DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/17

Workshop on Nagssugtoqidian and Rinkian Geology, West Greenland 2004

Abstract volume

Edited by Julie A. Hollis and Bo M. Nielsen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

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G E U S

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Introduction

Workshop on Nagssugtoqidian and Rinkian Geology, West Greenland, GEUS, Copenhagen, February 28 to March 1, 2004

This workshop on Nagssugtoqidian geology marks the end of GEUS' four year contract period – 2000 to 2003 – of research in the Nagssugtoqidian and southern Rinkian. In these four years, GEUS' Department of Economic Geology conducted a resource evaluation of the region between 66°N and 70°15'N, covering all of the Nagssugtoqidian orogen and the southern part of the Rinkian belt in the Disko Bugt region, and the Department of Mapping concentrated on investigations of the Palaeoproterozoic and Archaean tectonic evolution of the northern part of the Nagssugtoqidian orogen, predominantly from Nordre Strømfjord shear zone in the south to Jakobshavn Isfjord.

Parallel with this main project three others were carried out, largely as independent research projects. Two expeditions were organised into the central and northern part of the Rinkian belt in 2002 and 2003, to investigate the structural, metamorphic and geochronological aspects of Rinkian geology, in a comparison with the tectonic evolution of the Nagssugtoqidian orogen. In 2002, a team of geologists of the former "Agto group" investigated the eastern part of the Nordre Strømfjord shear zone and the Arfersiorfik Quartz diorite. Neogene uplift in West Greenland was the main subject of a third associated project that is represented in this forum. In this project geomorphology, fault and fracture analyses, and fission track dating are used to investigate the more recent part of the tectonic evolution of the rocks in the region, long after Nagssugtoqidian tectonics terminated.

The presentations in this workshop report mainly results of last summer's fieldwork of the Department of Mapping, mapping of the Kangamiut map sheet in the Aasiaat region, but includes also the general project conducted from 2001 - 2003 in the northern Nagssugtoqidian orogen, and aspects of the resource evaluation. Furthermore, are there several contributions from the parallel projects, but also material that originated from the Danish Lithosphere Centre (DLC) project, as well as earlier work in the Nagssugtoqidian. This gives the present meeting quite a wide base.

The end of the GEUS project also means the end of ten years of concentrated Nagssugtoqidian research in DLC and GEUS, though some of the research projects represented at this meeting will continue in 2004 and onward. Therefore we have initiated the publication of a Geological Survey of Denmark and Greenland Bulletin to gather a wide range of material concerning Nagssugtoqidian/southern Rinkian geology in one place. A second purpose of the workshop is for authors of bulletin papers to present a first outcast of their papers, and invite discussions of the presented material.

We would like to thank participants presenting material for their effort and enthusiasm directed both toward this meeting. We look forward to a productive meeting and to a successful bulletin drawing together an era of Nagssugtoqidian and southern Rinkian research.

Jeroen van Gool and Julie Hollis

Workshop programme

Programme for Saturday 28th February:

Unofficial get-together for dinner

Programme for Sunday 29th February:

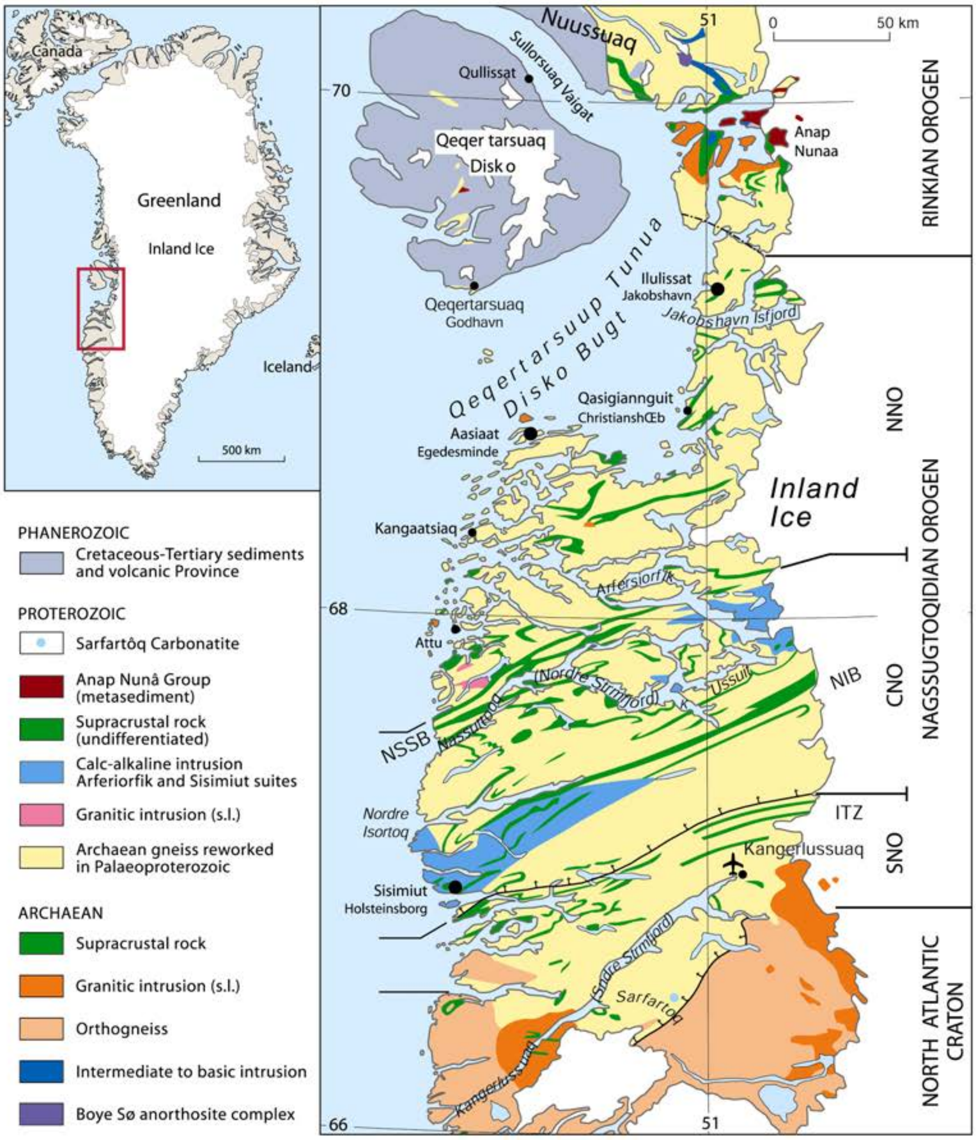
9.00 – 9.15	Leif Thorning (GEUS): Welcome
9.15 – 9.45	Jeroen van Gool (GEUS): Ten years of Nagssugtoqidian research
9.45 – 10.10	John A Korstgård (Univ. Århus): Magnetic anomalies and metamorphic boundaries in the Southern Nagssugtoqidian Orogen
10.10 – 10.35	Mogens Marker (Geol. Survey of Norway) and Ole Stecher (GEUS): Deposition, Provenance and Tectonic Setting for Metasediments in the Palaeoproterozoic Nagssugtoqidian Orogen, West Greenland
10.35 – 11.00	Coffee break
11.00 – 11.25	Marie Keiding (Univ. Copenhagen): Archaean mantle evolution deduced from Lu-Hf and Pb isotopes in single zircon grains
11.25 – 11.50	Adam Garde (GEUS): Well preserved basaltic, chemical and clastic supracrustal rocks north of Aasiaat: a low pressure, low strain zone of presumed Archaean age, northern Nagssugtoqidian orogen, West Greenland
11.50 – 12.15	Julie A. Hollis (GEUS): Poly-metamorphism in the northern Nagssugtoqidian orogen: a review and presentation of recent data
12.15 – 13.15	Lunch break
13.15 – 13.40	Adam Garde (GEUS): Crustal shortening and granite emplacement in the Rinkian fold belt, West Greenland: new field observations and implications for Palaeoproterozoic Laurentian evolution
13.40 – 14.05	Thorkild M. Rasmussen (GEUS): Regional interpretation of aeromagnetic and gravity data from West Greenland
14.05 – 14.30	Stanislaw Mazur (Univ. Potsdam): The interference of structural patterns produced by a multi-phase deformation in a high-grade metamorphic terrain – a case study from the Northern Nagssugtoqidian orogen, west Greenland

14.30 – 14.55	Sandra Piazolo (Univ. Liverpool): Comparison of two thick Archaean metasedimentary, mainly mafic sequences in the Northern Nagssugtoqidian Orogen: Field relationships and first interpretation
14.55 – 15.20	Coffee break
15.20 – 15.45	Agnete Steenfelt (GEUS): Palaeoproterozoic intrusive suites of the Nagssugtoqidian orogen featured in geochemical and geomagnetic maps
15.45 – 16.10	W.E.Glassley (Laurence Livermore Laboratories), John Korstgaard (Aarhus University) and Kai Sørensen (GEUS): Preliminary results of work in Arfersiorfik 2002
16.10 – 16.35	Knud Erik S. Klint (GEUS): Fractures and faults in central West Greenland, evidence of the youngest tectonic events? - preliminary results
16.35 – 16.45	Julie A. Hollis (GEUS): Hydrothermal alteration associated with brittle fracturing, Aasiaat region, northern Nagssugtoqidian
16.45 – 17.10	Peter Japsen (GEUS): Neogene uplift of West Greenland: evidence from studies of large-scale landforms, thermochronology and structural relations
19.00	GEUS funded dinner in town

Programme for Monday 1st March:

09.00 – 09.25	Kyle R. Mayborn (Western Illinois University): The Origin and Evolution of the Kangâmiut Dike Swarm, West Greenland
09.25 – 09.55	U. E. Árting (Univ. Copenhagen): A petrological study of basic dykes and sills of assumed Palaeoproterozoic age in central West Greenland
09.55– 10.20	John A. Korstgård (Univ. Århus): Metamorphism of the Kangâmiut dykes across the Southern Nagssugtoqidian Orogen
10.20 – 10.35	Coffee break
10.35 - 11.00	Frands Schjøth (GEUS): Mineral resources of Precambrian West Greenland from 66º to 70º 15’ N
11.00 – 11.25	Bo Møller Nielsen (GEUS): Cross-validated characterisation, potential, and probability of volcanogenic sulphide occurrences in West Greenland based on integrative statistical analyses
11.25 – 11.50	Jeroen van Gool (GEUS): Tectonics of the Northern Nagssugtoqidian orogen - the link between Nagssugtoqidian and Rinkian geology
11.50 – 13.00	Lunch break
13.00 – 13.30	Adam Garde (GEUS): Publication of proceedings in the Survey Bulletin
13.30 – 17.00	Group discussions

Map of central West Greenland



Abstracts

A petrological study of basic dykes and sills of assumed Palaeoproterozoic age in central West Greenland

U. E. Árting

The Geological Institute, University of Copenhagen and Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350, Copenhagen, Denmark. Email uni@arting.org Supervisors: Adam A. Garde, GEUS, Stefan Bernstein, GEUS, Kent Brooks, University of Copenhagen.

This thesis concerns the origin of three suites of metadolerite dykes and sills in central West Greenland. Elemental geochemistry of the dykes is investigated with the aim of adding to the understanding of the general geochemical evolution in the Disko Bugt region.
Figure 1 shows the areas where the samples were collected. Area A, is the Kangatsiaq map area situated in the northern Nagssugtoqidian orogen. Area a, is located within the Sydostbugten. Area B, is the area around Paakitsoq and Area C, is located on the southern peninsula Nuussuaq. Areas B and C are both situated within the Rinkian fold belt.

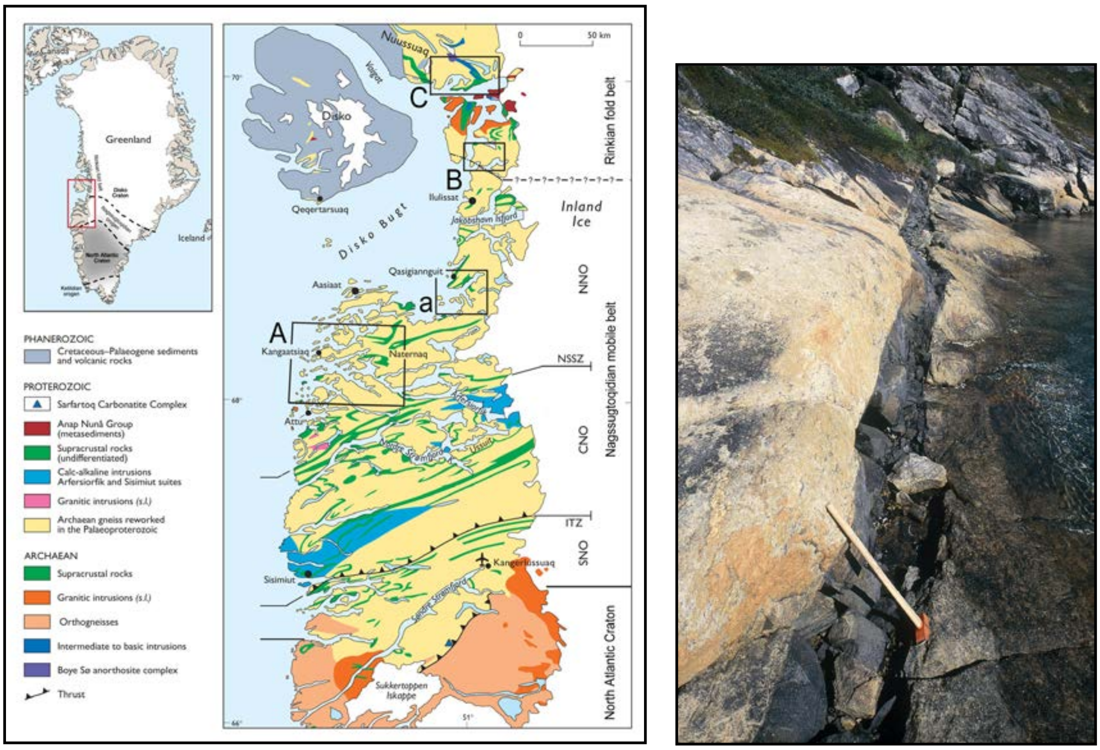


Figure 1. *Geological map showing the sample areas of interest. A, the Kangaatsiac map area, a) the south eastern Disko Bugt, B) the Paakitsoq area and C) the southern Nuussuaq peninsula. The picture to the right shows an Aasiaat metadolerite in the Kangaatsiaq region.*

These basic intrusions, some of which are up to 100 m thick, represent partially metamorphosed dykes and sills. The Aasiaat metadolerite dykes occur in areas A and a. Similar metadoleritic dykes have been recognized to the north of area A. These metadolerite dykes are the main focus of the thesis and show east-west orientated trends throughout the areas. The Aasiaat metadolerite dykes are all completely recrystallized and are comprised of a metamorphic mineral assemblage dominated by plagioclase, hornblende, orthopyroxene ± biotite ± Fe-Ti oxides ± garnet ± clinopyroxene ± quartz. The dykes show clear discordant relationships to the host rocks and vary in width from decimetres to some 30 m. Planar and linear tectonic fabrics are concentrated in the contact zones to the host rocks, which in most cases is the regional tonalitic orthogneiss, while the central parts of the dykes show relict igneous, subophitic textures.

The NE Disko Bugt metabasites are found both in areas B and C. These dykes and sills mostly show marginal deformation and are more silica rich than the Aasiaat metadolerites. They show geochemical similarities with the ultramafic olivine cumulate sill complex in area B.

Two Tertiary dykes area also included in the data set, and these serve as a reference frame in the petrological modelling.

The moderate to highly evolved olivine and quartz tholeiitic nature of the rocks is demonstrated by major and trace element variation plots such as bivariate plots, REE diagrams and multi element diagrams. Rayleigh fractionation and AFC models have also been made. Trace element ratios vary quite substantially between the various groups, but there is also evidence for similar petrogenetic evolutions. All the groups show LILE enrichments relative to the HFSE, and most show traces of contamination with crustal rocks (see figure 2). The analyses produced for this thesis have been compared to data from Cadman *et al*. (1999) on the Kangâmiut dyke swarm in the southern Nagssugtoqidian orogen. Figure 2 shows the striking similarities on a 28 element composite diagram. However the petrogenesis of these different magmas have been modelled with different P/T conditions and different fractionating assemblages.

It is suggested that these basic bodies were intruded during a rifting phase prior to the Palaeoproterozoic orogenesis in central West Greenland, e.g. van Gool et al. (2002). The results in this thesis further support this hypothesis.

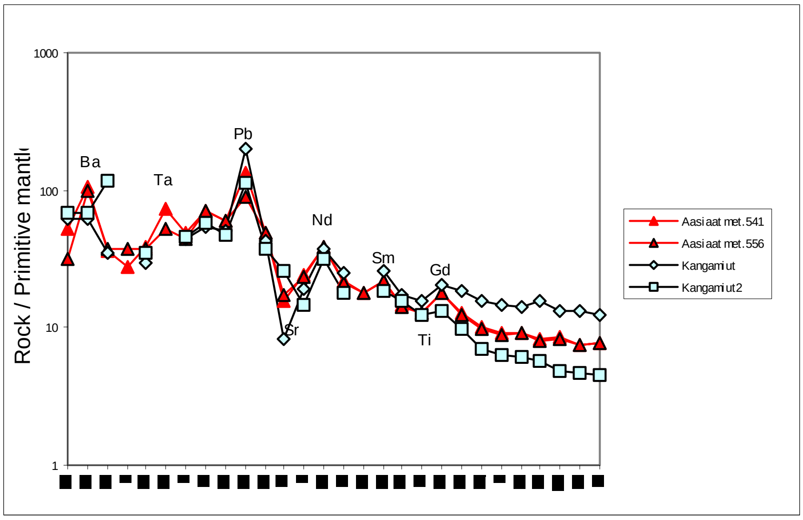


Figure 2. *Composite diagram showing the highly evolved Aasiaat metadolerites plotted together with the Kangâmiut swarm. The samples are normalized to primodal mantle values given by Sun & McDonough (1989).*

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Cadman, A.C., Tarney, J., Bridgwater, D., Mengel, F., Whitehouse, M.J., and Windley, B.F. *(*2001) The petrogenesis of the Kangâmiut dyke swarm, W. Greenland. *Precambrian Research 105*: 183-203.

van Gool J.A.M., Connelly, J.N., Marke, M., and Mengel, F.C. (2002) The Nagssugtoqidian Orogen of West Greenland; tectonic evolution and regional correlations from a West Greenland perspective. *Canadian Journal of Earth Sciences 39*: 665-686.

Well preserved basaltic, chemical and clastic supracrustal rocks north of Aasiaat: a low pressure, low strain zone of presumed Archaean age, northern Nagssugtoqidian orogen, West Greenland

Adam A. Garde[1], Mads Sylvest Christiansen[1,2], Julie A. Hollis[1], Stanislaw Mazur[3] and Jeroen A.M. van Gool[1].

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A small group of islands and skerries with supracrustal rocks a few kilometres north-east of Aasiaat, first described by Ellitsgaard-Rasmussen (1954), were revisited in 2003 during regional mapping of the Aasiaat region (Fig. 1). Spectacular, well-preserved aluminous metasedimentary rocks are interspersed with mafic sills in the eastern part of the island group, commonly with preserved graded bedding and other primary sedimentary structures. The western islands contain pillow lavas and associated layers of chert, manganiferous banded iron formation and up to metre-thick horizons of calcareous rocks as well as dark, fine-grained phyllites and abundant mafic sills. The metamorphic grade varies between lower amphibolite facies in the east (where andalusite, staurolite and garnet are widespread in the aluminous rocks) and upper greenschist to lower-most amphibolite facies in the west, where chlorite is the predominant aluminous silicate and garnet is rare. Along strike still further west (on the island of Maniitsoq and between Maniitsoq and Manertoq, Fig. 1) the supracrustal rocks, now again of amphibolite grade, are intruded by granodiorite and tonalite of presumed Archaean age. Lithologies similar to those on the small islands, in lower amphibolite facies but more intensely deformed, also crop out on Hunde Ejland about 15 km to the north-west (Fig. 1, inset).

The supracrustal rocks represent the deposits of a volcanic basin dominated by basic magmatism with associated chemical metasedimentary rocks such as chert and banded iron formation. The intercalated very fine grained clastic metasedimentary rocks were clearly deposited far from continental crustal sediment sources.

The whole island group is characterised by open folds with steeply SE- to SW-plunging fold axes and amplitudes between hundreds of metres a couple of kilometres. Generally only a spaced cleavage is developed in the metasedimentary rocks, and the greenstones are commonly devoid of a planar fabric. The structural style of the islands north of Aasiaat is thus in strong contrast to that of the Aasiaat region proper to the south, which is characterised by intensely deformed, ENE–WSW trending, amphibolite facies ortho- and paragneisses with a steep structural grain and a prominent subhorizontal stretching lineation.

Assuming that the intrusive felsic plutons are Archaean in age, and that the intense regional ENE–WSW structural grain is Nagssugtoqidian, the supracrustal rocks outline a low-grade, low-strain Archaean pocket that has largely escaped the Palaeoproterozoic reworking in the northern Nagssugtoqidian orogen. Other such domains of low Palaeoproterozoic strain have previously been described, e.g. from the Ataa area north-east of Disko Bugt and between Kangaatsiaq and Attu; at least the former area is generally assumed to consist of a tectonic block that was downthrown along a major extensional shear zone (Garde & Steenfelt 1999). At Aasiaat, however, the strain increase is gradual, taking place over a width of several kilometres.

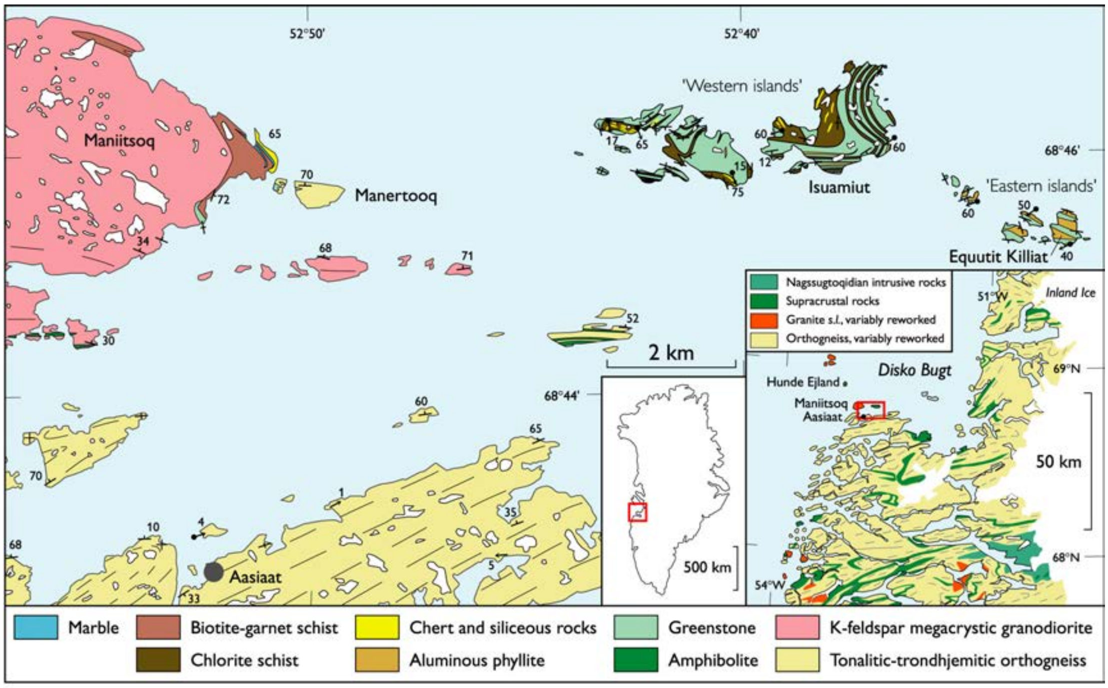

Fig. 1. Geological map of the low-grade, low-strain area north of Aasiaat. The well preserved supracrustal rocks on the island groups around Isuamiut and Equtiit Killiat were originally mapped by Ellitsgaard-Rasmussen (1954). Maniitsoq and the small island west of Manertooq still preserve intrusive contacts of ?Archaean granodiorite and tonalite into the supracrustal rocks, whereas the intensity of Palaeoproterozoic (Nagssugtoqidian) strain greatly increases towards the south. The index map shows the location of the study area in the northern part of the Nagssugtoqidian orogen.

Reference

Ellitsgaard-Rasmussen, K. (1954) On the geology of a metamorphic complex in West Greenland. The islands of Anarssuit, Isuamiut, and Eqûtit. *Bulletin Grønlands Geologiske Undersøgelse 5*: 70 pp.

Crustal shortening and granite emplacement in the Rinkian fold belt, West Greenland, and implications for Palaeoproterozoic Laurentian evolution

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New observations in 2002 and 2003 in the central and northern parts of the Rinkian fold belt support the view that the Rinkian belt forms the northern segment of a 1000 km-wide, highly asymmetrical collisional orogen in West Greenland that includes the Nagssugtoqidian orogen to the south and is linked with the Baffin-Ungava orogen in eastern Canada (Garde et al. 2003).

A large domain within the Rinkian belt, in the north-eastern Uummannaq region between 71° and 72°N, is characterised by early, E- to NE-directed tectonic transport. The displacement occurred both along discrete thrusts that ramp up-section to the east (north coast of Kangilleq), and as ductile shear zones revealed by asymmetric, lineated quartz lenses (Kangerluarsuk to Inngia Fjord). The transport direction changed to W or NW during a second intense phase of deformation in the western and southern parts of the Uummannaq district. During this phase, the previously recognised Kigarsima nappe and other major nappe-like folds of basement-cover sheets (Henderson & Pulvertaft 1987), were developed.

In the Upernavik region between 72° and 75°N, both basement and cover are metamorphosed at upper amphibolite to granulite facies conditions and only preserve records of NW- to SW-directed tectonic transport that was synchronous with or post-dated the thermal maximum. The variation between apparent NW and SW transport is at least partly due to reorientation by subsequent, kilometre-scale upright folds, but may also to some extent be an original characteristic of the main deformation in this area. Two small, low-strain domains with preserved bedding and early cleavage were identified but, due to the intensity of the later regional deformation, the direction of the earliest tectonic transport could not be established. Near Upernavik, solid-state fabrics in marginal phases of the Prøven granite complex, and their relationship with structures in the host rocks, suggest that it was emplaced towards the end of the second phase of deformation at or near the regional metamorphic maximum. In both the Uummannaq and Upernavik regions the regional flat-lying fabrics are folded by late upright folds, which also appear to fold large inliers of host rocks within the Prøven granite complex close to Upernavik.

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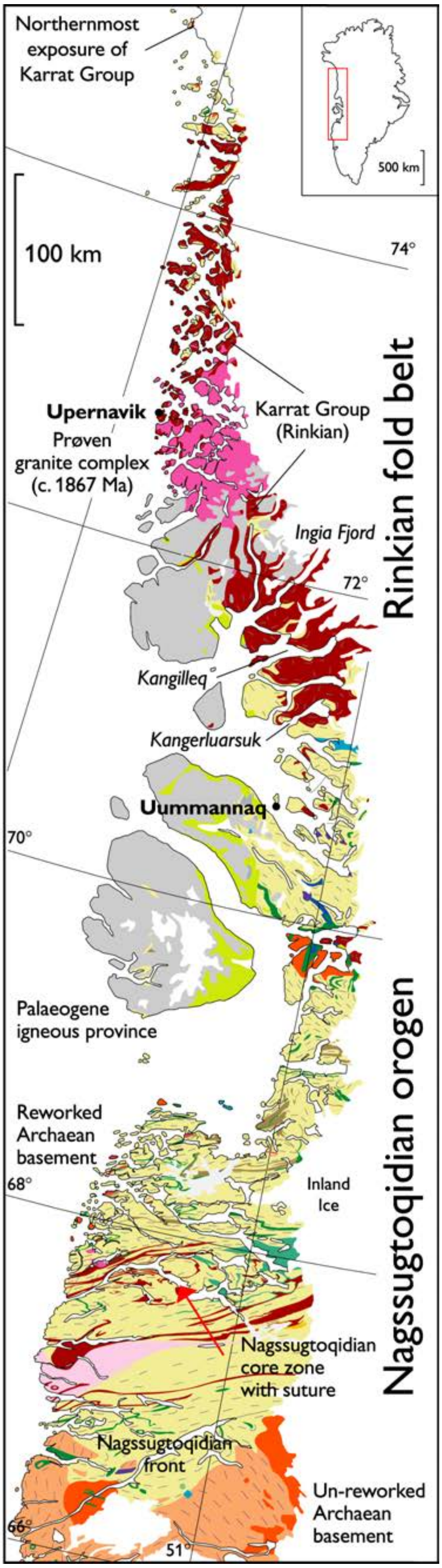
Henderson, G. and Pulvertaft, T. C. R. (1987) The lithostratigraphy and structure of a Lower Proterozoic dome and nappe complex. *Descriptive text to 1:100 000 sheets Mârmorilik 71 V.2 Syd, Nûgâtsiaq 71 V.2 Nord and Pangnertôq 72 V.2 Syd*. Copenhagen: Geological Survey of Greenland, 72 pp.

Garde et al. Fig. 1.
The Rinkian fold belt and its position as a northern extension of the Nagssugtoqidian orogen.



Quaternary
- Surficial deposits

Paleogene
- Basalt
- Picritic basalt
- Sandstone

Palaeoproterozoic
- Prøven granite complex
- Sisimiut charnockite
- Arfersiorfik quartz diorite
- Marble
- Metasedimentary rocks (may include Archaean components)

Archaean, variably reworked
- Granodioritic gneiss
- Granitic gneiss
- Orthogneiss
- Dioritic gneiss

Archaean
- Orthogneiss
- Metasedimentary rocks (may include Proterozoic components)
- Amphibolite (includes Proterozoic components)
- Metagabbro
- Anorthosite and ultrabasic rocks

Preliminary results of work in Arfersiorfik 2002

W. E. Glassley[1], John Korstgaard[2] and Kai Sørensen[3]

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Field work was carried out in the inner part of Arfersiorfik in 2002. Three weeks were spent visiting coastal exposures in the entire inner fiord, which offer good sections in the easternmost part of the Nordre Strømfjord shear zone.

The shear zone is approximately 7 km wide and is throughout its entire width characterized by vertical layering and foliation. Within the zone mineral lineations are horizontal. This confirms what was inferred about the transcurrent nature of the zone. The sense of movement as being sinistral is witnessed to both by the rotation into the zone as seen on aeromagnetic data as well as by small scale sense indicators within the zone.

The lithology within the zone can be described as an alternation of quartzo-feldspatic gneisses with units of pelitic schists containing varying amounts of amphibolitic schists with skarn lenses and ultramafic lenses and fine grained, rusty weathering sulphide and graphite bearing schists and schistose gneisses. Five such units occur in the profile. The intervening gneisses are both relatively homogenous and poor in inclusions and gneisses very rich in mafic and ultramafic inclusions. The former – in contrast to the latter- appear to have had a relatively simple history prior to the formation of the shear zone.

Among the homogeneous gneisses the Arfersiorfik Quartz Diorite (AQD) is of particular interest. It underlies a large area between the fiord and the Ice. Towards the north it is bounded by the shear zone. In most places the rock is tectonized, carrying a pronounced mineral lineation, which is conspicuously accentuated in the shear zone. Primary layering seems preserved in many places. At one locality, a lens of cumulates have been observed. At one locality in the shear zone a pronounced banding can in places be seen to have been derived from pillowed AQD. Outside the shear zone the contact between the AQD and adjacent rocks appear to be tectonic, with pelitic schist occurring as a smear between the AQD and acid gneisses.

In this part of the shear zone most of the deformation appears to have been taken up by the schist units. The intervening gneisses do exhibit a typical shear zone planarity in some places, in other places they appear less deformed. Since the northern boundary of the AQD is razor sharp for tens of kilometres it appears that the five schist units may represent structures which might be termed "ductile faults".

The aeromagnetic data allow the observations in Arfersiorfik to be linked with the coastal and mapped part of the shear zone and are suggestive of a need for a revised model for the Nordre Strømfjord shear zone.

Some main points and their context with earlier work on the Nordre Strømfjord shear zone are summarized in the attached table.

	Agto (Attu) field work 1966-1969 & earlier	Agto (Attu) field work 1975-1978 & later	Arfersiorfik 2002	New aeromagnetics
Shear sense and Pattern: kinematics	First obs by NB52, then E66? It is a sinistral trans-Current shear zone (B75a)	Confirmed by mapping (Agto sheet) Further interpreted at Tiggait (S83) Microstructures and fabric (see below)	Small scale indicators confirm sense Structures confirm Transcurrent movem (Korstgård, this presentation)	Confirms sense both internally and externally
Strain profile model and off-set	Wall-to-wall plateau off set at least 100 km (B75a)	Plateau w augens off-set 115 km (S83)	Augens disrupted by ”ductile faults”and off set several hundreds km (Sørensen, this presentation)	
3D form	Wedge shaped at coast (Bak ea 75a) **Tilt of crust exposing deepest level at coast** (B75a, B75b)	Wedge shaped in entire Agto map sheet (Olesen&Sør 1976) Paleomagnetic test of tilt w. null result (Beckmann ea 77) Tilt by T (Mengel 83)	Vertical slab (Korstgård, this presentation)	Downward widening below Arfersiorfik level (Nielsen, this presentation)
Metamorphism	Ramberg´s "complexes" Paragenetic model Agto metadolerites (GS80)	Experimental P (H81) Solution model T (M83, Glassley) opx synkinematic in NSZ (O78)	Muscovite isograd (Glassley, this presentation)	Granulite to amphibolite facies mapper?
Chemical mobility	Ramberg´s Isortoq to Egedesminde work	Tiggait work. Pegmatite sheets and bulk changes. Telescoping. (S83 and SW89)	**Evidence for chemical changes in the AQD near sz** (Glassley, this presentation)	
Tectonic significance Of zone/rocks	Intracontinental transcurrent shear as far field result of collision (B75b)	AQD signifies subduction driven collision (K87) Pre-shear thrust-stack-Ing (VG99)	Significance of AQD: The Sierra angle (Glassley, this presentation)	
Microstructure		Feldspar microstr, fabric and TEM (OK84 and OK85) Quartz microstruct and fabric (G80)		
Dating results	K-Ar ”Nagssugtoqidian” ages (LM69)	Rb-Sr 1840+/- for the sz at Tiggait (HG84)	AQD age 1920 Ma AQD shearing 1837 Ma (K87)	

Table 1. *Summary of main points and existing published data. Abbreviations are as follows: B75a - Bak et al. (1975a); B75b - Bak et al. (1975b); E66 - Escher, A. (1966); G80 - Getreuer (1980); GS80 - Glassley and Sørensen (1980); H81 - Hansen (1981); HG84 - Hickman and Glassley (1984); K87 - Kalsbeek et al. (1987); LM69 - Larsen and Møller (1969); M83 - Mengel, F. (1983); NB52 - Noe-Nygaard and Berthelsen (1952); O78 - Olsen (1978); OK84 - Olsen and Kohlstedt (1984); OK85 - Olsen and Kohlstedt (1985); OS76 - Olesen and Sørensen (1976); S83 - Sørensen, K. (1983); SW89 - Sørensen and Winter (1989); VG99 - van Gool et al., (1999)*

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Hydrothermal alteration associated with brittle fracturing, Aasiaat region, northern Nagssugtoqidian orogen

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Throughout the Aasiaat region of the northern Nagssugtoqidian orogen, steeply-dipping to vertical brittle fracture zones cut the host tonalitic-granodioritic orthogneiss and intercalated amphibolites. These fracture zones are spaced at ten- to hundred-metre scale intervals and strike 330-020 (ie. NNW-NNE). They are easily observable, for example, along the shores of Langesund, where individual fracture zones can be followed tens of metres to kilometres inland.

In the tonalitic orthogneiss distinct red alteration is associated with many of these fracture zones. The alteration haloes around fractures are typically centimetre- to decimetre-scale, though in some cases alteration is pervasive and has resulted in near-complete recrystallisation over tens to hundreds of metres distal to the fracture zones. A sample set taken from a profile across one of these alteration fronts illustrates distinct geochemical and mineralogical trends associated with the alteration.

The medium to coarse-grained tonalitic to granodioritic host orthogneiss comprised of plagioclase (30-40%), quartz (40-50%), K-feldspar (5-10%), biotite (5%), and accessory apatite and zircon. Associated with alteration are the following progressive mineralogical changes: grain boundary growth of fine-grained quartz; alteration of biotite to chlorite; sericitization of plagioclase; growth of magnetite; growth of muscovite; and development of microcline and myrmekite, particularly along plagioclase grain boundaries. In addition to these whole rock changes, epidote and magnetite are localised along fracture planes, particularly where fractures extend into adjacent amphibolites.

The corresponding geochemical changes involve bulk rock increases in Si and decreases in Al, Fe, Mg, Ca and P, in effect driving the bulk rock composition from tonalite-granodiorite through more K-rich granodioritic compositions into very Si-rich compositions outside the compositional field of normal granodioritic and granitic magmatic rocks. Minor element trends include enrichment in Rb and depletion in Sr, most likely due to a number of processes including (1) the release of Sr and Rb to the fluid via biotite, plagioclase, and apatite breakdown, and (2) Rb fixation via growth of K-feldspar.

In amphibolite units the geochemical changes have not been assessed, though the mineralogical changes observed indicate the same processes at work. The unaltered host amphibolite bodies are medium-grained gabbroic rocks in which plagioclase exhibits primary igneous zonation and clinopyroxene has been variably altered to hornblende and garnet during the regional amphibolite facies metamorphism. Alteration in the field is apparent from the occurrence of pale green and red bleaching around fracture zones within the dark green-black host amphibolites. Within these zones plagioclase shows extensive sericitization and actinolite and epidote have formed at the expense of clinopyroxene.

The hydrothermal alteration is thought to have occurred as a result of the influx of an oxidising, Si-rich fluid under low pressure conditions and temperatures of 300-450°C. This is based on (1) the alteration of biotite to chlorite in tonalitic-granodioritic gneiss, (2) the formation of epidote-actinolite assemblages in amphibolites, and (3) the formation of magnetite in tonalitic-granodioritic gneiss.

The orientations of the fracture zones are consistent with the general orientation of the Palaeocene “Cretaceous Boundary Fault System” along the eastern margin of Nuussuaq Basin, though dating is required to confirm this. This interpretation would suggest a link between the regional Palaeocene volcanism and the generation of the hydrothermal fluids responsible for the alteration. A young age of this thermal system may have annealed apatite fission tracks so that the post-fracture thermal history of the bed rock could be better determined in samples from the fracture zone than in the normal basement in the area where apatite fission track ages are in the range from 200 to 300 Ma.

Poly-metamorphism in the northern Nagssugtoqidian orogen: a review and presentation of recent data

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Regional studies show that metamorphic grade associated with Nagssugtoqidian orogenesis at *c*. 1.85 Ga varies on the scale of the whole orogen. It is generally accepted that the Central Nagssugtoqidian Orogen (CNO) experienced upper amphibolite to granulite facies metamorphism at mid to deep crustal levels associated with Nagssugtoqidian collisional orogenesis. Southward (into the SNO) and northward (into the NNO) the metamorphic grade decreases to the amphibolite facies and Archaean mineral assemblages and structural fabrics are variably preserved as a consequence of heterogeneous Palaeoproterozoic strain distribution: pervasive Palaeoproterozoic recrystallisation in the northern segment (north of Nordre Strømfjord shear zone, c. 67°45' to 69°00' N) is largely restricted to regions of high-strain, preserving early fabrics and mineral assemblages in low-strain domains (eg. Piazolo et al., 2004; Garde et al., this volume). This situation is reminiscent of that in the western part of the SNO (Korstgård, 1979).

The preservation of Archaean metamorphism across the Nagssugtoqidian orogen is quite different in the SNO compared with the NNO. In the SNO, the metamorphic grade of the Archaean gneisses prior to the Nagssugtoqidian overprint was predominantly granulite facies and easily distinguished form the amphibolite grade overprinting. In the NNO the Archaean metamorphic grade appears to the rather heterogeneous.

Most of the evidence for the metamorphic history of the NNO has been drawn from studies of metamorphic assemblages preserved in supracrustal rocks. Significant variation in metamorphic grade has been reported from within supracrustal belts in the NNO, ie. Qasigiannguit, Naternaq, Kangaatsiaq, Aasiaat, and Ikamiut. In general, pelitic rocks in this region record amphibolite facies conditions: a typical mineral assemblage is biotite-plagioclase-quartz ± muscovite ± sillimanite ± garnet, which unfortunately is relatively uninformative with regard to constraining the metamorphic history, as it has a wide pressure, temperature and compositional stability range. However, local preservation of early structural fabrics and relict mineral assemblages indicate a poly-tectono-metamorphic history. (The variable preservation of these early features may at least partly be attributed to heterogeneous Nagssugtoqidian strain and a northward decreasing sphere of influence of the Nagssugtoqidian thermal overprint).

Notably, in pelitic rock types, relict andalusite porphyroblasts are common - often partially or completely pseudomorphed by fibrous intergrowths of sillimanite and biotite. Relicts and pseudomorphs of andalusite have been observed in the Naternaq, Kangaatsiaq, Qasig-

Qasigiannguit, and Ikamiut supracrustal belts and occur in well preserved lower amphibolite facies assemblages, commonly with staurolite, in the Aasiaat supracrustal rocks (Garde et al., this volume). Other important mineralogical indicators in pelitic rock types include relatively rare occurrences of cordierite, and relict kyanite variably replaced by sillimanite. (The most widespread occurrence of kyanite is in the Qasigiannguit region).

These observations are consistent with Archaean low-pressure amphibolite facies metamorphism at 500-600°C and 2-5 kbar across a large region. However in the Qasigiannguit region there is also a large zone of extensive partial melting preserved in a regional synformal structure. As Nagssugtoqidian metamorphism is thought to be too low-grade to produce such extensive melting it is likely that this also represents an Archaean phenomena, and indicates significant regional variation in Archaean metamorphic grade. So can we correlate between these supracrustal belts and why are different Archaean metamorphic grades preserved in different regions?

The observed strong similarities in lithologies and mineral assemblages in supracrustal belts suggest that there may well be a genetic link between them. There is a close similarity in observed rock types and tectono-stratigraphy in widely separated supracrustal belts: sequences of micaceous schists and gneiss, quartzofeldspathic paragneiss, iron formations, and minor marble and calc-silicate rocks are found in Aasiaat, Naternaq (Østergaard et al., 2002), Qasigiannguit (Mengel et al., 1998) and Kangaatsiaq (van Gool et al. 2002). Another key to correlations is, of course, the depositional age of the supracrustal belts and the answer is, at present, enigmatic. Supracrustal rocks from the Qasigiannguit region were deposited in the Archaean (Keiding, this volume; K. Thrane, pers comm. 2002), whereas metasedimentary rocks from Naternaq give both Archaean and Palaeoproterozoic dominated ion probe or ICP-MS zircon spectra, indicative of a probable Palaeoproterozoic depositional age (Thrane and Connelly, Nagssugtoqidian workshop 2002). The latter results necessitate that if these regions can be correlated, the relict, prograde amphibolite facies assemblages were formed during the early Palaeoproterozoic, before the main phase of Nagssugtoqidian orogenesis. However, an observed intrusional relationship between a granodioritic pluton (tentatively correlated with the regional Archaean orthogneisses) and supracrustal rocks from the Aasiaat region, constrains low-pressure metamorphism of these rocks to the Archaean. Further geochronology is underway to address the age relationships of these rocks.

Since both Archaean and Palaeoproterozoic metamorphic grade appear to be variable across the NNO, it is possible that syn- to late-metamorphic Palaeoproterozoic movements on a crustal scale may have been important in juxtaposing areas of different metamorphic grade. Palaeoproterozoic high strain zones have been identified regionally, though whether these could accommodate such large-scale movements is yet to be resolved. However this scenario is consistent with the results of Ar/Ar amphibole ages across the orogen. Post-tectonic cooling was very slow in the SNO and CNO, but appears to have been faster in the NNO (Williger et al., 2002). To date, the preferred hypothesis is that high temperatures prevailed long after the latest deformation in the SNO and CNO, and that uplift was by isostatic rebound of the crust under erosion. In the NNO, Palaeoproterozoic metamorphic imprint is more variable, and in contrast with the remainder of the orogen, where all rocks show static re-equilibration textures, the NNO contains regions with dynamic recrystallisation in zones of Palaeoproterozoic high strain, i.e. uplift occurred during or shortly after deformation and a phase of static uplift at high temperatures is absent.

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Neogene uplift of West Greenland: evidence from studies of large-scale landforms, thermochronology and structural relations

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New insight into the Phanerozoic development of central West Greenland has resulted from two years of a multi-disciplinary study. Geomorphology, fission track geochronology and structural fracture analyses were used study the uplift history during the period of formation of large metasedimentary basins off shore.

A hilly bedrock surface associated with deeply weathered Precambrian basement in the Disko Bugt area is preserved by covers of Paleocene basalt and Cretaceous–Paleocene sediments. The hilly topography south of Disko Bugt suggests that the present land surface here is an exhumed etch surface, from which a protective Cretaceous-Palaeogene cover was stripped after Neogene uplift.

An erosional surface reaching above 1000 m a.s.l. with shallow valleys is clearly distinct from deeply incised glacial valleys and from the areas of hilly relief, e.g. on Nuussuaq, Disko and in the Sukkertoppen area to the south. The preserved high plain and the more or less glacially eroded incised valleys indicate a pre-Quaternary uplift in the investigated area. The surface was probably uplifted by as much as 1 km during the Neogene.

The one kilometre of uplift is in agreement with the occurrence of marine deposits of Paleocene age c. 1 km a.s.l. on Nuussuaq. The suggested timing of uplift is in agreement with previous studies of structural relations and basin modelling from Nuussuaq.

Results from an ongoing Apatite Fission Track Analysis and (U-Th)/He-dating programme have provided new information about the Phanerozoic burial and erosional history of central West Greenland. Preliminary interpretation suggests a prolonged history of erosion through Mesozoic and Cenozoic times, probably involving removal a kilometre-thick Palaeozoic cover during a series of episodes. We find that the thermochronological and geomorphological analyses are in good agreement in particular concerning the post-volcanic evolution of West Greenland which is characterised by two large-scale events. A late Eocene–Oligocene erosional event that led to the formation of the erosional surface that cuts across Precambrian basement and Paleogene basalt and a Neogene event that uplifted the erosional surface to its present altitude in the present onshore areas whereas subsidence took place offshore.

During the investigations of the Archaean and Palaeoproterozoic evolution of the rocks in West Greenland, all map patterns have been explained by Precambrian tectonism. Our results indicate that e.g. transitions across large lineaments have been affected significantly by differential uplift during the Phanerozoic.

These results are of interest for the development of the Greenland society. The late uplift, erosion and resedimentation led to redistribution of huge amounts of material and thus to increased burial and heating of hydrocarbon-generating sediments. An understanding of this development is also of practical importance in exploration for diamonds in West Greenland where kimberlite pipes have been eroded to different degrees.

Archaean mantle evolution deduced from Lu-Hf and Pb isotopes in single zircon grains

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Combined studies of Lu-Hf and U-Pb isotopes on rock samples and single crystal grains have over the last years become increasingly more important in the investigation of Earth's early history of crust-mantle evolution. This study is based on hafnium-isotope data for zircons from three rock samples, two metasediments and one orthogneiss, from the peninsula Kangilinaq close to Christianshåb, West Greenland. The zircons have been analysed for Lu-Hf and Pb isotopes with the LA-MC-ICPMS located at the Danish Lithosphere Center.

The $^{207}Pb/^{206}Pb$-ages, with precisions usually better than 20 Ma (2σ), show that the metasediments are of Archaean age and that they contain zircons as old as 3.6 Ga. The geochemical compositions of the metasediments suggest that they were originally deposited as shelf sediments in front of one of the old, Archaean cratons.

The orthogneiss contains a population of magmatic zircons with a weighted mean $^{207}Pb/^{206}Pb$-age of 2818 ± 1 Ma, and a metamorphic population of zircons with a weighted mean $^{207}Pb/^{206}Pb$-age of 1835 ± 1 Ma. These two ages correspond to the large magmatic event in the area around 2.70-2.85 Ga, and the Palaeoproterozoic continent collision around 1.85 Ga, respectively.

The Lu-Hf data of the analysed zircon grains have been used to calculate initial $\varepsilon_{Hf}(t)$ values taking the zircon's $^{207}Pb/^{206}Pb$-ages to represent the time of crystallisation. This assumption might introduce wrong values of $\varepsilon_{Hf}(t)$ for some zircons with discordant $^{207}Pb/^{206}Pb$-ages, but grains with presumably undisturbed $^{207}Pb/^{206}Pb$-ages show a consistent picture of increasingly positive $\varepsilon_{Hf}(t)$ values with time. These results indicate that the zircons were derived from a depleted mantle source, in which chemical depletion (i.e. crust extraction) was initiated well before 4 Ga.

Fractures and faults in central West Greenland, evidence of the youngest tectonic events? – preliminary results

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Fault and fracture systems play an important role in reflecting the brittle tectonic history of plate movements, uplift and basin formation. Knowledge of the fracture systems developed in the coastal areas in West Greenland will be an asset for understanding offshore basin development and the characteristics of potential hydrocarbon reservoirs.

Seismic data have revealed the existence of a number of sedimentary basins offshore Western Greenland. One such basin is the deep Sisimiut basin, located in the Davis Strait to the west of the Nordre Stromfjord region onshore. Its eastern border must be a major fault, but it is located so close to coastal skerries consisting of basement gneiss that it has not been possible to image it on the seismic lines. The western margin of the Sisimiut Basin is the Ikermiut Fault Zone, transpressional flower structures along the transform fault between the North American Plate and the Greenland Plate during the Palaeogene. The Nukik Platform is to the south of the Sisimiut Basin and separated from it by a line of faults that appear to have developed by reactivation of basement shear zone structures derived from the Central Nagssugtoqidian orogen. These faults affect Mesozoic sediments and are overstepped by Paleocene sediments, so latest significant movement on them must have been prior to the end of the Paleocene. Onshore a pronounced NNE-trending escarpment almost one kilometre high that drops down to the west lies between Nordre Strømfjord and Nordre Isortoq. This escarpment may be related to the structures offshore, so was selected for closer studies of faults and fractures.

Lineaments were plotted on aerial photographs and a detailed analysis of them was carried out in an area from north of Nordre Strømfjord south to the inlet of Nordre Isortoq. Four areas along the coast were chosen for detailed fracture/fault analysis in the field. Five main fault systems were identified using both air photography and field analysis. A set of ENE-WSW trending faults (system 5) appear to have reactivated strong shear zone fabrics in the areas of Nordre Strømfjord and Nordre Isortoq. Three younger regional fracture/fault systems were also encountered (systems 1-3), together with a more geographically localised system (system 4). Each fault system consists of parallel fault zones separated by non-faulted, but generally strongly fractured rock. The fault zones range typically between 1-50 m in width; and consist of multiple parallel faults with a very variable spacing. These zones are commonly situated in pronounced valleys/gorges, so identification of fault planes was often difficult, as the valleys were generally filled with sediment and vegetation.
System 1 fault zones are strongly developed in the Nordre Strømfjord shear zone (camps 0-3) and consist of major sub-vertical sinistral transverse faults striking NE-SW (20-30^{o}).

The fault zones have lateral displacements of up to 400 m in the western most part and the spacing between them increases from approximately 500 m at the coast to approximately 2 km further inland. The same lineament directions were encountered at camp 2, south of Nordre Strømfjord, but where the trend was weaker and more irregular, possibly due to differences in rock type and fabric between the two areas. On the southern shore of Nrordre Strømfjord, local transpressional thrust faulting was observed, which appears to be linked to sinistral movements against a step on this fault system.

System 2 faults are N-S trending (170-10^{o}), primarily sub-vertical, sinistral, transverse faults, with a general en-echelon and irregular trend. This fault system was traced from Nordre Isortoq to the northernmost part of the investigated area and earlier investigations indicate that they may continue as far north as Aasiaat, Disko Island and Nuussaq. The fault-zones are closely spaced (100-500 m), but the displacements range only between 0.2-30 m for individual faults.

System 3 faults are NW-SE trending (130-150^{o}), oblique dextral faults and fault zones. They are closely spaced (500-100 m), and truncation of marble beds showed net-displacement of the order of 20-40 m. The system, like system 2, is most pronounced in the Nordre Strømfjord shear zone, but varies to a much larger extent in the Nordre Isortoq shear zone. Systems 2 and 3 may possibly have formed as a conjugate/ orthorhombic system in the same tectonic event.

System 4 fault/fracture-zones were identified in the fold-belt south of Nordre Strømfjord and north of the Nordre Isortoq shear zone. They consist of WSW-ENE trending (70-110^{o}) oblique faults. Both sinistral and dextral movements were recorded within these fault-zones, with generally very small displacements (a few cm) along the single fault planes. The fault zones (valleys) are generally 10-30 m wide and have a very irregular trend, and relative age relations to truncating fault zones (valleys) were very difficult to determine.

System 5 faults are foliation parallel faults that were recorded throughout the area. They are always cross-cut by the system 1-4 faults and are accordingly older. The trend of the system 1 and/or system 2 faults is parallel to the pronounced NNE-WSW trending escarpment in the Nordre Isortoq Shear Zone area, and it is possible that these faults have been reactivated as normal faults during a later tectonic event. This conjecture still needs to be verified, as the escarpments were out of walking range during the fieldwork. The timing of tectonic events that are responsible for the formation of these fault/fracture systems is quite complex. Multiple directions of slickensides on several fault surfaces indicate that many faults were either reactivated, or that faulting was highly complex.

Several possible event-stratigraphic models may be constructed, and one plausible preliminary correlation of the different fault systems to offshore tectonic events is presented in Table 1. A large number of pseudotachylite samples have been collected from all the fault systems and dating of the samples is in progress. The results of the dating will hopefully clarify the picture and strengthen the interpretations.

Possible correlation between onshore and offshore tectonic events (oldest -youngest)		
Timing	*Offshore tectonic events*	*Onshore tectonic events*
5. Plio-Pleistocene tilting	Subsidence	Uplift (possible reactivation of systems 1-2 as normal faults)
4. Eocene Labrador sea-floor spreading (Ungava system)	NNE-SSW trending sinistral transverse faulting. Local transpressional and transtensional faulting	**System 1** NNE-SSW trending sinistral transverse faulting. Local transpressional thrust faulting near camp 2 and 4.
3. Late Cret.– Early Pal. Extension	N-S trending faults (E-W extension)	**System 2** N-S trending sinistral transverse faulting, poss. Reactivation of system 3 as oblique-dextral faults
2. Early to Mid Cret. – U. Cret. Extension and thermal subsidence	NW-SE trending normal faults (SW-NE extension)	**System 3** NW-SE trending normal faulting,
1. Could be Proterozoic plus localised reactivation later.	The WSW-ENE faults bordering the Sisimiut basin to the south were active offshore during one or both of event 2-3, but apparently not onshore.	**System 5** ENE-WSW foliation parallel sinistral transverse faulting.

Table 1. *major offshore tectonic events and possible correlation to onshore brittle structures.*

Metamorphism of the Kangamiut dykes across the Southern Nagssugtoqidian Orogen

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The structural evolution of the Southern Nagssugtoqidian Orogen is characterised by reworking of pre-existing Archaean rocks. At the southern Nagssugtoqidian boundary a swarm of basic dykes, the Kangamiut dykes, intruded after the earliest Nagssugtoqidian movements. These dykes act as time markers separating tectono-metamorphic events and record degree and extent of post-dyke metamorphism and deformation (fig. 1).

The structural and metamorphic evolution at the southern Nagssugtoqidian boundary can be summarised as follows: the rocks now exposed were stabilised in granulite and amphibolite facies in Archaean times. Uplift brought the rocks under low amphibolite facies conditions. Subsequent deformation (Nag. 1) caused the retrogression to low amphibolite facies and transformed the rocks into strongly schistose rocks along ductile E-W trending shear zones. The Nag. 1 deformation was followed by intrusion of the mainly NE-trending Kangamiut dykes. Later Nagssugtoqidian deformation (Nag. 2) affected country rocks with Nag. 1 fabrics as well as dykes and probably also Archaean gneisses unaffected by Nag. 1 deformation and metamorphism. In areas with intense Nag. 2 movements the deformation was characterised by ductile overthrusting towards the SSE along linear zones striking ENE. New Nag. 2 fabrics were imposed on the country gneisses and dykes were transformed into strongly deformed amphibolites. The ductile overthrusting brought granulite facies rocks into juxtaposition with amphibolite facies rocks so that across the areas affected by Nag. 2 deformation a prograde metamorphic sequence with facies boundaries parallel to the overthrusting zone was established.

Hornblende zone

This zone, extending from the north coast of Kangerdluarssuk to the southern coast of Ikertooq, is characterised by the occurrence of hornblende as the sole ferro-magnesian mineral in the dykes. The original igneous augite + plagioclase assemblage has been completely converted to a metamorphic hornblende + plagioclase assemblage. Anorthite content of plagioclase is around 30%, sphene is an ubiquitous accessory, replacing igneous ilmenite, and quartz is present in minor amounts. The typical mineral assemblage in country gneisses is quartz + alkali-feldspar + plagioclase + biotite + epidote with minor hornblende and muscovite.

Garnet-clinopyroxene zone

In the area between the south coast of Ikertooq and halfway into Maligiaq clinopyroxene and garnet commonly occur in addition to hornblende and plagioclase in the meta-dykes. The most common assemblage found in this zone is plagioclase + hornblende + clinopyroxene +/- garnet. Sphene is mostly replaced by ilmeníte and plagioclase is andesine. In the host gneisses epidote has disappeared and the typical assemblage is quartz + alkali-feldspar + plagioclase + biotite with hornblende, clinopyroxene and garnet as minor constituents.

Orthopyroxene zone

The appearance of orthopyroxene in meta-dykes and gneisses marks the transition from amphibolite to granulite facies. The orthopyroxene zone extends from halfway into Maligiaq and as far north as the map covers (fig. 1). The most common assemblage in the meta-dykes is plagioclase + hornblende + orthopyroxene + clinopyroxene +/- garnet. Sphene is no longer present and anorthite content of plagioclase has increased to 40%. In quartzo-feldspathic gneisses the typical assemblage is quartz + plagioclase + biotite + hornblende + orthopyroxene +/- clinopyroxene. The facies transition in Maligiaq is very sharp and takes place in both dykes and gneisses within a few hundred metres.

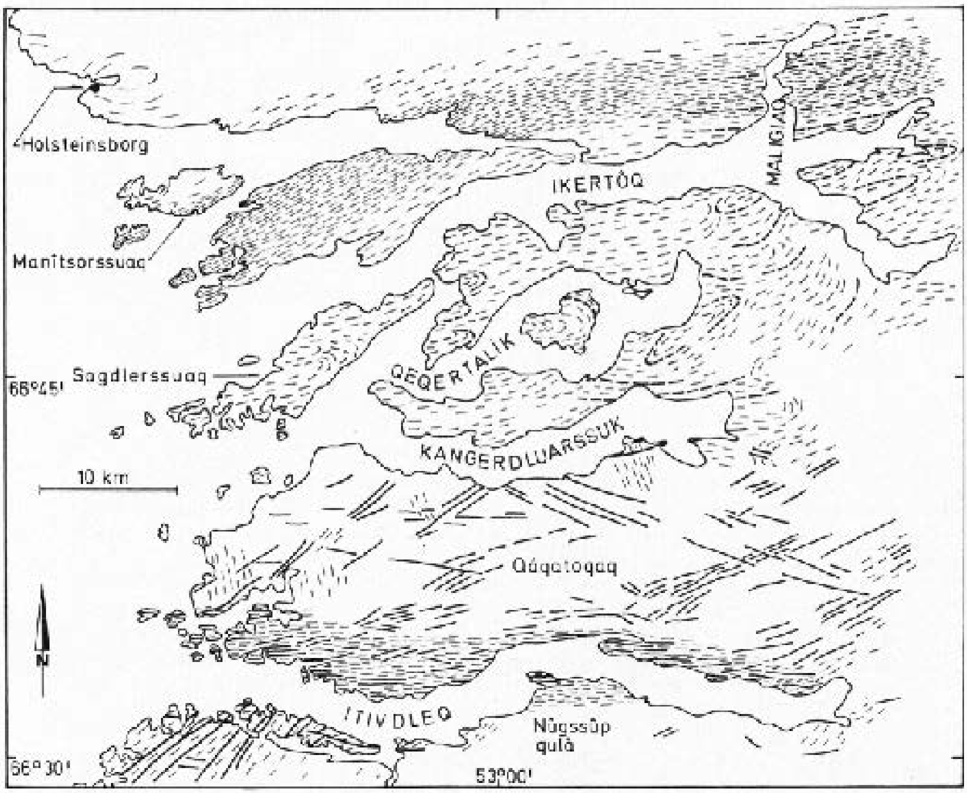

Fig. 1. Dyke and structural sketch map of the Itilleq-Ikertooq region. Thin dashed lines: structural trend in country gneisses. The intensity of lines reflects degree of deformation. Thick full lines: undeformed Kangamiut dykes. Thick dashed lines deformed and metamorphosed dykes. Only a few of the deformed dykes are shown on the map.

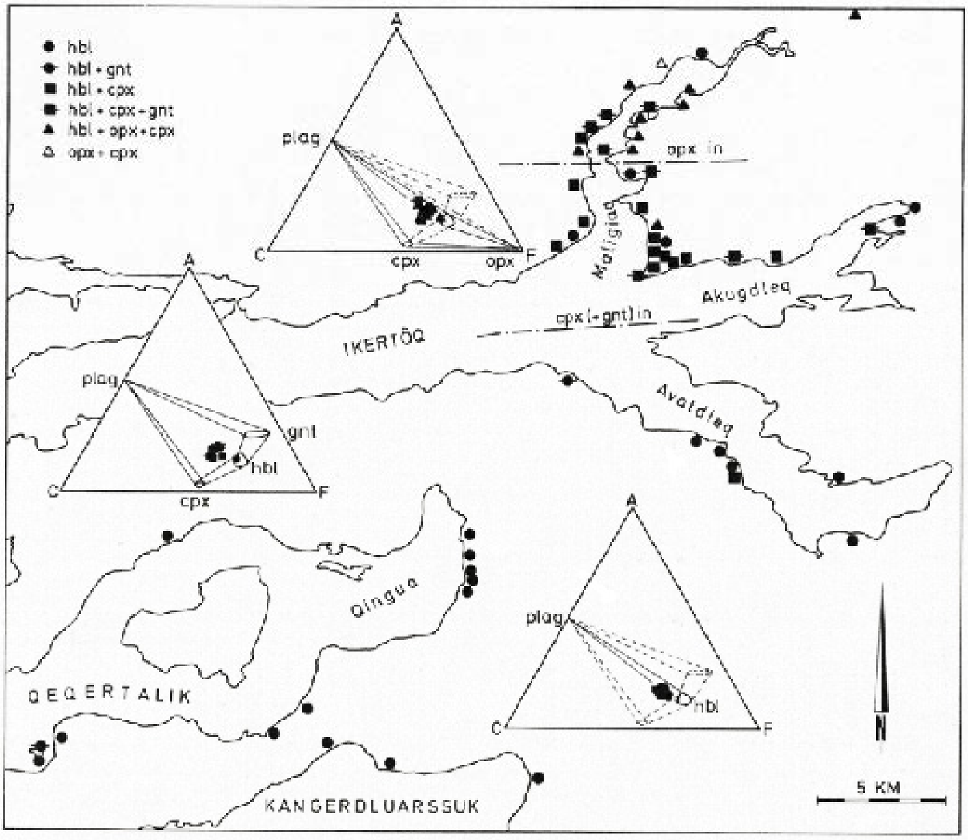

Fig. 2. Map of the Kangerdluarssuk-Maligiaq area showing location and mineral assemblages of the investigated dykes. The dash-dot line marked "cpx + (gnt) in" marks the southern limit of the garnet-clinopyroxene zone. The line "opx in" marks the southern limit of the orthopyroxene zone. The ACF diagrams show, from south to north, the mineral parageneses in the hornblende zone, the garnet-clinopyroxene zone, and the orthopyroxene zone respectively.

Magnetic anomalies and metamorphic boundaries in the Southern Nagssugtoqidian Orogen

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The metamorphic and structural division of the coastal areas of the Southern Nagssugtoqidian Orogen (SNO) (Fig. 1) is mainly based on intrusion, deformation, and metamorphism of the Kangamiut dykes. The SNO is situated between the northernmost part of the North Atlantic craton to the south and the central part of the Nagssugtoqidian orogen (CNO) to the north. South of and immediately north of Itilleq Fiord the 2.04 Ga Kangamiut dykes are largely undeformed and unmetamorphosed. Main dyke direction is NNE-SSW and subordinate direction E-W to ESE-WNW. Upon entering the Itilleq area, the dyke trends shift to E-W, parallel to the fiord. This change in trend also corresponds to a change in foliation trend in the host gneisses. However, dykes are still undeformed and unmetamorphosed within the E-W trend. The metamorphic grade of host gneisses north and south of Itilleq Fiord is granulite facies in western parts and amphibolite facies in eastern parts. However, all along the E-W trend in Itilleq Fiord gneisses are in amphibolite facies.

These field relations led to the interpretation that prior to intrusion of the Kangamiut dykes the area was stabilised in amphibolite-granulite facies with a variable northerly trend of the foliation. At some point prior to dyke intrusion an E-W zone of strong deformation was established along Itilleq Fiord, downgrading gneisses to low amphibolite facies (epidote - muscovite). At the time of dyke intrusion, this zone was still somewhat ductile as indicated by dyke shapes within the zone. Outside the zone dyke margins are straight-sided indicating that dykes intruded along brittle fractures whereas within the zone dykes show a variety of primary pinch and swell structures.

Further north dykes are thoroughly deformed and parallel to country rock structures. Both dykes and country rock structures are in amphibolite facies. Foliation trends are variable ENE-WSW around east plunging fold axes.

Continuing northwards metamorphic grade increases and north of Ikertooq reaches granulite facies. In addition, gneiss structures and meta-dykes take on a pervasive E-W orientation with steeply N-dipping foliation and N-plunging stretching lineations.

The interpretation of field observations in the northern SNO is that first of all the metamorphism and deformation is post-dyke, the metamorphic transition is prograde and the linear zone represents a zone of ductile thrusting whereby deeper seated rocks are brought up from the north.

Within the Itilleq-Ikertooq region four types of facies transitions or boundaries are recognised. Two of these are prograde and two are associated with strong deformation in ductile shear zones.

The amphibolite-granulite facies transition in the Archaean areas around Itilleq is prograde and static in the sense that the boundary was not established as a result of a deformational event, but reflects static equilibration of the mineral assemblages to the conditions that prevailed when the rocks were at their deepest crustal level. Due to absence of later deformation or metamorphism and later uplift the rocks reflects their initial Archaean state.

The granulite to low amphibolite facies and amphibolite to low amphibolite facies transitions along Itilleq are retrograde and dynamic in the sense that they were established as a direct consequence of the deformation in the Itilleq shear zone. Mineral assemblages in the shear zone were equilibrated to the metamorphic conditions of a higher crustal level and the shearing triggered this re-equilibration.

The amphibolite-granulite facies transition north of Ikertooq is both prograde and dynamic. It can be considered as a displaced prograde and static transition brought up in a subvertical position by the overthrust movement along the Ikertooq thrust zone.
A high correlation between magnetization and metamorphic boundaries is evident (Fig. 1 and 2).

Strong magnetization in pre-dyke Archaean granulite facies areas just north of Itlleq (label A Fig. 2) is attributed to a higher content of magnetite/magnetic minerals. A likely explanation for this observation is a production of magnetite by the breakdown of hydrous (Fe, Mg) Al-silicates (e.g. biotite, amphibole) during the transition from amphibolites facies to granulite facies according to the general reaction; hydrous (Fe, Mg) Al-silicates $\pm SiO_2 \pm O_2 \Leftrightarrow$ K-feldspar + (Fe, Mg)-silicates ± magnetite + H_2O. The lower magnetization in pre-dyke Archaean amphibolite facies areas (label B Fig. 2) relative to pre-dyke Archaean granulite facies areas indicates no additional production of magnetite. The gradual increase in magnetic intensity (label C Fig. 2) marks the gradual prograde facies transition.

The elongated low magnetic anomaly coincident with the Itilleq shear zone is caused by extensive breakdown of magnetic minerals. This may be caused by chemical breakdown due to e.g. metamorphic retrogression to pre-dyke amphibolite facies or circulating fluids in the shear zone, and mechanical destruction of the magnetic mineral grains. The abrupt changes in anomaly patterns from label D to A across the metamorphic facies transition and deformation boundary indicate the dynamic nature of this boundary.

Previous suggestion of possible shearing at Ikertooq (label E Fig. 2) contemporaneous with the shearing at Itilleq (label D Fig. 2) is supported by similarities in the character of the anomaly patterns. The post-dyke amphibolite facies areas at and south of Ikertooq (label F Fig. 2) indicate the Palaeoproterozoic retrogression to amphibolite facies and deformational reworking. The boundary between the pre-dyke Archaean amphibolite facies and the post-dyke amphibolite facies does not have a well-defined magnetic signature (between labels B and F Fig. 2).

The increase in magnetisation north of Ikertooq (label G Fig. 2) corresponds to post-dyke granulite facies rocks brought up by overthrusting. The offset between the mapped facies boundary north of Ikertooq (Fig. 1) and the boundary between high and low magnetisation (label H fig. 2) can be explained be contributed by non-exposed post-dyke granulite facies rocks and by an effect of stacked thrust panels (label I Fig. 2) of low magnetised post-dyke amphibolite rocks and high magnetised post-dyke granulite facies rocks.

Isolated high-magnetised anomalies can be correlated with distinct lithologies or intrusives (e.g. anorthosite complex at label J in Fig. 2). The presence or absence of Kangâmiut dykes is not reflected in aeromagnetic data.

The observed correlations between metamorphic faices, deformation and magnetisation can be extended to other areas of the SNO (Fig. 3).

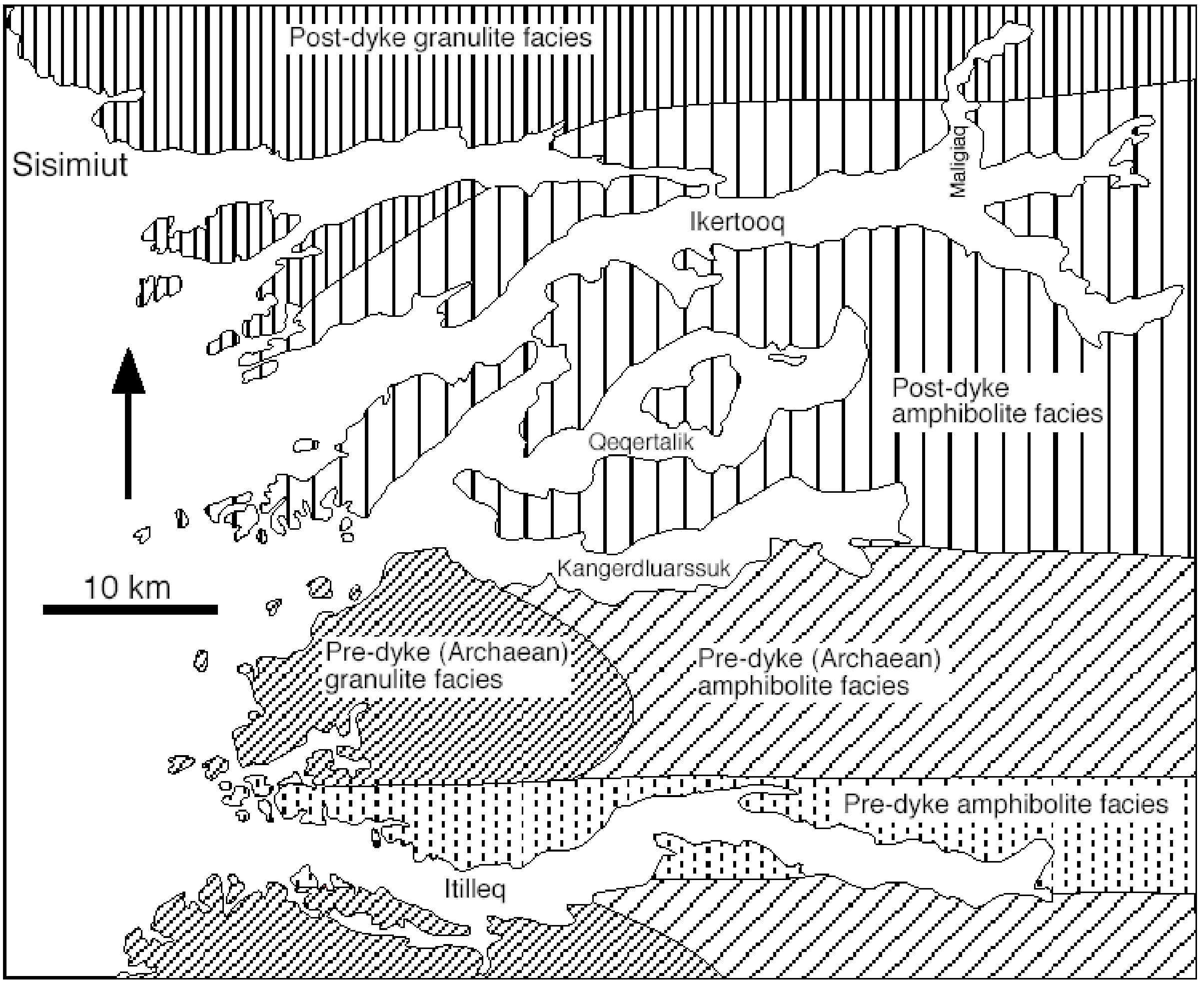

Figure 1. *Distribution and relative ages of metamorphic facies in the Itilleq–Ikertooq region. Geographic coordinates as for Figure 2.*

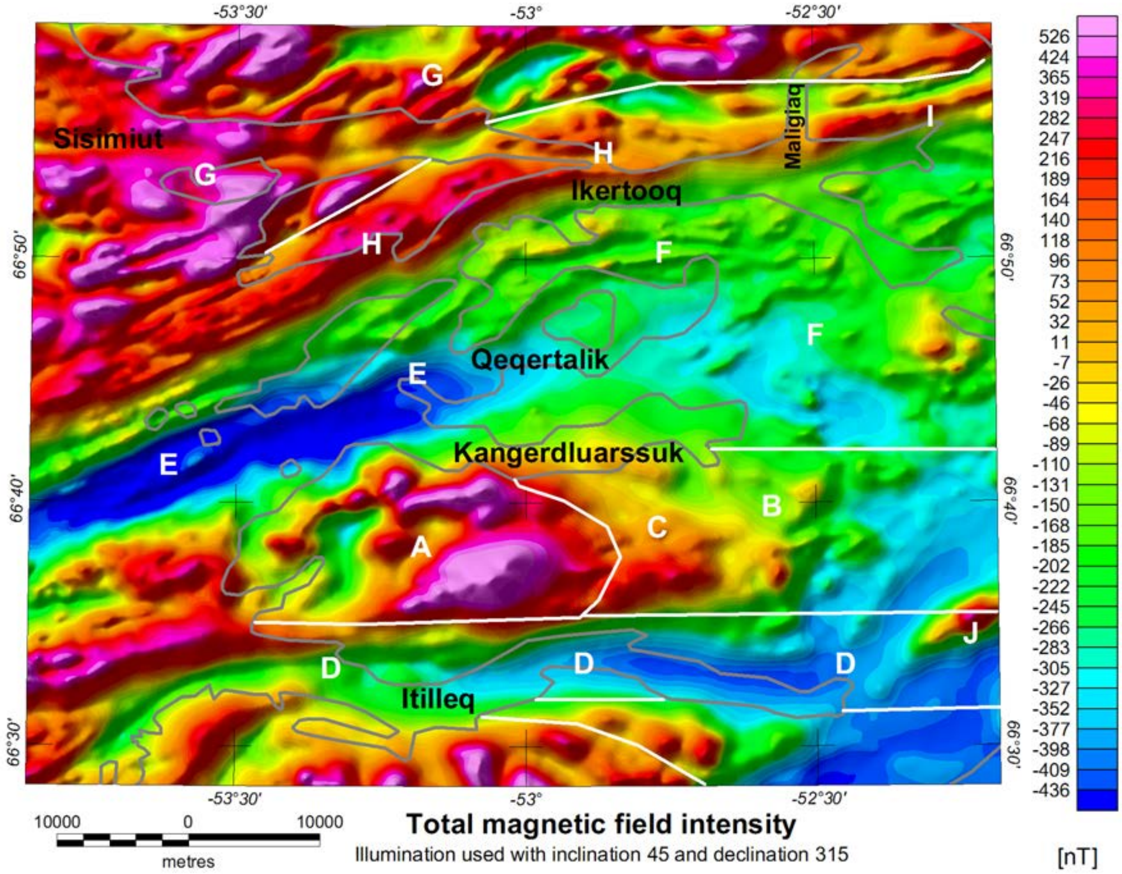

Figure 2. *Total magnetic field intensity for the Itilleq–Ikertooq region. White lines indicate metamorphic facies boundaries based on geological fieldwork. Labels from A to J are referenced in the text.*

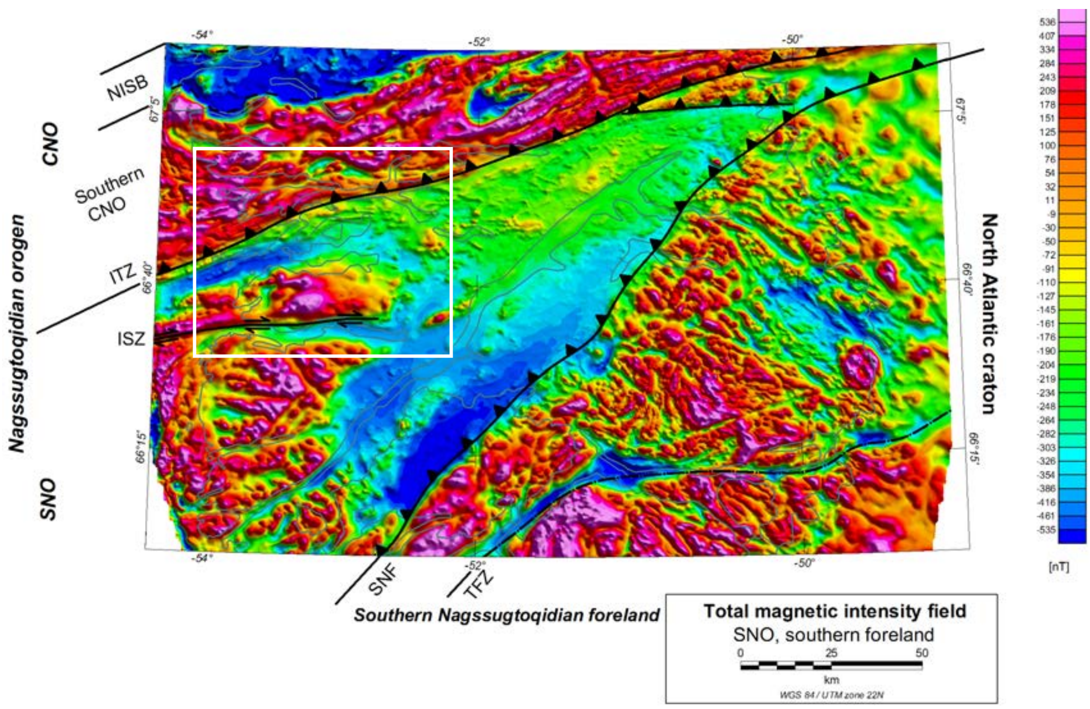

Figure 3. *Total magnetic field intensity for the SNO and parts of the CNO and northmost north Atlantic craton. The Itilleq–Ikertooq region is indicated by a white rectangle.*

Deposition, provenance and tectonic setting for metasediments in the Palaeoproterozoic Nagssugtoqidian Orogen, West Greenland

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The Palaeoproterozoic Nagssugtoqidian Orogen in West Greenland hosts a number of dismembered, partially melted supracrustal suites in upper amphibolite to granulite facies. Single zircon ion-microprobe U-Pb and LAM-ICP-MS ^{207}Pb/^{206}Pb dating, and whole rock Sm-Nd data show that most metasediments were deposited in Palaeoproterozoic time and contain detritus from both Proterozoic and Archaean sources. The Nagssugtoqidian Orogen is divided into a southern (SNO), central (CNO) and northern (NNO) segments. The SNO represents the deformed southern Archaean foreland juxtaposed against the CNO during thrusting. The Nordre Strømfjord steep belt (NSSB) separates the CNO from the NNO and has lithologies similar to the northern CNO.

^{143}Nd /^{142}Nd measurements of Nagssugtoqidian metasediments generally fall in two groups, which have quite similar Sm/Nd ratios. In most crustal processes, and particularly sedimentary processes, Sm-Nd fractionation is of minor importance relative to the more massive fractionation processes that take place, when melts are extracted from the mantle. If no significant Sm-Nd fractionation took place in the sedimentary and crustal processes we can project the measured ^{143}Nd /^{142}Nd-values back in time, using Sm-Nd ratios to correct for radioactive in-growth of ^{143}Nd from decay of ^{147}Sm. These projection lines will meet the evolution curves for the mantle at the time where melts were extracted from the mantle in order to form the crust. We can project back to the evolution line of a mantle composition which through time has maintained its original chondritic Sm-Nd ratio (CHUR), or to a curve for a mantle (DM) that through time has been depleted in fertile elements due to the extraction of melts to produce the crust, and thus the resulting depleted mantle has increased its Sm/Nd ratio.

The ^{143}Nd /^{142}Nd measurements of the Nagssugtoqidian metasediments give rise to two groups of T(DM) model ages. The older age group range from 2.7 to 2.9 Ga nd the younger age group has T(DM) ages of 2.2 to 2.4 Ga. Both groups of metasediments have quite narrowly constrained Sm/Nd ratios of 0.1694 +/- 0.0131 for the older group, and 0.1784 +/- 0.0082 for the younger group, and within each group they have subparallel projection lines in a ε_{Nd} versus age diagram (Fig. 1). The subparallel nature for each of the two groups of metasediments – as opposed to crossing distributions - give no suggestion of any significant later change of Sm/Nd ratio after the mantle extraction event.

Two distinct supracrustal suites were recognised in the SNO. The Maligiaq suite occurs thrust interleaved with Archaean gneisses along the northern margin of the SNO. Its metasediments show T(DM)= 2.82-2.76 Ga and detrital zircons of 2.85-2.1 Ga suggesting that clastic sediments derived from mainly Archaean sources were deposited in a continental basin or margin in Palaeoproterozoic time. The Ikertooq suite further south occurs tightly folded with Archaean gneisses and is dominated by mafic lithologies. A metasediment with T(DM)=2.41 Ga and 2.4-1.9 Ga detrital zircon ages indicates that also this suite is Palaeoproterozoic.

The CNO contains two major supracrustal sequences. The Nordre Isortoq suite in central CNO occurs as a ENE-trending steep belt of clastic metasediments. Isotope data (T(DM)=2.9 Ga, 3.4-2.4 Ga $^{207}Pb/^{206}Pb$ zircon ages) from metasediments in the west of the Nordre Isortoq suite suggest that these rocks were deposited in the Archaean while those in the east have ages that are similar to those of the Nordre Strømfjord suite (see below), deposited in the Palaeoproterozoic. The two suites occurring in this central steep belt cannot be distinguished on field criteria. The sediment-dominated Nordre Strømfjord suite in the northern CNO and the NSSB is spatially related to 1.90-1.94 Ga arc quartz-diorites and is tectonically interleaved with Archaean gneisses with mantle peridotite pods along the contacts. Detrital zircons have predominantly 2.20-1.95 Ga ages and the metasediments are interpreted as deposited from a now eroded island arc complex. T(DM) ages of 2.38-2.26 Ga agree with this conclusion. Lithological similarities and the age isotopic evidence suggest that the eastern Nordre Isortoq suite is part of the Nordre Strømfjord suite.

These data indicate that the Nagssugtoqidian Orogen hosts several Paleoproterozoic supracrustal suites that represent two distinct tectonic settings, one in the SNO, resembling a continental margin setting, while the one in the CNO is likely to represent an accreted terrane. Two of the suites are presently located at major tectonic boundaries in the orogen. The Maligiaq suite is located at the SNO/CNO thrust boundary, while the Nordre Strømfjord suite traces a proposed crustal suture.

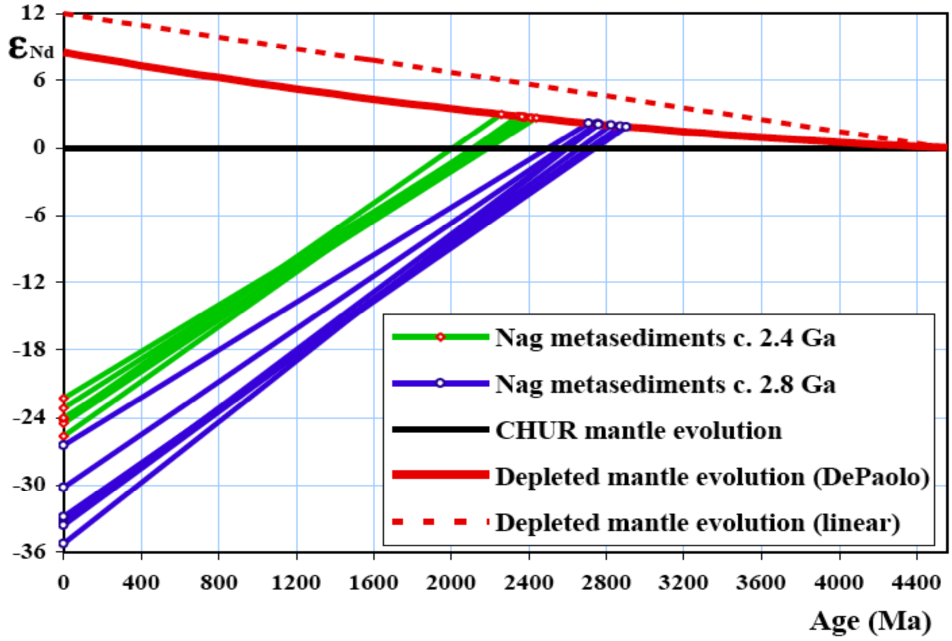

Figure 1. ε_{Nd} *values of Nagssugtoqidian metasediments projected back in time*.

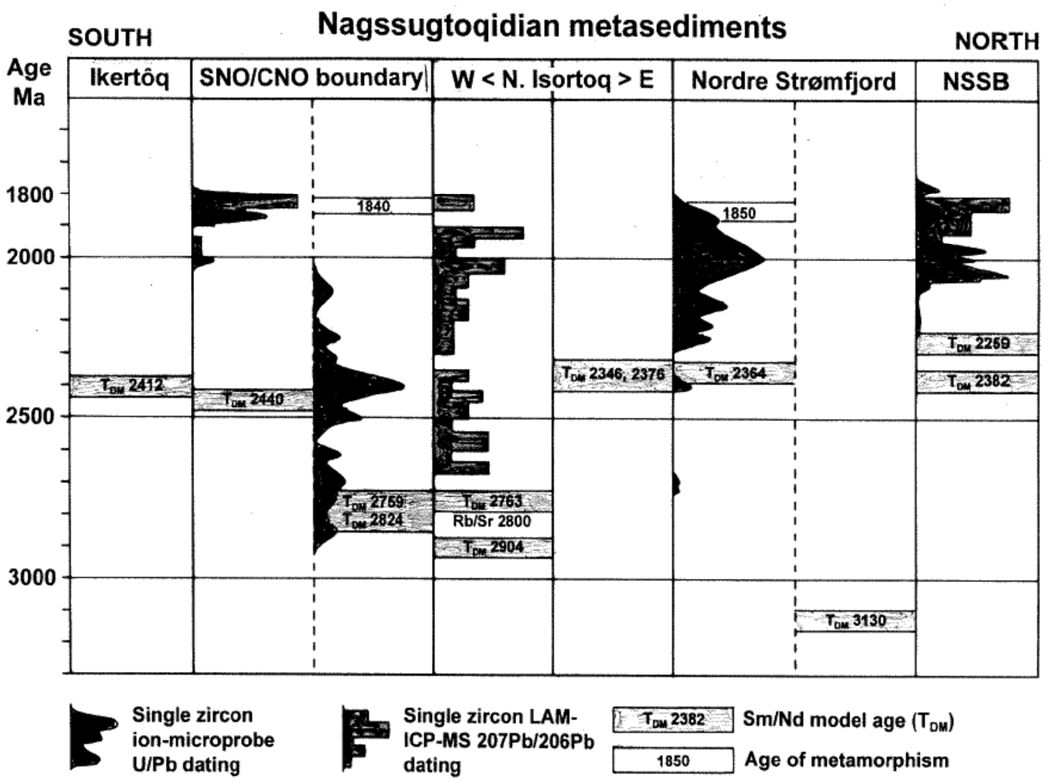

Figure 2. Summary diagram of age information from Nagssugtoqidian metasediments.

The origin and evolution of the Kangâmiut Dike Swarm, West Greenland

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The Kangâmiut dike swarm in west Greenland intruded Archean terrains at 2.04 Ga and its northern portion was subsequently metamorphosed to granulite facies during the Nagssugtoqidian orogeny (ca. 1.8 Ga.). Mineral and whole rock major and trace element chemistry show that the dikes' parental magmas differentiated by the fractionation of olivine, clinopyroxene, plagioclase and late stage Fe-Ti oxides. Petrographic observations and the enrichment of K_2O during differentiation indicate that hornblende was not an important fractionating phase. Field observations are suggestive of brittle emplacement, while combined clinopyroxene geothermobarometry and experimental petrology constrain the depth of Kangâmiut dike emplacement to less than ~ 10 km. Granulite facies metamorphism of the dikes and their host rocks in the northern portion of the swarm suggest subsequent burial to ~30 km, requiring roughly 20 km of crustal thickening between the time of dike emplacement and peak metamorphism during the Nagssugtoqidian orogeny. Kangâmiut dikes have Ba/La ratios of 12 ± 5, and Nb/La ratios of 0.8 ± 0.2, both of which are significantly different from subduction related basalts (Ba/La ~25; Nb/La ~0.35). These geochemical characteristics, among others, argue that the Kangâmiut dikes are not related to subduction processes, as previously proposed (Cadman et al., 2001). Forward modelling of rare earth element data require that primitive magmas for the Kangâmiut dikes originated from a moderately depleted mantle source with a mantle potential temperature of ca. 1420^{o}C. The inferred potential temperature is consistent with potential temperature estimates for ambient mantle at 2.0 Ga derived from secular cooling models and continental freeboard constraints (Richter, 1984; Galer 1991). The geochemistry and petrology of the Kangâmiut dikes do not support models linking this magmatic event to mantle plume activity or subduction, but rather to passive rifting of the proposed Kenorland supercontinent.

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The interference of structural patterns produced by a multi-phase deformation in a high-grade metamorphic terrain – a case study from the Northern Nagssugtoqidian orogen, west Greenland

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The study area is situated in the northern segment of the Nagssugtoqidian orogen between Ataneq fiord in the south and Qeqertarsuatsiaq Island in the north. This part of the orogen is composed of amphibolite- to granulite-grade Archean orthogneisses accompanied by relatively thin metasedimentary belts. The main foliation (S1) is developed parallel to the axial planes of isoclinal F1 folds, which fold lithological boundaries and cross-cutting basic dykes. These dykes are themselves rotated into parallelism with the foliation on the fold limbs. The S1 foliation was later folded into isoclinal folds, most probably due to the same progressive D1 deformation event. The S1 foliation and its subsequent folding during the progressive D1 event were accompanied by a long-lasting pervasive migmatization. The S1 foliation is also locally refolded by F2 folds of variable, often complex geometry with fold axes developed sub- parallel to the lineation. Associated F2 axial planes are locally marked by a subtle cleavage which cross-cuts the main S1 foliation.

On the map scale, the regional foliation displays a WSW-ENE to SW-NE strike associated with steep to moderate dips towards the NNW or SSE. Lineations within the area are defined by a parallel alignment of amphibole crystals and/or stretched quartz-feldspar aggregates. The lineation is WSW-ENE trending over the whole study area, and generally plunges gently towards the WSW. Meso-scale fold hinges are usually co-linear with the regional lineation, and this is also the case at the larger scale since the lineation maxima are located near the pole of the foliation girdle on stereoplots. A significant variation in the angle of lineation pitch angle on the regional foliation surface is observed; this may be caused by two independent factors: (1) variable plunge of the lineation, (2) variable dip direction of the foliation.

The systematic change in the plunge of lineations is clearly documented across the SW part of the study area. The steep SW-NE striking foliation around Tunarsuaq Fiord is associated with a gently plunging lineation which defines a low angle of pitch on the foliation. Towards the south, however, the lineation progressively becomes moderate to steeply plunging despite the generally uniform strike of foliation. This southward increase of lineation pitch is typically associated with the transition from “L>S” or “L-S” shape fabrics in rocks characterized by a low pitch to “S>L” or “S” fabrics in the zone of moderate to high pitch.

The described structural pattern allows subdivision of the study area into two domains: (1) southern domain mostly characterized by “S” or “S>L” shape fabrics and a moderate to high angle of lineation pitch, (2) northern domain showing “L>S” or “L-S” fabrics and a low angles of lineation pitch. The observed relationships can be tentatively interpreted in terms of strain partitioning occurring in a transpression zone. Accordingly, the northern domain represents a localized zone dominated by strike-slip kinematics whereas the southern domain shows evidence in favour of mostly coaxial shortening.

Cross-validated characterisation, potential, and probability of volcanogenic sulphide occurrences in West Greenland based on integrative statistical analyses

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Presently geo-scientific disciplines are challenged with the integration and interpretation of a wealth of historical and newly acquired data of varying complexity. Precise high quality validated results in both well or poorly known regions are needed for decision-making on future exploration campaigns. How do we meet these challenges? How do we establish an ideal assessment? How do we take advantage of the geo-researcher and the geo-data, and allow these to interact?

The talk will present different aspects of an assessment of mineral resource potential illustrated by former, present, and possibly future approaches to integration of geo-scientific data.

The talk will present a cross-validated statistical procedure, which enables the characterization of a geological feature, e.g. a mineral occurrence, in terms of the geo-scientific input data. Furthermore, the procedure allows us to quantitatively address the potential for the geological feature of interest and to estimate the probability for making new discoveries within a selected area. This is of interest for the general assessment of mineral resource potential and for a commercial exploration campaign. Similarly, the results of the procedure are useable as inputs to the constructions of regional geological models and models of the geological feature of interest.

The procedure is exemplified by an investigation of 67 known volcanogenic sulphide (VMS) occurrences in West Greenland (Fig. 1); all located in the northern and central part of the Nagssugtoqidian orogen. Characteristic signatures of the VMS occurrences are presented together with the calculated potential (see example in Fig. 1) for this type of mineral occurrence and estimates of the probability for new discoveries.

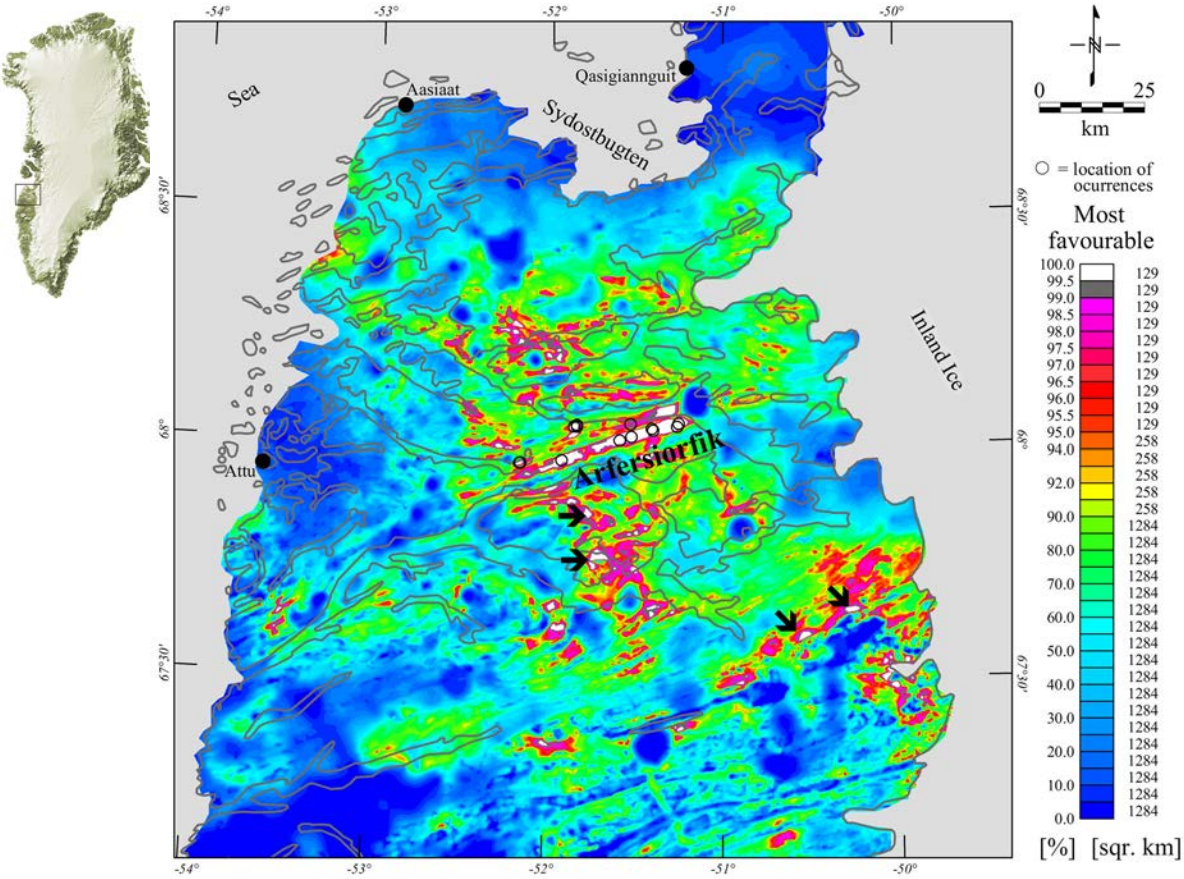

Figure 1. *Validated predictive potential map for the Arfersiorfik VMS occurrence group showing the most favourable areas for similar mineral occurrences. Black stars indicate locations of the 14 VMS occurrence members of the group. The top 0.5 percent most favourable area, representing the highest potential of finding an occurrence similar to the occurrence members of the groups, covers 129 km^2 (indicated by white colouring). The prediction is carried out by use of joint likelihood ratio functions. Black circles indicate the location of the largest towns in the study region.*

Comparison of two thick Archean metasedimentary, mainly mafic sequences in the Northern Nagssugtoqidian Orogen: Field relationships and first interpretation

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Two previously largely unknown up to 2.5 km thick sequences of low to middle amphibolite facies, predominately fine to medium grained metasediments were investigated in the Northern part of the Nagssugtoqidian Orogen. Both sequences show marked similarities to "typical" Archaean greenstone belts; nevertheless the individual sequences show marked differences in detail. One sequence occurs just south of the Isfjord (the "Isfjord sequence") and the other is positioned within the Akugdlinguaq area close to the inland ice (the "Akugdlinguaq sequence"). The Isfjord sequence is dominated by a laminated, compositionally banded amphibolite. In addition, a light grey, massive, homogeneous rock, a very fine grained, massive, dark rock, with a slightly greenish appearance and a sequence of fine to medium grained, felsic amphibolite with cyclic bands with marked gradation and load cast type features are observed. This mafic sequence is associated with up to 50 m thick bands of dark-grey, fine grained, massive Bt ± Grt gneiss, with variable amounts/intercalations of quartzo-feldspathic or schistose horizons of Bt-Grt semipelitic gneisses. Within most of the amphibolite varieties, felsic, quartzofeldspathic discontinuous streaks both parallel and perpendicular to the foliation, and irregular pods are abundant. Similar felsic material is seen in association with the fine grained, dark, massive Bt gneiss. These felsic streaks are interpreted as local melts.

The Akugdlinguaq sequence also shows a banded, laminated to layered sequence, as well as a massive, light-green fine grained sequence and intercalated Bt-Grt metasediments with felsic materials. In addition, though, some carbon rich layers, a mafic sequences with Ep rich parts which may resemble pillow lavas and coarse grained amphibolites interpreted as metamorphosed gabbros are observed.

On a large scale, the Isfjord sequence is marked by a central thick central predominantly metasedimentary body which is surrounded by a transition zone of roughly foliation-parallel "interfingering" orthogneisses and metasediments. Clear intrusive relationships between metasediments and Archean (?) orthogneisses are preserved. These field relationships and the foliation-parallel geometry of the metasedimentary and granodioritic "layers", suggest a forceful intrusion of the igneous granodiorite into an already layered and foliated sedimentary sequence. Subsequently, the whole sequence was subject to further regional deformation. The Akugdlinguaq sequence shows a similar but significantly thinner transition zone of bands of metasediments and foliation and layer parallel intrusive orthogneisses. The whole sequence is strongly folded with at least two major folding events which result in some pinched-out map patterns. In addition, the sequence is intruded after these deformation events by a largely undeformed felsic granodiorite in the centre of the area which has been dated to Archean ages (K. Thrane and J. van Gool, pers comm).

We conclude that both sequences are of Archean age and represent volcano-sedimentary basin fills with partly igneous intrusive gabbro and extrusive materials such as pillow lavas. These sequences were then intruded by granodiorites during the Archean and subsequently deformed. Differences in deformation style of the two sequences may be attributed to their regional structural position; the Isfjord sequence lies in the limb of a 50 km scale fold, while in contrast the Akugdlinguaq sequence is in the hinge zone of such a fold.

Regional interpretation of aeromagnetic and gravity data from West Greenland

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Quantitative and qualitative analyses on aeromagnetic and gravity data have been carried out for the Nagssugtoqidian orogen and adjacent areas.

Some of the results are:

- Correlation between lithologies, metamorphic facies, and magnetisation is described.
- Lineaments are outlined.
- Intrusives in the central part of the Nagssugtoqidian orogen are outlined.
- The Rodebay granodiorite is suggested to extent further southwards at depth than indicated by surface exposures.
- The Arfersiorfik quartz diorite continues eastward for 125 km beneath the Inland Ice.
- Dip estimates for large crustal blocks.
- Gravity and elevation data are analyses with respect to isostacy – long wavelength anomalies originating from large-scale structures are isostatically compensated.
- Models of the crust-mantle interface.

The results are discussed in relation to models of the lithosphere established from other geo-scientific data.

Mineral resources of Precambrian West Greenland from 66º to 70º 15' N: Compilation of earth science data on DVD

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The central West Greenland DVD released with this technical report contains the hitherto most com-prehensive digital compilation of earth science data from between 66° and 70°15' northern latitude and 49°15' and 55°00' western longitude. The digital data now available are part of the final reporting for the assessment of the mineral resource potential of central West Greenland, a project carried out under GEUS' Second Performance Contract (2000–2003) with the Ministry of Environment. The public release of digital data sets and accompanying descriptions, has been made with the basic philosophy in mind that quality controlled digital data should be available for general use and mineral exploration in particular.

The presentation of these data follows a range of previously published data on CD-ROM/DVD (see Schjøth & Thorning 1998; Pedersen 1999; Schjøth et al. 2000; Steenfelt 2001; Rasmussen et al. 2001; Appel et al. 2003; Jensen et al. 2003).

The central West Greenland DVD contains an ArcView project file and accessory data and text files. Topographic, geological, geophysical, geochemical, mineral occurrence, mineral exploration and remote sensing spatial data sets are presented as maps or images in the views of the project file. Bibliographies include published literature and company reports.

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Palaeoproterozoic intrusive complexes of the Nagssugtoqidian orogen featured in geochemical and geomagnetic maps

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The Arfersiorfik and Sisimiut meta-igneous complexes are related to the subduction stage of the Palaeoproterozoic Nagssugtoqidian orogeny in West Greenland and occur within the central part of this orogen (CNO), the site of subsequent collision. Chemical and isotope data have documented that the plutonic rocks are calc-alkaline in composition, have a largely juvenile origin and range in age from 1.94 to 1.87 Ga (Connelly *et al.* 2000; Kalsbeek *et al.* 1987; Kalsbeek & Nutman 1996). However, the spatial extent of the meta-igneous complexes is not well documented, except in the area covered by the Ussuit geological map sheet, soon to be published by GEUS. This is partly because of cursory mapping and partly because of the fact that the Palaeoproterozoic gneisses are visually indistinguishable from Archaean gneisses where both are in granulite facies metamorphic grade. We have studied the geochemical and geomagnetic properties of the Palaeoproterozoic and Archaean gneisses and found differences that enable us to identify and outline most of the Palaeoproterozoic plutonic rocks using stream sediment geochemical data together with aeromagnetic data.

The investigated area has been covered with stream sediment samples collected systematically at a density of one sample per 25 km^2 (Steenfelt 2001). The less than 0.1-mm grain size fractions of the samples have been analysed for *c.* 40 major and trace elements. An airborne magnetic survey has been flown at a nominal elevation of 300 m along N–S orientated lines spaced 500 m (Rasmussen & van Gool 2000).

The Arfersiorfik complex ranges in composition from diorite to granodiorite, but is dominated by quartz diorite, and therefore commonly known as Arfersiorfik Quartz Diorite (AQD). In the Ussuit map sheet area, members of the AQD are usually darker and less deformed than the tonalitic to granodioritic Archaean gneisses in the same area. The total magnetic field intensity map shows a strong positive anomaly that is clearly associated with the central part of the largest known body of the AQD in contrast to neighbouring Archaean orthogneisses and supracrustal sequences of both Archaean and Palaeoproterozoic age that have low magnetic response. The magnetic AQD body appears to continue eastwards blow the Inland Ice. However, sheets of AQD recognised during mapping are thinner and therefore more difficult to recognise in the magnetic map. The stream sediment data are not so helpful in the inner Arfersiorfik Fjord area as coverage is poor due to scarcity of proper streams, and the contribution from sheets of AQD to the stream sediment is low.

Members of the Sisimiut Intrusive Suite (SIS) have been identified by reconnaissance zircon geochronology at the coast near Sisimiut (and termed the Sisimiut charnockite). The suite ranges in composition from gabbro, diorite and quartz diorite to monzodiorite and monzonite. Some of the samples have a tonalitic to granodioritic composition. The plutonic rocks are in granulite facies like the Archaean orthogneisses into which they have intruded. Chemical analyses of samples of SIS show that very few contain enough potassium to deserve the name of charnockite, but they also show that SIS rocks have a characteristic chemical signature, whereby they can be distinguished from the Archaean gneisses. The signature is most pronounced in the monzonitic rocks and is defined by high concentrations of Ba, Sr, P and REE as well as a high content of magnetite. The total magnetic field intensity map displays a zone of strong positive anomalies interspersed with narrow magnetic lows over the entire southern part of the CNO. The magnetic lows can be ascribed to screens of supracrustal rocks, but the highs record both SIS and their Archaean counterparts.

The resolution is low in the stream sediment maps, and the location and limits of a source that has contributed sediment enriched in the above mentioned elements cannot be determined with accuracy. Therefore, our approach has been to use the shapes of strong magnetic anomalies within the catchment areas of anomalous stream samples to outline members of the SIS. Although we do not claim the resulting map of the Palaeoproterozoic complexes to be true in every detail, we regard the approach to be the most appropriate alternative to undertaking abundant new rock sampling and isotope age datings.

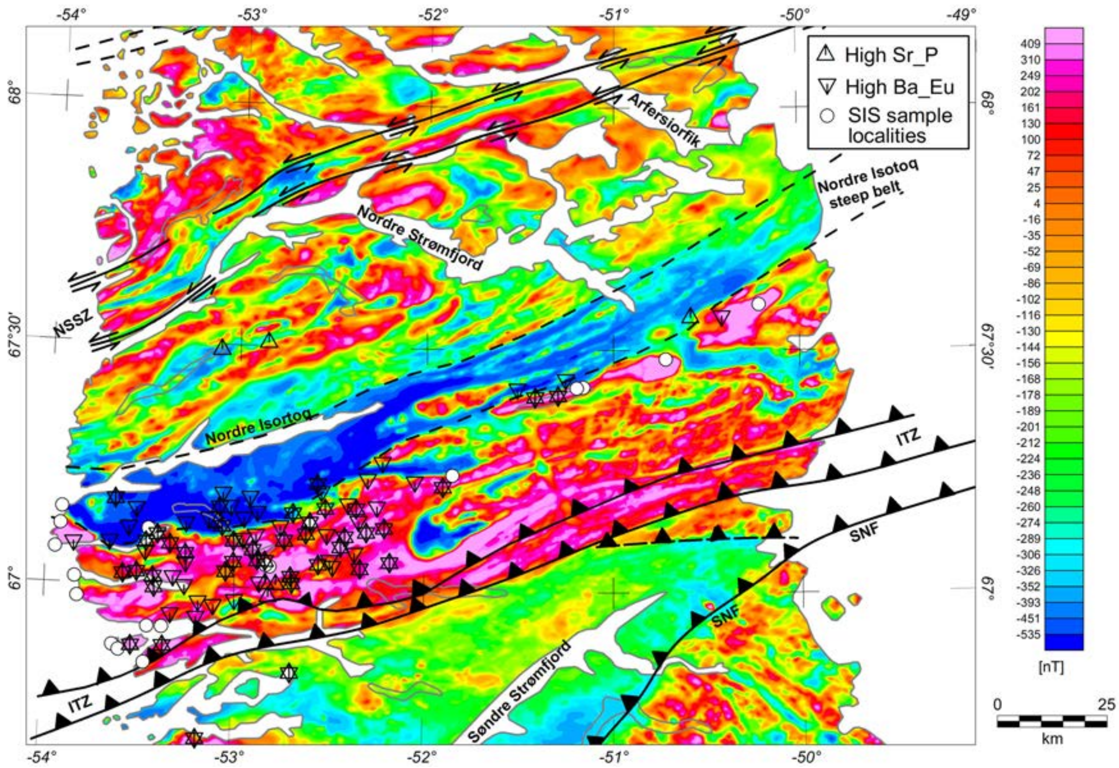

Figure 1. *Stream sediment geochemical anomalies and location of SIS samples on top of total magnetic field intensity.*

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Ten years of Nagssugtoqidian research – An orogen coming of age

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Ten years after the start of the Nagssugtoqidian project at DLC and after 4 years of research under GEUS, a period of intense investigations in this part of the Greenland Precambrian is about to be rounded off. The purpose of the DLC project, understanding the tectonic evolution of the Nagssugtoqidian orogen, has largely been attained (van Gool et al. 2002) and additionally, large parts of the orogen have now been mapped in reasonable detail during GEUS' Nagssugtoqidian project while the link to the Rinkian belt has been strengthened.

The first attempt to understand the geology of central West Greenland between Søndre Strømfjord and Disko Bugt, was by Ramberg, who carried out reconnaissance mapping in the region in the 1940's and 1950's together with Noe Nygård. Ramberg (1949) defined the "Nagssugtoqiderne" as a tectonic belt with a consistent ENE-trending fabric overprinting the Kangâmiut dyke swarm. Following attempts to investigate the Nagssugtoqidian geology in the 1960's and 1970's, had geologists of Aarhus and Liverpool universities working in respectively Nordre Strømfjord and the region between Sisimiut and Itivdleq. Much of the research at this time concentrated on the Kangâmiut dykes and on ENE-trending linear belts, which were interpreted as crustal scale shear zones. Discussions of which part of the geological history was Archaean versus Proterozoic were difficult to resolve, in the absence of easily accessible geochronological analyses. Although Bridgwater et al. (1973) described the region as a collisional belt, the general opinion of the Nagssugtoqidian was that of an intracratonic mobile belt, being the far-field result of collision in the Ketilidian belt in South Greenland (Watterson, 1978).

In a major breakthrough Kalsbeek et al. (1987) presented the Arfersiorfik Quartz Diorite in the centre of the Nagssugtoqidian as an arc magma, inferring the presence of a suture. The Nagssugtoqidian project of DLC, which was conducted from 1994 until 1999, was initiated in order to investigate the significance of these arc magmatic rocks, and the general tectonic setting of the Nagssugtoqidian belt. The final result of this project led to the recognition of a number of tectonic events which all could be interpreted in terms of a full Wilson cycle. These events include the opening of an oceanic basin and formation of oceanic crust, sediment deposition, destruction of the basin, subduction and arc magmatism, collisional tectonics and high grade metamorphism, jumping of the subduction to the Ketilidian orogen, subsequent deformation during ongoing convergence and finally slow uplift of most of the orogen. The subsequent timing of these events fits well with modern day plate tectonic processes. This evolution can be correlated in time and character with that of the Torngat orogen, which was the focus of the Canadian Lithoprobe ECSOOT project, which

was conducted concurrently with the DLC project. The Torngat and Nagssugtoqidian orogens are now believed to have developed contemporaneously on respectively the western and northern margins of a northwest-ward indenting Archaean block, the North Atlantic Craton/Nain Province in respective Greenlandic and Canadian terminology.
During the course of the DLC project, the suspicion arose that a tectonic division of the Greenland west coast in a Nagssugtoqidian and a Rinkian orogen was artificial, and that these two belts formed some form of continuum (Mengel et al. 1998).

The GEUS project in central West Greenland lasted from 2000 to 2003 and had two elements, on the one hand geological mapping and tectonic investigations in the northern part of the Nagssugtoqidian orogen and the southern part of the Rinkian belt. On the other hand a resource evaluation was carried out in this most populated part of Greenland.

Fieldwork by GEUS' mapping department concentrated in four 1:100 000 scale map sheets in the central and northern Nagssugtoqidian Orogen. Results show that the Northern Nagssugtoqidian Orogen (NNO) north of the Nordre Strømfjord shear zone has a significant different character than the centre of the orogen. In the NNO Palaeoproterozoic deformation and metamorphism is quite variable in intensity, but overall decreasing northwards. Archaean orthogneisses still predominate and the majority of supracrustal rocks are of Archaean age, while Palaeoproterozoic arc rocks have not been recognised. But some Proterozoic key elements still persist, kilometre-scale fold structures and ENE-trending high strain zones. Furthermore, there is no obvious reason to assume that the Nagssugtoqidian and Rinkian orogens developed separately. The majority of the papers in this volume give more detailed accounts of these results.

The resource evaluation conducted by GEUS' department of economic geology, concentrated on gold and diamond prospects in the area. All known mineral occurrences in the Nagssugtoqidian Orogen were visited and several new ones were found. Of these, volcanic massive sulfide deposits are the most interesting, but none of the showings are at present economically interesting. Investigations of the diamond potential in the Søndre Strømfjord area have not yet led to economical findings, but this work will continue after the closing of the present evaluation project. All results of the resource evaluation and pertinent material are published on a DVD.

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Tectonics of the Northern Nagssugtoqidian orogen – the link between Nagssugtoqidian and Rinkian geology

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Escher and Pulvertaft (1976) established an arbitrary boundary to separate the distinct Rinkian and Nagssugtoqidian mobile belts. The Rinkian belt (RB) was characterised by large scale fold structures (at that time interpreted as gneiss domes), thick sequences of Palaeoproterozoic and Archaean supracrustal rocks, variable Palaeoproterozoic metamorphic and structural imprint and consisting of several lithotectonic domains. In contrast, the Nagssugtoqidian orogen (NO) is characterised by an ENE-trending tectonic fabric, dominated by reworked Archaean orthogneisses and only minor Archaean and Proterozoic supracrustal sequences, up to granulite grade metamorphism, which until recently was assumed to be gradually decreasing away from the core of the orogen, and the orogen was subdivided in several segments, more for convenience of description than for their significant differences. Mengel et al. (1998) emphasised similarities between the two belts, including an early phase of NW-directed thrusting, E-W trending crustal scale fold structures and timing of deformation and metamorphism. In subsequent publications, the northern segment of the Nagssugtoqidian orogen has been presented as a transitional zone to the Rinkian belt.

Results of GEUS' mapping project in the area between Nordre Strømfjord shear zone and Jakobshavn Isfjord and an associated project studying the geology of the central and northern parts of the RB, have confirmed these assumptions of a strong link between the development of the two belts. The recent work in the northern NO has shown that both the Archaean and the Palaeoproterozoic metamorphic grade and structural imprint are quite variable. The predominant amphibolite facies metamorphism is alternating with pockets of upper greenschist grade (Naternaq, islands north of Aasiaat and Hundeejlande) while south and east of Qasigiannguit an extensive area of partial melting occurs. Generally open, upright E-W trending folds and ENE-trending strike-slip shear zones appear to be the main Palaeoproterozoic structural imprint on the area and Palaeoproterozoic metamorphism appears concentrated in the high strain zones. In the Qasigiannguit area these shear zones are dipping moderately to the northwest and consistently form on the southern limbs of large synforms. Furthermore, up to 2.5 km wide Archaean greenstone belts were found in the Qasigiannguit area. The ages of some of the large metasedimentary belts are still uncertain. In general, the northern segment of the NO shows a very heterogeneous development during the Palaeoproterozoic.

The general tectonic model for the tectonic evolution of the NO showed the presently exposed rocks in the middle crust by the end of orogenic movements and the main uplift is by isostatic compensation during erosion. Observations from the northern NO do not allow for such a period of static uplift, which would homogenise metamorphic imprint. It is more likely that uplift of at least sections of the crust occurred syn- to late tectonically, allowing for the preservation of areas with lower metamorphic grades.

The observations from the northern NO, together with the consistent presence of north-west-directed thrust structures in the central and northern RB, strengthen the assumption of a parallel evolution of the two belts, making this a ca. 1000 km wide orogenic region. Since no suture has been recognised within the RB, the overall tectonic picture is that of a very asymmetric orogenic belt with the site of collision near the southern margin. This could place significant question marks on the viability of this model, since it would be mechanically difficult to sustain orogenic forces in a shallow orogenic belt over such distances. Furthermore, indications that the metamorphism increases in age towards the north would be in conflict with a simple model of an orogenic belt expanding outwards from a single collisional core in the south.

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