GEOLOGY AND ORE

Exploration and Mining in Greenland

Minerals in Greenland

No. 12 - February 2008

Minerals in Greenland

Minerals are an integrated part of the geological history. The variation and wealth of minerals in Greenland have been significant in rendering the country with its prominent place on the geological world map, shared with only very few other regions. In their widest context, minerals understandably attracted a great deal of attention from the first explorations in the early 1800s.

Introduction

Minerals and mineral resources have been identified as a cornerstone of Greenland's economical development. Therefore many initiatives have been implemented to accelerate the establishment of the mineral industry. After 150 years of almost continuous mining, and following a brief break since 1990, Greenland now seems to be entering a new phase of mineral exploitation, with the opening of new mines: a gold mine in South Greenland in 2005 and an olivine mine in West Greenland in 2005.

From being a classical collection of museum curiosities, the mineral wealth of Greenland has turned into a foundation for modern mineral exploitation. Today tradition and mineral know-how give us a detailed picture of Greenland's mineral resources. It all began in the early 1800s when the German actor, playwright and mineralogist, Karl Ludwig Giesecke, became one of the first to work systematically with Greenland's mineralogy. Giesecke stayed in Berlin from February to June 1801, and here he wrote a comprehensive 'manuscript' (350 pages) on the classification of minerals. This 'manuscript' was preserved probably because Giesecke kept it with him during all the six summers and seven winters he later spent in Greenland. Many of his belongings and mineral collections, which Giesecke sent to Denmark on several occasions during his travels in Greenland 1806-13, was seized by British warships during the uncertain years following the Napoleonic wars.

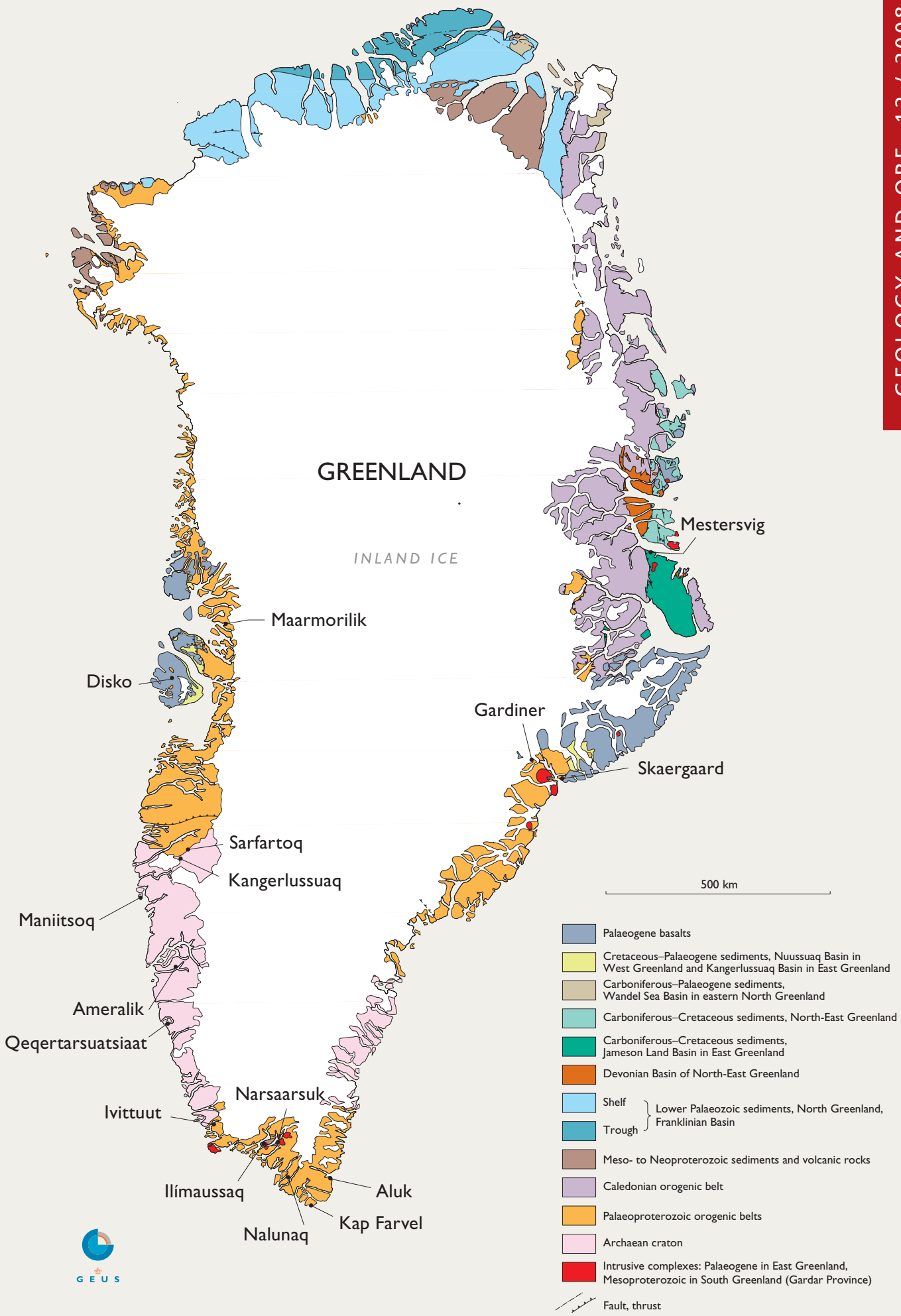
Slab of basalt from Disko in West Greenland studded with grains and crystals of metallic iron. Field of view: 20 x 24 cm.

Giesecke travelled by umiaq - an open Inuit skin boat - in South and West Greenland from 1806-13. Several mineralogical records were made during this long period and these later formed the basis of modern mineralogical research of Greenland minerals. At a site by Aluk near Kap Farvel, Giesecke collected a black mineral, believing it to be the well known mineral, hornblende. Giesecke's samples from this trip were stolen by English warships and ended with Robert Allan, a Scottish mineralogist. A Scottish chemist, Thomas Thomson, later studied the samples and discovered that they contained a hitherto unknown mineral which he named 'allanite' in 1811. All this was due to the divisions in Europe caused by the Napoleonic wars, which also meant that Giesecke was unable to leave Greenland. Since then, allanite has become known as a common accessory mineral in the granite bedrock areas the world over.

Following Giesecke's journey, a research tradition of the study of minerals developed rapidly in Denmark and Greenland and this influenced the studies of the geology of Greenland and sharpened the awareness of the significance of minerals in geological

Well developed crystal of allanite from the type locality near Aluk in south-east Greenland. Crystal size: 1.2 x 3.5 cm. Photo RB.

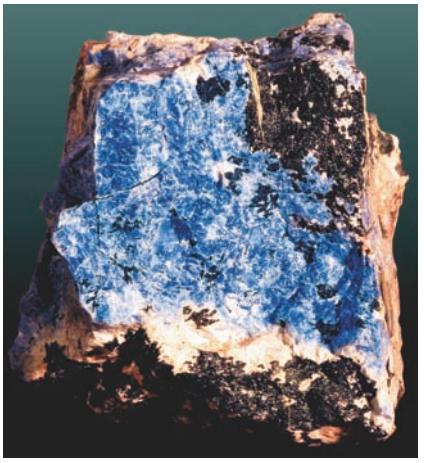
Geological map of Greenland with mineral localities



processes. Almost 80 recognised minerals from Greenland were found and described for the first time. A larger number of known minerals were described in more detail, contributing to the completion of the geological history. Today more than 500 minerals from Greenland have been registered; a significant proportion of the world's approximately 4000 known minerals.

As the type locality for 77 minerals (2008), Greenland has been rendered a special place in mineral research, even though many minerals are limited to unusual and rare formations. At all events, several of them have shown the way to understanding the geological processes and identifying possible deposits of mineral resources. In naming minerals from type localities, mineralogists in complete accord with tradition, have helped retain the knowledge of the history, geography and geological exploration. Mineral names such as eskimoite, leifite and vikingite have a clear reference to Greenland's cultural history. Important sites in Greenland have similarly become world famous through names such as kaersutite, narsarsukite, naujakasite, tugtupite and tuperssuatsiaite. Examination of names which directly refer to important people in early geological exploration such as bøggildite, bøgvadite, kornerupine, lorenzenite, rinkite, steenstrupine and ussingite, brings to mind the Danish exploration work. A similar list of minerals named after contemporary geologists is just as extensive and a reminder that exploration is still alive and well.

Group crystals of red corundum (ruby) in mica schist, Maniitsoq area, West Greenland. Longest crystal: 15 cm. Photo OJ.



Blue Lazurite cystals surrounded by white scapolite and black amphibole, Maniitsoq area, West Greenland. Size of sample: 5.0 x 5.5 cm. Photo OJ.

Minerals and mineral resources

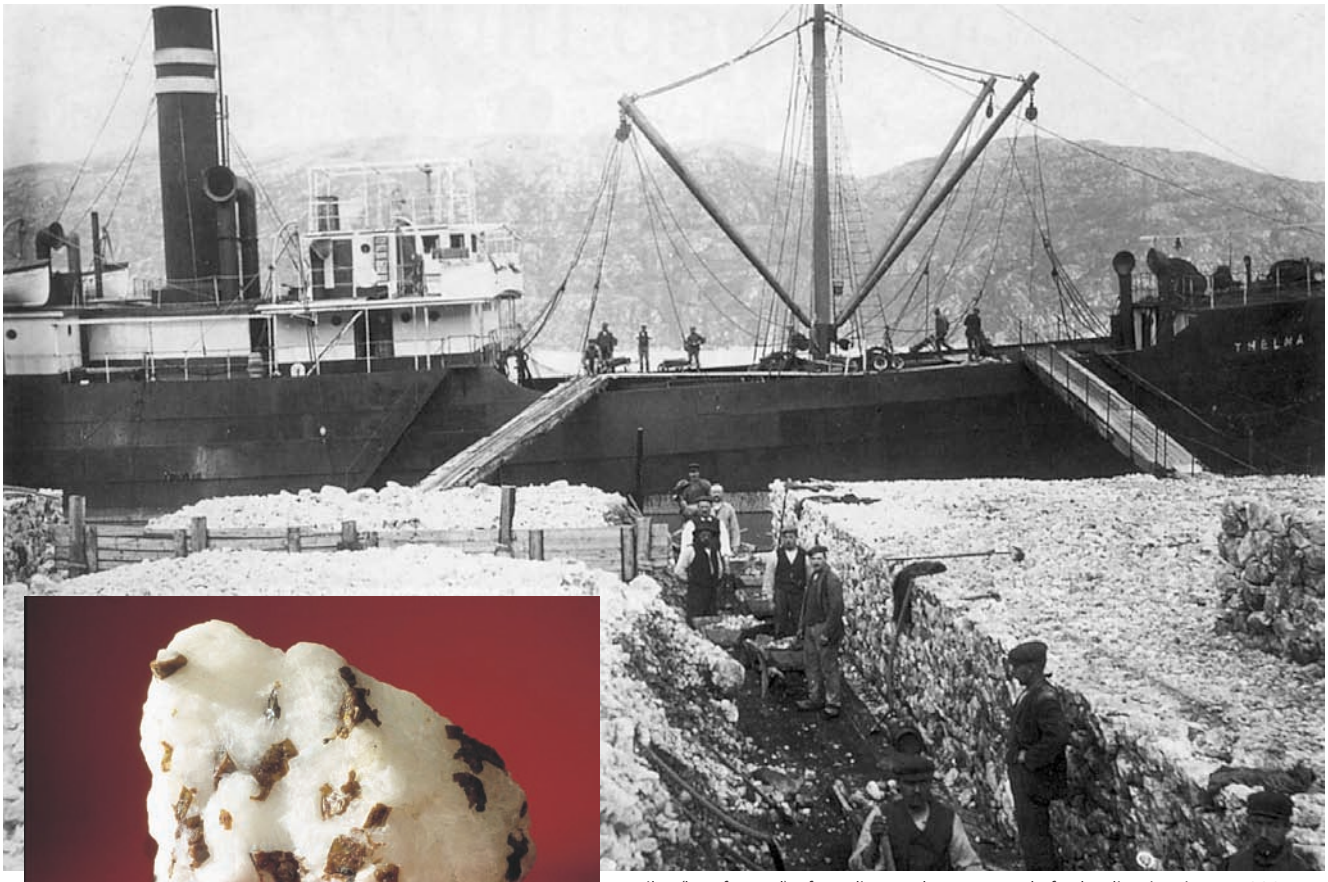
Mineral resources have a high priority in the socio-economic development of today's Greenland. Such priorities require the presence of a large number of mineral resources which form the foundations of mineral exploitation and mining, just as in other parts of the world. From 1990 to 2004 there was no exploitation of minerals, after almost 150 years of mining. On the other hand, there has been great activity in the exploration for new deposits and surveys of existing finds. Mineral resources known in Greenland so far are primarily located as the primary in-situ deposits. This contrasts with the secondary supergene deposits where the mineral resources are enriched in gravel and sand in rivers and on beaches, formed by erosion of the mountains. Many of the secondary deposits in Greenland were probably removed by glaciers of the Ice Age. The geological conditions in the Greenland geological environment are now well known and the many useful minerals provide good opportunity for identifying localities where exploitation of mineral resources could take place. Known mineral deposits contain gold, the platinum group elements, molybdenum, nickel, the specialty metals tantalum and niobium (in the mineral pyrochlore) as well as several forms of industrial minerals. Industrial minerals are a large group of mineral resources which can be used directly after mining without particular refining. This may include minerals for the construction sector, for casting and grinding as well as minerals used as fillers for the paper and dyeing industry. Efforts up to now may also lead to new finds of diamonds as well as exploitation of well known deposits of rubies.

Mineral exploitation in Greenland can be accomplished under very varying conditions, and this is illustrated in the history of the three most important mining companies. From 1856–1987 the mineral cryolite was exploited as an industrial mineral near Ivittuut in South Greenland where a total of 3.7 million t of cryolite ore was mined from an open pit. The brief period from 1956 to 1963 saw lead-zinc exploitation in Mestersvig in East Greenland, when 0.6 million t of galenite and sphalerite ore were extracted via underground mining. From 1973 to 1990 there was extensive zinc-lead-silver mining in Maarmorilik, from where 11.3 million t of ore containing sphalerite and silver-containing galenite were extracted in underground mining. All these activities ceased because the reserves of ore had more or less been exhausted.

Cryolite – Greenland's 'white gold'

'White gold' has with good reason become the term associated with exploitation of cryolite in Greenland. This wealth meant that the owners of the mining company really did have free access to something which approached a 'vein of gold', or better, for money flooded in and expenses were small. There was no way of foreseeing this adventure when mining began at the site in 1856.

The cryolite deposit was first described in detail during the exploration in 1806-1813 carried out by the mineralogist K.L. Giesecke. The chemist, Professor Julius Thomsen, described a process whereby cry-



Piles (box formed) of cryolite on the quay ready for loading in Ivittuut 1920, South Greenland. Photo: IMMM archive. Insert : Cryolite rock (white) with siderite crystals (brown) from the Ivittuut cryolite mine, South Greenland. Size of sample: 8 x 10 cm.

olite could be converted into soda, which at that time was an important element in a spiralling chemical industry. In 1854-56 the first shipments of cryolite were sent to Denmark, and in 1859 the first cryolite factory could be opened in Copenhagen. At the same time there were also experiments with other uses of cryolite: manufacture of alum and as a fluxing agent in the manufacture of mirrors and enamelling. Minerals such as jarlite, thomsenolite and weberite from the site are named after people who were important for exploitation of the deposit. Cryolite belongs to a group of minerals containing fluorine, all of which are extremely rare and only found in very few - other places in the world.

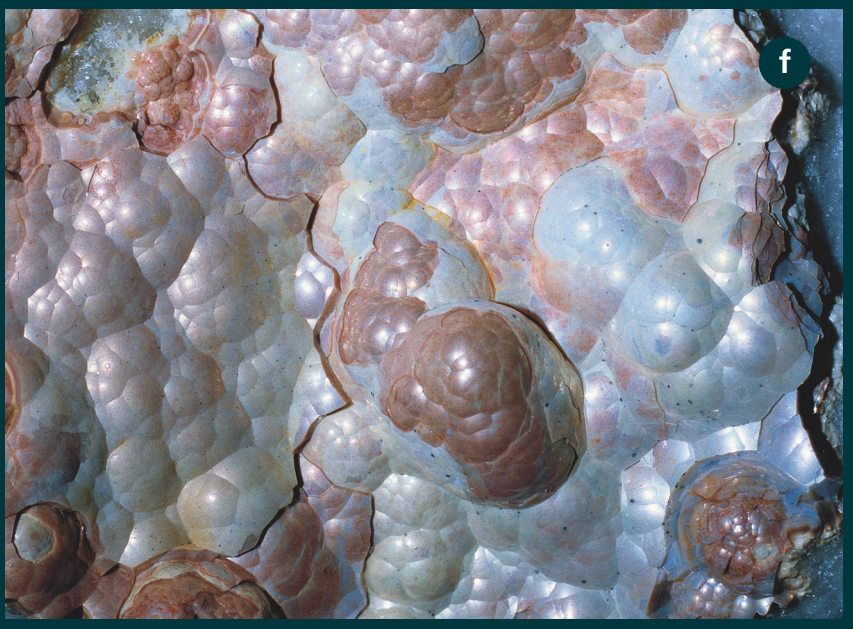
In 1886 two scientists, the American C.M. Hall and the Frenchman P.T. Héroult, independently of each other, were ready with a method to make aluminium, and cryolite was an essential additive in the process. The metal had already been demonstrated in 1825 by the Dane, Professor H.C. Ørsted, who was also Julius Thomsen's tutor. At that time the experiment was very difficult as the only aluminium ore available, bauxite, had a melting point of 2000°C. The new process, using cryolite, halved this temperature. With the aluminium industry as the customer, the way was now paved for the future use of cryolite, which no longer required costly processing in the factory in Copenhagen. Now, the ore only needed cleaning of a few impurities such as the minerals siderite, galenite and chalcopyrite. However, demand for aluminium was not great in 1902, when the firm became a limited company under the name Øresunds Chemiske Fabriker. The First World War changed this situation dramatically and revenues rocketed as new applications in the rapidly growing aviation industry began to show themselves.

Since the issue of the first exploitation concession in 1859, the state had secured itself a moderate tax for each tonne of cryolite extracted. In 1940 the concession was up for renewal and the Danish state took over half of the shares in the company, which was converted to Kryolitselskabet Øresund A/S. During World War II, the mine continued to produce cryolite, which was instrumental in the procurement of aluminium to the allied forces.

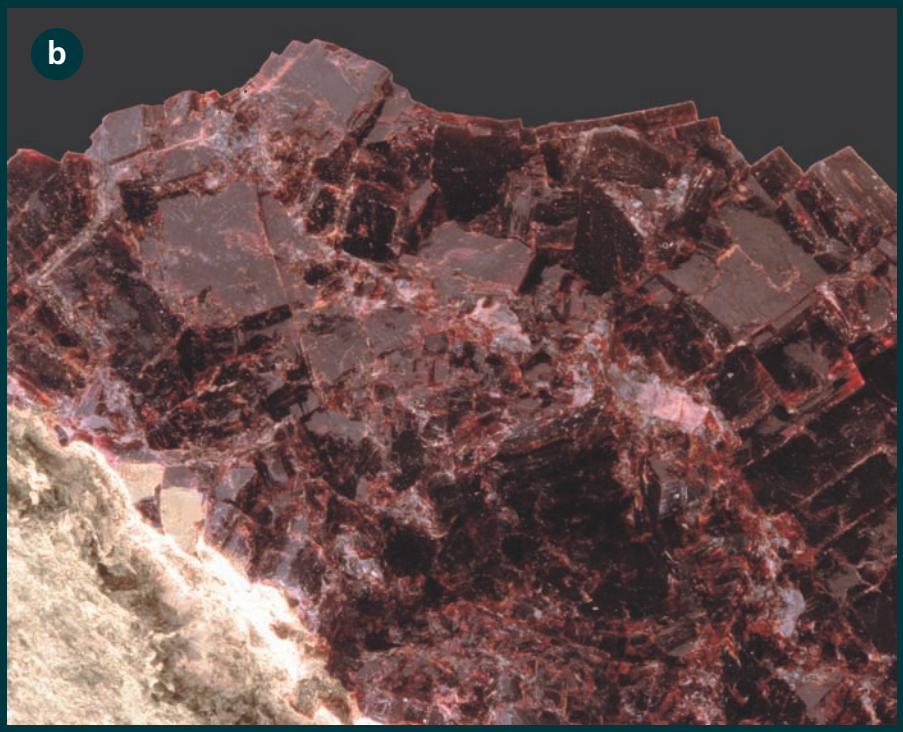
Rapid industrial expansion in the post war years saw increasing demand for aluminium and after 100 years, purified cryolite was still the main product of the mine. In 1987 the final profitable residues of cryolite ore were shipped from Ivittuut, however, and the company was closed. An important part of the story is that, throughout its lifetime, the cryolite mine in Ivittuut was the only one of its kind in the world. Today the former mine site is an open pit quarry full of

Minerals from the Ivittuut cryolite deposit

a: *Group of cryolite crystals, Ivittuut. Field of view: 11 x 16 cm. Photo: OJ.*
b: *Group of pachnolite crystals, Ivittuut. Field of view: 3 x 3 cm. Photo: OJ.*
c: *Cassiterite crystals in cryolite, Ivittuut. Field of view: 2.0 x 2.0 cm, Photo: OJ.*
d: *Siderite crystals, Ivittuut. Field of view: 4.5 x 4.0 cm. Photo: OJ.*
e: *Column of ikaite from the type locality near Ivittuut. Length of column: 40 cm. Photo: IMMM.*
f: *Botryoidal fluorite masses, Ivittuut. Field of view: 2,5 x 4.0 cm. Photo: OJ.*



Minerals from the alkaline complex Ilimmaasaq



a: *Steenstrupine crystal in albite, Ilimmaasaq. Field of view: 1 x 1.2 cm. Photo: OJ.*
b: *Group of villiaumite crystals, Ilimmaasaq. Field of view: 6 x 6 cm. Photo: OJ.*
c: *Granular mass of ussingite, Ilimmaasaq. Size of sample: 7.4 x 9.4 cm. Photo: OJ.*
d: *Polylithionite mica, Ilimmaasaq. Size of sample: 8.3 x 11.3 cm. Photo: OJ.*
e) *Sorensenite (pink) in albite rich rock, Ilimmaasaq. Size of sample: 5 x 7 cm. Photo:OJ.*
f: *Tugtupite (red) together with white albite and brown sphalerite, Ilimmaasaq. Size of sample: 8 x 10 cm.*

Minerals from the alkaline complex at Gardiner

a: *Group of magnetite crystals, Gardiner. Field of view: 3.6 x 7.5 cm. Photo: OJ.*
b: *Titanite crystals in natrolite, Gardiner. Field of view: 2.4 x 3.0 cm. Photo: OJ.*
c: *Bundle of pectolite crystals, Batbjerg near Gardiner. Field of view: 7.4 x 9.4 cm. Photo: OJ.*
d: *Perovskite crystal, Gardiner. Field of view: 5.5 x 7.8 cm. Photo: OJ.*
e: *Apatite crystals, Gardiner. Photo: OJ.*
f: *Andradite garnet crystals in natrolite, Gardiner. Field of view: 4.8 x 7.2 cm. Photo: OJ.*

Group of crystals of narsarsukit in quartz from the type locality at Narsaarsuk in South Greenland. Field of view: 4.4 x 5.2 cm. Photo: OJ.

invasive seawater and as an innocent inland lake it says very little about the greatest mineral adventure Greenland has seen to date.

The classic mineral collection

The research tradition surrounding Greenland's minerals, which developed after Giesecke's travels in Greenland in the early 1800s, quickly became visible in Denmark and the rest of Europe in the increasingly popular natural science museums. Giesecke generously donated collections and valuable pieces to royalty, scientific societies and selected individuals from throughout Europe; collections which understandably included unique mineral samples from Greenland. Cities such as Berlin, Weimar, Munich, Frankfurt and Augsburg in Germany, Graz and Vienna in Austria, and not least Copenhagen benefited from these collections. The largest collection ended in Vienna with the Austrian Kaiser. The collection included 872 mineral samples, mostly from Greenland. The extremely unusual minerals cryolite, arfvedsonite and eudialyte were amongst the classic mineral samples which at that time could only be obtained from Greenland. Even though tourmaline was already well known in collections from other places than Greenland, one of Giesecke's colleagues in Scotland, Robert Allan, remarked in 1813 on the impressive tourmaline crystals from Greenland, "that they were not lacking in any museum".

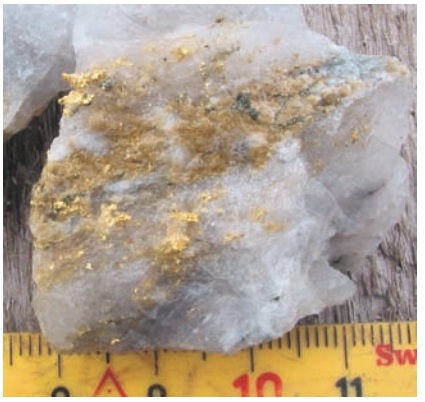
The deposits at Ivittuut (Ivigtut) and later at Ilimmaasaq (Ilímaussaq) soon contributed new, much sought-after minerals as research developed. Disko, further north along the west coast, yielded samples of telluric (metallic) iron, which were also amongst popular museum pieces. The Danish mineralogists of the time also had access to Norwegian specialities such as metallic silver, Icelandic materials of double spar (calcite) and rare zeolites, and these provided a formidable basis for publicity, and for exchanges of minerals. Thus, from early on, the Geological Museum in Copenhagen could establish a collection in a class of its own, which still provides the reference foundation for innumerable mineralogical and geological studies.

Famous mineral occurrences in Greenland

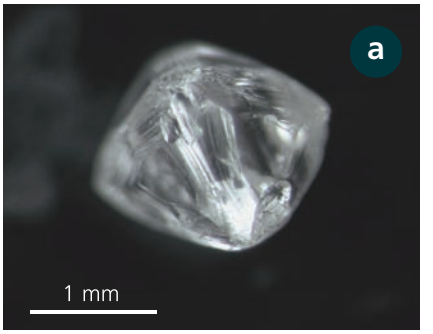
As demonstrated since the early 1800s, Giesecke initiated the reputation of the site known as the cryolite mine at Ivittuut (Ivigtut) in South Greenland. For about 200 years the deposit has been the breeding ground for much of the mineralogical and geological exploration in Greenland. Activities in Ivittuut resulted in finds of numerous minerals in the cryolite mass and the surrounding rocks. Close to 20 of the minerals were new to science and they have received a reputation as being characteristic minerals of the site.

Other geological deposits in Greenland have later received correspondingly great attention because of the unique mineral accumulations. The Ilímaussaq nepheline-syenite intrusion near Narsaq in South Greenland has made a particular contribution to the number of new minerals. The pegmatite deposit at Narsaarsuk (Narssârssuk) is in the same category of famous mineral deposits, and all these are from the same geological environment and period; the Proterozoice Gardar period. In East Greenland the Palaeogene formations, the Gardiner alkaline complex and the Skaergaard layered gabbro intrusion, are deposits with many notable minerals. The Fiskenæsset anorthosite complex at Qeqertarsuatsaat in West Greenland is an example of a famous mineral location with-

Trenching for samples at the type locality Narsaarsuk in South Greenland. Photo: OJ.



In-situ gold in ore (quartz vein) from the Nalunaq Gold Mine in South Greenland.



Diamonds from kimberlite dykes in the Kangerlussuaq area in West Greenland.
(a) is a microdiamond.
(b) is a 2.4 carat diamond. Photo: HR.

in the bedrock environment. Because of the mineral knowledge now available, all these formations are at the centre of modern mineral resources exploration in Greenland. The Ilímaussaq intrusion in South Greenland will perhaps receive the same attention as the cryolite deposit, mineralogically speaking as well as from a geological history perspective. The intrusion was to become an enormous research field and the naming of rock types enriched geological nomenclature with several more Greenlandic-sounding names. The deposit has made great contributions to the number of new minerals of which 11 are still only known from this one location. A few of the many examples are steenstrupine, eudialyte and tugtupite, and these have made the intrusion world famous in both a research and mineral resources context. Steenstrupine, which has been at the centre of attempts to extract uranium, and eudialyte is an extremely well suited zirconium ore. Tugtupite is recognised as a much sought after stone for jewellery after its origin was described from Greenland.

The minerals in Greenland's Archaean basement have often attracted attention. From the basement in West Greenland, these include, graphite, beautiful crystals of reddish corundum (such as rubies and sapphires), and black tourmaline, azure-blue lazurite, sky-blue sapphirine, turquoise amazonite or grains of gold in quartz veins, and there are many more. It is characteristic that many of these mineral types have also been at the centre of mineral resources projects and expectations of financial adventures.

The oldest bedrock in the West Greenland Kangerlussuaq area has recently gained attention with a number of dykes of kimberlite and ultramafic lamprophyre from the Cambrium period. These dykes have revealed diamond contents and to date explorations have demonstrated more than 1000 microdiamonds and a small number of macrodiamonds. The largest diamond found so far of 2.39 carats, was reported in 2006.

From younger periods in the Palaeogene there are examples of minerals which resulted from the dominant alkaline, ultrabasic and carbonatitic magmatism. The Gardiner complex in East Greenland has turned out to be one of Greenland's treasure chests of crystals. There are 60 different minerals here, developed in the most perfect crystal shapes and often in sizes of several centimetres. There are incredibly well-developed examples of perovskite, magnetite, titanite, and apatite which bear witness to the perfect conditions for crystal formation found here.

A mineralogical speciality is the deposit of telluric iron in the Palaeogene basalts of West Greenland. Lumps of elementary

Plenty of coarse-grained phlogopite on the surface of eroded ridges of phlogopite rich rocks in the alkaline deposit Gardiner in East Greenland. Photo: OJ.

Minerals from West and South Greenland

a: *Large group of leifite crystals, Narsaarsuk, South Greenland. Field of view: 8.5 x 14.0 cm. Photo: OJ.*
b: *Greyish green crystals of apatite in carbonatitic dolomite, Sarfartoq, West Greenland. Size of sample: 8 x 12 cm.*
c: *Crystals of epididymite grown as trillings, Narsaarsuk, South Greenland. Length of crystal: 1 cm. Photo: RAG.*
d: *Cleavage fragment of red corundum (ruby), Qeqertarsuatsiaat, West Greenland. Field of view: 4.9 x 4.4 cm. Photo: OJ.*
e: *Crystal of kornerupine in anorthosite rock, Qeqertarsuatsiaat, West Greenland. Field of view: 5.0 x 5.6 cm. Photo: OJ.*
f: *Crystal of black tourmaline, Ameralik fjord, West Greenland. Size of crystal: 5 x 14 cm. Photo: OJ.*

metallic iron have been formed in nature by processes in which the basalt has been in contact with earlier coal deposits.

Of course, if mineral names are to be approved by international bodies, the minerals must be well defined natural chemical compounds. When naming minerals, mineralogists have demonstrated no lack of imagination, but even so it has not been possible to reserve Greenland's most obvious name sources for genuine minerals. On the other hand exciting rocks have received these names: the flaming amphibole rock 'Nuummit' after Greenland's capital, and the grass-green fuchsite quartzite 'Greenlandite'.

Concluding remarks

Although many mineral finds in Greenland are from deposits of varying number and rarity, in many cases they have been vital for mineral research. Together with the well-described and comprehensive special deposits, it is clear that Greenland's minerals have affected mineral resources development to an exceptional degree. Accordingly, Greenland has been rendered an internationally high status as the keeper of a unique wealth of minerals and mineral resources.

Key literature

Appel, P.W.U. 1995: Ruby occurrences in the Fiskenæsset area, West Greenland. Open File Series Grønlands Geologiske Undersøgelse, **95/11**, 24pp.

Bøggild, O.B. 1953: The mineralogy of Greenland, Meddelelser om Grønland **149**, 442 pp.

Harpøth, O., Pedersen, J.L., Schønwandt, H.K. & Thomassen, B. 1986: The mineral occurrences of central East Greenland. Meddelelser om Grønland, Geoscience **17**, 139 pp.

Herd, R.K., Windley, B.F. & Ghisler, M. 1969: The mode of occurrence and petrogenesis of the sapphirine-bearing and associated rocks of West Greenland. Rapport Grønlands Geologiske Undersøgelse, **24**, 44pp.

Jensen, A. & Petersen, O.V. 1982: Tugtupite: a gemstone from Greenland. Gems and Gemology, **18**, 90–94.

Johnsen, O. 2002: Minerals of the World, Oxford University Press, Oxford, 439 pp.

Johnsen, O., Petersen, O.V. & Medenbach, O.1985: The Gardiner complex a new locality in Greenland. Mineralogical Record, **16**, 485–494.

Pauly, H. & Bailey, J.C. 1999: Genesis and evolution of the Ivigtut cryolite deposit, SW Greenland, Meddelelser om Grønland, Geoscience **37**, 80 pp.

Petersen, O.V. 1989: Der Narssârssuk-Pegmatit. Mitteilungen der Österreichischen Mineralogischen Gesellschaft **134**, 63–72.

Petersen, O.V. & Johnsen, O. 2005: Mineral species first described from Greenland, The Canadian Mineralogist, Special Publication **8**, 184 pp.

Petersen, O.V. & Secher, K. 1993: The minerals of Greenland, Mineralogical Record 24, 2, 67 pp.

Secher, K., Steenfelt, A. & Garde, A.A. 2008: Pegmatites and their potential for mineral exploitation in Greenland. Geology and Ore **10**,12 pp.

Sinkankas, J. 1997: Gemstones of North America, (Vol III). Tuscon, Arizona: Geoscience Press, 527 pp.

Sørensen, H. (ed): 2001: The Ilímaussaq alkaline complex, South Greenland: status of mineralogical research with new results. Geology of Greenland Survey Bulletin **190**, 167 pp.

Sørensen, H (ed), 2007: Geological Guide South Greenland. GEUS, Copenhagen, 132 pp.

Steenfelt, A., Secher, K. & Garde, A.A .2007: An overview of pegmatite occurrences in Greenland and their economic potential, Danmarks og Grønlands Geologiske Undersøgelse Rapport **2007/2**, 46 pp.

Stendal, H., Secher, K., Nielsen, B.M., Schønwandt, H.K. & Thorning, L. 2007: Greenland geological environments and mineral resources, Danmarks og Grønlands Geologiske Undersøgelse Rapport **2005/8**, 211 pp.

Bureau of Minerals and Petroleum (BMP)
Government of Greenland
P.O. Box 930
DK-3900 Nuuk
Greenland

Tel: (+299) 34 68 00
Fax.: (+299) 32 43 02
E-mail: bmp@gh.gl
Internet: www.bmp.gl

GEUS

Geological Survey of Denmark and Greenland (GEUS)
Øster Voldgade 10
DK-1350 Copenhagen K
Denmark

Tel: (+45) 38 14 20 00
Fax.: (+45) 38 14 20 50
E-mail: geus@geus.dk
Internet: www.geus.dk

Front cover photograph

Eudialyte crystals (red) surrounded by white sodalite from the Ilimmaasaq, South Greenland. Field of view: 2.0 x 3.4 cm. Photo OJ.

Authors
K. Secher and O. Johnsen

Editor
Karsten Secher, GEUS

Graphic Production
Henrik Klinge Pedersen, GEUS

Photographs
GEUS unless otherwise stated
IMMM: Ivittuut Museum Archive
HR: Hudson Resources
OJ: O. Johnsen
RB: R. Bode
RAG: R. A. Gault

Printed
February 2008 © GEUS

Printers
Schultz Grafisk

ISSN
1602-818x