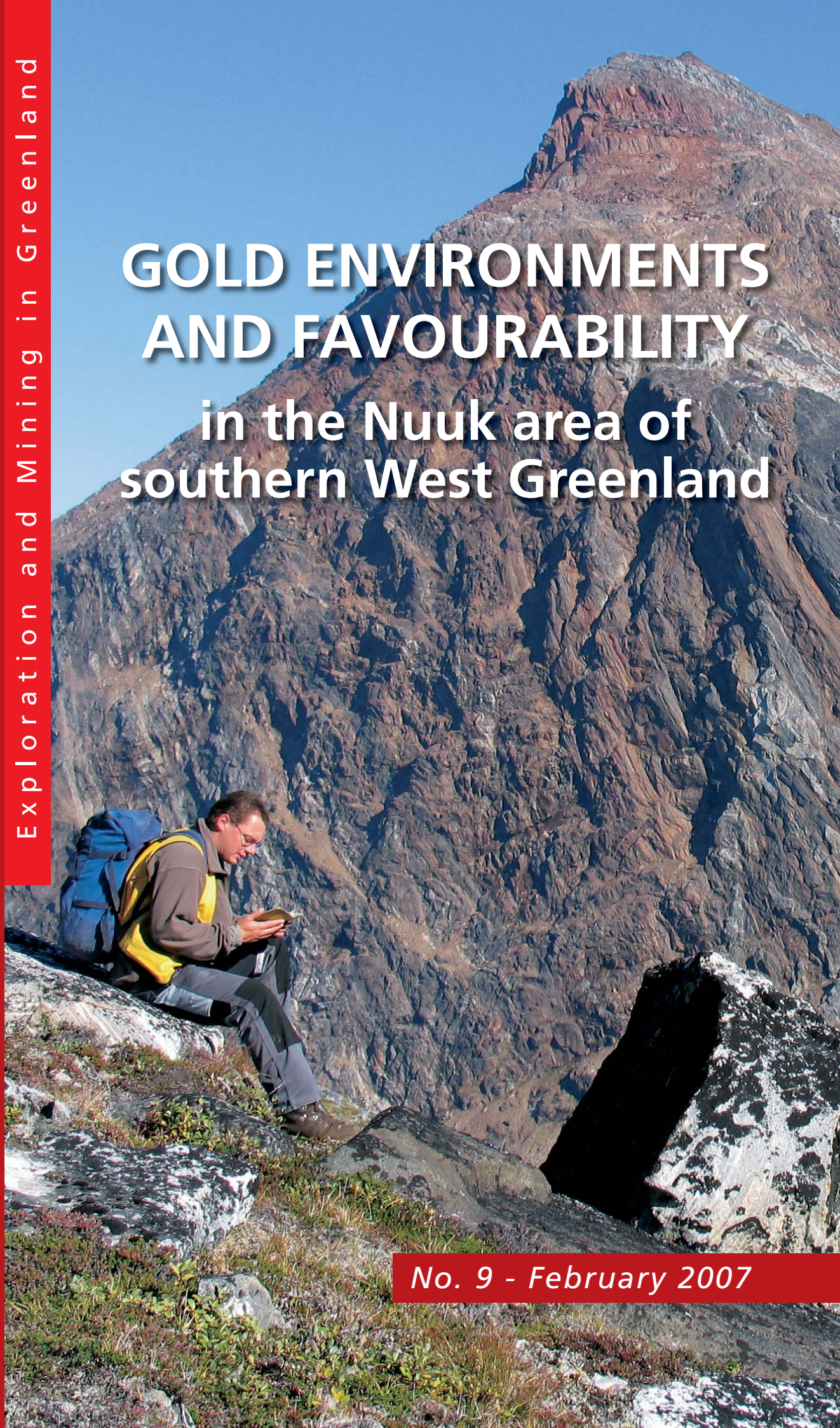
GEOLOGY AND ORE

Exploration and Mining in Greenland

GOLD ENVIRONMENTS AND FAVOURABILITY

in the Nuuk area of southern West Greenland



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So far the interplay between the magmatic, tectonic and metamorphic evolutions and their mineralising events has been the main resource evaluation.

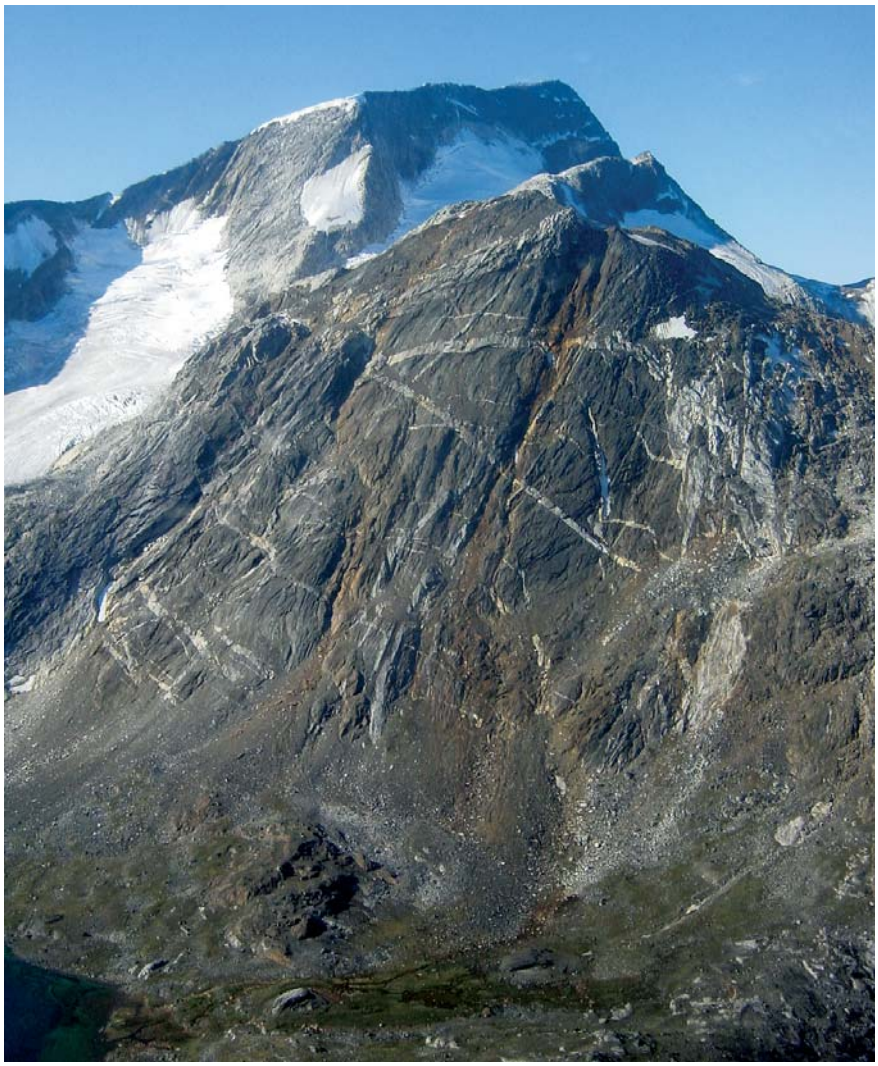
During the last couple of years, focus on the primary geological environment hosting the mineral deposits has started to improve the evaluations. Multidisciplinary, spatial, quantitative analysis of geo-data is used for this purpose. The construction of quantitative, favourability maps for a specific element, such as gold, is a result of this.

The "new" approach has been used in the Nuuk region in West Greenland, where the statistical, spatial analysis has been used to evaluate the gold potential. The analysis also provides valuable input to the interpretation of the mineralisation and the primary geological environments.

Geological environments and mineralisation in the Nuuk region

The Nuuk region, located within the Archaean North Atlantic craton (the Nain craton in Canada), comprises several different tectono-stratigraphic terranes, which had independent, geological evolution until they were tectonically assembled at c. 2.7 Ga. The terranes host several supracrustal belts; the oldest is the Isua greenstone belt with an age of c. 3.8 Ga and younger belts are Mesoarchaean. The different belts and areas are described according to their dominating environment.

Volcaniclastic, meta-andesitic rock from Bjørneøen with fiamme textures.



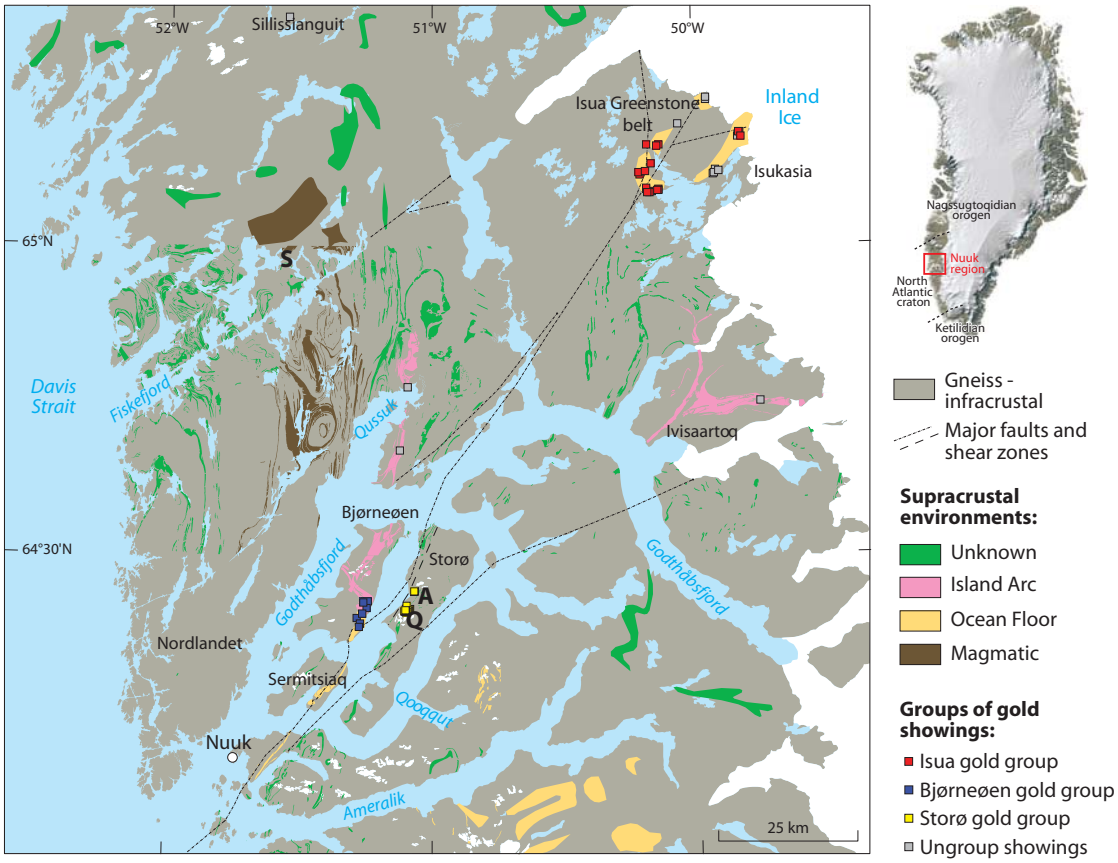
The Qingaaq gold prospect at Storø located within a supracrustal sequence. The prospect is currently being drilled and evaluated by NunaMinerals A/S. The lake in the lower left corner is 470 m above sea level. The top in the background is the mountain Qingaaq (1616 m. a.s.l.), and the top in the foreground is Little Qingaaq (1070 m.a.s.l). Photo courtesy: NunaMinerals A/S.

The investigations of the environments require the combination of detailed geological mapping, geochemistry, petrography work, isotope work and geochronological studies.

Island-arc environment

Recently volcaniclastic rocks of andesitic composition were discovered in the region. The belt forms major parts of the Mesoarchaean, amphibolite facies supracrustal belt around Qussuk bay, on central and eastern Bjørneøen and on central Storø (3071 Ma). Meta-volcanic rocks have been subject to intense synvolcanic hydrothermal alteration associated with gold-copper mineralisation (grab samples with up to 2 g/t Au). Later hydrothermal events may also have affected the occurrences of gold in certain areas.

The Ivisaartoq supracrustal belt, with a maximum age of 3075 Ma, is interpreted as a forearc supra-subduction environment. This belt underwent at least two stages of calc-silicate, metasomatic alteration between 3075 and 2963 Ma attrib-



Simplified schematic geological map of the Nuuk region with general indication of different geological environments.

Outlines of the rock units are from digital versions of 1:100 000 and 1:2 500 000 scale geological maps published by the Survey.
Q: Qingaaq;
A: Aappalaartoq;
S: Seqi Olivine mine.

The statistically defined groups of gold showings in the region are also indicated (a gold showing is defined as a locality where in situ rock samples yielded 1 g/t Au).

uted to seafloor hydrothermal alteration. The Ivisaartoq belt hosts volcanic massive sulphide deposits (semi-massive to massive pyrite-pyrrhotite) and disseminated tungsten in altered komatiites (channel samples with 0.44% WO_3 over 2.5 m). Showings with up to 3.5 g/t Au are recorded within the Ivisaartoq belt.

Ocean-floor environment

The 3.8 Ga Isua greenstone belt represents an ocean-floor environment. The dominating rock types in this belt are pillow-structured tholeiitic and high Mg-basaltic rocks with intercalated, extensive bands of chert and banded iron formation, turbidites as well as garnet-mica schist representing metamorphosed sediments. Gold occurrences have been found in several settings within the Isua greenstone belt.

- In silicate facies iron formation (up to 1.2 g/t Au)
- In fuchsite-stained quartz-rich rocks (up to 3.1 g/t Au over 3 m)
- In shear-zone hosted, carbonate-altered ultrabasic rocks (grab samples with up to 100 g/t Au).

A hydrothermal episode affected a c. 3.8 Ga intrusive tonalite sheet in the western part of the Isua greenstone belt. The belt contains up to 14% combined Pb and Zn with up to 6.8 g/t Au and 180 g/t Ag.

Well-preserved, volcanic successions interpreted as environments dominated by ocean-floor settings are described from several other areas in the Nuuk region. Bimodal, volcanic succession in greenschist facies is described from the 'Nunatak 1390' in the Tasiuarsuaq terrane. Voluminously layered amphibolites and well-preserved pillow lava at Bjørneøen, associated with homogenous, metagabbroic amphibolite are also interpreted as a primary ocean floor environment. A small VMS showing is located in the south-western part of the belt at Bjørneøen. This showing contains up to 3.55% Zn, 1.33% Pb, 33 g/t Ag and 0.153 g/t Au.

Magmatic environment

The Nordlandet and Fiskefjord areas are dominated by mafic to ultramafic sequences including dunite, peridotite, pyroxenite, norite and amphibolites hosted by tonalitic and trondhjemitic gneisses. In many cases relict magmatic layering is preserved. This area comprises probably both primary magmatic environments and relicts of greenstone belts. The mafic to ultramafic complexes south of Fiskefjord show enhanced values of Au and PGE. The Seqi Olivine Mine operated by Minelco AB is located just north of central Fiskefjord. The deposit contains at least 100 million tonnes of high-quality olivine and is hosted within a large dunite body.

The supracrustal belt at central Storø is of a complex character and much debated. It seems that this belt may contain characteristics of both continental and oceanic volcanic and sedimentary rocks. The area is furthermore affected by intense folding and major shearing, making straight interpretations even more difficult. The area may represent an accretion environment along boundaries of different terranes (amalgamated around 2.7 Ga). Central Storø hosts the Qingaaq Gold prospect which is investigated and drilled by NunaMinerals A/S. Several gold bearing structures, 4–36 m wide, have been found at Qingaaq with grades from 0.5 to 6 g/t Au and locally 2–4 m wide zones with grades up to 20 g/t Au.

Deformed pillow lava from southern part of Bjørneøen.

Mineral potential - addressing multivariable datasets

Visual inspection and comparison of e.g. lithological, topographical, geochemical and geophysical maps are necessary ways of interpreting geological features across poorly exposed or little explored areas. In mineral exploration the maps and data are used visually to identify anomalies believed to reflect the existence of mineral occurrences. However, if the regional data are widely spaced, and if the occurrences are of limited size or poorly exposed, the anomalies may be too subtle to be recognised by a simple visual approach. In such cases, statistical data analyses may help identify deviations from the background variations and trends in the data. Furthermore, visually based correlation between distributions is often limited to a few parameters and with the wealth of to-day's digital data, multivariable relationships are easily overlooked or not possible to deduce visually.

The principles of the statistical methodology

All spatial datasets are converted info a form, where they can be compared and subjected to statistical analysis. Each dataset is presented as a regular grid using a common grid cell size denoted a pixel. In the case of gold potential in a region, pixels with and without gold showings are registered. To construct a gold favourability map includes analysing the characteristic data signatures of the pixels, with and without gold showings, in multiple datasets and then integrating the data signature to calculate the gold showing probability for each pixel. Besides enabling the quantification of the gold favourability in a certain area, the statistical approach provides quantitative signatures of specific geological features, e.g. the gold showings, which can be used and integrated in geological models and interpretations.

Rusty chromite-magnetite banding from magmatic layered norite in the Fiskefjord area.

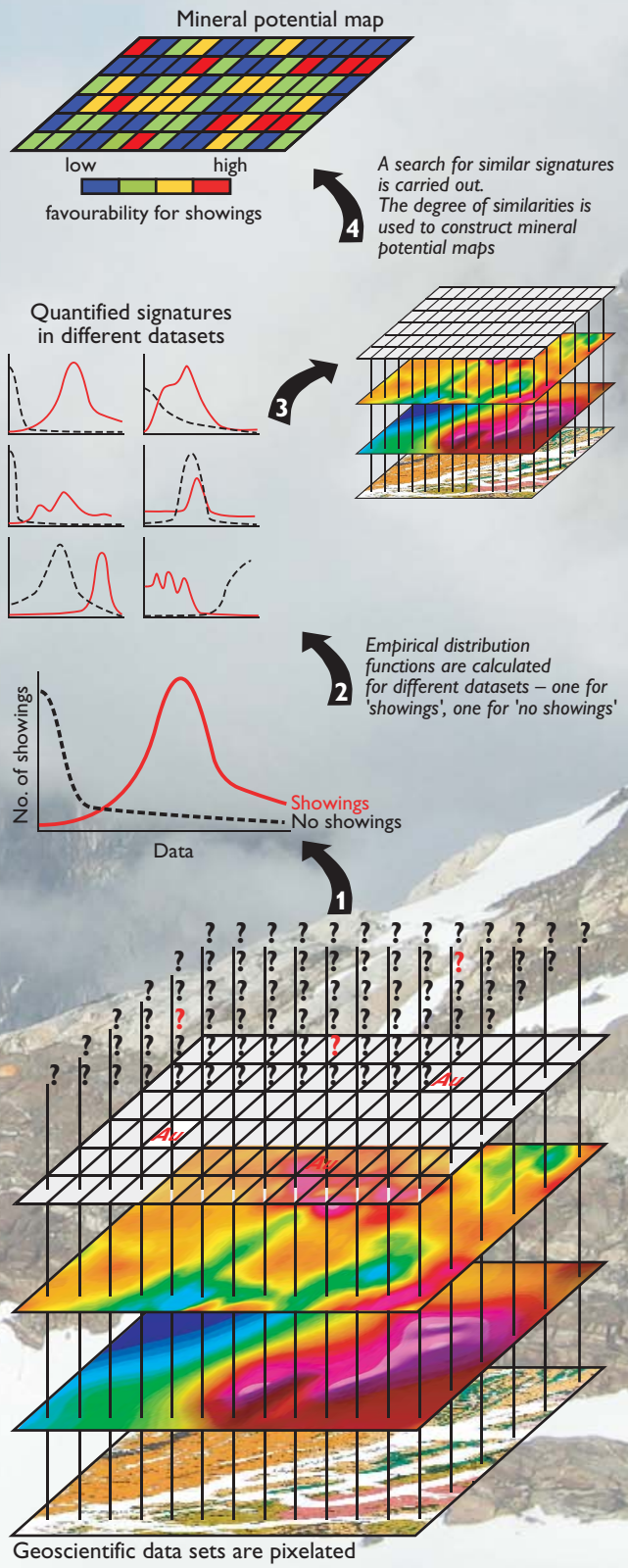
Illustration of the statistical approach:

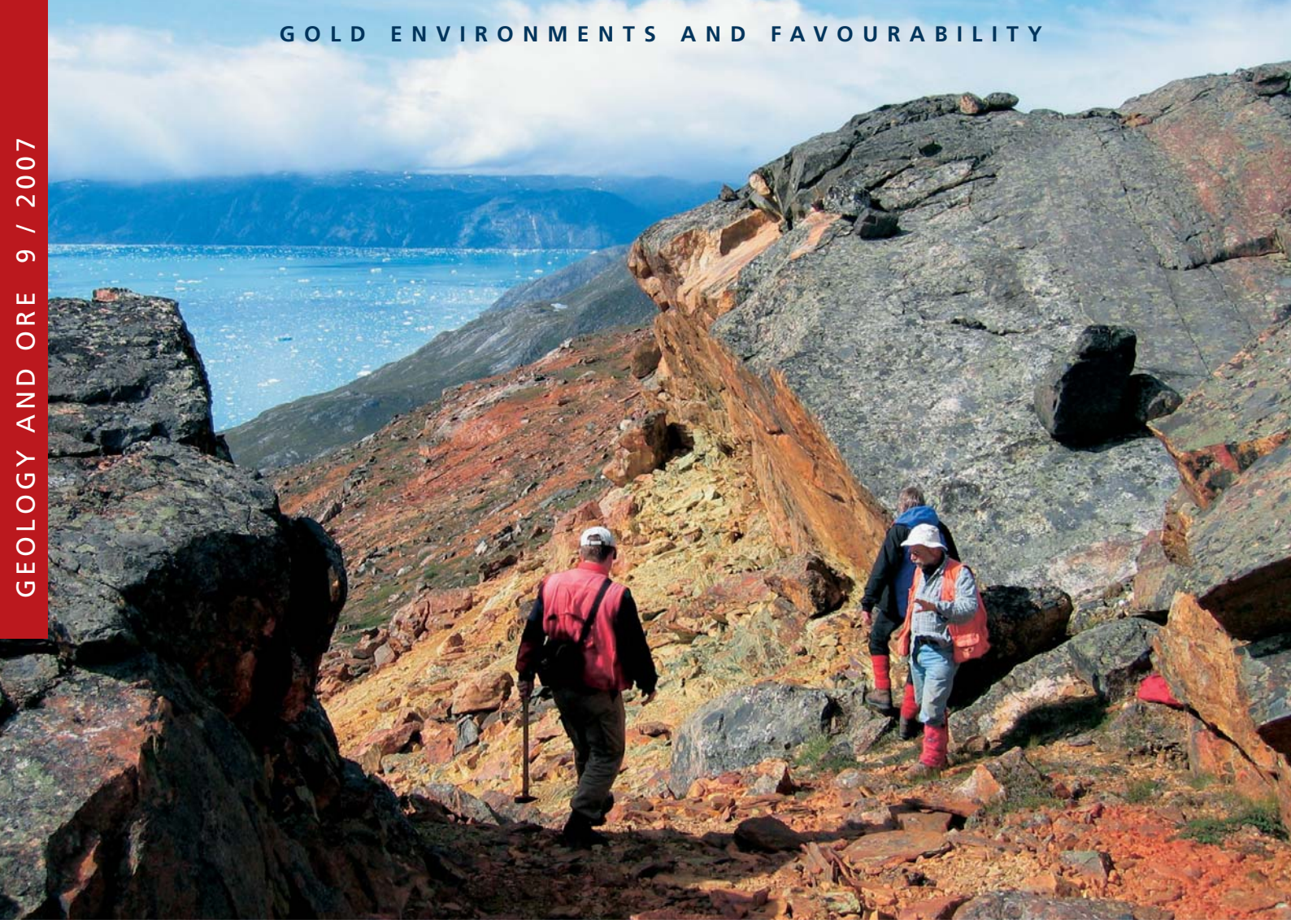
1: Regional datasets and gold showings (Au) are referred to a common grid with fixed cell size; a pixel.

2: Empirical distribution functions for pixels with and without known gold showings are used to establish the signatures of the showings in each dataset.

3: Likelihood ratio functions for all datasets are calculated on the basis of the two previous functions, expressing the likeliness of a showing to be present. Groupings of gold showings are based on constructed mineral potential maps for each showing. Pixel by pixel, these maps outline the predicted favourability for data signatures similar to the selected showing, i.e. the potential for a similar showing to be present.

4: Finally, mineral potential maps are calculated for each identified group of showings. These maps are based on the signatures found to be indicative for each of the different groups.





Rust zone in massive sulphide occurrence at Ivisaartoq.

Gold favourability map for the Nuuk region

Data analysed

Sixty-nine different geoscientific datasets – including location of known gold showings, data from geological maps, stream sediment geochemistry, aeromagnetic data, aeroradiometric data and data from lineament analysis have so far been included in the statistical analysis. All datasets are pixelated. A gold showing is in the current study defined as a locality where a rock grab sample has yielded >1 g/t Au.

Grouping of gold showings

Instead of treating all known gold showings as one group, it is statistically analysed whether the showings should be split into groups according to common signatures in the datasets. For the Nuuk region, this analysis resulted in the identification of at three main groups of gold showings: the Storø, the Bjørneøen and the Isua group.

Resulting gold favourability map

By using the identified common signature for gold showings, it is possible to estimate the probability for similar data signatures within all pixels. It is not surprising that areas immediately surrounding known gold showings are predicted as favourable, but more interestingly, a number of favourable areas are also predicted outside areas with known gold showings.

Gold bearing rustzone in the Qussuk area.

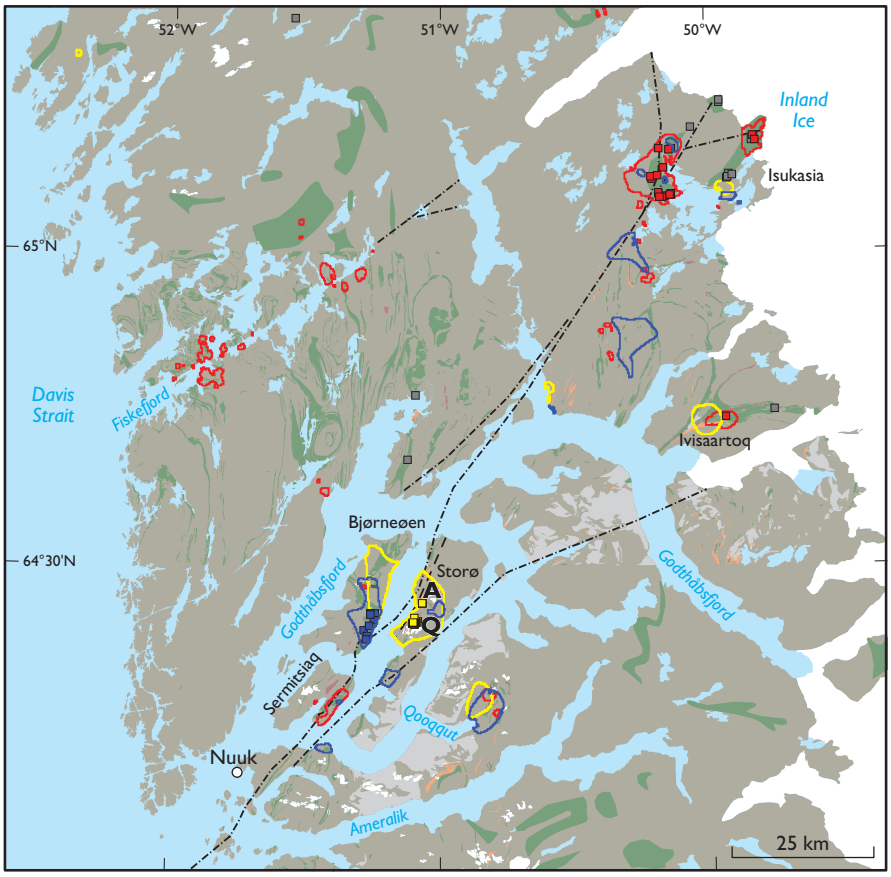
Ice
Gneiss
Amphibolite
Metasediment
Ultramafic rock
Late Archaean granites
Fault and shear zones

Isua showings
Bjørneøen showings
Storø showings
Ungrouped showings

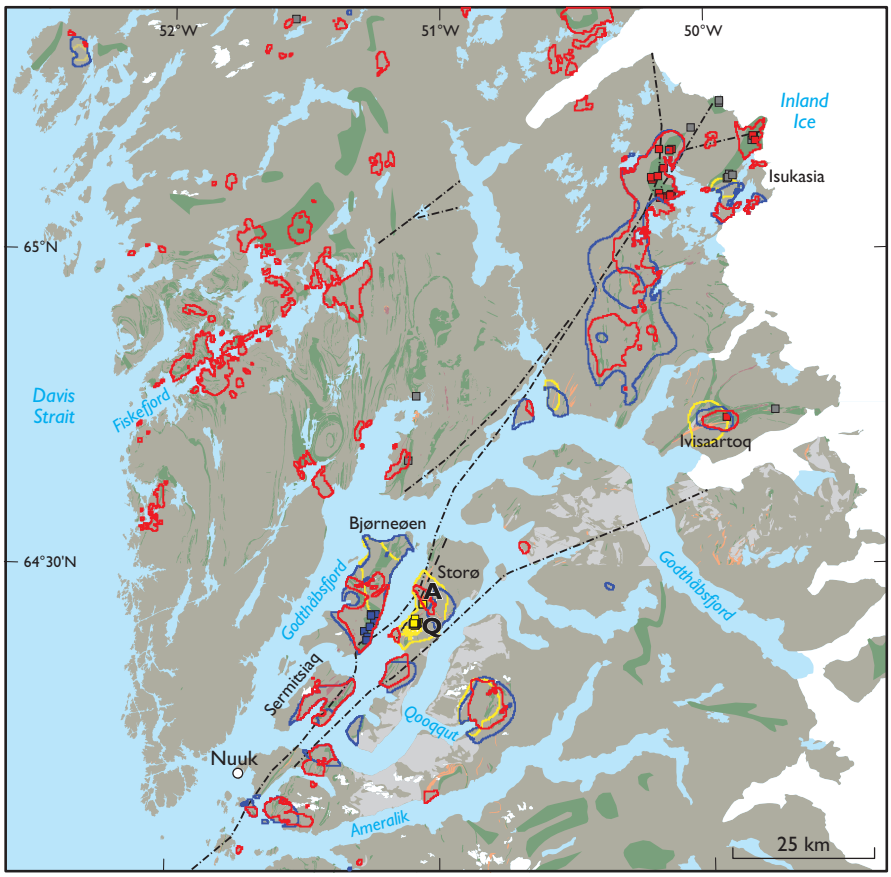
The top 137 km^2 and 685 km^2 most favourable areas for:

Isua gold group
Bjørneøen gold group
Storø gold group

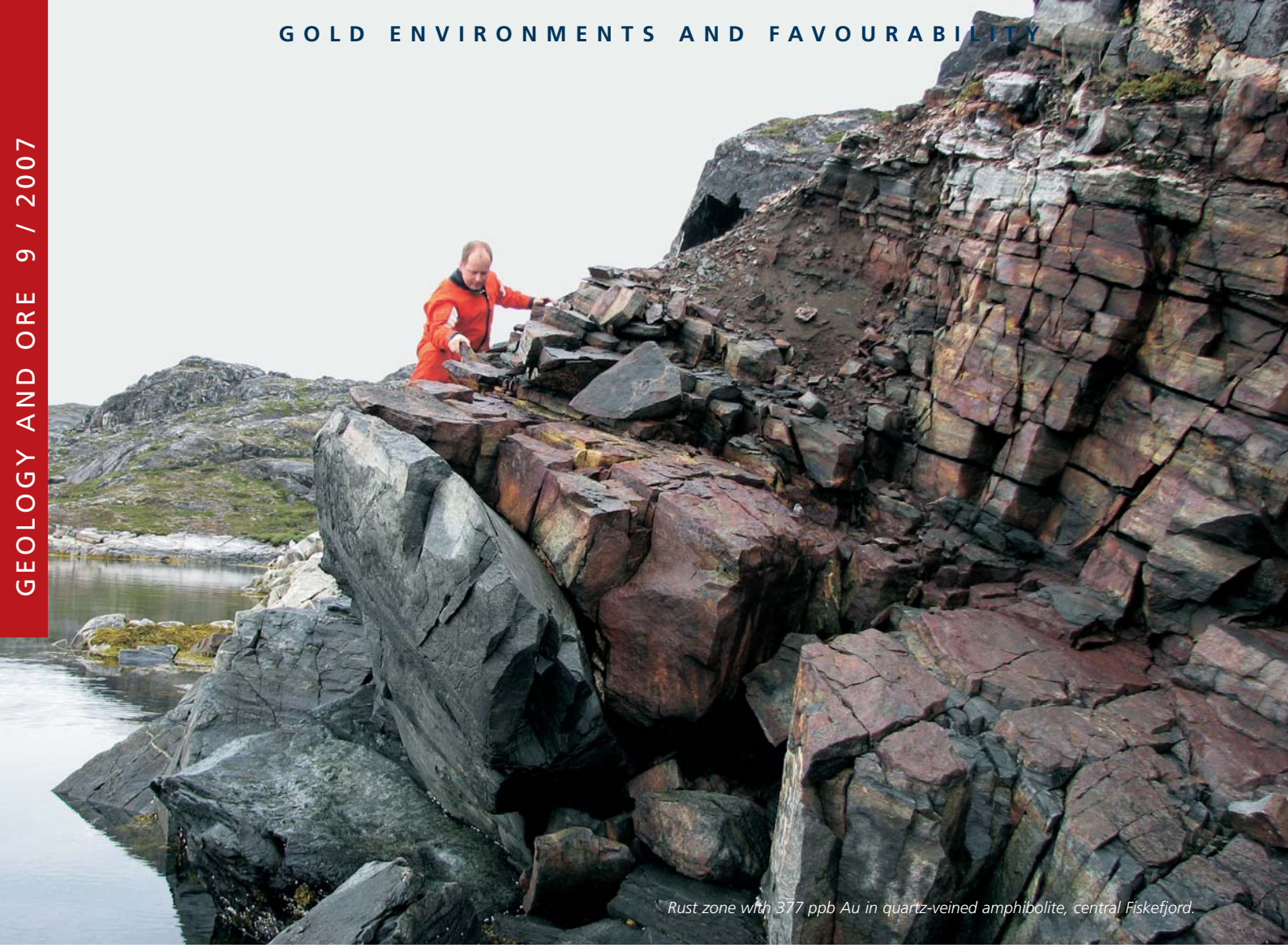
Top 137 km^2 most gold favourable area (1% of entire study area)



Top 685 km^2 most gold favourable area (5% of entire study area)



Simplified geological maps with the top rated 137 km^2 and 685 km^2 (respectively 1% and 5% of the analysed area) outlined as most gold favourable area for the three groups of gold showings (Isua, Bjørneøen and Storø groups). Outlines of the rock units are from digital versions of 1:100 000 and 1:2 500 000 scale geological maps published by GEUS.

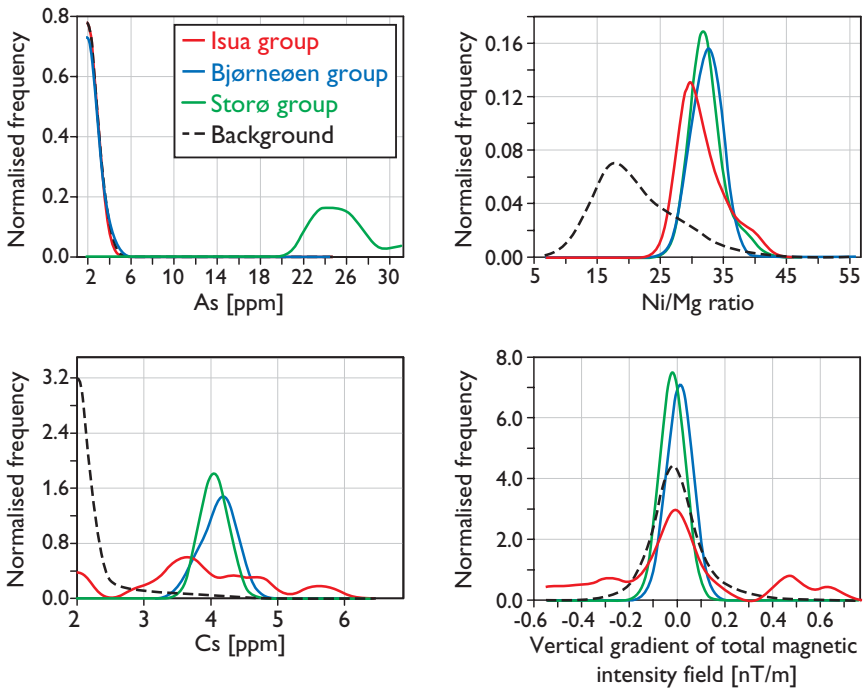


Rust zone with 377 ppb Au in quartz-veined amphibolite, central Fiskefjord.

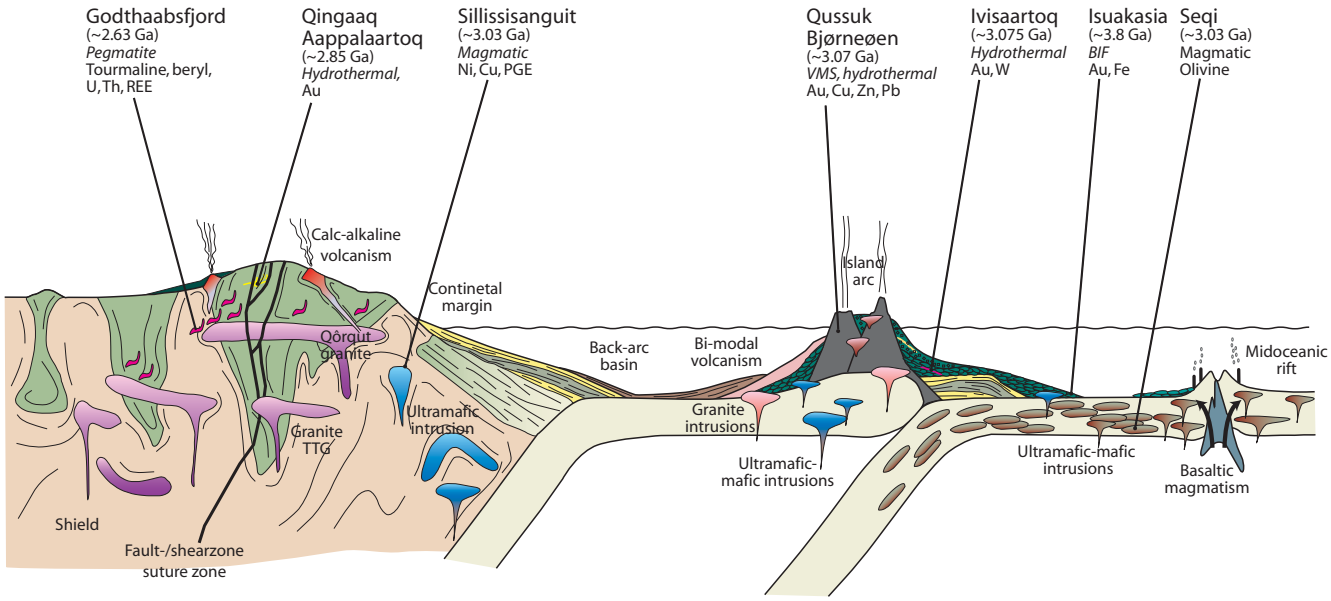
Some of the most notable areas outlined as most favourable for gold are east of the fjord Qooqqut, areas at Storø, areas at Sermitsiaq, areas south and west of Isuakasia and areas in outer and inner part of Fiskefjord. Especially in the latter area, hardly any prospecting for gold has been done, but the area comprises both supracrustal rocks and structures that are similar to those in areas with known gold showings. Field work in the inner part of Fiskefjord recently revealed a strong alteration of the country rock in that area; mainly bleaching, silicification and epidotization. Rocks from the area yield elevated gold content with up to 0.377 g/t Au in amphibolite-hosted quartz veins.

The spatial distribution

The spatial distribution of all outlined favourable areas suggests the existence of a main regional tract favourable for gold and gold mineralising environments. Most of the favourable areas for the different groups of known gold showings are situated within a



Four examples of statistically derived data signatures for the three main groups of gold showings in the Nuuk region, displayed together with the background signature (pixels without any gold showings).



Empirical simplified model of geological environments and mineral occurrences present in the Nuuk region.

NNE-trending tract from the town of Nuuk to Isukasia. The tract embraces most of the previously known gold showings in the region as well as geochemical gold anomalies, and the zone has previously been suggested as being prospective for gold.The NNE-trending tract outlined as being favourable for gold is common to the general orientation of the supracrustal belts in this area and to the regional large-scale faults. In general, supracrustal units outside the tract constitute similar proportions, but these are not indicated as being within the most favourable areas by the present statistical analysis. This indicates that the supracrustal units within the tract deviate from those outside.

Signatures of gold showings

The systematic construction of data signatures of showings and the background draw attention to the significance of parameters that are not immediately or traditionally regarded as indicative of gold mineralisation. It has previously been established that the combination of elevated As in stream sediment and gold mineralisation has not been found outside Storø. However, the possible significance of the Ni/Mg ratio in relation to gold has not previously been substantiated in a quantitative way. This observation is an incentive to conduct further studies of host rock properties in terms of their Ni and Mg behaviour. The rare and unique As signature of the Storø group poses a problem in the search for areas holding a potential for new showings. Since this signature exists on Storø solely, this area will be outlined as favourable only for the Storø group. Consequently, the As data are omitted in the calculation of pixels with a potential for Storø-type showings. It has before been argued that Cs may be considered a pathfinder element for gold mineralisation associated with granite-related, hydrothermal alteration. The signature for Cs in stream sediment confirms that the gold at Storø and Bjørneøen is indeed located in a Cs-rich environment, but also suggests that the mineralisation at Isua has a different nature.

The last example illustrates the indicated significance of the vertical gradient of the total magnetic field intensity (denoted VGTMI). This signature for the Storø and Bjørneøen groups (–0.2 to 0.1 nT/m) is identical to the background signature, and is consequently regarded as non-indicative for these groups. The Isua group has a more dispersed signature (–0.5 to 0.8 nT/m), with an indicative positive and negative VGTMI than the other groups. This probably reflects local-scale changes in lithology. Other datasets, which yield a characteristic signature of one or more of the groups of gold showings, are the Au, Cs, Rb, La, Th, and U concentrations in stream sediment geochemisty.

Visible gold in drill core from the Storø prospect. Photo: NiunaMinerals A/S.

Perspectives

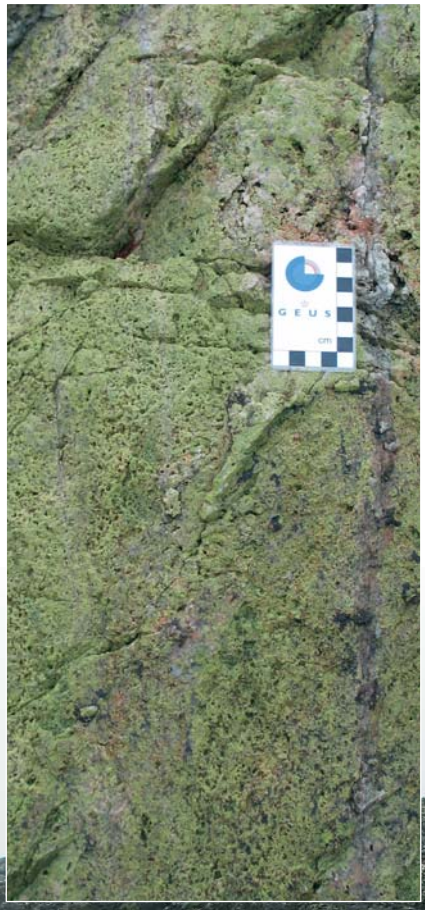
The statistical approach has a potential of identifying and mapping other types of mineral occurrences as well as specific tectonic units in poorly known areas and can be used on local or regional scale, depending on the resolution of the involved datasets. The statistical approach has been used to examine gold showings in a moderately explored region.

The approach could also be applied to economic deposits from well-known historic or active mining camps. As shown in the case in the Nuuk area, the statistical approach should always be used in combination with other geological approaches.

The results of a statistical analysis should be cross-validated and critically balanced according to geological knowledge.

Concluding remarks

The detailed investigations of primary geological environments of supracrustal rocks in the Nuuk region have revealed a great diversity in environments, which all carry gold. The results from the statistical analysis have been positive in the sense that areas with high favourability for new gold occurrences have been outlined.



Hydrothermal alteration with epidotization, south of Ameralik fjord.

Drill cores are lifted by helicopter during operation at Little Qingaaq. Photo courtesy: NunaMinerals A/S.

Gold-mineralised quartz veins hosted in amphibolite at the Qingaaq gold prospect, central Storø.

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Front cover photograph

The mountain Aappalaartoq (1440 m) – named after the Greenlandic word for red mountain – in the background. Several gold-bearing structures have been located within the supracrustal package making up the mountain. Photo courtesy: NunaMinerals A/S.

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