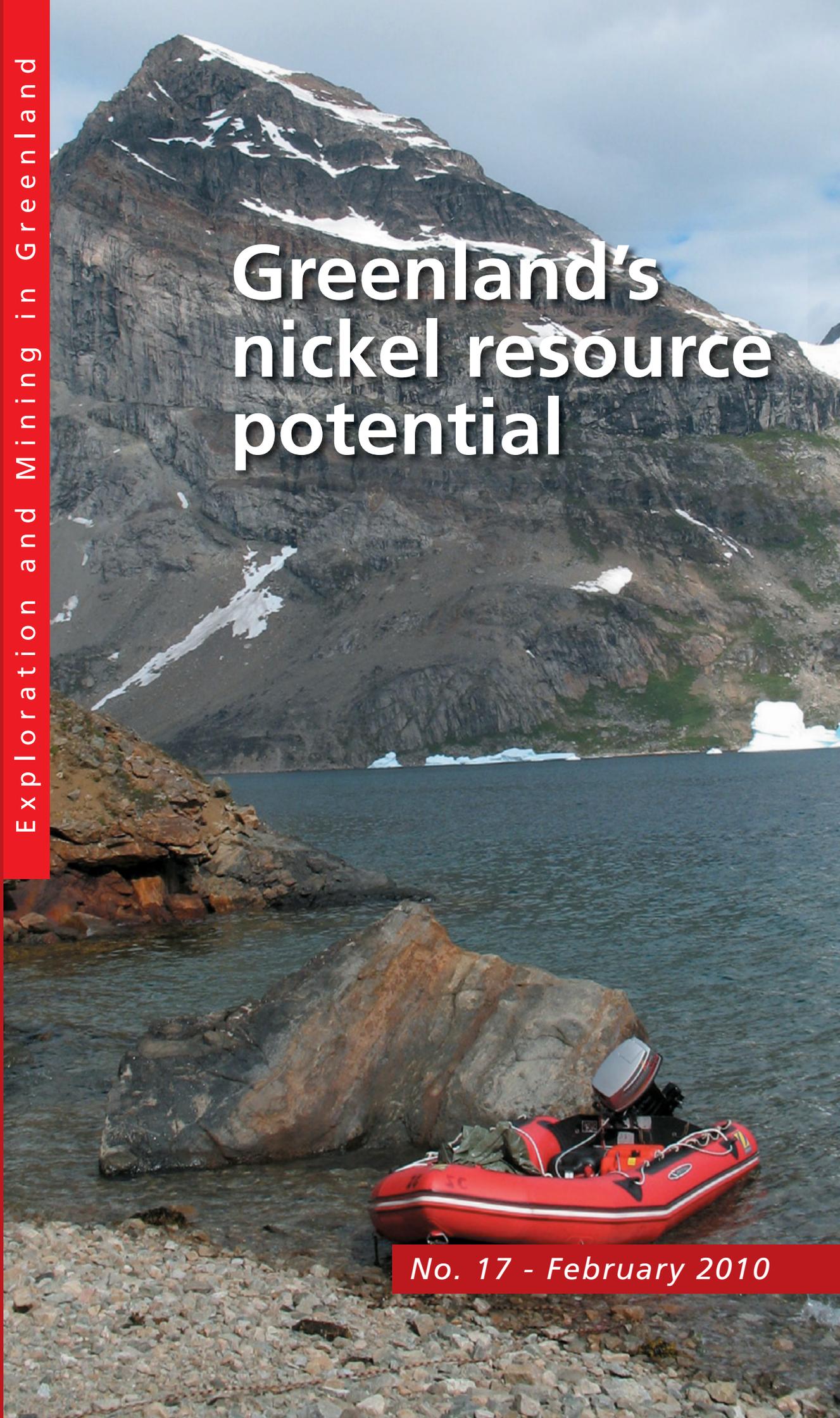




Greenland's nickel resource potential

No. 17 - February 2010



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There is clear potential for nickel resources in Greenland, encompassing mineralisations from Precambrian to Palaeogene environments. Nickeliferous sulphides were noted early on, and these became part of Greenland exploration history, being noted in the GEUS's reports since the 1950s. The current commercial interest in nickel targets in Greenland was initiated by Kryolitselskabet Øresund in the early 1960s and was related to a suite of norites in West Greenland. Platinomino A/S was established in 1968 to search for Ni-PGM type deposits within the Fiske­næsset Complex. In the late 1980s, Platinova Resources prospected known Ni-PGE indications in Amitsoq peridotites in southern Greenland. Since 1995 norites in the Tasiilaq region, East Greenland have been the target for Ni-Cu exploration by several companies. In 2005 NunaMinerals initiated exploration in the mafic intrusions of the Fiskefjord area. In the 1980s GEUS and university groups focused on the formation of massive sulphides in the Palaeogene basalts on Disko Island, and this has led to continued exploration for Noril'sk type mineralisations. The find of the Voisey's Bay deposit in Labrador in 1994 revived exploration activity worldwide, not least in Greenland. Today nickel exploration can benefit from the more intensive search for PGEs.



Typical weathered surface of a norite outcrop showing magmatic layering from the West Greenland norite belt, Sillissanguit nunat, southern West Greenland.



Gossan zone developed in a nickeliferous sulphide lump within a norite pod, the northeastern part of the norite belt in southern West Greenland.

Nickeliferous settings in Greenland: Archaean

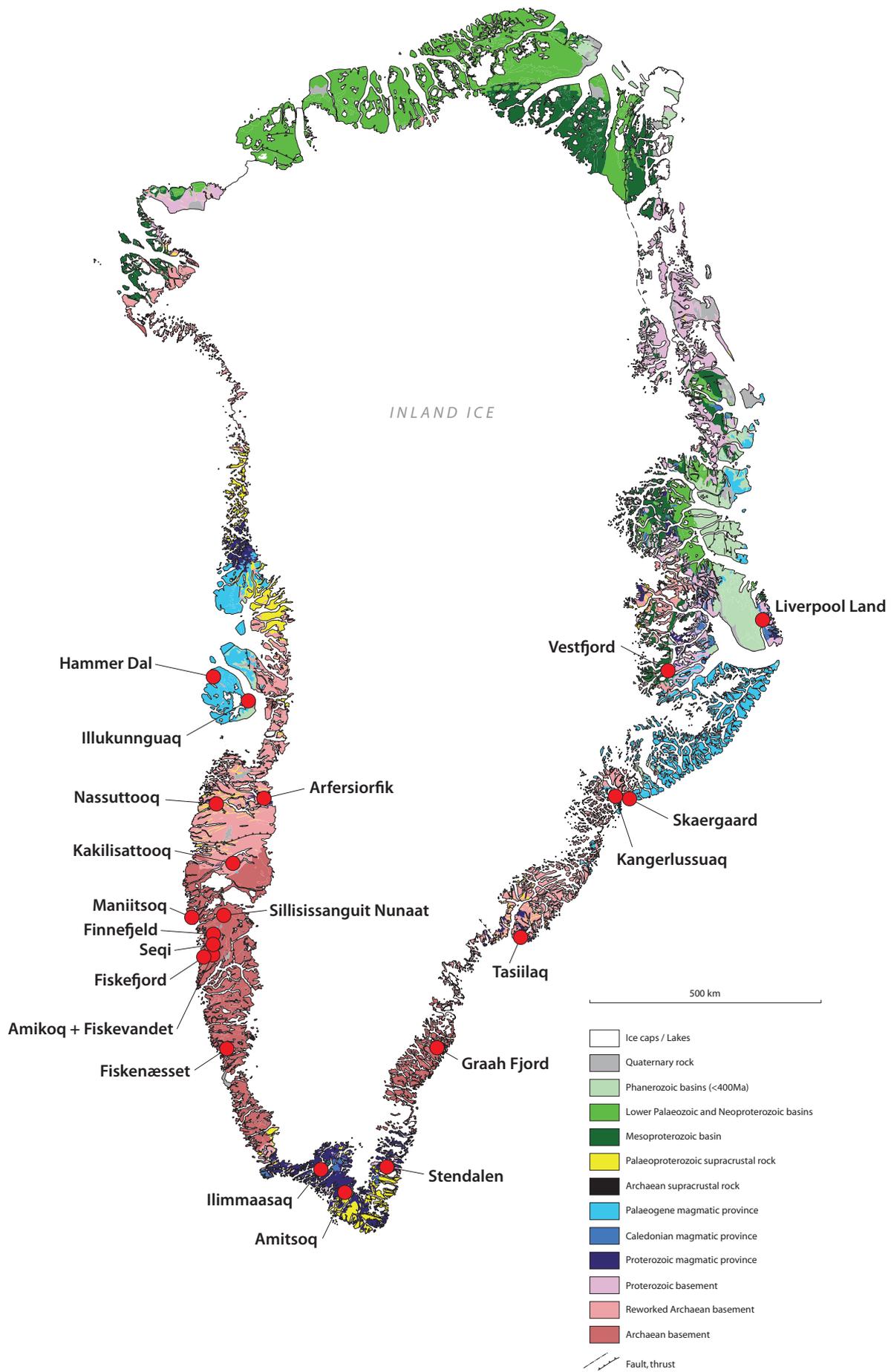
Traces of nickel accumulations are numerous; in the Precambrian terrain located within the Archaean shield as well as in the Palaeoproterozoic orogenic belts.

Fiske­næsset anorthosite complex (West Greenland - WG)

The Archaean Fiske­næsset anorthosite complex, with a strike length of over 200 km, is hosted in a high-grade tonalitic gneiss basement. The complex is named

after the village Fiske­næsset/Qeqertarsuaat. The floor of the intrusion has not been identified, but the roof has been found immediately below flows of mafic pillow lava. Detailed stratigraphy shows a succession with a lower gabbro unit followed by an ultramafic unit with dunites, peridotites and hornblendites. These are followed by a lower leucogabbro unit

with minor ultramafic layers and a middle gabbro unit with minor layers of anorthosite as well as ultramafics and peridotites (hornblende-orthopyroxene-spinel). Above these units is the upper leucogabbro unit with abundant chromitite bands, followed by an anorthosite unit and the upper gabbro unit. The complex has been repeatedly deformed and metamorphosed under



Map of the main geological environments in Greenland.



Slope with weathered dunite from the Fiskevandet region, southern West Greenland. Photo: NunaMinerals A/S.

amphibolite, and locally, granulite facies conditions.

In the 1970s Platinomino A/S searched for Ni-PGE enriched deposits. The impetus was the discovery of an approximately 1-metre-wide bronzitite layer with discrete chromite banding. The bronzitite contains minor nickel sulphides. Associated amphibolite has average Ni content of 400 ppm.

The Ni-content soon proved to be very scattered and as the company focus was moved to other commodities than nickel, the exploration never resulted in a comprehensive picture of the Ni-distribution. Based on later regional geochemical mapping, however, it is obvious that the Ni-content in the rocks of the complex is enlarged and represents a target for further exploration.

Sillisissanguit Nunaat - Maniitsoq norite belt (WG)

The norite belt (15 x 75 km) is located east of Maniitsoq and hosts a suite of irregular bodies of basic rocks intruded into the regional gneiss complex of the Akia terrane. The bodies vary in size from 2 x 4 km to only a few metres. They are predominantly composed of norite and leucogabbro, collectively referred to as norite. Primary textures, such as igneous layering, are locally preserved. Elevated Ni as well as Cu and PGE concentrations are found in sulphide showings of apparently magmatic origin. The norite rocks are very homogeneous bodies with rare igneous banding composed of alternating layers of plagioclase and hypersthene with accessory chromite. Amphibolite layers are locally associated to the norites.

The norite belt is located along the eastern flank of the dome of the Archaean Finnefjeld gneiss complex and the structural setting seems to be somehow guided by the margins of the Finnefjeld gneiss. The norites appear almost unaffected by the high grade retrograde metamorphism observed in the surrounding basement. The norite belt can be divided into a northern part, characterised by few large norite bodies, and a southern part of several, but smaller bodies and pods of norite.

The age of the norite belt is uncertain, but probably around 3.0 Ga, based on a tentative correlation with post-kinematic diorite intrusions in the Niaqunngunaq/Fiskefjord region (south of the norite belt), dated at 2975 ± 13 Ma. Neighbouring the norite belt to the south, a number of large ultramafic bodies and mafic layered complexes locally show signs of Ni-enrichment.

The norite bodies have been targets for exploration since 1965 by the Kryolitselskabet Øresund A/S. Elevated Ni-contents of up to 2% are reported in norites and amphibolites related to zones enriched in sulphides. Rust zones and gossans indicate the presence of zones enriched in sulphides. The sulphides occur as disseminations, veinlets, interstitial fillings and as more massive lenses. The showings are generally 10-100 metres long. The sulphide occurrences show an uneven distribution. No financially viable



deposit has so far been located, despite the common occurrence of sulphide accumulations. The mineral assemblage is rather uniform, with pyrrhotite as the predominant mineral, accompanied by chalcopyrite, pyrite and pentlandite in a primary texture together with pyrite, linneaite, bravoite and magnetite in replacement textures. The average sulphide content in the mineralised rocks is around 2 vol % and locally up to 25 vol %.

Close-up of the gossan zone. The norite host rock is completely disintegrated and replaced by limonitic alteration of the sulphide minerals, the norite belt in southern West Greenland.





The Stendalen layered gabbro complex, South East Greenland. In the foreground psammites (light coloured), followed by a rust zone (to the right) within the layered gabbro complex. The cliff-face is 600–700 m.

Fiskefjord - Mafic and ultramafic intrusions (WG)

Several layered mafic to ultramafic intrusions and irregular bodies of dunite and peridotite are embedded in a supracrustal belt within the Archaean gneiss terrain. Igneous layering is common, despite strong deformation. NunaMinerals A/S acquired the Fiskefjord licenses in 2005 and initiated PGE exploration soon after. NunaMinerals introduced the names Amikoq and Fiskevandet to the two prospect sub-areas.

Reconnaissance work on samples of whole rocks has returned contents of Cr and Ni (up to 3.7 % and 2.8 %, respectively) and moderately high Cu. The majority of samples are depleted in S and sulphides are rarely observed in hand specimens. As exploration progressed there were good indications that the physical conditions were favourable for substantial PGE enrichment in the melt during mantle development. Accordingly nickel became a secondary target in the exploration.

Vestfjord nickel-mineralisation (East Greenland - EG)

Ever since the beginnings of exploration in the 1930s, the Vestfjord area has been known for its nickel indications situated in the Archaean gneisses. The Nordisk Mineselskab A/S carried out reconnaissance exploration in the area in the 1960s and reported disseminated pyrrhotite mineralisation with minor chalcopyrite and pentlandite related to mafic and ultramafic sequences within the gneiss. At the other localities in the area a number of pyrrhotite showings related to fault systems in amphibolite sequences have been reported to carry up to 0.3–2.0 % Ni, often together with up to 1.15 % Cu and traces of gold. The observed element association is regarded as an indication of segregation-type of sulphides in mafic and ultramafic rocks, whereas the fault-associated mineralisation is expected to represent mobilisation of primary disseminated accumulations.

In another basement locality in easternmost East Greenland, in Liverpool Land, some Ni-Cu-bearing sulphide lenses were discovered in Archaean gneiss in contact with marble in an area with a number of faults. Selected samples of semi-massive pyrrhotite lenses contain 0.3–0.7% Ni, up to 1.5% Cu, and traces of gold. These modest nickel indications from the Archaean of central East Greenland have not been systematically traced or evaluated.

Nickeliferous settings in Greenland: Palaeoproterozoic

After the discovery of the Voisey's Bay world class deposit of Ni-Co sulphides in the Canadian northern Labrador in the mid-1990s, much effort has been put into looking for similar deposits in Greenland. There has been speculation that a correlation exists across the Davis Strait with specific emphasis on settings resembling the Palaeoproterozoic Voisey's Bay deposit. Although the correlation is generally



Sea view to the hill slope with the outcropping nickeliferous dyke (center of view above the white gravel field) at Illukunnguaq, the eastern coast at Disko Island, central West Greenland. (See pge 9–11).

accepted, so far there has been no breakthrough in locating similar sulphide bodies on the Greenland side.

However, the exploration being carried out by several companies since the mid-1990s has not yet been fully concluded, and a number of definite prospects have been identified. The Nagssugtoqidian and the Ketilidian orogens are considered the Greenland counterparts of the Canadian Torngat and Makkovik belts, where the Voisey's Bay type is hosted in the Torngat terrain. Previous knowledge about Ni-sulphides on the Greenlandic side has also been reconsidered in the light of this correlation.

The geological environment often referred to as the 'nickel belt' in Canada continues across the Davis Strait to the West Greenland Nassuttooq area and into the Nagssugtoqidian orogen. Furthermore this orogen can be traced under the ice cap to the eastern coast of Greenland, as the Ammassalik mobile belt.



Aerial view of the outcropping nickeliferous dyke (center of view above the white gravel field) at Illukunnguaq, the eastern coast at Disko Island, central West Greenland. The dyke is vertical, 2–3 m wide and is eroded free as a natural wall from the hosting sandstone. (See pge 9–11).



Outcropping hornblendite at the Amitsoq Island in the Nanortalik area, South Greenland.

Arfersiorfik – VMS occurrences (WG)

Many companies are reporting Ni traces in the inner part of the Nassuttoq area. Early reports of discrete Ni-arsenide carrying mineralisation with up to 0.25% Ni are especially noteworthy. Recent exploration in areas with supracrustal sequences containing several pods of ultramafic rocks along the Nassuttoq fjord failed to locate magmatic nickeliferous sulphides.

However, Ni values of the ultramafics are in the range 0.2-0.3%. Several horizons and lenses with disseminated and massive pyrrhotite have also been discovered. NunaMinerals A/S conducted a helicopter-borne electromagnetic survey (TEM) covering parts of their Giesecke prospect in the area in 2007. Preliminary interpretation of the electromagnetic data reveals a number of significant conductors within a distance

of 12 km, which may represent Ni-bearing sulphide accumulations.

Kakilisattooq – Ni-sulphides (WG)

This location is close to the border zone between the Nagssugtoqidian orogen and the Archaean basement craton. Company activities report nickeliferous sulphides from a drill target. The mineralisation is found as stringers with up to 30 vol% of sulphides in amphibolitic sequences within the reactivated basement, where the maximum Ni content of up to 0.67% is in a drill coring within a 150 x 300 m geophysical target. This indication points to an unknown type of Ni-mineralisation in the area.

Tasiilaq – igneous complex (EG)

Exploration has been carried out in the Tasiilaq (Ammassalik) area (now named the Kitak prospect by NunaMinerals A/S) and this has led to the discovery of several nickel-bearing structures, traceable within a total strike length of more than 20-40 kilometres. This is now recognised as the Ammassalik Igneous complex; an igneous diorite complex composed of three plutonic centres which are exposed for more than 500 km². Average element contents of around 1.45% Ni and 0.5% Cu have been reported, and the company estimates a resource of at least 15-30 million tonnes of ore containing 1-2% Ni. Recent exploration activity reports average Ni values of around 1% from a number of sulphide mineralised lenses, which can be observed for several kilometres along the contacts of the Ammassalik Igneous complex.

Ketilidian orogenic belt (South Greenland - SG)

Nickeliferous indications are known from various settings of the Palaeoproterozoic Ketilidian orogen at the southern border of the Archaean craton, where a number of occurrences were described during survey activities in the 1970s.

Amitsoq – ultramafic mineralisation (SG)

Peridotitic dyke and sill bodies contain zones of up to 1.5 m with a concentration of various sulphides including pentlandite

as a part of a small dyke-like intrusion complex. The intrusion has been mapped over a length of 1.5 km, and it varies within the field between 90 and 250 m. The sulphide content is about 0.2 vol. % but can reach 15% in 10–20 cm wide zones. Pyrrhotite, pentlandite, chalcopyrite, and cubanite dominate the sulphides accompanied by 5–10 vol. % magnetite. The ultramafic rocks are thought to be a part of an appinite suite found throughout the Ketilidian orogen. Ni analyses indicate low contents of nickel up to 0.07%. Because of the PGE and Ni contents, these showings were explored by a number of companies in the early 1980s.

Stendalen – gabbro complex (SEG)

The Stendalen layered gabbro complex, Lindenow Fjord, was discovered during the GEUS regional resource assessments in the 1990s. It is reported to contain sulphide accumulations in assumed rafts within a sequence of the sheet-like layered gabbro complex which covers at least 8 km². The complex is composed of gabbro, leucogabbro, and diorite, locally with

primary banding, and it is divided into two main units: a lower layered gabbro unit and an upper homogeneous gabbro to diorite unit. The ore minerals are dominated by pyrrhotite, minor pyrite, chalcopyrite, cobaltite, and graphite. A magnetite-rich zone separates the lower layered gabbro from the upper homogeneous gabbro. Rusty zones are traceable for 2 km or more with disseminated sulphides carrying up to 0.5% Ni. The economic potential has not been tested.

Ililmaasaq – alkaline intrusion (SG)

Spectacular mineral accumulations containing nickeliferous ore minerals have been investigated within the Gardar intrusion at Ililmaasaq. A suite of noble Ni-minerals (nickeline, westerveldite) is known as vein-related mineralisation of suggested hydrothermal replacement genesis within this peralkaline Gardar intrusion. The nickel content of the mineralisation is in the order of 20–40%. The extent of this unusual mineralisation is unknown.

Nickeliferous settings- Palaeogene

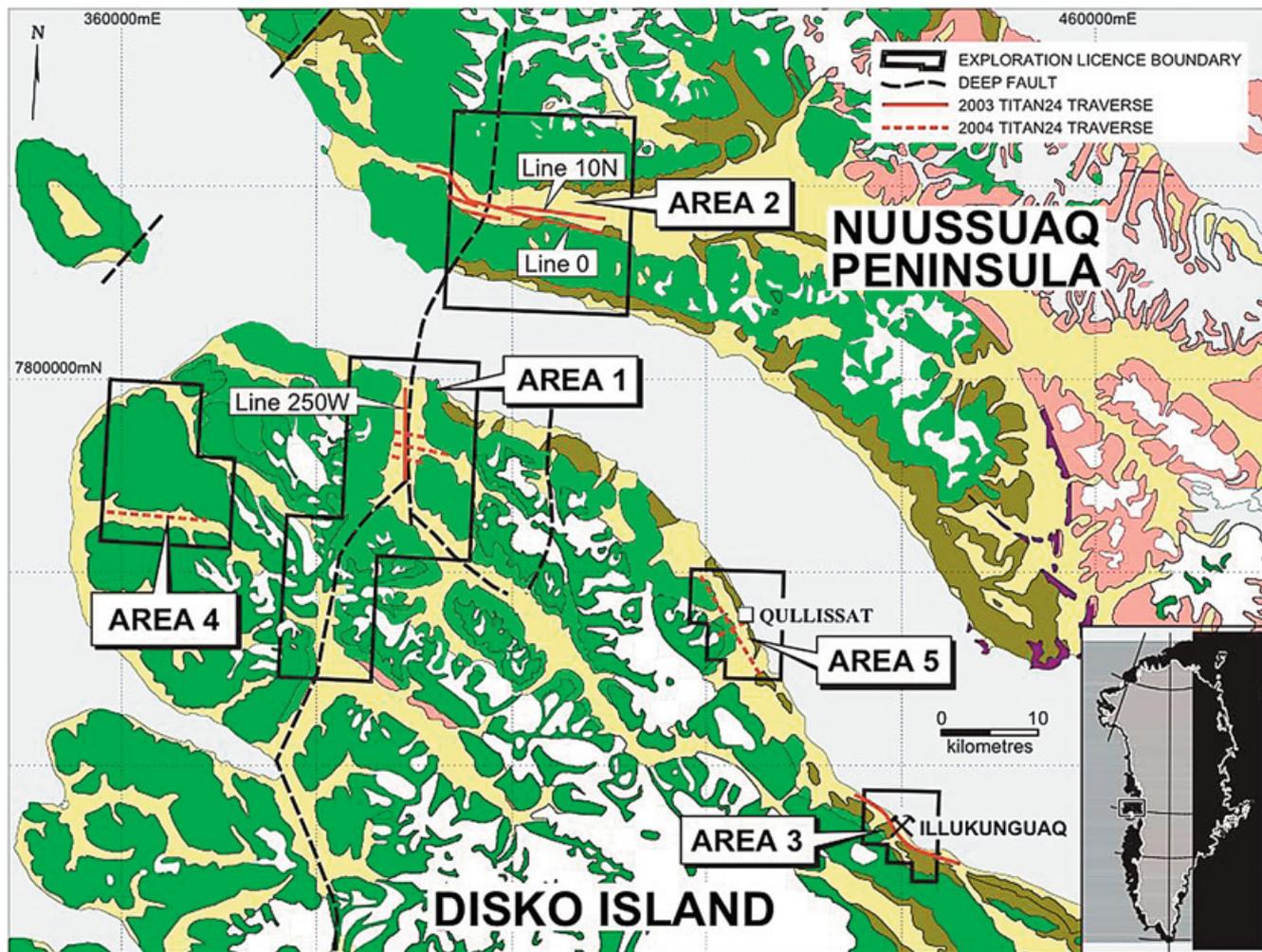
Palaeogene Ni-sulphide accumulations are confined to the West Greenland Basalt Province where there have been mineral searches since the early days of Greenland exploration. Known occurrences are mainly hosted in presumably sediment-contaminated lavas and dykes at the base of the basalt sequence in the Disko region. However, the basalt regions in West and East Greenland are generally viewed as having a promising potential for nickel accumulation.

Disko Island – plateau basalts (WG)

For more than a century the Palaeogene West Greenland Basalt province has attracted exploration for Ni-sulphides. The known occurrences in the Disko Bay region are mainly hosted in contaminated lavas, and in dykes at the base of the volcanic succession. The province is believed to have a significant potential for Ni- PGE-mineralisation. Palaeogene picrite and basalt lavas overlie thick Upper Cretaceous

Nickel exploration drilling in basalts near Illukunnguaq on the eastern coast at Disko Island, central West Greenland.





Nickel exploration in central West Greenland. Map showing Titan 24 traverses in the Disko Bay area. Courtesy: Vismand Exploration Inc.

and Palaeogene sediments. Most of the voluminous onshore volcanics were deposited in a short period of time 61–59 Ma ago. The Palaeogene dyke intrusions, such as the Hammer Dal complex on northwest Disko, contain Ni-bearing pyrrhotite and native iron formed by processes akin to Noril'sk type Ni-Cu-PGE deposits. The analogy to Noril'sk has attracted exploration, e.g. by Falconbridge Ltd. and Vismand Exploration Inc. (Green Mining Ltd.) The Hammer Dal complex on Disko belongs to a swarm of mineralised dykes fed by contaminated magma and the complex has a number of attractive characteristics which may imply the existence of a large intrusion at depth. Ground geophysics has revealed a large conductor at 400–500 m below the present surface. The conductor could represent a

volcanic body with sulphides and native metallic iron. The dykes of the Hammer Dal complex were probably feeders to large volumes of contaminated lavas. The intrusions host deposits of metallic iron and sulphides, all of which at the moment are too small to be economically viable.

The presence of iron cumulates suggests considerable magma transport capability in the magma. The amount of deposited iron typically reflects local conditions of deposition rather than the general potential of the intrusive system. Apart from native (metallic) iron (and alloys), pyrrhotite and pentlandite are common. Sulphide-enriched basalt (together with accumulated, metallic iron) shows > 1% Ni and elevated PGE contents of up to 0.5 ppm. Exploration was carried out in the area in the 1980s

by Greenex/Cominco Ltd. A joint venture, Platinova A/S-Falconbridge Greenland A/S, conducted an extensive programme between 1991 and 1996. The programme included regional mapping and sampling as well as diamond drilling. Since 2003 Vismand Exploration Inc. (Green Mining Ltd.) has searched for possible deposits on Disko Island and on the Nuussuaq Peninsula. Using the advanced geophysical method "Titan 24", the company measured three cross-sections in the northern part of Disko Island.

At the long-known Illukunnguaq site, a sediment-contaminated sulphide-rich dyke has a 28 t lump of solid sulphide ore, which was dug out in 1931 and the occurrence has been explored several times since. The Ni-content of the sulphide ore reaches 8%.

An evaluation of the potential for copper-nickel and platinum group elements of the Neogene basalts in West Greenland supported a comparison with the Noril'sk region and suggested that both regions are characteristic for depletion of copper-nickel and platinum group elements in the basalts. However, the West Greenland system is smaller than the Noril'sk system. The emplacement of sulphide saturation took place at high levels in the crust in West Greenland, whereas at Noril'sk the saturation event took place at depth with subsequent emplacement of sulphide-bearing magmas into high-levels of the crust. This means that it is not reasonable to expect that the West Greenland flood basalts will carry the same scale of deposits as the Noril'sk system, but this does not exclude considerable Ni potential. The Palaeogene Illukunnguaq sediment-contaminated sulphide-rich mafic dyke may be a direct candidate for a Noril'sk type deposit.

Palaeogene gabbro intrusions (EG)

More than sixty layered gabbro intrusions have been recorded in the Palaeogene East Greenland volcanic rifted margin. The plutonic suites range from ultramafic to felsic, from depleted basaltic to highly alkaline, and from upper crustal intrusions to sub-volcanic centres and breccia pipes with related epithermal vein systems. The East Greenland magmatism occurred from 61 to 13 Ma ago. The province hosts the world-class Skaergaard PGE and Au deposit. The flood basalt succession is over 7 km thick. Major sill complexes occur in Mesozoic to Palaeocene sediments below the lavas.

Mafic intrusions at Kangerlussuaq (68°N) and along the east coast to Nualik (67°N) have been focussed on PGE exploration since 1987. Platinova A/S, Quadrant Resources and later Galahad Gold Ltd and Skaergaard Minerals Corp. have been conducting the exploration. In 1987 the Skaergaard intrusion was recognised as a large low-grade PGE and Au deposit. The concession is presently held by Platina Resources Ltd. Several other mafic intrusions show PGE mineralisation, but apart



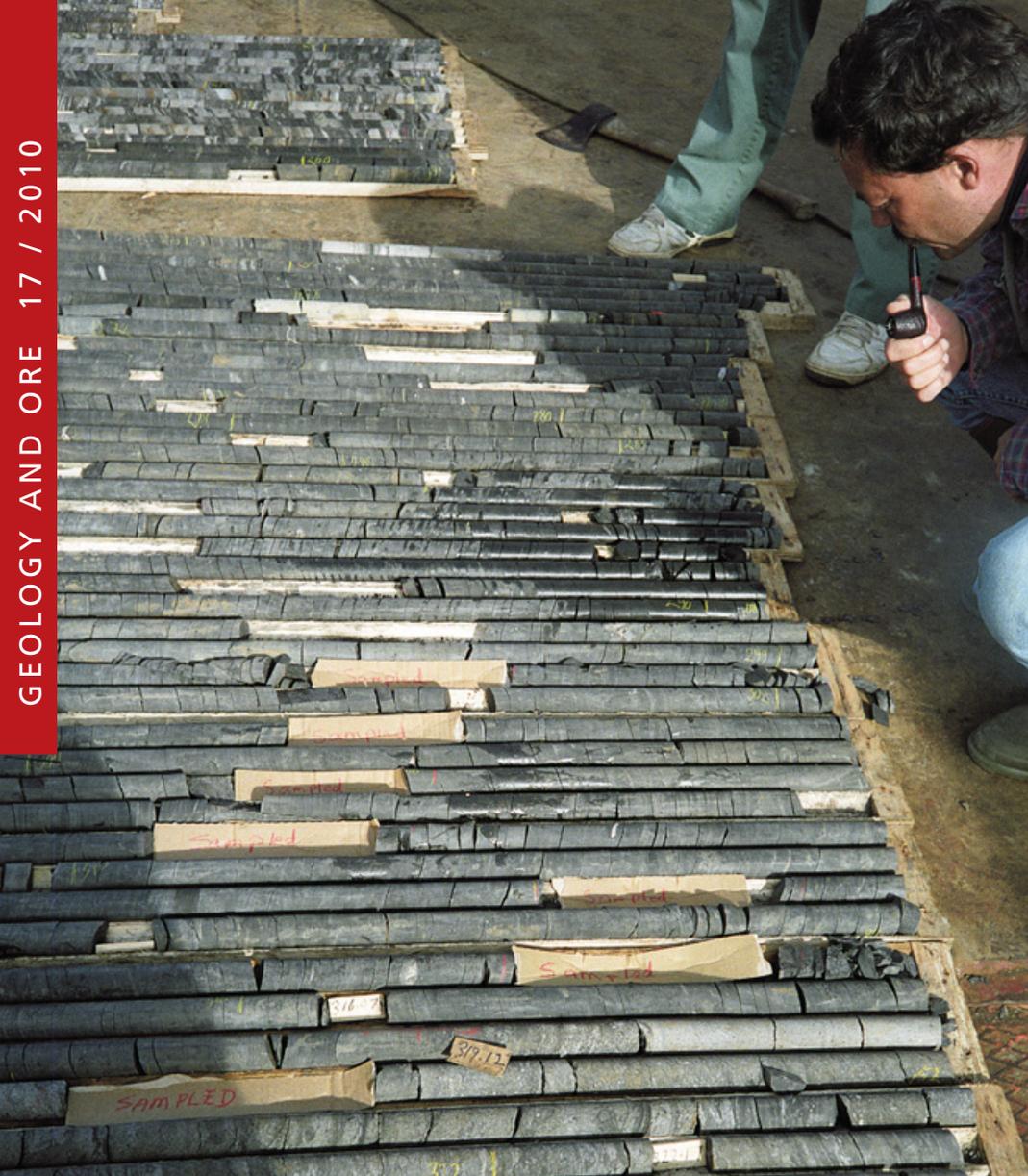
Core boxes, collected at the base for inspection of the nickel exploration drilling in basalts near Illukunnguaq on the eastern coast at Disko Island, central West Greenland.

from Skaergaard, no significant deposits have been identified. Neither of the mafic intrusions has so far demonstrated reasonable nickel accumulations although the potential is obvious.

Concluding remarks

Exploration for nickel used traditional methods as well as newly developed geophysical techniques. Mineralisation models referring to Voisey's Bay style deposits are

in particular focus within the Palaeoproterozoic of West Greenland. The Noril'sk style deposits have recently been tested in the Palaeogene of the Disko Bay area, both by traditional exploration and geophysical mapping, and by new geophysical techniques as well as scientific modelling. Taken as a whole the results of reviewing the Greenland geological environments are promising for nickel, but many of the prospects still need to be matured and refined.



Core boxes from the nickel exploration drilling in basalts near Illukunnguaq on the eastern coast at Disko Island, central West Greenland.

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Front cover photograph

Northern face of Graah Fjord, South-East Greenland. The two dark bands represent Archaean meta-peridotites with sulphides, mainly pyrrhotite, pentlandite and chalcopyrite. The ore contains about 0.3 wt.% Ni and is enriched in Cu, Cr and Pd.

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Graphic Production

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Photographs

GEUS unless otherwise stated

Printed

February 2010 © GEUS

Printers

Rosendahls · Schultz Grafisk a/s

ISSN

1602-818x