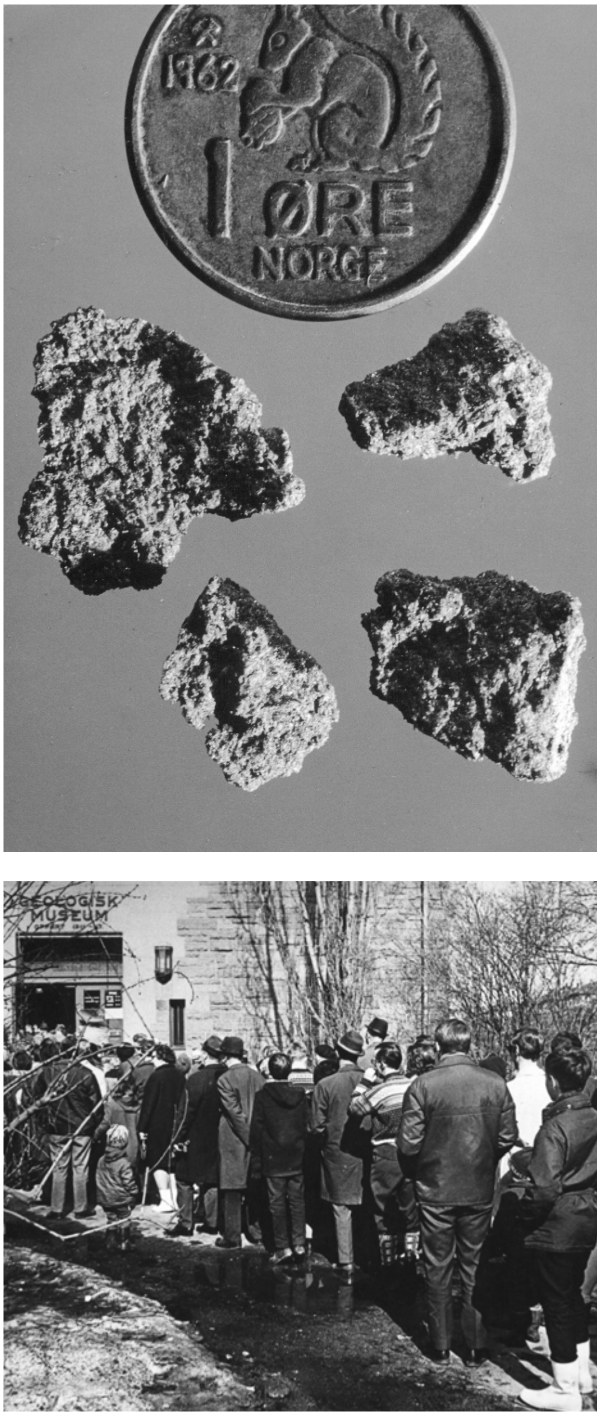


*Fig.16: The moon rock samples from the Apollo 12 Mission attracted considerable attention when put on display at the Geological Museum, University of Oslo.*

**The Norwegian Geotraverse Project** (1969-1975) was led by Professor Knut S. Heier and was Norway's contribution to the International Upper Mantle Project (UMP), later incorporated in the International Geodynamics Project (IGP). Its objective was the study along a 150 broad zone across central parts of Southern Norway and further across the North Atlantic to Greenland. One of the main goals of the project was to stimulate increased interdisciplinary work. It resulted in more than 130 scientific papers and contributed much to the cooperation between geophysical, geochemical and geological disciplines in Norway together with foreign organizations such as the Lamont-Doherty Geological Observatory (USA), Bundesanstalt für Bodenforschung (Germany), MIT, and the University of Oxford (UK). The project led to increased international interest in the geology of Norway, but also represented the starting point for what became international careers for a number of young Norwegian geoscientists (Heier 1977). The project was funded by the Norwegian Research Council for Science and Humanities (NAVF).

A more focused event was **the NATO Advanced Study Institute "Paleorift Systems with Emphasis on the Permian Oslo Rift"** held in Oslo in 1977. In the aftermath of plate tectonics, the study of continental rifts, active and passive, received significant international attention, and this conference was one of several symposia in the 1970s and 1980s which discussed one of the world's best exposed paleorifts (Dons & Larsen 1978; Neumann & Ramberg 1978; Ramberg & Neumann 1978).

**UNESCO** and the **The International Union of Geological Sciences** sponsored **International Geological Correlation Programme (IGCP)** was started in 1973. Norway joined in 1974 after the proposal which came to be known as "The Caledonide orogen" was accepted by the IGCP Board. When the project finished in 1985, over one thousand geologists from 12 countries had cooperated in trying to unravel the Precambrian to Devonian evolution of the mountain belt now straddling the present Atlantic seaboard but stretching from Svalbard in the north to Mauritania in the south. The project provided for the first time generous funding to Norwegian bedrock geologists to engage themselves in a truly international effort, with participation in numerous working groups, map compilation workshops, excursions, and project symposia of which 10 resulted in published volumes (Gee & Sturt 1985). The yearly two-day meetings held at the Sundvolden Hotel north of Oslo provided a valuable forum for Norwegian participants and their research students, many of whom joined the international excursions with generous funding from NAVF. Correlation means comparison and to compare rocks international cooperation is imperative.

**Looking towards the future in 2008,** Norway and the Nordic countries (Sweden, Denmark, Finland and Iceland) will host *the 33rd. International Geological Congress (IGC)* in Oslo. It is expected that between 5000 and 6000 geoscientists from all over the world will participate, many of whom will join excursions in all the countries and as far a field as Greenland, Svalbard and the Kola peninsula.

The last time an international conference of this size was organised by the Nordic countries was in Copenhagen in 1960. This, the *21st International Geological Congress* was a huge success. It encouraged many young geologists to help with the planning, provided much new information, the publication of new maps, books and excursion guides whose value lasted for many years (Holtedahl 1960). The forthcoming congress in 2008 is expected to do much the same and is expected to provide an exciting challenge for Nordic cooperation.

Together with plans for IGC 2008 are those for the *International Polar Year (YPE), 2007-2008.* Norway's polar traditions demand active participation in this programme and the Norwegian Research Council (NRF) has approved new, relatively ambitious research plans for the Arctic and Antarctica. The polar regions are the last little known frontiers representing key areas for the understanding of fundamental processes influencing the earth's regional and global climate. Geoscientists are expected to participate and a project committee has already been established for this purpose.

In summary, Period 5, which leads up to our own time, is characterized by several dramatic changes, a paradigm shift (Plate Tectonics), powerful new technologies, the advent and culmination of the 'petroleum era' on the Norwegian continental shelf. We have seen a significant increase in international cooperation and interdisciplinary work. 'Geology and Society' has become a meaningful term, with geoscientists now being involved in a much broader spectrum of activities than just the 'classical' geological disciplines, taking more direct responsibility for societal needs. These trends are expected to continue and even broaden in the future.

## Conclusions

By this brief and incomplete excursion through the history of geoscience of Norway, we have tried to emphasize some characteristics that we think are of importance when trying to understand its present state. We suggest that a continuous and logical line can be recognized from the earliest systematic hammer blows taken in several mines in the early 17$^{th}$ century to the present.

Firstly, there seems to be a logical development from basic geological observation and systematization of observations, through systematic field study and data collection to the establishment of generic hypotheses and to testing of hypotheses by targeted field investigations, and finally, modelling studies. Present-day geoscientists have computer power and modelling facilities at their disposal, that enable further testing of theories, performance of cross-disciplinary studies and development of predictive models.

Secondly, we suggest that the history of geoscience in Norway reveals a particularly close relationship when it comes to basic research and application and contact with industry. This tradition may reflect that geological research has grow from the incipient mining industry established nearly 400 years ago. It is acknowledged that geoscience in Norway presently holds an internationally very respectable standard in many of its disciplines. We also find, not surprisingly, that the present, healthy situation for geosciences in Norway to a large extent reflects the investments in research and technology development.

Giants of Norwegian geology


*Fig. 17: Portrait stamps issued in 1974 illustrating the giants of Norwegian geology. From the left: Johan H-L. Vogt, Victor M. Goldschmidt, Theodor Kjerulf & Waldemar Christopher Brøgger.*

In our musings on the history of the geosciences of Norway, we have found that its evolution can be divided into five main periods: In the period 1600 and 1760, practical knowledge created an economic environment for scientific reasoning, while between 1760 and 1850 we see the documentation of geological data. These data were in turn used for a detailed study of geological processes from 1850 to 1910, which formed the basis for the theories established from 1910 to 1960. It was in these last two periods that Norwegian geologists entered the international scene to become acknowledged as outstanding.

We suggest that the rapid adjustment to meet the needs of the growing petroleum industry in the 1960's and its development was only possible because of the Norwegian geological tradition of combining theoretical and academic study and putting this to practical use. Today Norway's standing internationally is something of which we can be proud and for this we owe the fact that we, to a certain degree, are standing on the shoulder of giants (Fig. 17).

We are now celebrating the centennial of the founding of the Norwegian Geological Society, on February 15th 1905. In that same year, Norway became an independent nation and the industrial giant Norsk Hydro was founded. For Norway, these important historical and economical-industrial events introduced a new social environment heralding the industrial development we enjoy today. These 100 years have seen a huge and impressive development of the geosciences built on traditions first established more than three hundred years ago. We believe this will continue and adapt to meet new demands which will arise and be solved using new technologies.

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