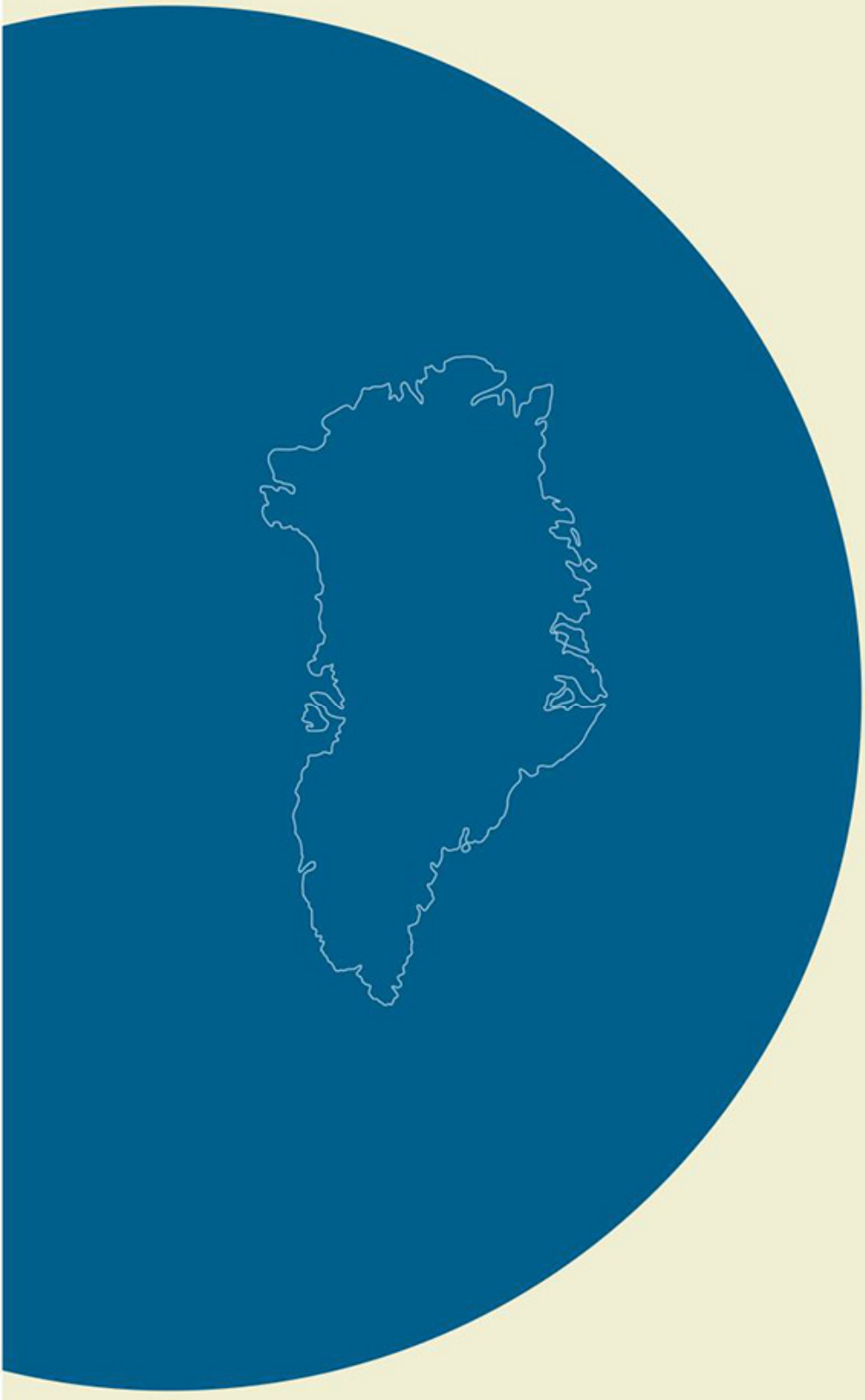
DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/37

# Report on the Ketilidian workshop including listing of published papers and data collections since 1992

Troels F. D. Nielsen



GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/37

# Report on the Ketilidian workshop including listing of published papers and data collections since 1992

Troels F. D. Nielsen

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE
MILJØMINISTERIET

GEUS

# Contents

## Aim

The Ketilidian workshop was held at GEUS, Copenhagen, January 24th and 25th, 2002. Day 1 was reserved for open presentations and discussions at GEUS and Day 2 for internal discussion and planning sessions. The workshop was initiated by Troels F.D. Nielsen (GEUS) and John Grocott (Kingston University, UK) to revitalise the information flow and the discussions between the different groups of researchers active in projects on aspects of the Ketilidian orogen.

## Participants

**GEUS:**
Trine Dahl-Jensen (geophysics)
Adam A. Garde (geological mapping, metamorphism and architecture)
Troels F.D. Nielsen (petrology, regional geology, organiser)
Thorkild Rasmussen (geophysics)
Agnete Steenfelt (geochemical mapping)
Henrik Stendal (economic geology, regional compilations)

**Kingston University, London, UK**
John Grocott (structural geology and modelling)

**Durham University, UK**
Ken McCaffrey (structural geology and modelling)

**Geological Survey of Canada, Ottawa, Canada**
Mike Hamilton (geochemistry, isotopic investigations and regional compilations)

**The open session was also attended by:**
Chris Pulvertaft (GEUS)
Kristine Thrane (GEUS)
Jeroen v. Gool (GEUS)
Bo Møller Nielsen (GEUS)
Bjørn Thomassen (GEUS)

## Report from the workshop

**DAY 1**

Open session, Thursday January 24th

*Introduction*

The open session was planned as a series of presentations that should ensure a common information basis for the discussion between presentations and the themes to be discussed on Day 2. Following the programme the open session started at 9:15:

1) **Short introduction and logistic information (Troels F.D. Nielsen)**
2) **Historical overview (Agnete Steenfelt)**

The overview concerned plate-tectonic models and chemical characteristics of the domains in the Ketilidian orogen based on regional information collected over the last 30 years. The main results of the uranium exploration programmes SYDURAN and SYDEX were presented.

*The three presentations before lunch included:*

1) **Seismic studies along the south-east coast of Greenland (Trine Dahl-Jensen)**

A presentation and discussion of the seismic wide-angle data previously published by Trine Dahl-Jensen and co-authors. The discussion concerned the level of confidence that was applied to the conclusions and suggestions for the main architecture of the Ketilidian orogen along the east coast of Greenland. A major issue was the shape of the batholith and the nature of the crustal layer beneath the psammite and pelite zones. The main point of divergence was the understanding of the substructure of the batholith: 1) Archaean crust, 2) mafic intrusions from which the felsic part of the Proterozoic batholith formed or 3) Archaean crust with Proterozoic intrusions (cumulates of the batholith magmas).

2) **Geochemical signature and geophysical characteristics of domains in the Ketilidian orogen (Agnete Steenfelt)**

The presentation focused on the chemical characteristics of the domains in the Ketilidian. Many compilations and multi-element distributions were shown to highlight especially the geochemical differences between the sediments in the psammite and pelite zone and the source rocks in the Julianehåb batholith. Aeromagnetic compilations were shown and discussed and illustrated the significant differences between batholith intrusions. In accordance with the age distributions the batholith intrusion may be

divided into earlier relatively non-magnetic suites (c. 1854-1835 Ma.) and the younger highly magnetised intrusions (c. 1810-1872 Ma.). Most of the Intermediate ages in the databases are from samples that were collected close to each other near the Sardloq shear zone. A continuum in ages of batholith intrusion could exist, but has not yet been demonstrated.

The main geochemical difference between the batholith lithologies and the sediments supposed to be derived from them is a relative enrichment in As, Th, U, Au, Rb, Cs in the sediments. This suggests that sources other than eroded batholith contributed to the sediment packages. Discussion of this was moved to the internal discussions on Day 2.

**3) Gold mineralisations of the Ketilidian orogen (Henrik Stendal)**

The Ketilidian orogen and its borderland are in general anomalous in gold. The identified gold mineralisations can be divided into several types depending on setting. Gold mineralisations are found in:

1) the Palaeoproterozoic border zone: Arsuk Ø and Kobberminebugt
2) the Julianehåb Batholith: Qurormiut, Niaqornaarsuk, Igutsait
3) the Julianehåb batholith margin: Kangerluluk and Sorte Nunatak
4) the supracrustals: Nalunaq, Lake 410, Ipatit and Kutseq

and in:

5) the Archaean greenstone belts: Taartoq and Sermiligaarsuk

The gold occurrences in the Ketilidian orogen can be classified as ‘Intrusion-related Gold Systems'. The gold occurrences are found both within the Julianehåb Batholith and outside as proximal deposits. Within the batholith gold is associated to veins, shears, and sheets. This Au-Bi-W-(Mo) type has disseminated gold and is dispersed. A Cu-Au association is found in mafic volcanic rocks deposited directly on the batholith. Quartz veins Proximal to the batholith in mafic rocks are gold-bearing (Au-As) and presently the most promising type of gold mineralisation in the region (e.g. Nalunaq).

The gold prospects in Nalunaq, Ipatit, Lake 410, Kutseq, Sorte Nunuatak and Kangerluluk are all located on the south side of the Julianehåb Batholith. Initial gold mineralisation was genetically related to metalliferous fluids associated with the emplacement of late intrusive stages of the Julianehåb Batholith (1800-1770 Ma.) followed by local remobilization.

*The four presentations after lunch included:*

**1) Isotopic characteristics and radiometric ages from the Ketilidian orogen with emphasis on provenance (Mike Hamilton).**

The large body of age determinations and isotopic information was presented. Some of the important messages from the data are listed as follows:

1) The existence of magmatism older than the early main phase of Julianehåb batholith intrusions is suggested in accordance with detrital zircons in whole rocks from the psammite and pelite zones. This includes the Pyramidefjeld intrusion (c. 1880 Ma.).
2) Bimodal age distribution of the batholith intrusion at c. 1854 –1835 and c. 1820–1792 Ma.
3) Known intermediate ages are all derived from areas around the Sardloq shear zone.
4) Nd-signature shows Archaean contamination down to the southern border of the batholith. The contamination probably decreases toward the south.
5) The best-preserved basalt from Nalunaq has depleted mantle signature at 1800 Ma.
6) Most basaltic lavas have epsilon Nd between 0 and plus 3 suggesting mixing of Nd from juvenile Proterozoic source and other older sources.
7) Contaminated and non-contaminated felsic intrusions occur side by side. That no Archaean Nd signature is observed does not exclude the presence of Archaean crust at depth.
8) The lack of information on inherited zircon (cores in zircon grains) from batholith samples may be due to the selection of clean zircon grains for the investigation. Complex grains have been avoided in investigation, but could potentially have given important information (pers. com., Mike Hamilton).

The investigations have confirmed that the bulk of the felsic batholith magmatism was juvenile, but Archaean components have often been incorporated. Three processes are suggested:

1) recycling of Archaean sediments into mantle source
2) incorporation of Archaean upper crustal sedimentary components.
3) interaction with Archaean crust

**2) Structural modelling of the profile through the Ketilidian orogen along the east coast of Greenland: discussion of bottom driven deformation (John Grocott)**

Based on a compilation of the kinematic indicators the deformation is – as generally accepted – seen as the result of transpression with sinistral movements. The main new understanding relates to the interpretation of the marked flat lying structures in parts of the psammite and pelite zone as de-

tachment/attachment zones between a ductile lower portion and a brittle upper portion of the crustal succession. Top and bottom driven clutch zone tectonics were discussed.

The detachment/attachment zone was modelled to underlie the Julianehåb batholith. In view of the strong deformation of certain older batholith units (c. 1854-1835 Ma.) the batholith exposed on east coast in the Kangerluluk area could hypothetically be alloctoneous. The structural modelling would seem to indicate that a south-dipping ramp of Precambrian basement would be an integrated part of the tectonic framework in the section along the east coast of Greenland and that the driving force would be northward subduction.

**3) Emplacement of rapakivi granites in the Kap Farvel area (Ken McCaffrey)**

Based on the field observations and the structural modelling the rapakivi bodies in the Kap Farvel could well be parts of the same large and sheet-like intrusion. The recognition that the rapakivi intrusions are gently folded is important in this context. The feeder system for the intrusion could well be a NW-SE striking dike-like body in the area between Prins Christian Sund and Lindenow Fjord. These observations would seem to reduce the number of intrusive event, even though a large age range has been observed.

**4) The appinite magmatism and metamorphic development of the arc (Adam Garde)**

Appinite intrusions occur through out the Ketilidian, in the border zones and in Archaean basement areas beyond the limits of Ketilidian deformation and metamorphism. The volumes are significant and may be an important heat source in the development of the Ketilidian. Appinite (s.l.) melts mostly formed dike like bodies. Many show commingling structures between basic, intermediate and felsic components.

Such appinite and commingling between basic to felsic magmas is a characteristic of batholith areas (e. g.) the Appalachians in New England and the Canadian Maritimes and the batholith areas in western US.

There was some discussion about the bulk heating effect of these magmas and the origin of the melts. It was also noted that the term appinite is a wastebasket term and that a petrologial and geochemical study seemed needed.

Field observations and textural evidence indicate that high-grade metamorphism and partial melting (anatexis) occurred concurrently with the deformation (D1-D3, 1792-1785 Ma) in the psammite and pelite zones. The supracrustal successions have both detrital zircons and metamarphic zircons formed around 1792 Ma. The confining pressure was low and possible effects of telescoping were discussed.

The P-T evidence also suggests significant uplift prior to emplacement of rapakivi granites beginning at c. 1750 Ma. The geothermal gradient remained high (50-60oC/km).

*The session ended at 5:15 p.m.*

**DAY 2**

Day 2 was reserved for the participants currently active in Ketilidian research projects. Day 2 was held at the home of Agnete Steenfelt in Gadevang, North Zeeland. The programme was initiated at 9:30 a.m. The programme was quite flexible to allow time for discussions, new themes and room for unfinished business.

*Morning session: 9:30 a.m. to 1 p.m.*

**1) The north-west border zone of the Ketilidian (Adam Garde)**

A presentation of the general setting of the supracrustal successions in the Grænseland-Arsuk Ø area in the NW Border Zone had been moved from Day 1. The main focus was on the structural interpretation of the region and the information available for this part of the Ketilidian orogen.

The most wanted information from the volcanics is emplacement age. No attempts to date the volcanics have been successful. The Sortis Group volcanics are tholeiitic basalts and quite different from the other groups of Ketilidian volcanics. Although no age information is available - apart from the relative field chronology – there seemed to be an increasing support for the suggestion that these volcanics could represent an early Ketilidian passive margin succession. For what it is worth, the old age for the Pyramidefjeld intrusion (c. 1880 Ma.) may point to a pre-batholith magmatic evolution (as do detrital zircon) in the 100 Ma. prior to the convergence/collision development.

**2) Discussion theme: The geochemistry and isotope characteristics of the magmatic suites in the Ketilidian**

The discussion was as much a review of the available information. As described below geochemical data for the Ketilidian successions and formations are available from the individuals indicated:

1) NW Border Zone (Mike Hamilton and Adam Garde)
2) Kangerluluk (Henrik Stendal)
3) Sorte Nunatak (Adam Garde and Troels Nielsen)
4) Kutseq (Henrik Stendal)
5) Nanortalik Halvø (Mike Hamilton and Adam Garde)
6) Batholith as such (Mike Hamilton and Adam Garde)

7) Stendalen gabbro (Henrik Stendal)
8) Appinites (Mike Hamilton and Adam Garde)
9) Rapakivi granite (Aberdeen Group, Peter Brown)

**Areas where data may be or is insufficient include:**

1) The pre-Ketilidian magmatic development in the NW Border Zone is only well covered for some of the magmatic components. Compositions of lavas are available from Mike Hamilton and Adam Garde, but recent analytical data is not available for the assumed related Iggavik dykes. Also, as noticed above, precise age information is not available for the main bulk of the volcanic successions and sills in the NW Border Zone. Ages for the basaltic magmatism in the NW Border Zone would be most welcome.
2) The volcanic successions at Sorte Nunatak have not been sampled in situ due to the exposures in vertical walls. All available material originates from the screes below the walls, but does undoubtedly sample the local volcanic succession. Still the existing data has not been used for any dynamic modelling. The initial geochemical data suggests a bimodal succession of calc-alkaline volvanics form mafic andesite to rhyodacite. One sample may be an ignimbrite. A report should be prepared to make the data available to others.
3) Mafic and ultramafic magma are represented by a number of intrusions, including the Stendalen gabbro and the peridotitic bodies in the Nanortalik area. The Stendalen gabbro has been investigated (Birkedal, see appendix), but no geochemical summary or overview exists for this suite of intrusions.
4) A significant amount of material exists from the appinitic suite. Mike Hamilton and Adam Garde have collected geochemical data from a significant number of appinites. Evaluation of the geochemical data requires a petrographic study of the appinites – possibly as a thesis project. It is probably a good guess that the appinites represent a suite of calc-alkaline to alkaline lamprophyres typical for batholith environments.

**B. Access to data:**

A WEB page was suggested developed to ensure the access to geochemical (and possibly other?) data for all acknowledged participants in the project. The task of developing the WEB page is described below.

**3) Discussion theme 2: the development of the psammite and pelite zones: timing, metamorphism and deformation**

The detailed age information and the geothermal information presented by Garde and Hamilton demonstrate the very short time lapse between erosion of batholith, sedimentation, high temperature metamorphism and concurrent deformation in three structural stages (D1-D3). In short, the psammite and

pelite zones contain detrital zircons with ages of 1792-1793 Ma. and the peak of metamorphism is believed to have occurred at *c.* 1786 Ma. This leaves less than 6 Ma. for the initial erosion, sedimentation, heating and deformation of the psammite and pelite zones. The origin of this rapid heating is not explained. Several models exist and three shall be mentioned:

1) Heating by injected magmas (appinites and granites, s.l.).
2) Heating by diffusion due to under-plating and plutons in the base of the succession.
3) Heating due to deep burial (high P and T) followed by rapid uplift in active collision/convergence dynamics.

There is no consensus as to the origin of the heating, but some of the comments to the suggestions were:

Add 1) The very high temperatures would require very large volumes of hot, intrusive material – maybe app. half the volume of the entire sedimentary succession. This has not been observed

Add 2) The very short duration of the heating seems to exclude diffusion as means for the general metamorphism to higher amphibolite facies to a stage of extensive anatexis.

Add 3) Deep burial at a more 'normal' geothermal gradient (30oC/km or less) in unconsolidated sediments would require depth of 20 to 25 km (600-800oC). That seems somewhat unlikely.

No consensus was achieved.

The morning session ended at 1p.m.

*Afternoon session*

The afternoon session focused on the publication plan and the completion of the data background for the planned publications. The list is given below. Papers in press are not included. Publications and data packages published since 1992 in the Suprasyd project, related mapping projects and other continuation projects, and geochemical mapping and geophysical programs concerned with the Ketilidian region are listed in the Appendix.

A number of publications are already in the process of being published or written, whereas others are planned. A good part of the session was used for descriptions of the publications in production and the relations between the publications to avoid unnecessary overlap. The publications in production or planned prior to the workshop include paper nos. 1, 2, 3 and 4. Of these only paper no. 1 and 4 are in part written. The data necessary for papers 2 and 3 is available apart for minor additions. No deadlines are presently agreed due to future assignments, but will be discussed subsequently.

Papers nos. 5, 6 and 7 are planned as a suite. Papers 5 and 6 are back-to back papers with quite detailed descriptions, whereas paper 7 will build on these two papers, papers 1-4 and all previous publications. Deadlines will be evaluated in the near future.

## Manuscripts being prepared and manuscripts planned:

1) **Hamilton, Garde, Nutman, a. o.?:** On the Ultra-fast sedimentation, metamorphism and deformation in the forarc of the Ketilidian orogen.

   This paper focuses on the narrow time window during which the sedimentation, metamorphism and deformation of the psammite-pelite zone took place. The amount of dynamic modelling is suggested to be minor. ***Is being prepared for Geology- is 2/3 done, Adam Garde has the lead.***

2) **Garde, Venance and Swager:** On the high T low P metamorphism of the psammite-pelite zone.

   The paper describes the PT variations in the Ketilidian sedimentary basin. The amount of dynamic modelling is un-decided. ***J. Metamorphic Geology, Precambrian geology, EPSL, CMP or Canadian Earth Sciences. Data available, not written. Adam has the lead.***

3) **Garde, Hamilton and Steenfelt:** On the chemistry etc. of the Julianehåb batholith.

   The paper will cover the chemistry and petrology of the Julianehåb batholith. The data is available and will be available on the WEB page planned to be located on the Durham University server (see below). Mike Hamilton has collected the main body of the data. ***Adam Garde and Mike Hamilton have the lead.***

4) **Garde, McCaffrey, Hamilton, and Chadwick:** The NW Border Zone of the Ketilidian orogen.

   *The paper focuses on the correlation of discrete tectonic events in 7 sub-areas, supported by new geochronology and a general geotectonic interpretation indicating softening of the basement and a southward strain progression.* ***Precambrian geology. Exists in part, but needs shortening and conclusions. Adam Garde and Ken McCaffrey have the lead.***

5) **Grocott, Dahl-Jensen, Garde, Hamilton, McCaffrey, Steenfelt, Chadwick, a.o. (?):** On the structural architecture of the Ketilidian orogen based on structural and seismic profiles along the SE coast of Greenland.

   The first of two back-to-back papers (see below). The paper will focus on the structural model developed by John Grocott and Ken McCaffrey and the overall agreement with the seismic section of Trine Dahl-Jensen et al. (see

appendix) and the time frame provided by the age information. Will include shrimp ages from Adam Garde. ***Precambrian Geology or similar. Not written – John Grocott has the lead.***

6) **Steenfelt, Hamilton, Nielsen, Stendal, , a. o. (?):** On the characteristics and origin of domains in the Ketilidian orogen.

   The second of two back-to-back papers (see above). This paper will describe the different domains in the Ketilidian orogen and their possible origin and inter-relationships. Will be based on the geochemical characteristics (Mike Hamilton, Agnete Steenfelt and Henrik Stendal data - including data in M.Sc. theses), the geological setting and the isotopic information pointing for the precursors of the lithologies and their origin. ***Precambrian Geology or similar. Not written; Agnete Steenfelt has the lead.***

7) **Nielsen and many, many others:** On the architecture of the Ketilidian orogen, a highly dynamic Proterozoic crust accretion.

   This paper will attempt to develop a large scale plate and dynamic model for the formation of the Ketilidian orogen. It will build on the papers above and pre-existing literature. The paper will – including illustrations, tables and references – be 8-10 manuscript pages and prepared for Geology. **Has to wait for papers # 5 and 6. Troels Nielsen will have the lead.**

## Specific tasks and databases

***WEB page with chemical database and discussion forum (Ken McCaffrey)***

To ensure maximum flow of information it is suggested that a WEB page be established. The WEB page should contain all chemical data, including isotopic information on whole rocks and a discussion forum. Access will be limited to the accepted co-operators in the project. Geochemical data from stream sediment programmes remain housed in the GEUS databases.

Due to common problems with external access to WEB-pages inside the firewall in Copenhagen the WEB page is suggested located on the server system of University of Durham. Ken McCaffrey has volunteered to look into the possibilities for the establishment of the WEB page.

***Compilation of data from theses and various unpublished sources (Henrik Stendal, Agnete Steenfelt, Troels Nielsen)***

A number of theses and unpublished sources contain chemical data from various lithologies, including data from basaltic extrusions and intrusions. The data will be formatted for the WEB page and made available to all in the working group.

***Template for the WEB page (Troels Nielsen)***

Troels Nielsen will supply the format for the chemical data sheet for the WEB page in accordance with the format in the GEUS Greenland database to ensure simple transfer of data between systems.

## Future programmes

***The earliest Ketilidian development: the Grænseland basaltic magmatism***

During the discussions and based on the existing data it is suggested that the tholeiitic magmatism in the Grænseland region including lavas, dykes and sills and the recently dated Pyramidefjeld intrusion most likely form a magmatic suite predating the main Ketilidian deformation and arc building. The genesis and plate tectonic setting of this suite is not well understood. There is a general consensus that the suite may represent the magmatism at a passive continental margin. No solid age information exist for the basaltic suite, where as the Pyramidefjeld intrusion gives an age of ca. 1880 Ma., about 30 Ma. older that the oldest part of the batholith proper. Other older ages are also known from detrital zircons.

Age information has to be obtained for the basaltic magmatism. Unfortunately attempts to date the volcanics have failed and possibilities for dating of sills in the volcanic successions should be investigated. With new age information and the currently available chemical and geological information, models for the petrogenesis and plate tectonic setting of the magmatic suite should be possible.

Note should be made that investigations of the geochemistry of the Sortis Group by Garde, Hamilton and Upton hopefully will develop into a publication with interpretation of the geotectonic setting of the Sortis Group.

***The basaltic magmatism in the psammite and pelite zones***

The magmatism recorded in basaltic and differentiated successions at Kangerluluk, Sorte Nunatak, at several locations in the psammite and pelite zones including the successions related to the gold prospects and deposits on Nanortalik Halvø is only partly described. The may contain important information on the setting and dynamics of the Ketlidian development.

The successions at the southern margin of the Julianehåb batholith are calc-alkaline whereas the information on the successions inter-layered with the psammite and pelite successions at e. g., Kutseq and on Nanortalik Halvø are tholeiitic – some of them quite enriched in TiO2. The combined evidence may suggest that the Kangerluluk and Sorte Nunatak successions are syn-magmatic with the younger sequence of batholith intrusions, whereas the tholeiitic sequences on Nanortalik Halvø and in, e. g. the Kutseq Fjord area are from a different tectonic setting. It has been suggested that the extrusives and related

sediments on Nanortalik Halvø have been emplaced into the sedimentary succession by thrusting.

***The high T and low P metamorphism***

The high T and low P metamorphism of the psammite and pelite successions is a very important feature of the Ketilidian orogen. Equivalent metamorphic characteristics are known from other orogens in other parts of the world. Is this unique to a specific plate tectonic development? Could this be the theme for a research project involving modelling of the P and T variations assuming some of the following processes: 1) magmatic under-plating, 2) magma injection, 3) staking by thrusting, 4) rapid uplift and erosion (telescoping)? Does this suggest rapid heating by stacking and very rapid erosion leading to a compressed geothermal gradient? Could this reflect rapid uplift due to un-leached buoyancy of under-riding continental crust?

Could this be developed into a money making research project?

## Co-ordination:

Until further notice the main communication address and the dump for data to be included on the WEB page is: **Troels Nielsen**, tfn@GEUS.dk.

## Appendix

List of publications resulting from the Suprasyd Project, continuation projects and related projects since 1992.


Birkedal, N. 1998: Mineralization in the Illukulik area and in the Stendalen gabbro, Lindenow Fjord, Southeast Greenland. M.Sc. thesis, University of Copenhagen, 109 pp.

Chadwick, B. & Garde, A.A. 1996: Palaeoproterozoic oblique plate convergence in South Greenland. A re-appraisal of the Ketilidian orogen. In: Brewer, T.S.(ed.): Precambrian crustal evolution in the North Atlantic region. Geological Society Special Publication (London), **112**, 179-196.

Chadwick, B., Erfurt, P., Frisch, T., Frith, R.A., Garde, A.A., Schønwandt, H.K., Stendal, H. & Thomassen, B. 1994: Sinistral transpession and hydrothermal activity during emplacement of the early Proterozoic Julianehåb batholith, Ketilidian orogenic belt, South Greenland. Rapport Grønlands Geologiske Undersøgelse, **163**, 5-22.

Chadwick, B., Erfurt, P., Frith, R.A., Nielsen, T.F.D., Schønwandt, H.K. & Stendal, H.. 1994: Re-appraisal of the Ikermit supracrustal suite of the Ketilidian border zone in South-East Greenland. Rapport Gønlands Geologiske Undersøgelse, **163**, 23-31.

Chadwick, B., Garde, A.A., Grocott, J., McCaffrey, K.J.W. & Hamilton, M.A. 2000: Ketilidian structure and rapakivi suite between Lindenow Fjord and kap Farvel, South-East Greenland. Geology of Greenland Survey Bulletin, **186**, 50-59..

Chadwick, B., Garde, A.A., Grocott, J. & Swager, C. 1997: Batholith-forarc structure in the Palaeoproterozoic Ketilidian orogen, South-East Greenland. In: Wardle, R.J. & Hall, J. (eds): Lithoprobe Eastern Canadian Shield Onshore-Offshore Transect (ESCOOT), Report of 1997 transect meeting. University of British Colombia, Lithoprobe Report **61**, 27-35.

Dahl-Jensen, T., Thybo, H., Hopper, J., & Rosing, M.T. 1998: Crustal structure at the SE Greenland Margin from wide-angle and normal incidence seismic data. Tectonophysics **288**, 191-198.

Dyreborg, A. W. 1998. Gold quartz veins on the amphibolite Ridge, Niaqornarssuk peninsula, South Greenland. M.Sc. thesis, University of Copenhagen, 100 pp.

Garde, A.A. & Chadwick, B. 1996: Geological map of Greenland 1:100.000, Søndre Sermilik, 60 V.3 Nord. Copenhagen: Geological Survey of Denmark and Greenland.

Garde, A.A., Chadwick, B., Grocott, J., Hamilton, M.A., McCaffrey, K.J.W. & Swager, C.P. 1998: An overview of the Palaeoproterozoic Ketilidian orogen, South Greenland. In: Wardle, R.J. & Hall, J. (eds): Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT), Transect Meeting (May 4-5, 1998). University of British Columbia, Lithoprobe Report **68**, 50-66.

Garde, A.A., Chadwick, B., Grocott, J. & Swager, C.P. 1997: Metasedimentary rocks, intrusions and deformation history in the south-east part of the c. 1800 Ma. Ketilidian orogen, South Greenland: project SUPRASYD 1996. Geology of Greenland Survey Bulletin **176**, 60-65.

Garde, A.A., Chadwick, B., Grocott, J., Hamilton, M.A., McCaffrey, K.J.W. & Swager, C.P. 2002.:Partitioned transpression during oblique convergence in the Palaeoproterozoic Ketilidian orogen, southern Greenland. Journal of the Geological Society (London), *in press*

Garde, A.A., Chadwick, B., McCaffrey, K.J.W. & Curtis, M. 1998: Reassesment of the north-western border zone of the Palaeoproterozoic Ketilidian orogen, South Greenland. Geology of Greenland Survey Bulletin, **180**, 111-118.

Garde, A.A., Chadwick, B., Grocott, J. & Swager, C. 1998: Geological map of Greenland, 1:100 000, Lindenow Fjord 60 Ø. 1 Nord. Copenhagen: Geological Survey of Denmark and Greenland.

Garde, A.A., Chadwick, B., Grocott, J. & Swager, C. 1998. Geological map of Greenland 1:100 000. Lindenow Fjord 60 Ø.1 Nord. Geology of Denmark and Greenland Map Series, **CD 15**. Copenhagen: Geological Survey of Denmark and Greenland.

Garde, A.A., Grocott, J., Cruden, A.R. 1997: Rapakivi granites emplacement in the Palaeoproterozoic Ketilidian orogen, South-East Greenland. In: Wardle, R.J. & Hall, J. (eds): Lithoprobe Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT), Report of 1997 transect meeting. University of British Columbia, Lithoprobe Report **61**, 92-99.

Garde, A.A., Grocott, J. & McCaffrey, K.J.W. 1999: New insights on the north-eastern part of the Ketilidian orogen in South-East Greenland. Geology of Greenland Survey Bulletin **183**, 23-33.

Garde, A.A., Hamilton, M.A., Nutman, A.P., Chadwick, D., Grocott, J. & McCaffrey, K.J.W. 2000: Detrital zircon populations in the Eastern Ketilidian orogen, South Greenland: sources of sediments and unroofing of the Julianehåb batholith. In: Eide, E. (ed.): 24. Nordiske Geologiske Vintermøte. Trondheim, 6.-9. Januar 2000, Geonytt **1**: 60-70.

Garde, A.A., Hamilton, M.WA., Chadwick, B., Grocott, J. & McCaffrey 2002: The Ketilidian orogen of South Greenland: Geochronology and tectonics, magmatism and forarc accretion during Palaeoproterozoic oblique convergence. *in press*

Garde, A.A., Venance, K. & Swager, C.P. 1998: HT-LP metamorphism in the psammite and pelite zones of the c. 1800 Ma. Ketilidian orogen, southern east Greenland. Abstract Volume, 1998 GAC-MAC-APGGQ meeting, Québec City, Canada, p. A-62.

Grocott, J., Garde, A.A., Chadwick, B., Cruden, A.R. & Swager, C. 1999: Emplacement of rapakivi granite and syenite by floor depression and roof up lift in the Palaeoproterozoic Ketilidian orogen, South Greenland. Journal of the Geological Society (London) **156** (1), 15-24.

Grocott, J., Garde, A.A., Chadwick, B., Cruden, A.R. & Swager, C. 2000: Discussion on emplacement of rapikivi granite and syenite by floor depression and roof uplift in the Palaeoproterozoic Ketilidian orogen, South Greenland. Journal of the Geological Society (London) **157**(3), 703-704.

Hamilton M.A. 1997: U-Pb geochronology and Nd isotopic evolution of the Ketilidian Orogen, South Greenland: implications for correlations with the Penokean, Makkovikian and Svecofennian Orogens on the south margin of Laurentia-Baltica. COPENA-IGCP 371 Conference: Proterozoic Orogenies and Plate Interactions – The North Atlantic Region in Space and Time, Trondheim, Norway, 2p.

Hamilton, M.A. 1997: Synopsis of new U-Pb geochronological results from the Ketilidian orogen, South Greenland. In: Wardle, R.J. & Hall, J. (eds): Lithoprobe Eastern Canadian Shield Onshore-Offfshore Transect (ECSOOT), Report of 1997 transect meeting. Lithoprobe report **61**, 118-134.

Hamilton, M.A., Garde, A.A., Chadwick, B. & Swager, C. 1995: Ketilidian Orogen, south Greenland: Paleoproterozoic accretion, sedimentation and metamorphism recorded by U-Pb geochronology. Precambrian '95: Tectonics and Metallogeny of Early/Mid-Precambrian Orogenic Belts, Montreal. p.181 (only).

Hamilton., M.A., Chadwick, B. & Garde, A.A. 1996: Ketilidian orogen, South Greenland: a Palaeoproterozoic accretionary arc on the south margin of proto-Laurentia-Baltic.

Evolutionary constraints from U-Pb, Nd and Sr isotopic studies. Geological Society of America Abstracts with Programs, **28**, 313 (only).

Hamilton, M.A., Garde, A.A., Chadwick, D., Grocott, J. & McCaffrey, K.J.W. 1999: Temporal evolution of the Palaeoproterozoic Ketilidian orogen, South Greenland: a synopsis of results from convetional SHRIMP U-Pb geochronology. European Union of Geosciences 10th annual meeting, Journal of Conference Abstracts, **4**(1), 129 (only).

Hamilton, M.A., Chadwick, B., Garde, A.A. & Swager, C.P. 1996: Observations on Palaeoproterozoic for-arc sedimentation and deformation: preliminary U-Pb results from the Ketilidian orogen, South Greenland. In: Wardle, R.J & Hall, J. (eds): Lithoprobe Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT). Report of 1997 transect meeting. Lithoprobe Report **57**, 112-122.

Hansen, E.I. 1998: En geologisk og geokemisk undersøgelse af metavulkanitter og hydrothermale omdannelser, Kangerluk, Sydgrønland. M.Sc thesis, University of Copenhagen, 118 pp.

McCaffrey, K.J.W., Chadwick, B., Garde, A.A., Hamilton, M.A. & Curtis, M.L. 1998: New structural and isotopic age data from the north-eastern border zone of the Ketilidian orogen, South Greenland. In: Wardle, R.J. & Hall, J. (eds.): Eastern Canadian Shield Onshore-Offshore Transect (ESCOOT), Transect Meeting (May 4-5, 1998). University of British Columbia, Lithoprobe Report **68**, 103-114.

Mueller, W.U., Garde, A.A. & Stendal, H. 2000: Shallow-water, eruption-fed, mafic pyroclastic deposits along a Paleoproterozoic coastline: Kangerluluk volcano-sedimentary sequence, southeast Greenland. In: Mueller, W.W, Chown, E.H. & Thurston, P.C. (eds): Processes in physical vulcanology and vulcanoclastic sedimentation: modern and ancient, Precambrian Research **101** (2-4), 163-192.

Mueller, W.U., Dostal, J. & Stendal, H. 2002: Inferred Palaeoproterozoic arc rifting along a consuming plate margin: insights from the stratigraphy and geochemistry of the Kangerluluk sequence, southeast Greenland. International Journal of Earth Sciences **91**, 209-230.

Nielsen, T.F.D., Chadwick, B., Dawes, P.R., Frith, R.A. & Schønwandt, H.K. 1993: Project SUPRASYD 1992: opening season in the Ketolidian of South Greenland. Rapport Grønlands Geologiske Undersøgelse, **159**, 25-31.

Schjøth, F., Garde, A.A., Jørgensen, M.S., Lind, M., Moberg, E., Nielsen, T.F.D., Rasmussen, T.M., Secher, K., Steenfelt, A., Stendal, H., Thorning, L. & Tukiainen, T. 2001: Mineral resource potential of South Greenland: the CD-ROM, Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/57**, 36 pp. 1 CD-Rom.

Steenfelt, A. 1994: Large scale geochemical variations in the Precambrian of West and South Greenland. Rapport Grønlands Geologiske Undersøgelse, 160, 41-44.

Steenfelt, A. 1999: Compilation of data sets for a geochemical atlas of West and South Greenland based on stream sediment surveys 1977 to 1997. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1999/41**, 99 pp.

Steenfelt, A. 2000: Geochemical signatures of gold provinces in South Greenland. In: Stendal, H.(ed.): Exploration in Greenland: discoveries of the 1990s, Transactions of the Institution of Mining and Metallurgy, Section B, Applied Earth Science **109** (January - April), B14-B22.

Steenfelt, A.. 2001: Geochemical atlas of Greenland - West and South Greenland, Danmarks og Grønlands Geologiske Undersøgelse Rapport **2001/46**, 398 pp, 54 plates.

Steenfelt, A.2001: Calibration of stream sediment data from West and South Greenland. A supplement to GEUS report 1999/41, Danmarks og Grønlands Geologiske Undersøgelse Rapport **2001/47**, 43 pp.

Steenfelt, A. & Tukiainen, T. 1991: Geochemical mapping: distribution of gold, arsenic, antimony and tantalium in South Greenland. Rapport Grønlands Geologiske Undersøgelse, **159**, 25-31.

Steenfelt, A., Nielsen, T.F.D. & Stendal, H. 2001: Mineral resource potential of South Greenland. Review of new digital data sets, Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/50**, 47 pp.

Stemp, R.W. 1997: Helicopter-borne geophysical surveys in the Grønnedal region, South-West Greenland. Results from Project AEM Greenland 1996. Danmarks of Grønlands Geologiske Undersøgelse Rapport **1997/12**, 76 pp.

Stendal, H.1997: Frank Vokes symposium. Formation and metamorphism of massive sulphides, Trondheim: Norwegian University of Science and Technology (NTNU), Marts 1997. Minerals Industry International. Bulletin of the Institution of Mining and Metallurgy **1037**, 28-30.

Stendal, H. 1997: The Kangerluluk gold prospect. Shear zone hosted gold mineralization in the Kangerluluk area, South-East Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1997/53**, 18 pp.

Stendal, H. & Frei, R. 2000: Gold occurrence and lead isotopes in Ketilidian Mobile Belt, South Greenland. In: Stendal, H.(ed.): Exploration in Greenland: discoveries of the 1990s, Transactions of the Institution of Mining and Metallurgy, Section B, Applied Earth Science **109** (January - April), B6-B13.

Stendal, H. & Grahl-Madsen, L. 2000: Geochemical investigation over a gold prospect, Niaqornaarsuk peninsula, South Greenland. In: Stendal, H.(compiler): Exploration in Greenland: discoveries of the 1990s, Transactions of the Institution of Mining and Metallurgy ,Section B, Applied earth science **109** (January - April), B60-B66.

Stendal, H. & Schønwandt, H.K. 1997: Project Suprasyd, South Greenland. Minerals Industry International. Bulletin of the Institution of Mining and Metallurgy **1038**, 32-37.

Stendal, H., Frei, R., Hamilton, M.A. & Mueller, W.U. 2001: The Palaeoproterozoic Kangerluluk gold-copper mineralization (southeast Greenland): Pb and Nd isotopic constraints on its timing and genesis. Mineralium Deposita **36**, 177-188.

Stendal, H.; Mueller, W.; Birkedal, N.; Hansen, E.I.; Østergaard, C. 1997: Mafic igneous rocks and mineralisation in the Palaeoproterozoic Ketilidian orogen, South-East Greenland: project SUPRASYD 1996. Geology of Greenland Survey Bulletin **176**, 66-74.

Thorning, L. & Stemp, R.W. 1997: Projects Aeromag 1995 and Aeromag 1996. Results fom aeromagnetic surveys over South Greenland (1995) and southern West Greenland (1996). Danmarks og Grønlands Geologiske Undersøgels Rapport **1997/11**, 44 pp.

Tukiainen,T., Erfurt, P. & Thorning, L.1993: Project to assess the application of Spot and Landsat TM imageries to geological reconnaissance, South-East Greenland. Final report. Open File Series, Grønlands Geologiske Undersøgelse 93/8, 32 pp., 2 figs, 5 tables, 8 plates.

Østergaard, C. 1998. Geology and geochemistry of mafic rocks and associated gold mineralization in the Kutseq area, Southeast Greenland. M.Sc thesis, Unibversity of Copenhagen, 155 pp.