GEOLOGY AND ORE

Exploration and Mining in Greenland

IRON ore potential in GREENLAND

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Iron ore potential in Greenland

The Greenland iron ore potential is mainly based on Archaean sedimentary and chemical iron deposits (BIF). However, notable occurrences related to Achaean and Proterozoic magmatism have recently demonstrated prominent iron ore accumulations. BIF type occurrences deliver the majority of iron ore and are amongst the world's most important iron sources. Greenland also has vast potentials in deposits related to banded iron formations (BIF) of the so-called Algoma type, which are typical for Archaean greenstone belts formed in continental rifts or at continental margins. Deposits related to magmatism have been found in the Palaeoproterozoic of Inglefield Land and in the Mesoproterozoic Gardar province.

Regional distribution and age of Greenland BIF

In Greenland BIF deposits are located at Isua (~3.8 Ga) in southern West Greenland, at Itilliarsuk (~2.85 Ga) in central West Greenland, and in North West Greenland along the Lauge Koch Kyst (~2.7 Ga). The deposits are all characterised by their large size, with some approaching gigantic dimensions.

Within the Nuuk region it has been known for some 30 years that the Isua Greenstone Belt (IGB) rocks at Isukasia are at least 3.8 Ga old. There is no convincing evidence for in situ rocks older than ca. 3.8 Ga, but recent Pb-isotope data on IGB metasediments suggest that important geochemical features pertaining to a pre-4.0 Ga mantle and crust can be recognised.

The IGB consists of high and low strain domains, some of which appear to be of slightly different ages. The dominant rock types are pillow-structured tholeiitic and high Mg-basaltic rocks. Intercalated within the lavas are extensive bands of chert and banded iron formation as well as garnet-mica schists that represent metamorphosed fine-grained sediments. Also intercalated in the belt are abundant ultramafic bands of various compositions but of unknown origin. The IGB has suffered several metamorphic events, and the area has been repeatedly deformed. Several post-metamorphic events have been recorded in the IGB. A granite magmatism heating event has been recorded followed by late shear-zone-hosted quartz veins from different parts of the IGB.

Notable iron ore potentials are also recognised within NW Greenland Archaean greenstone belts in Disko Bugt and Lauge Koch Kyst. The latter is underlain by tonalitic to granitic orthogneisses and quartzo-feldspatic paragneisses of the Thule mixed gneiss complex of 2.9 Ga age, the Kap York meta-igneous complex of 2.7 Ga age and the tonalitic to granitic gneisses and granites of the Lauge Koch Kyst orthogneisses of 2.7 Ga age. Along the northern part of Lauge Koch Kyst 2.7–2.6 Ga quartzo-feldspatic to pelitic paragneisses (including BIF) are located. This sequence includes magnetite-bearing quartzites and amphibolites of the Lauge Koch Kyst supracrustal complex. These rocks belong to the so-called Rae craton also found in northern Baffin Island. To the south, in the northern part of Disko Bugt, enclaves of Archaean supracrustal rocks are enveloped in the middle of a combined orogen; the Nagssugtoqidian– Rinkian orogen.

The Saqqaq-Itiilliarsuk belt is typical of an Archaean greenstone succession, with a lower ultrabasic to basic metavolcanic rock series including exhalative rocks with gold mineralisation and BIF. This succession is overlain by an upper part, dominated by a more clastic metasedimentary sequence, gabbroic sills and acid metavolcanic rocks. The area also has large intrusive bodies such as the Itilli diorite and the Boye Sø anorthosite complex.

The supracrustal belts in the Arveprinsen Ejland and Eqi-Maniitsoq areas, can be divided into three units: (a) a lower unit of massive to pillowed greenstones; (b) a middle unit of greenstones with frequent layers of mafic and felsic volcaniclastic sediments; and (c) an upper unit dominated by greenstones of mixed extrusive (pillow lavas) and intrusive origin. The total thickness of the greenstone sequence is about 3–4 km and can be followed along strike for more than 50 km. The thickness is a minimum estimate, since the Inland Ice covers the base of the sequence.

Boulder of banded hematite ore (23 x 53 cm), found along the ice margin at Isua, southern West Greenland.

Isua deposit in southern West Greenland. View to the north-east along the margin of the Inland Ice. The iron deposit is situated along the ice margin near the arrow.
Photo: Claus Østergaard.

Archaean BIF deposits

The Isua BIF

The Isua Greenstone Belt (IGB), hosting the Isua deposit about 150 km north-east of Nuuk, is an up to 4-km-wide and about 40-km-long crescent with enclaves of greenstones a few hundred metres wide and up to several kilometres long. Large ultrabasic bodies with minor mafic volcanic rocks and a banded iron formation dominate these greenstone belts. The BIF occurs mostly as quartz-magnetite banded iron formation, but silicate facies of alternating grunerite and magnetite bands are also common. In addition, but more rarely, there are carbonate facies iron formations consisting of alternating bands of siderite and magnetite. Silicate facies with grunerite contain pyrrhotite, chalcopyrite and locally small amounts of gold. In the easternmost part of the IGB a major body of oxide facies iron formation occurs. Two-thirds of the body is concealed under the Inland Ice. With an age of around 3.8 Ga, the Isua iron deposit is probably the oldest banded iron formation in the world.

The Isua structure and deposit were first discovered by the company Kryolitselskabet Øresund A/S (KØ) during field

Close-up of folded banded quartz-magnetite ore in a 1 m outcrop at Isua, southern West Greenland.

Close-up of the BIF sequence south of Pituffik, North-West Greenland. A chip sample over 1.4 m returned 29.1% Fe (27.2% Fe_2O_3 + 15.5% FeO) and 54.3% SiO_2.

Drilling through the Inland Ice near the Isua deposit, southern West Greenland. Photo: Claus Østergaard.

activity in 1962. Since that time an iron resource of around 2 billion tonnes of ore averaging 32.9% Fe has been estimated. A large number of drill holes were made, some of them through the inland ice. Twenty years later, Rio Tinto took up a concession and carried out two drilling campaigns. Rio Tinto aimed at finding high-grade hematite lump ore, but was not satisfied with the results. In January 2006, IMC Group Consultants Ltd (IMC) estimated JORC indicated-inferred resources of 955 million tonnes averaging 34% Fe, including an indicated-inferred open pit resource of 181 million tonnes averaging 33.43% Fe, and accordingly London Mining Plc. took over the concession of the area.

London Mining Plc. has obtained similar figures with 951 million tonnes averaging 36.48% Fe. According to London Mining Plc. recent test work has confirmed that the Isua ore can produce a concentrate with a specification of 70.2% Fe, 1.9%

Outcrop of multiple chert layers at the Itilliarsuk iron BIF occurrence, central West Greenland.

The geologist field camp at the Itilliarsuk iron BIF occurrence, central West Greenland.

SiO_2, 0.05% Al_2O_3 and 0.12 % S. This product has potential for application as a premium blast furnace pellet feed for sale to the European and Chinese steel markets.

The Itilliarsuk BIF

The geotectonic setting of the Archaean supracrustal rocks of the area south of Nuussuaq Peninsula in central West Greenland represent a rift or continental margin environment with more meta-sediments intercalated in the volcanic sequences than in the island arc setting further south. The thickest succession of supracrustal rocks occurs in the Itilliarsuk area. The supracrustal sequence is at least 2.5 km thick and a banded iron formation deposit occurs 200 m above an often visible 'rust zone' within the supracrustals. The banded iron formation is an approximately 200-m-wide sequence of 2–10 cm magnetite-rich cherty bands alternating with quartz-mica schists. A gradual transition zone between the iron-formation and the adjacent rocks in the sequence is characterised by a garnet-hornblende-magnetite bed. The iron-rich beds gradually become poorer in magnetite and richer in garnet and hornblende. Cyclic repetition occurs between the magnetite-bearing bed, and the occurrence of garnet and hornblende in distinct beds can be traced over 500 m along the strike. This indicates that the transition from iron oxide to iron silicates reflects a primary chemical gradation in the sediment.

The KØ company initiated exploration in the Itilliarsuk area in the 1990s. NunaMinerals A/S later carried out exploration in the area, mainly targeted for gold. The company estimated that the iron mineralised part, covering an area of 130 x 1000 m, has a resource of 150–200 million tonnes of ore grading 20% Fe. Renewed interest from other companies in the iron ore potential of the area resulted in new applications for exploration licences in 2007 and Avannaa Exploration Ltd. now holds an exploration licence at Itilliarsuk.

BIF in the Qaanaaq (Thule) region

The Qaanaaq (Thule) region of North-West Greenland exposes a high-grade Archaean–Palaeoproterozoic crystalline shield overlain by the intracratonic Mesoproterozoic Thule Basin, which extends across Baffin Bugt into Canada.

The southern part of the Qaanaaq region hosts a Neoarchaean iron province which spatially is the largest in Greenland. It forms a WNW–ESE-trending belt, traceable for more than 400 km from Kap Seddon in the south-east throughout the Lauge Koch Kyst to Wolstenholme Island and the Carey Islands. This belt correlates with the iron-rich rocks on northern Baffin Island, Canada. Iron in the form of magnetite and hematite occurs both as oxide-facies quartz banded iron formation (BIF) and massive lenses and layers, and it is disseminated, mainly in pelitic and mafic schists in the Lauge Koch Kyst supracrustal complex. BIF occurs in units of varying thickness, from less than a metre and up to 40 m, where iron concentrations are typically 30–35%. Furthermore, oxide-facies BIF as well as silicate-facies BIF with minor iron sulphides occur scattered in the northern part of the Qaanaaq region.

No systematic mineral exploration has been carried out in the North-West Greenland iron province, which is mainly known from the regional geological mapping carried out by the Greenland Geological Survey in 1971–80. However, a company has just applied for licence rights in the area. It is worth noting that a similar occurrence in the northern Baffin Island of Nunavut in Canada has been explored recently by the Mary River iron ore project and mine construction is planned to start in the near future.

Iron ore potential related to magmatic environments

The Archaean Sinarsuk - titanium, vanadium & iron ore occurrences in anorthosite-gabbro rocks

Significant vanadium and titanium values have been reported from Sinarsuk within the eastern part of the Fiskenæsset Anorthosite complex, southern West Greenland. Titanium-vanadium accumulation occurs in magnetite/ilmenite-rich horizons within layered anorthosite-gabbro zones. The deposit is confined to gabbroic

One to two metre thick BIF horizon in a sequence of pelitic gneiss (rusty brown) and amphibolite (dark), south of Pituffik, North-West Greenland.

Grab samples of typical solid BIF magnetite-rich mineralisation, south of Pituffik, North-West Greenland.

layers, which occur as stratigraphic horizons in the layered complex. The complex has later suffered folding in at least three fold phases. The oxide-rich areas form semi-massive layers (35–65 % oxides) up to 1 m, often showing a gradual transition laterally into layers of disseminated oxides (< 35% oxides) in up to 15 m wide sections. A section of at least 8 km in length locally shows vanadium enrichment with values of V_2O_5 up to 2.68 wt% in magnetite rich layers. The main oxide minerals are vanadiferous magnetite and ilmenite,

(Opposite page) View to the north-east of the eastern part of the Fiskenæsset anorthosite complex showing the environment around the Sinarsuk occurrence, South-West Greenland. Outcrops of the ultra basic layers within the complex are seen in the centre.

The original trench site for sampling the iron ore of the ferroan carbonatite within the Grønnedal-Ika alkaline complex, southern West Greenland. Recent photo.

comprising 30% to 90% of the rock volume and the ratio of magnetite to ilmenite ranges from 3:2 to 4:1.

The Inglefield Land iron ore prospect

The Inglefield Land Iron prospect is located 115 km north of Qaanaaq in North West Greenland. The Palaeoproterozoic Inglefield mobile belt is an east–west trending belt of high-grade metamorphic rocks and igneous complexes of felsic to intermediate to basic and magnetite-rich rocks.

The Minturn magnetic anomaly was discovered by the Geological Survey of Denmark and Greenland (GEUS) in 1994 during an airborne electromagnetic and

(Below) View towards north from the centre of the Grønnedal-Ika complex with an outcrop of the dolerite dyke intruding the iron-ore occurrence. The naval base at Grønnedal is located at the coast (centre right).

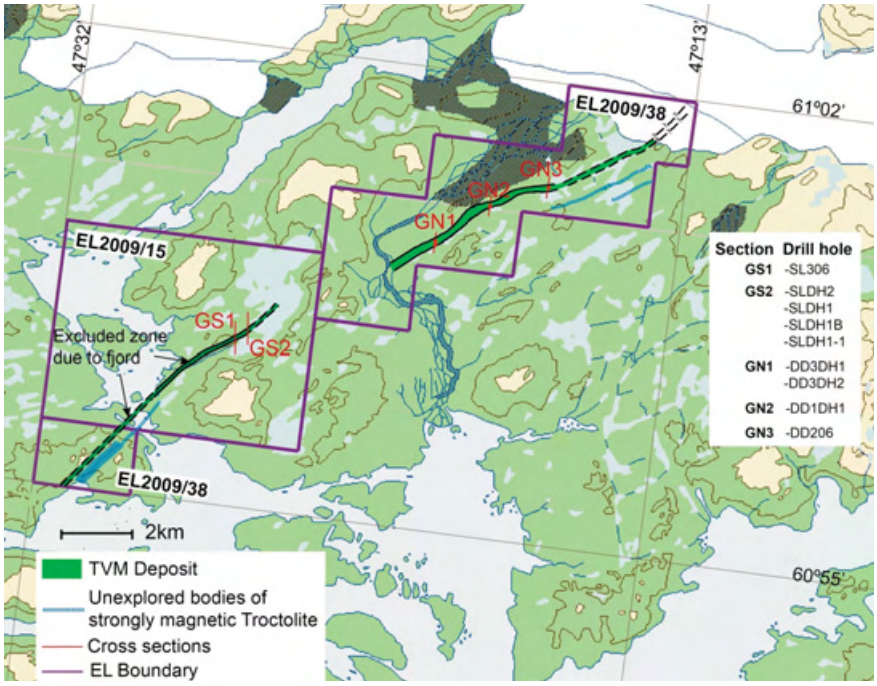
magnetic survey. It occurs along a more than 80 km linear magnetic high and it is largely covered by a thin regolith. The peak magnetic value is 15,400 nT above background and is part of a 7–8 km long, straight magnetic high. The magnitude of the anomaly indicates that the magnetic source probably contains abundant magnetite as the dominant magnetic mineral. An initial interpretation of the Minturn anomaly suggests a steeply dipping structure with a potential width of around 200 m. Follow-up ground-truth work by GEUS in 1995 discovered abundant magnetite-rich float at the peak site.

In 2008, NunaMinerals A/S conducted a limited helicopter-borne magnetic survey and confirmed the presence of the Minturn anomaly with a peak anomaly of 36,000 nT over background. The peak anomaly is part of a linear magnetic high at least 7 km long. In 2009, NunaMinerals A/S commissioned GEUS to carry out an investigation of the mineralogy and mineral chemistry of magnetite-rich float samples. Five of these samples were found to be near-massive magnetite with an average iron content of 62.4%. The contents of other elements such as silica, aluminium and sulphur are low. The iron ore deposit is interpreted to be of the so-called Kiruna iron ore type.

The iron ore accumulation at the Grønnedal-Ika alkaline complex

At the Grønnedal-Ika alkaline complex iron ore accumulation is hosted in carbonatitic rocks of the Proterozoic Gardar period, where the carbonatite has intruded the syenites of the complex. The iron-rich part of the carbonatite is characterised by siderite and magnetite with the latter as the most frequent iron mineral, where the carbonatite is cut by younger dolerite dykes. Apparently the habit of magnetite is as pseudomorphs after siderite, which suggests formation during contact alteration of the ferroan carbonatite during the dyke intrusion. After ground magnetic mapping, possible targets for drilling and trenching could be established. Trenching was completed in 1948 by the company Kryolitselskabet Øresund A/S, who soon after stopped further evaluation of the iron ore occurrence. The amount of ore with a grade of 25-30% iron was estimated to at least 0.8 million tonnes early in the exploration history.

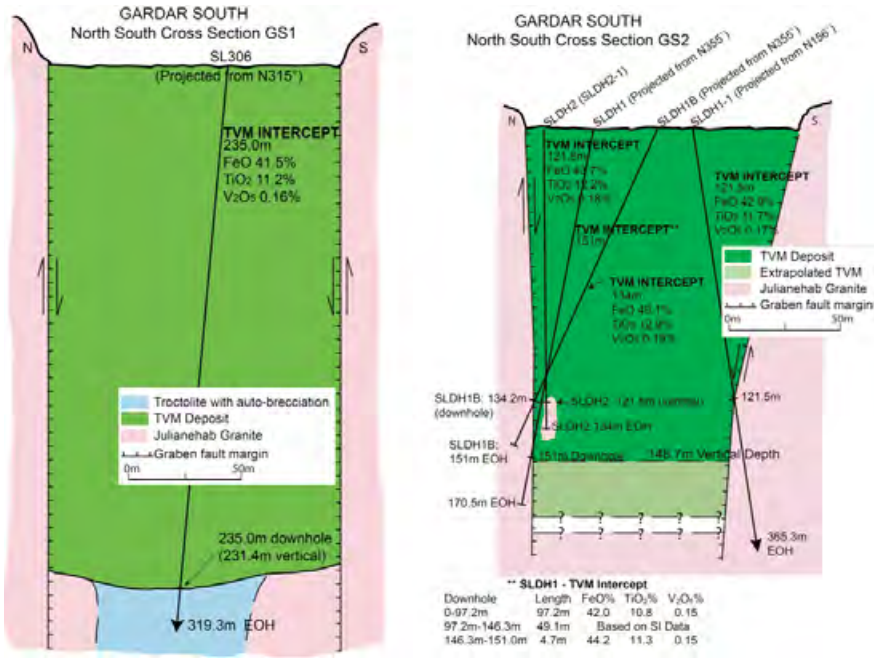
Beach sand accumulation and drill site at the iron rich troctolite project in South Greenland. The exposure in the area is rather poor because of heavy vegetation. A fault contact bordering one of the dykes is marked with a red line. Photo: Hunter Minerals Pty Ltd.



Topographical map of the Isortoq project area in South Greenland, outlining licence areas, and drill site locations. Map: Hunter Minerals Pty Ltd.

The Proterozoic Isortoq iron ore occurrence

The background for this recent discovery was inspired by the location of the Voisey's Bay nickel-copper deposit in



Cross sections of the troctolite intrusions of the Isortoq project in South Greenland showing drill intersections of trocotolite with vanadium-rich magnetite accumulation (TVM). Illustration: Hunter Minerals Pty Ltd.

Labrador, which is associated with troctolite magmatism. Environments in Greenland with possible similar mineral accumulations have often been thought to include the Proterozoic Gardar Province which has known occurrences of major basic intrusions and dykes.

The Isortoq project area is located in the Proterozoic Gardar Province of South Greenland east of the Nunarsuit peninsula and it has impressive magnetic and electromagnetic geophysical anomalies which after drilling tests proved to be magnetite-rich troctolites generated by assumed graben-faulted lopolithlic intrusions. The iron ore accumulation is located in titanium and vanadium-rich magnetite-carrying troctolite dykes.The company Hunter Minerals Pty Ltd estimates an inferred resource of at least 1 billion tonnes with concentrate grades of 62.6% FeO, 19.1% TiO_2 and 0.32% V_2O_5, divided between to subareas striking least 8 km in length in a 120 m to 175 m wide graben-faulted lopolith with thicknesses in the general range 150 m to 230 m.

Iron accumulation shown in a slab from a lava flow from Saviaqqat, northern Nuussuaq. The cut slab is 14 cm high. The iron droplets accumulated during flowage of the lava and assembled c. 0.5 m above the base of the flow. Photo: Asger Ken Pedersen.

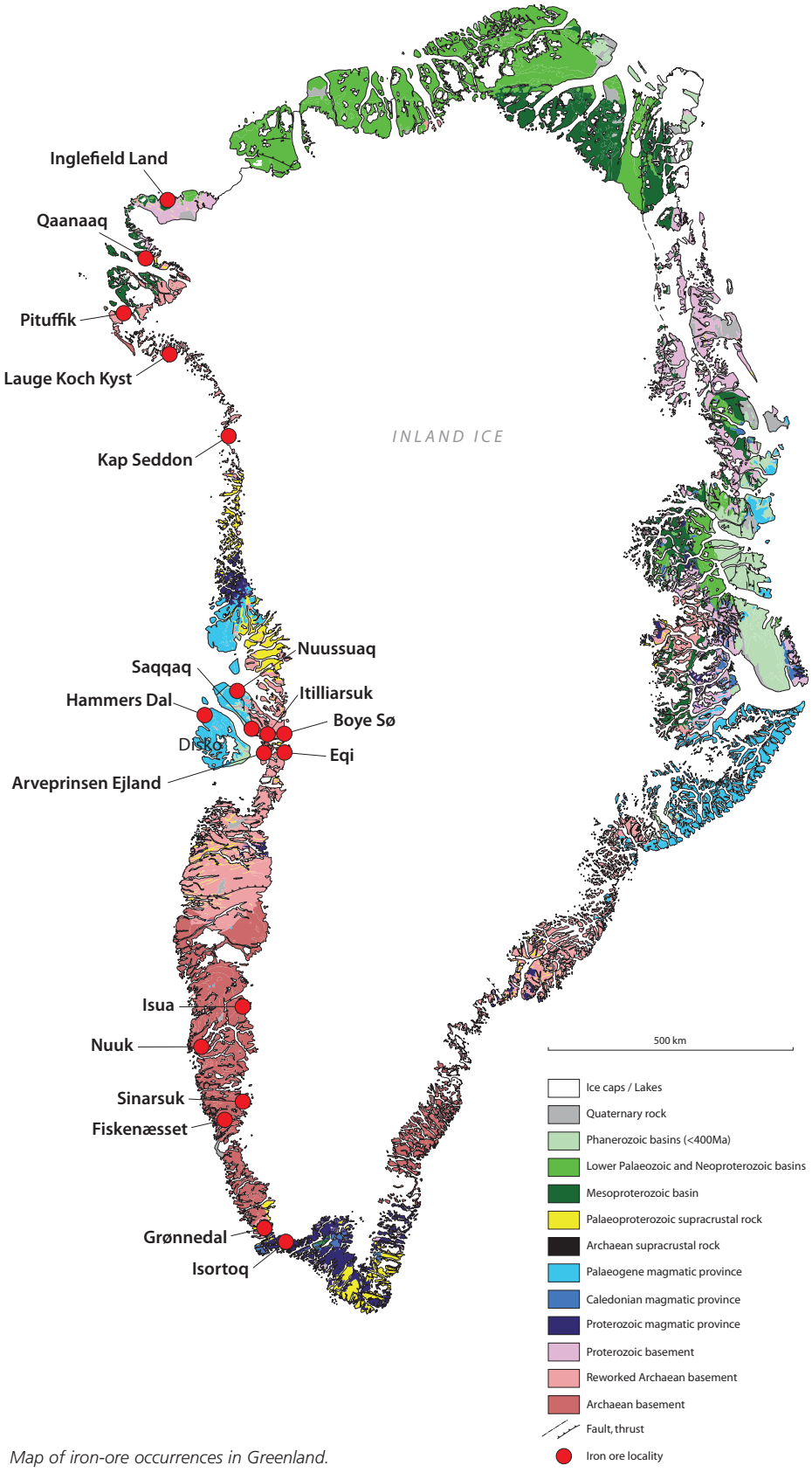
Native iron on Disko and Nuussuaq

The native iron has been famous since its discovery around 1870. The iron occurs in Paleocene (62-60 Ma) intrusions and lavas in the Nuussuaq Basin, and because of the high contents of nickel in the iron it was first thought to be of meteoritic origin. It is now known that the iron was formed in a natural reduction process during reaction between hot magmas and organic-carbon-bearing Mesozoic sediments of the Nuussuaq Basin. Exploration in the period 1984–1994 was mainly after Ni and PGEs in high-level iron-bearing intrusions such as the Hammers Dal complex. This complex is the largest of a number of intrusions in western Disko emplaced at shallow depths as volcanic necks and dykes which probably served as feeders for lavas of the Nordfjord and Niaqussat Members of the Maligât Formation. Ground geophysical measurements across the Hammers Dal complex have revealed a conductor with much larger dimensions than the outcrops 400-500 m below the present surface.

Intrusions (sills in sediments) and lava flows with native iron are also present in northern Disko and Nuussuaq. The iron was formed in a similar process as the iron in western Disko, but the rocks belong to the earlier Asuk Member of the Vaigat Formation. The iron accumulations may be spectacular; however, whereas the potential for economically viable Ni and PGE deposits is present, the resource as an iron ore is negligible.

Concluding remarks

The potential for iron resources of the BIF type in Greenland is promising, taking into consideration that a number of deposits are large and that they are located in accessible tracts. Recent exploration has demonstrated increased interest in iron ore deposits in Greenland. The recent finding of the huge magmatic iron ore deposits at Isortoq in South Greenland underpins that Greenland are highly underexplored and that there still is a potential of finding undiscovered huge iron ore deposits in Greenland.



Map of iron-ore occurrences in Greenland.

Two drill sites at the Isua deposit, illustrating the field conditions near the Inland Ice margin. Photo: Claus Østergaard.

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Front cover photograph
One to two metre thick BIF horizon in a sequence of pelitic gneiss (rusty brown) and amphibolite (dark), south of Pituffik, North-West Greenland.

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