DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2015/32

South-East Greenland Mineral Endowment Task (SEGMENT) - Project status 2014

Bo Møller Stensgaard

GEUS

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

Introduction

The SEGMENT project (**S**outh-**E**ast **G**reenland **M**ineral **EN**dowment **T**ask) was initiated in 2011 and will terminate by the end of 2015. It is financed jointly by GEUS and the Ministry of Mineral Resources, Government of Greenland (MMR; formerly the Bureau of Minerals and Petroleum). The objective of the SEGMENT project is to increase the data coverage and improve the knowledge-base for the evaluation of the mineral endowment of the North-Atlantic Craton, the Ammassalik Mobile Belt, and the Palaeogene magmatic suite in South-East Greenland between 62°N and 67°N.

SEGMENT was initiated with regional geological reconnaissance, stream sediment, till, and fresh water sampling program through 2009 and 2010. In combination with previous geological reports the analytical data obtained from these sample sets constituted is the first modern and comprehensive data sets from the region and were the basis for the planning of the investigations to be carried out in the following years.

In 2011 and 2012 the focus of the SEGMENT project was centred on the Skjoldungen area of the North Atlantic Craton in South-East Greenland (62°N to 64°N). Major field campaigns were completed, and in the original plan for the field work related to the SEGMENT project was to be continued in the Tasiilaq region in 2013. However, due to budget considerations the fieldwork in the Tasiilaq region was postponed until 2014. Year 2013 was instead used for continued investigations of already sampled material, archived data and results from the Skjoldungen region, as well as the preparation of the 2014 campaign in the Tasiilaq region.

The current report provides an overview of the work carried out in the SEGMENT project in 2014, as well as the fiscal information for the project. Obtained scientific results, as well as compilations of new data and geological maps, are presented in separate reports.

South-East Greenland
Mineral ENdowment Task (SEGMENT) 2014

The 2014 work divided into four main tasks:

1) Continued work on the Skjoldungen region, and interim workshop,
2) Preparation of fieldwork and preparations of data compilations for the Tasiilaq region, and a pre-fieldwork Workshop,
3) Fieldwork campaign in the Tasiilaq region, and
4) Post-fieldwork reporting on collected observations and obtained analyrtical data from the Tasiilaq region.

Task 1: Continued work in Skjoldungen region and interim workshop

Task 1 of SEGMENT 2014 was directed toward the continued reporting and compilation of information on the Skjoldungen region. A status for the studies was given in connection with the pre-fieldwork workshop for the 2014 fieldwork in theTasiilaq region. One day was devoted to reports for on-going research on the Skjoldungen region.

The workshop was well attended with abstract contributions/presentations by authors representing 15 national and international institutions:

- Geological Survey of Denmark and Greenland (GEUS)
- Ministry of Mineral Resources, Government of Greenland
- University of Copenhagen, Department of Geosciences and Natural Resource Management
- Nordic Center for Earth Evolution and Natural History Museum of Denmark
- University of Stellenbosch, Department of Earth Sciences
- Lund University, Department of Geology
- University of California, Department of Geology
- University of Aarhus, Department of Geoscience
- Geotrack International, Australia
- University of Oulu, Department of Geosciences
- RWTH Aachen University, Institute of Mineralogy and Economic Geology
- University of Western Australia
- University of Bern, Institute of Geological Sciences
- Université Montpellier, Géosciences Montpellier
- University of Cologne, Department of Geology and Mineralogy

The abstracts from the workshop can be found in Stensgaard (2014). Two abstracts, which due to an editorial issue did not appeared in the abstract volume, are found in Appendix A of this report. The abstracts and presentations provide an overview for the data compilation, the research, and the investigations carried out in the Skjoldungen region until early 2014.

The results and conclusions in presentations given at the workshop are listed here in bullet-form.

Geochronology

Provenance study and characterization of the South-East Greenland basement – detrital zircons from glacial till and stream sediments analysed by zircon U-Pb and CCSEM (from Thrane 2014a)

- The detrital zircons from Skjoldungen and Tasiilaq regions reveal characteristic age distributions (Fig. 1) and starting from the north: (1) a zone between ~67°30'N and ~66°15'N (the southern extend being at the latitude of the Niflheim thrust zone) yields detrital zircons with a main peak at 2800-2700 Ma, (2) an E-W zone from ~66°15'N to just north of Tasiilaq has a large spread in the zircon ages (3300-1900 Ma) and a comparatively high frequency of older zircons, (3) an E-W zone centred on Tasiilaq and Kulusuk with detrital zircons with a main peak around 1950-1900 Ma, (4) one sample with a distinct peak at ~2520 Ma from the edge of the inland ice east of Kap Tycho Brahe, (5) a zone from the Isortoq area and all the way down to Bernstorff Isfjord at-63°45'N that is dominated by a 2900-2700 Ma zircon age distribution with some older zircons in addition, and (6) the area from Graah Fjord to Timmiarmiut area (63°30'N-62°30'N) that is characterized by a main peak at 2800-2700 Ma.
- Cretaceous Kangerlussuaq sediments at ~68°N, were fed from both the north and the south.

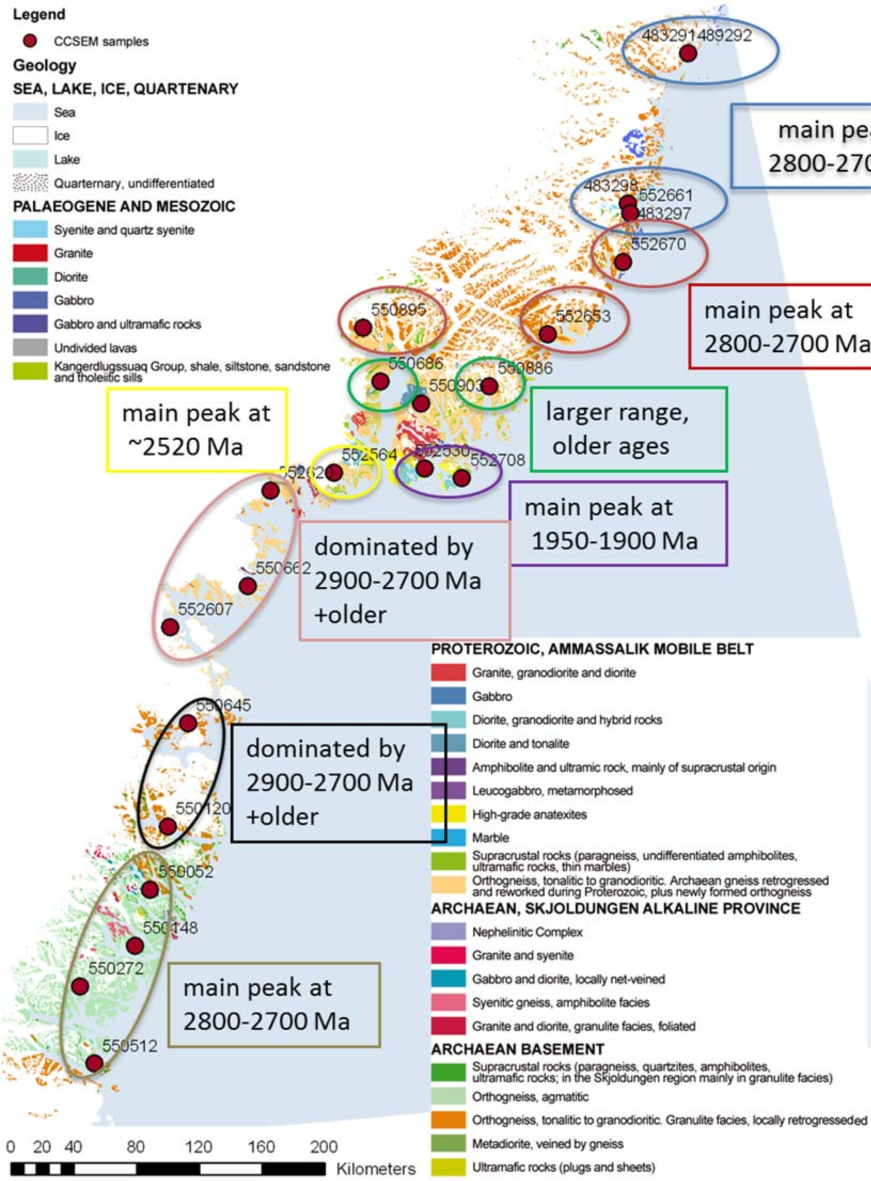


Figure 1. *Summary of characteristic age distributions of detrital zircons from stream sediment samples from the Skjoldungen and Tasiilaq regions (after Thrane 2014a).*

Zircon geochronology for the Skjoldungen region – status for the South-East Greenland geochronological database (from Næraa et al. 2014).

- Handlede samples: Total number of samples: 105 (Fig. 2), number og interpreted ages: 164, total number of spots: 7278
- Intrusive granitoids
    - Granitoid intrusion ages range from 2679 to 2760 Ma and these ages are related to the Skjoldungen orogeny and the intrusion of the Skjoldungen Alkaline Province (SAP)
    - The main age populations are at 2700, 2710, 2737 and 2753 Ma
    - Zircon ages become younger from Kong Dans halvø and toward the north
- Inherited zircon ages

- The inherited zircons show overall younger ages from south to north. In the Tingmiarmiut region inherited zircons range from ~3200 to 3885 Ma
  - Samples from Skjoldungen Island and Langenæs provide a significant population of 3000-3100 Ma old zircons.
  - Thors Land is characterised by ca. 3000-3050 Ma inherited zircons
- An additional suite of inherited zircon grains with ages of ~2900 Ma is found from Kong Dans Halvø and northward.
- Youngest inherited zircons have ages at ~ 2800 Ma, and found throughout south-east Greenland.
- Pegmatites
  - Most zircon ages are confined to 2694±2 Ma
  - A few samples with ages >2700 and up to 2721 ± 7 Ma are recorded
  - One young age of 2600 Ma is recorded.
- Gneiss protolith ages
  - Main populations care confined to the age intervals ~3020-3050, ~2860-2880 and around 2800 Ma
    - 3020-3050 Ma ages dominate Thors Land and correspond to the ages of inherited zircons in intrusive granitoids

Figure 2. *Location of samples (green circles) used for geochronological (zircon) studies in the Skjoldungen region (status as of March 2014, Figure based on Næraa et al. 2014).*

Basement characterization

Investigations of heavy mineral assemblages from glacier, till, and stream sediment samples using computer-controlled scanning electron microscopy (CCSEM) (Keulen, 2014).

- Five different regions of basement orthogneiss can be distinguished from the CCSEM heavy mineral investigation (Fig. 3)
- A northern zone (marked A in Fig. 3), between Niflheim thrust and Kialineq (~67°30'N-66°15'N) is characterized by heavy mineral assemblages indicating a basement orthogneiss equilibrated at a lower granulite facies peak temperature, with a peak metamorphic paragenesis of clinopyroxene, orthopyroxene and magnetite and additional biotite, ilmenite and hornblende.
- A zone between Niflheim thrust and Tasiilaq (marked B in Fig. 3) characterized by an amphibolite facies peak temperature and a metamorphic paragenesis of hornblende, clinopyroxene, biotite, garnet and additional muscovite, sphene, Ti-magnetite. The occurrence of omphacitic pyroxene corroborates with the already recorded presence of lithologies with eclogitic parageneses within this zone.
- A zone between Tasiilaq and southern Jens Munk Ø (marked C in Fig. 3) characterized by heavy mineral assemblages indicating a basement orthogneiss at an amphibolite facies peak with a metamorphic paragenesis composed of hornblende, biotite and ortho-amphibole/ortho-pyroxene, epidote, sphene, Ti-magnetite. Hastingite-hornblende may be indicative for slightly higher pressure metamorphism in this zone.
- A zone between southern Jens Munk and Graah Fjord (marked D in Fig. 3) is characterized by mineral assemblages indicating upper(?) amphibolite facies peak temperature with metamorphic minerals being hornblende, clinopyroxene, biotite and sphene, muscovite, and garnet. This zone of orthogneiss has previously been described as being a zone of Palaeoproterozoic gneisses reworked from granulite facies; no evidence for reworking to granulite facies is presented by the heavy mineral investigations
- A zone between Graah Fjord and south of Timmiarmiut is defined by a peak granulite facies assemblages composed of clinopyroxene, orthopyroxene, (Ti)-magnetite and ilmenite, biotite, muscovite and garnet.

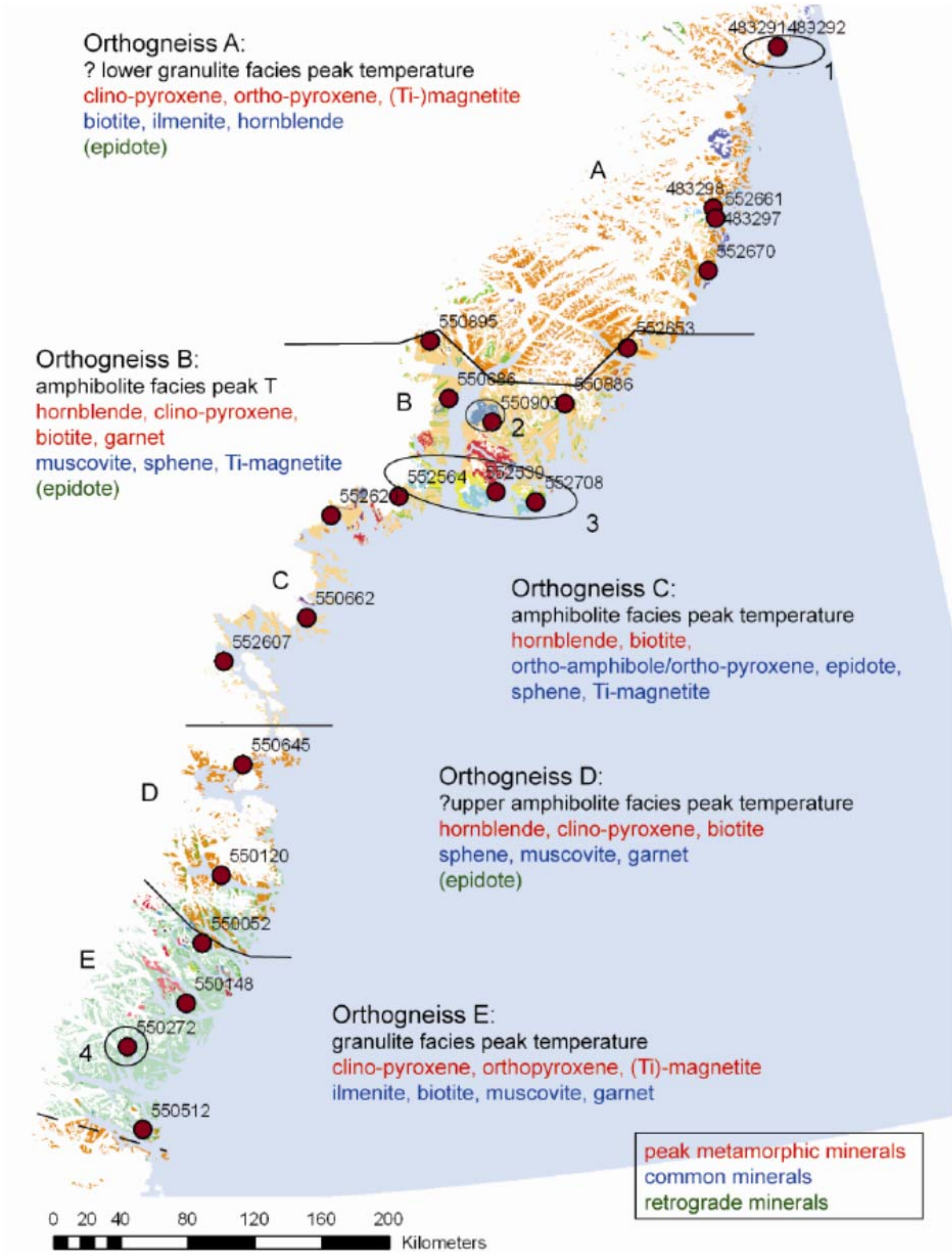


Figure 3. *Summary of some of the findings from CCSEM heavy mineral investigations of glacier till and stream sediment samples from South-East Greenland. See Keulen (2014) for more information.*

Intrusions and host rocks in the Skjoldungen Alkaline Province (SAP)

Field observations and geochemical results for the Skjoldungen Alkaline Province (SAP) (from Kokfelt et al. 2014)

- new geochronology and geochemical data show systematics within part of the SAP and point to crustal interaction as critical parameter for the development of distinct differentiation trends

- Detailed work on selected intrusions provides new insights to formation of early alkaline magmatism, including the origin of magnetite-rich layers and the nelsonite association (e.g., in the Ruinnæsset intrusion)
- Occurrences of syenitic gneiss, mainly in the Kassortoq and Skirner Bjerge areas, are with an age of ~2.75 Ga confirmed to be syn-orogenic felsic intrusions, most likely related to the SAP.
- Agmatitic gneiss in Skirner Bjerge reveals three distinct events of crustal formation at c. 3.22, 2.99 and 2.76 Ga. Further isotopic work (Lu-Hf whole rock and Hf on Zr) will provide constraints on sources, timescales of magma formation in the mantle and contributions from crustal reservoirs.
- Syn- to late-orogenic 2.74-2.71 Ga felsic intrusions (syentitic and granitic) occur in Thrymheim nunatak and Sfinksen areas (marked 8 and 6 in Fig. 4).
- Syn- to late-orogenic 2.74-2.71 Ga(?) mafic intrusions also occur at e.g. Halfdan Fjord, Stærkodder Vig, Hermod Vig, and in other areas; they are foliated mafic (gabbroic-noritic) or ultramafic in composition and are intruded by at least four generations of felsic pegmatites
- Late- to post-orogenic (2.71-2.69 Ga) mafic intrusions occur, e.g., at Vend Om, Ilugdlermiut, Njord Geltscher, Balder Fjord, Ruinnæsset. Some of these intrusions are well preserved and shows concentric and well-developed magmatic layering. Magnetite-rich concordant layers are observed locally in some of these intrusions.
    - The Ruinnæsset intrusion has been studied in more detail and shows a much wider range of lithologies than previously rekcognized, including hypersthene-bearing hornblendites, leucogabbros, monzodiorites, monzonites and syenites.
        - The feldspar-rich rocks make up the main body of the intrusion. These rocks often show pronounced near-vertical modal layering with thin hornblende-, pyroxene-, biotite- and oxide-rich layers alternating with broad bands rich in feldspar.
        - Late magnetite-apatite rich veins (nelsonite association) intrude the main lithologies of the intrusion and could evidence late stage liquid immiscibility.
- Deformed syn-orogenic SAP dykes cut earlier intrusions and gneisses and offer the possibility for insight into the compositions of the melts responsible for the SAP.

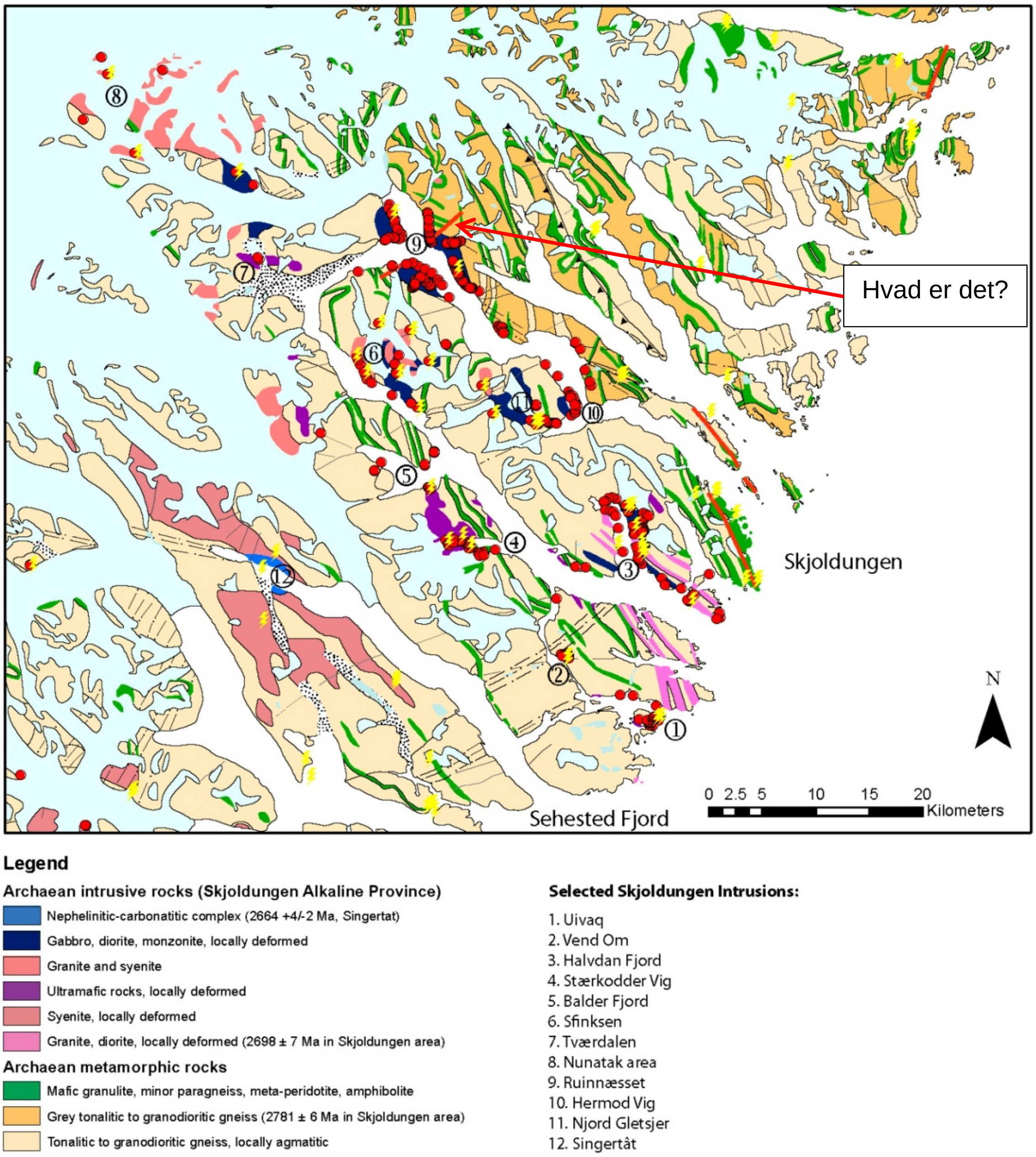


Figure 4. *Map of localities visited in the Skjoldungen Alkaline Province (red circles >700 stations;). The lightning symbols (yellow) identify samples selected for U/Pb- La-ICPMS age determination (after Kokfelt et al. 2014).*

Mafic dykes in the Skjoldungen region

Mafic dykes across theNorth Atlantic Craton in Greenland: an updated record of at least seven major magmatic events between 2.5 to 0.06 Ga (Klausen et al. 2014)

- Dykes within the North Atlantic Craton, including the Skjoldungen region, record magmatic events at ~2.4 Ga, ~2.2 Ga, ~2.0 Ga, ~1.6 Ga, ~1.3 Ga and ~60 Ma (Fig. 5).
- Three areas have been surveyed in detailed: (a) the Timmiarmiut area, (b) the eastern part of Skjoldungen island and neighbouring areas, and (c) the Umivik area.

- Preliminary baddeleyite U-Pb ages identify the presence of two Palaeoproterozoic dyke swarms stretching across from SW Greenland (2.37 Ga and 2.21 Ga)
- At Skjoldungen, ~2.135 Ga ages and four preliminary 2.1-2.2 Ga ages and two 2.37 Ga ages are all from dykes with indistinguishable WSW-ENE strikes
- The Umivik area is cross cut by two conspicuous and relatively intense swarms including an older WNW-ESE trending swarm of amphibolite dykes (senso lato, >10% plag) and a younger and more E-W trending swarm of dolerites, with better preserved igneous textures). No age information is yet available.
- Late-Ketilidian appinites in the Timmiarmiut area. They crosscut E-W trending Palaeoproterozoic dykes. Both are cut by younger N-S oriented dykes.of probable Tertiary age.
- 1630 Ma aged dykes in the Skjoldungen region have been referred to the 1.63 Ga Melville Bugt Dyke Swarm.
- 1.27 Ga old dykes belonging to the Gardar Province have been found in the Timmiarmiut area. They have same strike as Palaeoproterozoic dykes, but cut the dykes referred to the 1.63 Ga Melville Bugt Dyke Swarm
- Two dykes, very similar to those referred to the Melville Bugt Dyke swarm, but with conspicuously different incompatible trace element patterns were sampled in the Umivik area. They coincide with aeromagnetic anomalies across the Tertiary rifted margin on the shelf of the Irminger Sea. They show OIB-like spidergram patterns, are likely Tertiary dykes and tentatively relatedto the proto-Icelandic mantle plume. Their Tertiary age has yet to be confirmed.

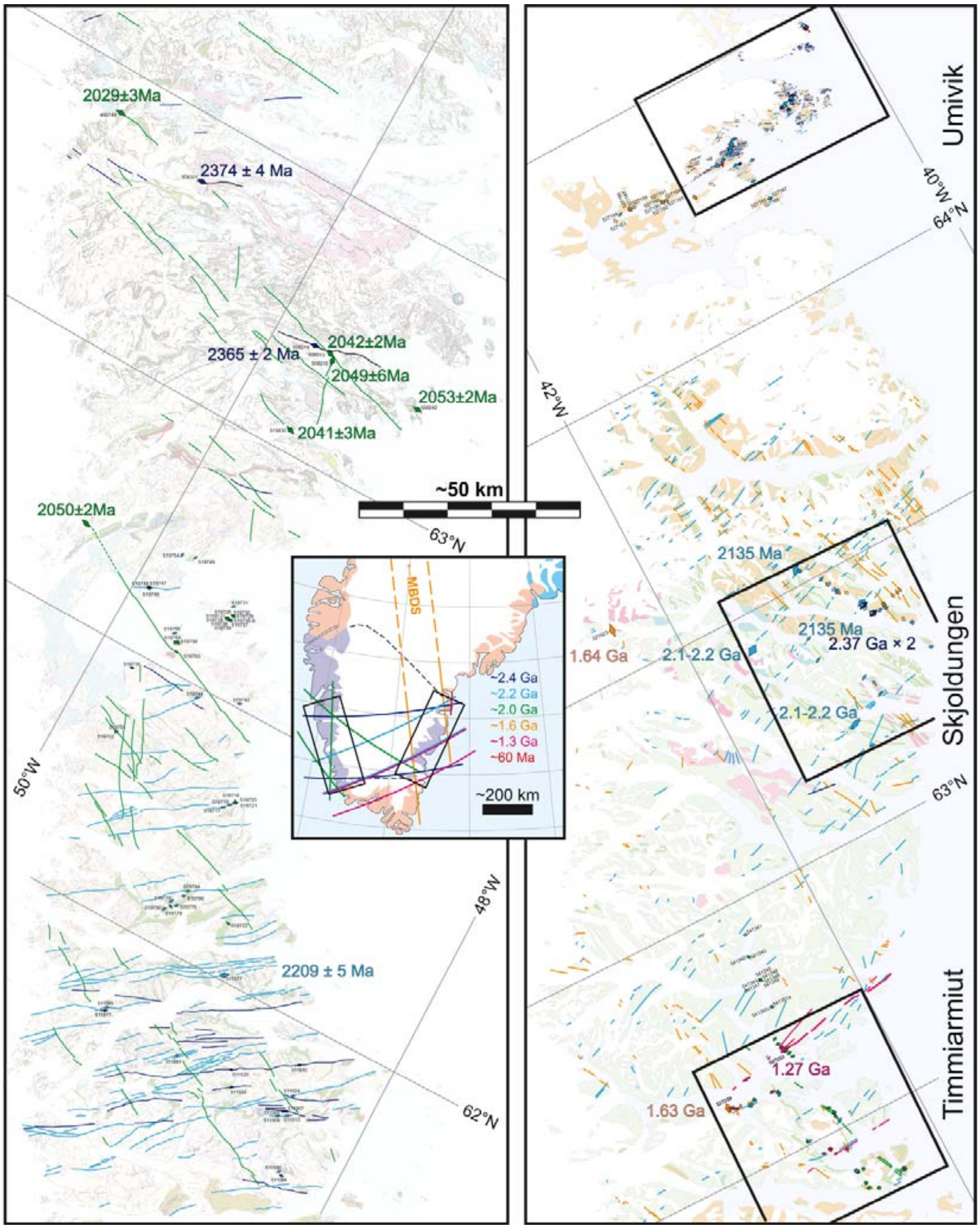


Figure 5. *Maps of the dyke distribution and ages in South-West Greenland and South-East Greenland (left and right maps respectively). The three areas in South-East Greenland that were investigated in detail are shown. The insert map shows the interpreted continuation of the dyke swarms across Greenland and approximate ages (after Klausen et al. 2014).*

Carbonatite dykes and complexes

Carbonatite dykes; new occurrence, re-discovery, and carbonatite intrusions confined to a specific 60 km long zone of the basement? (Tukiainen 2014)

- Besides the larger and late to post orogenic carbonatite-bearing Singertât complex at Kassortoq two other areas have been found to host carbonate-rich rocks in the form of dyke intrusions (Fig. 6).
    - The Uummannaq Kangertiva area (at the south-eastern part of the peninsula that hosts the Singertât carbonatite) and the Timmiarmiut area both host one or more dykes up to 40 m in width in 400 m broad zone. The carbonatitic occurrences are affected by strong deformation and granulite facies metamorphism. The granulite conditions often transform the carbonate to calc-silicate rocks. The carbonatite-rich rocks classify as søvite and silico-carbonatite. They are in places rich in magnetite. They show only low concentrations of REE, Nb, etc. and are only enriched in Sr.
    - Together, the caronatitic occurrences define a major and 60 kilometre long zone of pre- or syn-orogenetic carbonatitic activity– stretching from the northern shore of Uummaannaq kangeriva to to south of Timmiarmiut.

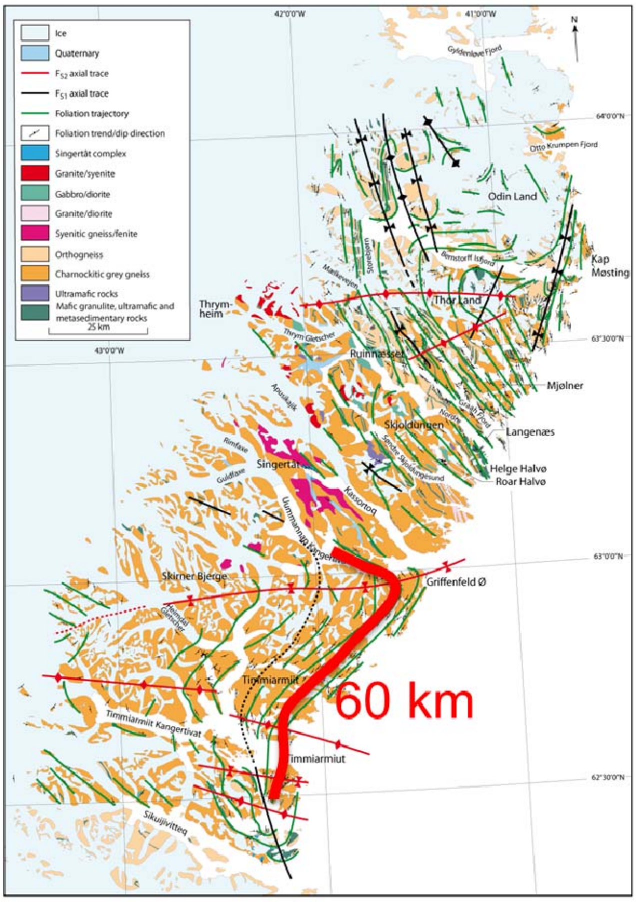


Figure 6. *Outline of the suggested 60 km long zone with carbonatite-activity in South-East Greenland (red zone, after Tukiainen, 2014).*

Post orogenic tectonic evolution

Reactivation of Proterozoic structures along the South-East Greenland margin, Skjoldungen region (Guarnieri et al. 2014)

Structural data have been collected on brittle structure/faults in the entire Skjoldungen region (Fig. 7) and can be summarised as follows:

- Four phases of likely Proterozoic deformation are ptroposed; starting with (1) the oldest which shows NE-SW extension and is accompanied by dikes intruding along the foliation planes; this followed by (2) comprising SE-NW extension and dikes cutting the foliation; (3) a strike-slip event, which in turn is followed by (4) a SE-NW extension with dikes cutting the faults
- A much younger Cretaceous-Paleocene (?) strike-slip event is also suggested (see below).

All dikes in the Skjoldungen have been digitalised from geological maps and aerial photos and are used for the establishment of the structural regimes.

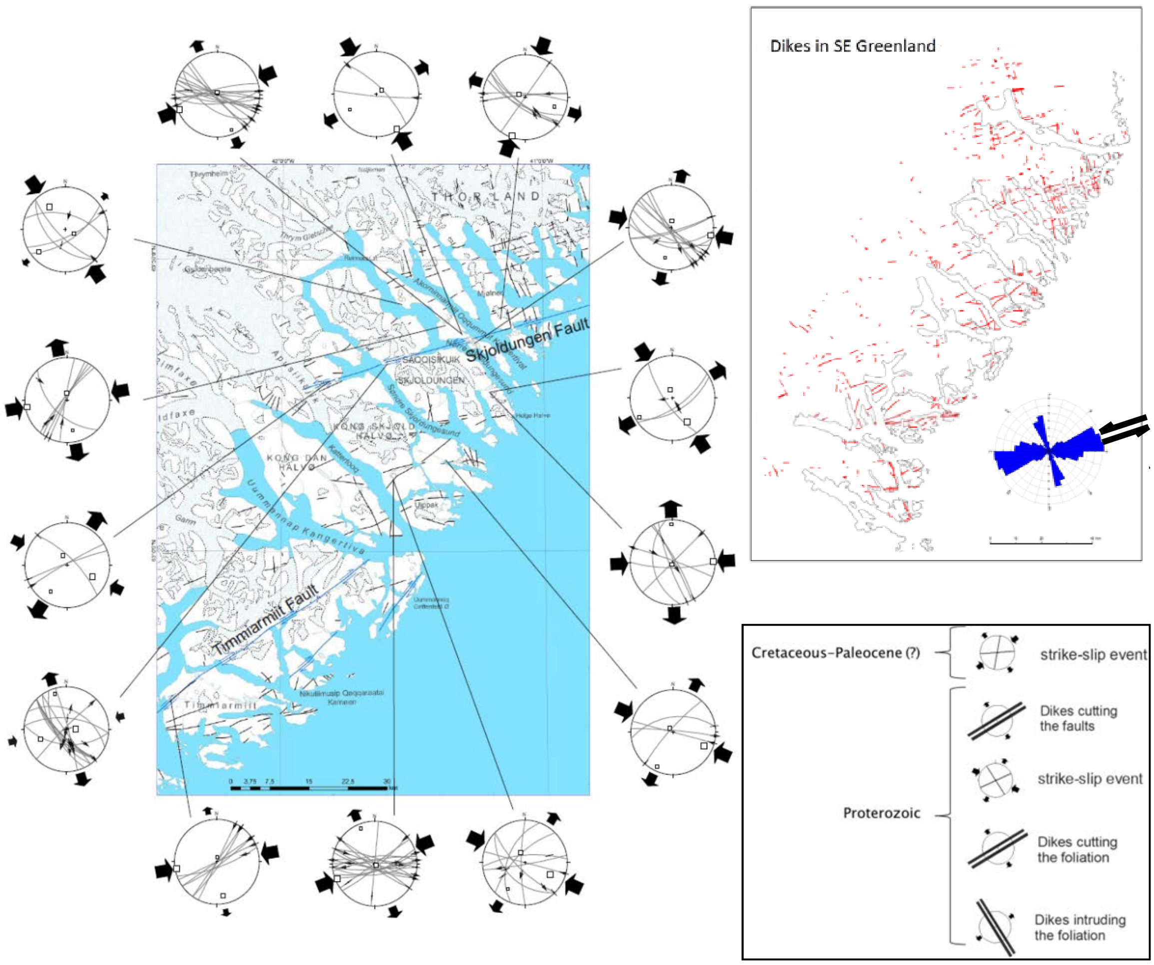


Figure 7. *Kinematics of the brittle faults i in the Skjoldungen area (left part of the figure) and the digitalised dyke distribution and the corresponding structural rose diagram (upper right part of figure). Interpretation of the four phases of Proterozoic deformation and the suggested Cretaceous-Palaeocene deformation is illustrated (lower right, after Guarnieri et al., 2014).*

Constraints for the Cretaceous-Tertiary geotectonic history of the Skjoldungen region (Guarnieri 2014)

- Several late structures, assumed to be Phanerozoic in age, have been recorded in South-East Greenland and their presence is supported by new aeromagnetic and gravity data.
- The off-shore seismic lines and the location of the Skjoldungen region in the Tertiary East Greenland Volcanic Rifted Margin, the distributions of flood basalts, and the distribution dyke swarms provide robust constraints for the tracing of the Cretaceous-Tertiary geotectonic evolution.
- Paleo-drainage systems – remnants of westward directed paleo-drainage are in part controlled by then active faults and document late tectonic movements on pre-existing faults.
- Constraints from a reconstruction of the North Atlantic at Chron 23 times.
- Cooling events (periods of uplift) deduced in a study of apatite fission tracks, but awaits refinement before final conclusion on ages of events. A simple interpretation based on relative probability of ages in more samples suggests at least 6 events; one event >220 M, one event between 130-210 Ma, one between 90-105 Ma, one between 55-60 Ma, one between 30-40 Ma and one between 5-20 Ma.

Apatite fission tract analysis (Green 2014)

- In a more rigorous complex approach to the ages of the fission track analysis Green (2014) deduce seven cooling events at 460-360Ma, 240-235 Ma, ~175 Ma, 135-130 Ma, 70-50 Ma, 40-30 Ma, 10-0 Ma

Burial, uplift and exhumation history of southern East Greenland after the opening of the NE Atlantic (Japsen et al 2014)

- At Kangerlussuaq, further to the north, three post-breakup uplift phases at 35, 10 and ~5 Ma shaped the present-day margin. The uplift phases overlap with uplift phases deduced for South-East Greenland and may be common to the Volcanic Rifted Margin of the North Atlantic in Greenland.

Mineral occurrences

W-Mo quartz vein and W-rich amphibolite horizons from the Thrudvang peninsula, Skjoldungen, SE Greenland (Rosa & Ulrich 2014)

- A Sub-vertical quartz-wolframite-molybdenite vein with phyllic alteration has been found on Thrudvang peninsula, Skjoldungen region (Fig. 7). It is hosted in a package of mafic granulite gneiss. Two rusty amphibolite horizons of the mafic granulite package hosting the vein are anomalous in W, but not in Mo. UV light studies documented that the W is present, not as wolframite, but as scheelite.
- A molybdenite concentrate from the vein was dated using the Re/Os method at Acme Labs (Canada) and yielded a Neoarchean age of 2749±11 Ma. This age is similar to the ~2740 Ma porphyritic granitic rocks and the 2753±5 Ma Skirner Bjerge syenites, and interpreted to have been emplaced during the first stage of regional transpression (DS1of the Skjoldungen Orogeny,Kolb *et al*., 2013).

- The vein records a previously unknown tungsten-molybdenum mineralising event in South-East Greenland, in addition to the previously described molybdenite occurrences related to Palaeogene intrusions further north in East Greenland
- According to Stein (2006), rhenium concentrations in molybdenite can be used for assessment of mineralisation type and economic potential. Occurrences with <20 ppm, or even sub-ppm Re, are typically sub-economic and formed by local melting and dehydration of biotite gneiss, whereas occurrences with 100s-1000s ppm Re typically are of possible economic interest and related to porphyry-style intrusions. The molybdenite of the identified showing shows 54 ppm Re. Discrimination between the two mineralisation types is not possible as the analytical data is inconclusive. However, the possibility that the studied vein can be linked to an intrusive body and that it could be part of a wider system with an economic potential remains a possibility.

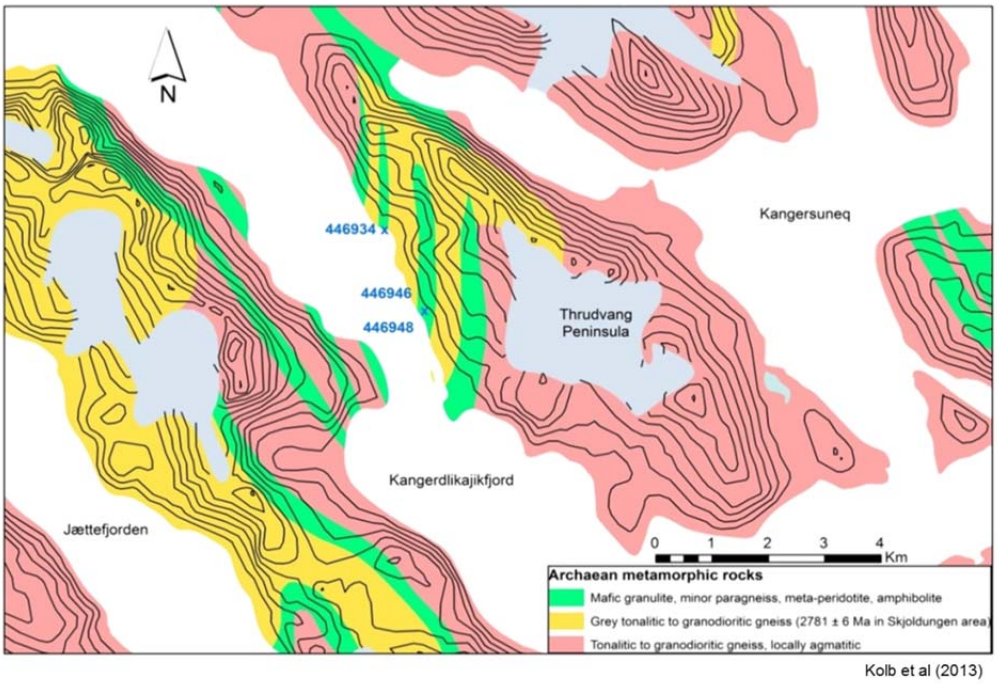


Figure 8. *Map showing the location of the described W-Mo quartz vein (sample no. 446946) and W-rich amphibolite horizons (sample no. 446934 and 446948) (After Rosa & Ulrich, 2014).*

Detailed study of a Fe-Ti oxide layers in the Njords Glacier Gabbro, Skjoldungen Alkaline Province, South-East Greenland (Árting et al. 2014)

- The Fe-Ti oxide bands occur in the lower part of the Njords Glacier gabbro which is part of the Skjoldungen Alkaline Province (Fig. 8).
- Investigations of the Fe-Ti oxide bands shows that they formed by gravitational settling of Fe-Ti oxide(s) from a single melt.
- Ore grade of the magnetite bands is 0.6 ± 0.2 % V_2O_3 compared to 1.6 ±0.2 % in the main magnetite seam in Bushveld complex, South Africa.

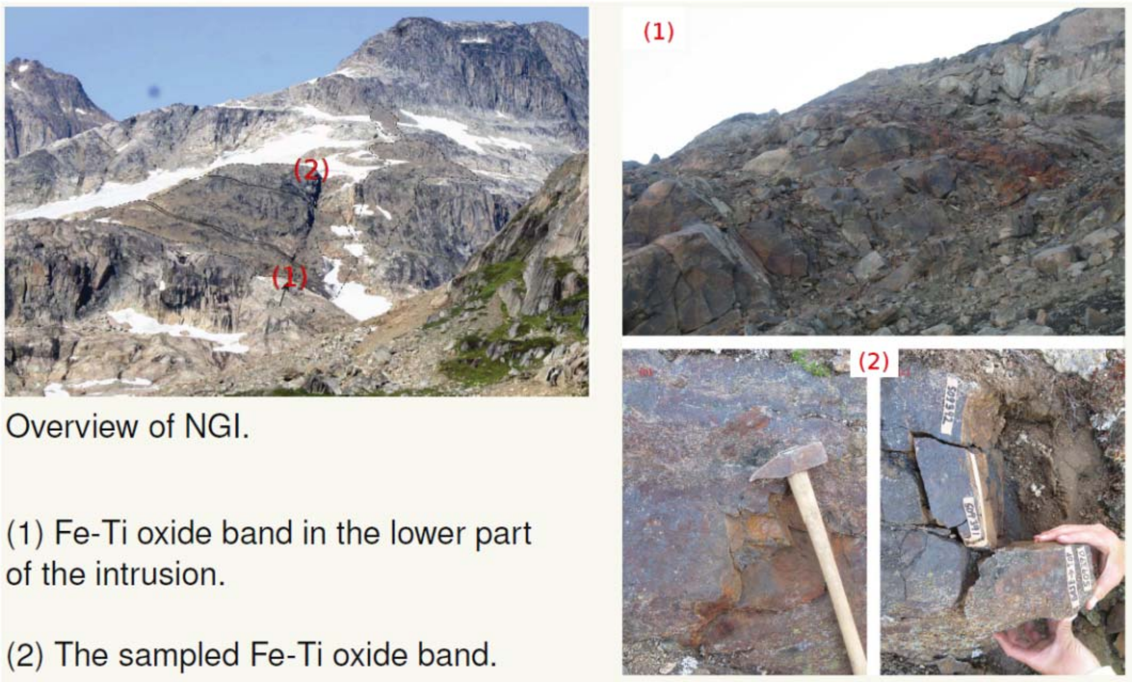


Figure 9. *Field photos of the Fe-Ti oxide bands in the Njords Glacier Gabbro, Skjoldungen Alkaline Province. Figure from Árting (2014).*

Task 2: Preparation of data from Tasiilaq, planning of fieldwork and pre-fieldwork workshop

Task 2 of SEGMENT 2014 divides in three parts: I) processing, preparation, and assessment existing data from the Tasiilaq region, II) a pre-fieldwork workshop, and III) planning of the fieldwork.

I) Processing, preparation, and assessment existing data

Processing, preparation, and assessment of existing data was initiated in 2013 and continued into 2014. The resulting data sets are stored in the SEGMENT data folder on the central server system at GEUS. They will be made public by the end of 2015 or beginning of 2016 and at the termination of the SEGMENT project. The data that were assessed and stored included, e.g., old geological field maps and reports, geophysical data packages, existing geochemical data including released and accessible company data, processed ASTER satellite images and aerial photos, and data produced therefrom. A selection of digital data was made accessible in to participants in the fieldwork on hand-held tablets and/or smartphones using GEUS' digital fieldwork software 'aFieldWork'.

II) Pre-fieldwork SEGMENT workshop, March 2014

The data and earlier investigations of the Tasiilaq region presented, discussed, and assed at a pre-fieldwork workshop held in March 2014. The presentations and accompanying abstracts can be found in Stensgaard (2014).

A summary and listing of the presented results and conclusions from presentations is given below. Most speakers reviewed the then present geological knowledge within in their field and outlined their scope for the fieldwork to be undertaken in the Tasiilaq region in 2014.

Palaeoproterozoic in SE Greenland revisited:
The Nagssugtoqidian Orogen of South-East Greenland: Facts, new interpretation and research needs (Kolb & Stensgaard 2014)

- Defined Terranes
    - The Thrym Complex, which forms the North Atlantic Craton in the Skjoldungen region is characterised by 2850-3450(?) Ma mafic granulite paragneiss and ultramafic rocks; 2870-2790 Ma TTG gneiss and monzogranite; 2755-2740 Ma granodiorite, monzogranite and syenite; the 2720-2700 Ma old Skjoldungen Alkaline Province; and hosts a 2680-2665 Ma old nephelinitic complex..
    - The Schweizerland Terrane, bounded to the south by the Niflheim Thrust (at the head of Sermilik Fjord and its equivalent toward the East) and continuing northward, is dominated by polyphase orthogneiss (Qtz-Pl-Kfs-Cpx-Opx, granodiorite) with zircon ages of 2835 +6/-8 Ma, 2863 ± 11 Ma, 2756 ±

6 Ma, 2734 ± 34 Ma. Pegmatite from the terrane yields a zircon age of 2630 ± 65 Ma which is assumed to be a syn-amphibolite facies retrogression age.

- The Kuummiut tTerrane, which stretches from north of the E-W oriented Ammassalik Intrusive Complex (AIC; 1885 Ma) to the Niflheim Thrust and its continuation to the East consist mainly of migmatitic orthogneiss (granodiorite; Qtz-Pl-Kfs-Bt-Hbl) with zircon ages of 2636 +22/-18 Ma. A separated gneiss domain, the Blokken gneiss complex has been dated at c. 2920 and 2960 Ma and 3035 ± 14 Ma – with zircons having metamorphic rims that yields 2723 ± 49 Ma.
- The Isortoq Terrane, which stretches from south of AIC southwards towards Skjoldungen region and the Thrym Complex, is as yet poorly known. It consist of polyphase mainly granodioritic orthogneiss and narrow bands of mafic and ultramafic rocks and local paragneiss.

- Questions to be addressed include:
  - subduction lasting to a ~1870 Ma collision and a late orogenic collapse represent do the Thrym and Isortoq terranes belong to the one and same Archaean continent or do they represent two different continental fragments?
  - Do the gneisses of the Isortoq terrane include an older Archaean precursor?
  - Does a system of 2200-2050 Ma old mafic dykes and subsequent WSW-vergence a complete Paleoproterozoic Wilson-cycle?

- Síportoq Supracrustal Association
  - Supracrustal units of the Kuummiut terrane consist dominantly of paragneiss and schist (often graphitic), and garnet-amphibolite with marble and occur in doubly folded belts
  - Kap Tycho Brahe supracrustal units are dominantly composed of banded garnet gneiss, amphibolite, ultramafic rock, quartz-mica gneiss, metavolcanoclastic rock, marble. These too occur in doubly folded belts.

Geochronology

Geology of the Archaean and Palaeoproterozoic parts of the Tasiilaq region – new zircon U-Pb ages (Thrane 2014b)

- A sample of brown granulite facies gneisses from the hanging wall of Niflheim Thrust yields an age of 2702±15 Ma
- A grey amphibolite facies gneisses from the footwall of Niflheim Thrust yields an age of 2733±5 Ma
- A syn-kinematic granitic vein was emplaced at 2646±5 Ma
- Granodioritic gneiss north of Niflheim Thrust yields ages of 2785±7 Ma and 2744±4 Ma.
- Garnet-sillimanite-kyanite gneisses at Blokken, south of the settlement Kuummuit, yield ages with peaks around 1900-2000 and 2600-2800 Ma.
    - Pegmatites crosscutting the paragneiss are syn-tectonic and provide a minimum age of shear. They yields an age of 1854±7 Ma.
- Ikasartivaq complex (Late Proterozoic Ammassalik intrusive complex)
    - It's more complex and composed of a large number of intrusive phases, apparently emplaced over millions of years. Two samples have yield the following ages:
        - Granite; 1545±15 Ma
        - Diorite; 1634±14 Ma
- A banded gneiss from the Isortoq area yields an age of 1937±7 Ma
- Intrusive sheets of granite in the Isortoq area yields an age of 1523±12 Ma
- A white garnet-bearing gneiss at Umivik yields an age of 2688±8 Ma
- A granodiorite just south of Jens Munk Ø yields an age of 2750± 8 Ma

These new data have not yet been fully evaluated and embedded into the regional geological evolution.

Ujarassiorit samples from Tasiilaq

Results in South-East Greenland from the Ujarassiorit-program (Petersen 2014)

We have recorded 419 analysed Ujarassiorit samples from the greater Tasiilaq area, and several of these have been awarded a price. During the SEGMENT program, many of the localities have been revisited. The priced samples include:

2000: 2nd prize. Tasiilaq. Ti-rich.
2007: 2nd prize. (2007-0065) Sermiligaaq. Au-bearing.
2008: 1st prize. (2008-0483). NE of Kuummiut. Qtz-rich rock with iron sulfides with 2% Cu, 0.5% Ni, 0.23% Co of 1 ppm. Pd+Pt.
2008: 3rd prize. 2008-0576. Isortoq vest for Tasiilaq. Qtz vein with pyrrhotite. Enriched in Cu, Pd and Pt.
2009: 1st prize. West of Tasiilaq. Pink sapphire.
2009: 4. prize. Basaltic breccia. Sermiligaaq. Enriched in Au..
2011: 1st prize.. Graphite-garnet-gneiss (2011-0092). Sermilik. Enriched in Au and Fe.

2012: 4.prize. 2012-0121..Sulphide mineralization. Kulusuk. Enriched in Cu and Ni.
2013: 3rd prize. Tiniteqilaaq. Sample with 335 ppm Mo,
2013: 4rth prize. Sulphide mineralization. with Au (4.06 g/t), Cu (0.37 %), Pb (0.69 %) and Ag (320 g/t).

Earthquakes in East Greenland
Earthquake swarms in South-East Greenland (Larsen et al. 2014) and relocated local earthquakes in the Ammassalik Region in South-East Greenland align on old geological structures (Pinna 2014)

- A swarm of earthquake has been recorded in the Umiivik area in the years 2008 and 2009
    - Magnitudes are from 1.8 to 3.8, and almost 200 earthquakes were recorded per year in the years 2008 to 2009 and since then dropping to half that half that,
    - the uncertainty on the location of the earthquakes is around 100 km N-S, 50 km E-W, with a relative uncertainty of ~10 km.
- In the greater Tasiilaq area earthquakes are concentrated in the Umivik area, in the Kap Tycho Brahe area (near Sermilik Fjord), and the Ikasartivaq fjord area.

III) Planning of fieldwork 2014

The planning of the 2014-fieldwork was initiated late-2013 and continued into first-half of 2014.

In previous year's, fieldwork in the Skjoldungen region was carried out from a ship-borne basecamp due to the remoteness of the Skjoldungen region and the lack of local infrastructure, and especially absence of fuel supply in the region. The central part of the Tasiilaq region, which constituted the main area for the 2014 fieldwork, is much more accessible due to its infrastructure, including an easy access via the airport at Kulusuk. A base camp was accordingly planned to be established in one of the settlements. The settlement Kuummiut was chosen because of its central location in the Tasiilaq region and the easy access from Kulusuk Airport by helicopter, as well as, by smaller boats. In addition, through contacts to locals in Kuummiut we were able to rent good and suitable accommodation. The local school (Fig. 10) was used for the basecamp for 2/3 of the field season; and in the remainder of the season private homes were rented in Kuummiut.

Renting of the school and the private homes provided facilities such as kitchen, toilets and bathrooms, accommodation for pilots and logistic personnel throughout the field-season, as well as accommodation for participants passing through basecamp during mobilisation, demobilisation, and shifts of working areas. The establishment of the base camp in Kuummiut also provided easy and reliable access to tele-communication which eased the logistic coordination between participants and with locals services.

Figure 10. *The front entrance at the school in Kuummiut, our basecamp during two thirds of the field season.*

At the school, all equipment was stored behind the building either in two containers belonging to the school or on pallets. A portable diamond saw was also placed behind the school and allowed samples to be cut during the field season. Cut and cleaned samples were sent from Greenland directly to commercial laboratories for analysis. The cutting of the samples also provided the geologists with clean sample section for further inspection.

Figure 11. *The expedition's cargo on the key in Kuummiut after demobilisation by the end of the field season.*

All equipment and provisions were shipped to Kuummiut prior to the arrival of the expedition. It was send on wooden-pallets as the carrier, Royal Artic Line (RAL), had informed GEUS that it was not possible to unload containers from the RAL M/V Johanna Kristina that service the smaller settlements in the Tasiilaq region. It was later realised, while the base camp was in operation, that it was possible to unload the smaller MC-5 size containers ('Greenland containers'). They would have been preferred compared to the partly open pallets. On demobilization the equipment was again packed on pallets and handed in to RAL (Fig. 11). Due to unfortunate mistakes by RAL the cargo was not taken on board at the first visit and remained in Kummiut until the second visit of M/V Johanna Kristina. This meant that the cargo was delayed out of Greenland and that preparation of samples and analytical work was delayed ~2 months.

Figure 12. *Local boats were chartered on many occasions. The summer of 2014 was planned to be the only field-season in the Tasiilaq region and it was important to establish a setup which enable a large operation with many participants to in a vast area and to cover as many geological aspects as possible. The fieldwork was planned to last 6-7 weeks with a group of 35-40 participants.*

Through local contacts, both in Tasiilaq and Kuummiut, ensured the access to smaller local speed-boats operated by local skippers (Fig. 12). These boats were used for local to semi-regional transport operation; for transport between Kulusuk Airport and the base camp, moves of i camps, as well as day-to-day work of teams operating out of base camp.

For a longer reconnaissance trips to the south and north of Tasiilaq was charterered the medium-sized vessel M/V Uiloq (Fig. 13). It was operated out of Kuummiut by skipper Sigurdur Petursson, approved for transport of up to 12 persons, and with accomodation for 8-10 passengers. It was also chartered for the establishment of a fuel and equipment depot in the Kialineq region.(66-67°N).

Figure 13. *M/V Uiloq that was chartered for longer reconnaissance trips and carrying more teams of geologist and for the establishment of a fuel and equipment depot at Kialineq.*

An AS-350-B3 helicopter (OY-HGU) was chartered from Air Greenland (Fig. 14). The mountainous terrain and the geographical extend of the area to be covered within six weeks constituted a challenge. Efficient transport and a sufficient number of helicopter hours were required. Two pilots were available throughout the season. This ensured much operational flexibility within the strict regulations for air operations. The pilots from Air Greenland were in the period 12/7 to 12/8 Joachim Hauglund ('JOM') and Jan Erik Lorentsen ('JAZ'), and in the later part of the season, from 14/8 to 24/8, Halldur Hreinsson ('HHR') and Mattias Axelsson ('AXE'). In addition to the expedition's own charter, the Air Greenland AS-350-B3 (OY-HUB) based in Tasiilaq was chartered on an ad-hoc basis when appropriated. The Tasiilaq AS 350-B3 was mostly piloted by Marco Peyer ('MAC')

Figure 14. *The Air Greenland AS-350 B3 (OY-HUG) that was used during the 2014 expedition. A 'helipad' was established in an unused corner of the soccer field in Kuummuit.*

The geologists generally worked in two-man teams or three-man teams. For safety reasons and coordination of logistics was contact between the base camp and field teams maintained twice a day (08:00 and 20:00) throughout the field season.

Communication was ensured using either HF-radios ('Racall' receiver and transmitter stations) with satellite telephones as a back-up. Mapping and sampling by field teams was done on foot or using GEUS zodiacs with outboard engines sailing in the vast fjord and sound system of the Tasiilaq region. The teams were supported by the helicopter for drop-of/pick-up missions to areas with inaccessible mountainous topography. The field teams were also supported by regular helicopter-assisted reconnaissance to the extent needed for the completion and fulfilment of their work-program and objectives. The teams were though out the season supplied and services from the base camp, including the help of technicians for the cutting of channel samples using a portable rock saw.

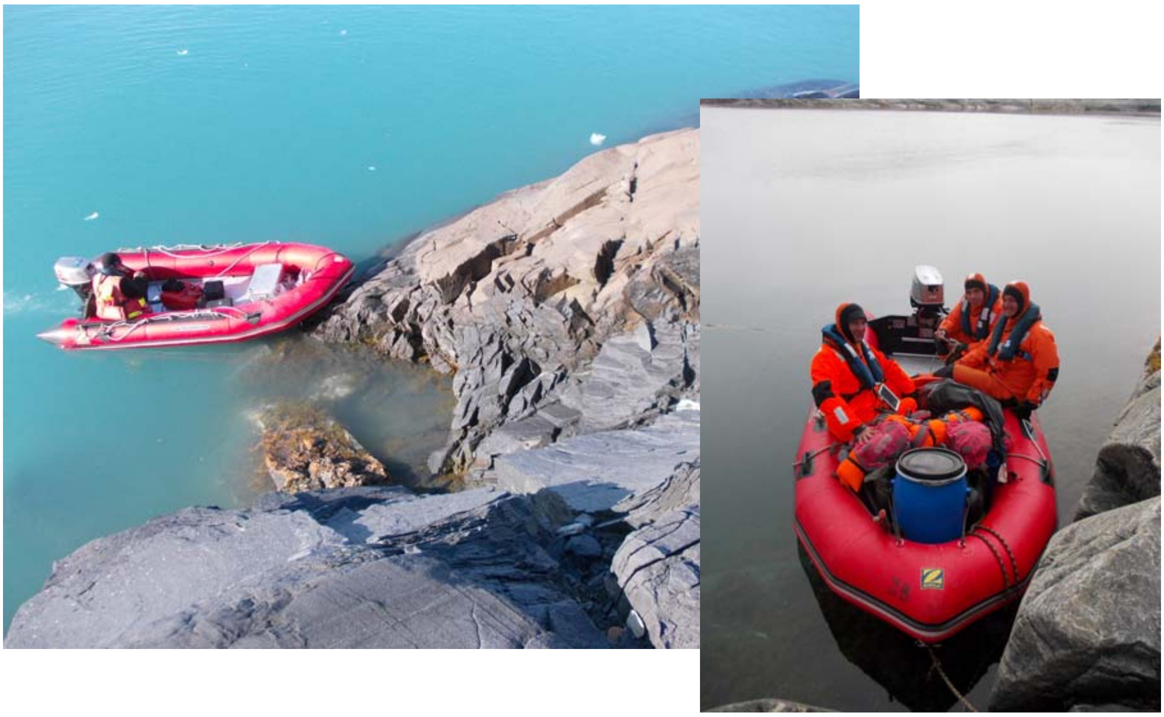


Figure 15. *GEUS zodiacs were used for daily transport of field teams; in some cases the zodiacs were also used for transportation entire two-man camps.*

Task 3: Fieldwork in the Tasiilaq region

Participants and organization

A total of forty geologists and technical staff members took part in the 2014 field work in the Tasiilqa region (Table 1). Operations were initiated July 10th with the establishment of the base camp in the school in Kuummiut. The first major group of geologist arrived July 15th. Besides a couple of participants who arrived from Nuuk, all others travelled from Copenhagen via Keflavik and Reykjavik to Kulusuk. The last group of geologist left the base camp in Kuummiut August 23rd after a field season of 42 days. The technical staff closed the base camp and returned to Copenhagn on August 25th

Bo Møller Stensgaard (GEUS) acted as expedition leader until August 9th and was relieved by Kristine Thrane for the remainder of the season. The expedition leaders coordinated and oversaw all logistics and field investigations. Two or three technical staff members were responsible for the day to day management of the base camp. They ensured contact to and supply of field team and meals for the helicopter crew.

In addition to the participants from GEUS, eleven researchers from national and international universities and government institutions participated in the fieldwork. All external participants were teamed up with a person from GEUS or assigned a contact person from GEUS to ensure that field work was carried out in accordance with safety regulations of GEUS, theát the field work was coordinated, that the objectives of the SEGMENT project were met, and that all results were embedded in GEUS/MMR data depositories.

Table 1. *Participants in the SEGMENT 2014 fieldwork*

Name	Affiliation	Function
Anne Brandt Johannesen	University of Oulu, Finland	MSc student
Annika Dziggel	University of Aachen, Germany	Geologist
Asta Fabricius Jørgensen	University of Copenhagen	MSc student
Benedicte Danshøj Grøtner	University of Copenhagen	MSc student
Bo Møller Stensgaard	GEUS	Geologist, SEGMENT project manager and expedition leader
Bjørn Henning Heincke	GEUS	Geophysicist
Charles Edward Lesher	University of Aarhus	Geologist
Christian Tegner	University of Aarhus	Geologist
Diogo Rosa	GEUS	Geologist
Holger Paulick	GEUS	Geologist
Jakob Lautrup	GEUS	Logistics
Jakob Kløve Keiding	GEUS	Geologist
Jens Therkelsen	GEUS	Geologist
Jochen Kolb	GEUS	Geologist

(Table 1 continued)

Name	Affiliation	Function
Jonas Tusch	University of Köln, Germany	MSc student
Kisser Thorsøe	GEUS	Logistics
Kristine Thrane	GEUS	Geologist
Kristoffer Szilas	Columbia University, New York, United States of America	Geologist
Leon Bagas	Centre of Exploration Targeting, University Western Australia	Geologist
Lærke Louise Thomsen	Department of Geology, Ministry of Industry and Mineral Re-sources, Greenland	Geologist
Majken Djurhuus Poulsen	GEUS	Geologist
Marco Fiorentini	Centre of Exploration Targeting, University Western Australia	Geologist
Martin Bromann Klausen	University of Stellenbosch, South Africa	Geologist
Matti Nellemann Petersen	GEUS	IT - digital capturing of fielddata
Michael Nielsen	GEUS	Logistics
Nanna Rosing-Schow	University of Oulu, Finland	MSc student
Nicolas Thebaud	Centre of Exploration Targeting, University Western Australia	Geologist
Peter Alsen	GEUS	Geologist
Peter Riisager	GEUS	Geologist
Pierpaolo Guarnieri	GEUS	Geologist
Riaan Bothma	University of Stellenbosch, South Africa	MSc student
Rune Hende	GEUS	Logistics
Samuel Mark Weatherley	GEUS	Geologist
Sascha Müller	University of Aachen, Germany	PhD student
Tapani Tukiainen	GEUS	Geologist
Thomas Find Kokfelt	GEUS	Geologist
Thomas Ulrich	University of Aarhus	Geologist
Tomas Næraa	University of Lund, Sweden	Geologist
Trygvi Bech Árting	University of Copenhagen	MSc student
Vincent van Hinsberg	McGill University, Montreal, Can-ada	Geologist

Region of operation

Fieldwork was carried out from ~64°30'N in the south to 67°N to the north and close to 300 km along east coast of Greenland. Ammassalik Island at 66°N, and the adjacent land are-as, however, constitute the most accessible and largest ice-free land area and were conse-quently the focus of the operation. Throughout the entire field season more teams were active in this central area. The focus of all teams are outlined in Table 2.

At 67°N, in the most northerly parts of the operational area, Palaeogene intrusive and ex-trusive constituted an important focus for the field work. The southernmost outcrops on the east-coast of Greenland of assumed Cretaceous to Palaeocene sediments are also found in this area. Three teams, supported by helicopter, worked in the area for two weeks to collect field evidence and rock samples for an improved the basis for an evaluation of economic potential within the area of Palaeocene intrusives, sediments and volcanics.

The region from around 64°30'N and northwards to around 65°N, comprises the formerly defined border zone of the Archaean craton and the region of Palaeoproterozoic deformation related to the orogenic collisional events through the Tasiilaq region. It is a little visit part of the South East Greenland coast and constitutes an important area for additional field work. It is an area of very difficult access and the work between 64°30'N and 65°30'N was supported by M/V Uiloq, operated by skipper Sigurdur Petursson. Three teams participated in a 6 day long operation along the coast.

The northern and southern areas are of major importance for the understanding of theregional geological evolution of the Precambrian terranes in South East Greenland. The central Tassilaq area, however, remained the main focus of the 2014 field work and can be described as the E-W zone defined by Isortoq (around 65°30'N) in the south and the Nilfheim thrust (around 66°30'N) in the north. This the core area is the site of a continental collision and reworking of Archaean basement and supracrustals, deformation of Proterozoic sedimentay successions and magmatism, and the site of shown mineralisations, Furthermore it is a relative wide strip of ice-free land and is the most populated and accessible area in South-East Greenland with good infrastructure Throughout the fieldwork around 8 teams were concerned with aspects of the geology of the Tasiilaq area; including studies of the basement units, sampling for geochronological studies, structural, tectonic and metamorphic investigations, detailed investigations of specific localities, mapping and sampling within supracrustal and intrusive units, detailed follow-up on known mineral occurrences and evaluation of mineral potential including a follow-up on localities where Ujarassiorit samples had been collected. The evaluation focused on the potential for rubies, graphite, gold, platinum group elements, nickel, copper and zinc. In addition to these was carried out geophysical work including a magnetotelluric profile, follow-up on aeromagnetic anomalies and processed ASTER data, and hyperspectral measurements to provide ground-truth for interpretation of hyspectral imaging.

Table 2. *Summary of topics covered by field teams and participants during the 2014 fieldwork.*

Topic	Description	Number of field teams involved	Persons
Tectonics and structural evolution	Establishment of geotectonic and structural model including collection of structural data throughout the region. Both older Archaean/Palaeoproterozoic as well as younger structures were investigated; the later also to understand structural linking to offshore tectonic development.	2-3 teams	Jochen Kolb Pierpaolo Guarnieri Leon Bagas Martin B. Klausen
Regional basement investigations and geo-chronological investigations	Follow-up on different geological basement units including sampling for geochronological and isotopic mapping.	1-2 teams	Tomas Næraa Kristine Thrane Jochen Kolb Thomas Find Kokfelt
Intrusives in the Ammassalik Island area	Investigations on the intrusives at Ikasartivaq, at Cassiopefjeld (the ‘2200 Ma intrusion), at Augpalugtoq and at Ivnartivaq. This work included mapping, detailed petrographical and geochemcial investigations and sampling.	2 teams	Thomas F. Kokfelt Jakob K. Keiding Samuel M. Weatherley Christian Tegner Thomas Ulrich Charles E. Lesher Kristoffer Szilas Bo M. Stensgaard
The Ammassalik Intrusive Complex (AIC)	Detailed investigations and mapping within the Johan Petersen and Ammassalik center of the Ammassalik Intrusive Complex (AIC) including evaluation and follow-up on the potential for Ni-PGE-Cu-Au-bearing mineralisations within AIC itself including comparison with earlier known Ni-sulphide mineralisations located outside the AIC. This work also comprised detailed petrogenetical and geochemical investigations and sampling of AIC.	3-4 teams	Jochen Kolb Thomas F. Kokfelt Jakob K. Keiding Samuel M. Weatherley Holger Paulick Marco Fiorentini Nicolas Thebaud Anne B. Johannesen Benedicte D. Grøtner Jonas Tusch Trygvi Bech Árting
Paleogene intrusive province at Kialineq	The Kialineq region host the southernmost district with onshore Paleogene intrusions related to the opening of the North Atlantic; several of these were investigated in details with petrological sampling and observations as well as mapping. Also reconnaissance and photogrammetry surveys were carried out.	2 teams	Thomas F. Kokfelt Jakob K. Keiding Samuel M. Weatherley Christian Tegner Thomas Ulrich Charles E. Lesher
Dyke investigations	The dykes and their spatial distribution throughout the region were investigated. This included sampling, mapping and structural observations.	2 team	Martin B. Klausen Riaan Bothma Christian Tegner Thomas Ulrich Charles E. Lesher

(Table 2 continued)

Topic	Description	Number of field teams involved	Persons
Metamorphic conditions	Establish regional metamorphic conditions as well as investigate the ultra-high pressure conditions within the area north of Ammassalik Island to Niflheim Thrust zone. Also metamorphic studies and garnet-dating of the metamorphic halo surrounding the AIC.	2-3 teams	Annika Dziggel Jochen Kolb Majken Djurhuus Poulsen Lærke Louise Thomsen Sascha Müller Vincent van Hinsberg Jonas Tusch
Investigation on sedimentary succession at Kap Gustav Holm	Follow-up on described late (Cretaceous?) sedimentary successions at Kap Gustav Holm including sedimentary logging, search for fossils and mapping	1 team	Peter Alsen Jens Therkelsen Pierpaolo Guarnieri
Follow-up on Ujarassiorit samples	Numerous samples have been handed in to the Ujarassiorit 'public hunt for minerals' program; many of these seems to cluster in specific areas; others are located in interesting geological settings that in some cases also are supported by geochemical stream sediment anomalies. Follow-up in selected areas were carried out – in several cases were the local collector contacted and brought to the place where they had collected their sample. Panning was also carried out in selected areas.	2 teams	Holger Paulick Diogo Rosa Kisser Thorsøe Lærke Majken D. Poulsen Louise Thomsen Jonas Petersen
Ruby potential	Detailed follow-up on Ujarassiorit ruby samples including detailed sampling, mapping and genetic studies – including evaluation of the possibility for finding other occurrences	1 team	Vincent van Hinsberg Majken D. Poulsen Lærke L. Thomsen
Regional mineral evaluation	The greater Tasiilaq region host a potential for several different commodities; throughout the work the potential for these commodities were evaluated – and in some cases direct follow-up on geochemical anomalies, remote sensing data or specific geological settings were carried out in order to verify or disprove the potentials.	2-3 teams	Bo M. Stensgaard Jochen Kolb Holger Paulick Diogo Rosa Nicolas Thebaud Marco Fiorentini Kristoffer Szilas Leon Bagas

(Table 2 continued)

Topic	Description	Number of field teams involved	Persons
Magnetelluric survey	N-S-oriented profile across the presumed suture-zone of the Nagssugtoqidian in South-East Greenland.	1 team	Peter Riisager Asta Fabricius Jørgensen Bjørn Henning Heincke
Local geological descriptions around towns and settlements	As an potential future outreach activity and to obtain results that potentially could be used to increase the local populations understanding of the surrounding geology as well as being able to produce small geological excursions/tourist guides all smaller settlements and towns in the Tasiilaq region were visited and a number of key-localities exemplifying some of the local geology was recorded and described.	1 team	Vincent van Hinsberg Majken D. Poulsen Lærke L. Thomsen

Conclusion on fieldwork

The SEGMENT 2014 fieldwork met its objectives. A wide range of aspects of the geological evolution, from the very earliest to the latest in the southern parts of East Greenland and including observations that might impact on the interpretation of offshore development, were covered during the field season. Together with the result of a major analytical program, geophysical investigations, results from remote sensing and photogrammetry, they combined into a major and regional data set and the basis for better geological understanding of the geological evolution of South-East Greenland and provide the basis for the mineral endowment of the region.

Task 4: Post-fieldwork work and reporting on collected observations and data from the Tasiilaq region

All digital field data were quality controlled and archived in the GEUS database after the return of the field parties. Also the transformation of field diaries into field reports and the compilation and interpretation of data acquired in the field was initiated shortly after the return of the field parties.

The handling, description, and analysis of materials collected during the 2014 field season were delayed due to the later arrival of the equipment and collections (see description of Task 3). Preparation of samples for analysis was not possible before November/December 2014.

The post-field-season investigation of collected materials and observations, and reporting will continue through 2015. Data and results of the maps obtained in 2014 will be released in the form of an updated 1:500 000 scale geological digital map and as an ArcGIS data-package, and include the compiled geochronological data from all of South-East Greenland..

SEGMENT 2014 fiscal

The jointly financed GEUS-MMR/Government of Greenland SEGMENT project has been active since 2011. A total of 12,505,592 kr. was used within the SEGMENT project in 2014. The breakdown of the expenditure and funding for the 2014 activities is shown in Fig. 16. The equivalent numbers for the SEGMENT project in the years 2011-2013 are shown in Fig. 17.

In 2014, 5,332,918 kr (42.6%) were spent on logistics and equipment required for the fieldwork and nearly 3 million kr. was spent on the charter of helicopters, boats and purchase of fuel. An amount of 637,364 kr. (5.1%) has been spend on geochemical analysis. This expenditure does not include the cost of zircon geochronological analysis as these are accounted as GEUS man hours and not as a specific analytical cost. A total of 6,474,541 kr. was used for man hours at GEUS in Copenhagen and in the field.

The expenditures were covered by funding from GEUS, MMR and external partners. GEUS contributed 6,138,497 kr., of which c. 150,000 kr. were transferred from the previous year as non-used MMR contribution to SEGMENT 2013), MMR contributed 6,000,000 kr. and 367,095 kr. were the contributions from external partners. The external partner contributions covered fuel bought for the external partner (Grønlands Naturinstitut/Pinngortitaleriffik) and placed in a joint fuel depot in accord with a joint cooperation agreement. An overhead was charged the services provided to the partner. The overhead was transferred to the SEGMENT project.

All man hour rates and expenditures are calculated according to the general agreement for joint cooperative projects between GEUS and MMR/Government of Greenland. This means that the amount indicated for man hours is calculated in accordance with the ‘rate for scientific work’ (the so-called ‘ITF-rate’); a rate reduced relative to the ‘rate for commercial work’. In addition, no overhead has been applied to costs associated with the project. The equivalent numbers for the SEGMENT the years 2011-2013 are shown in Fig. 17.

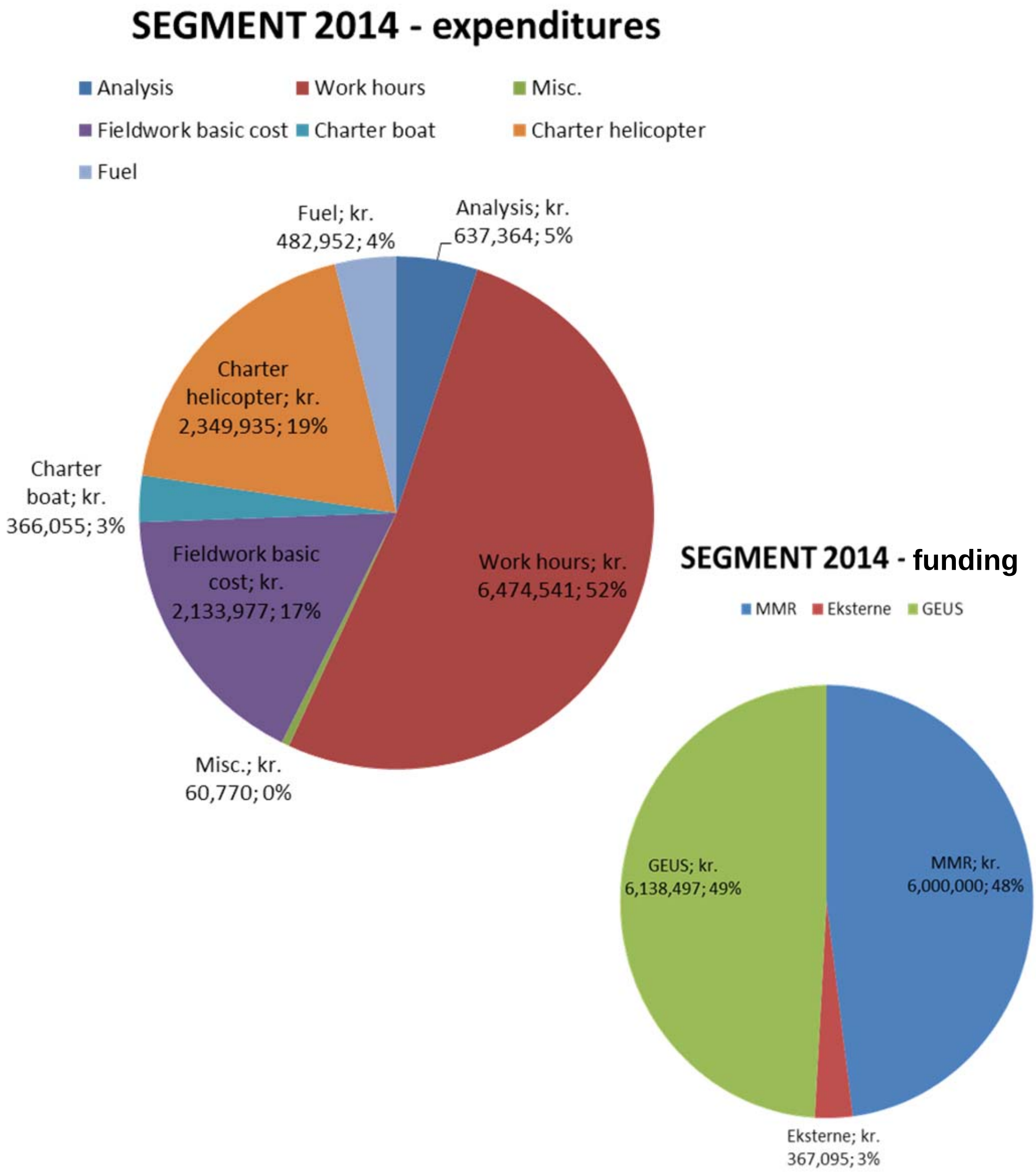
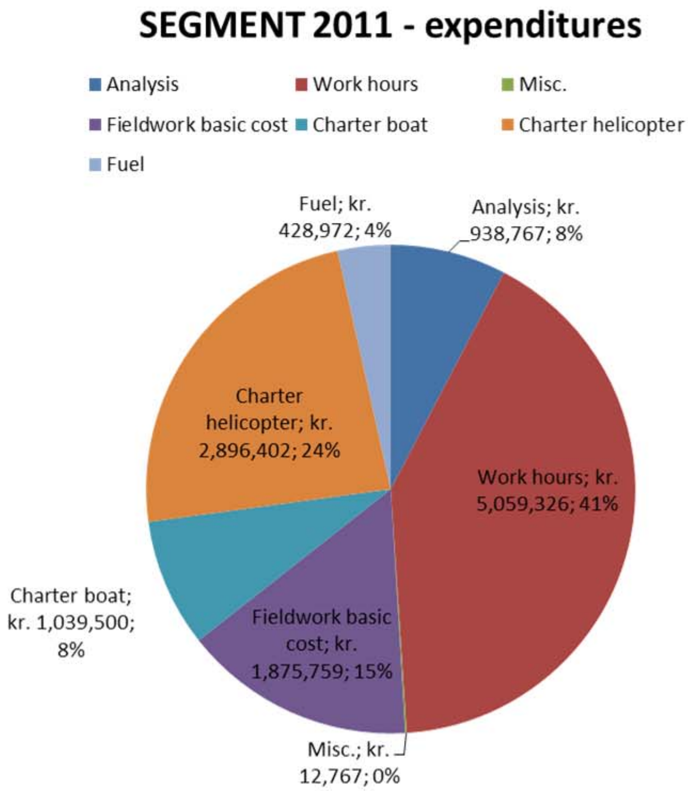
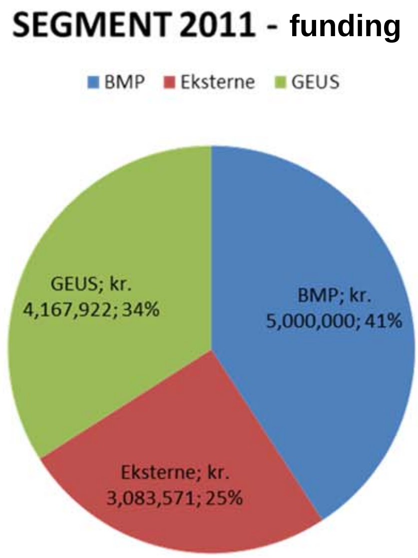
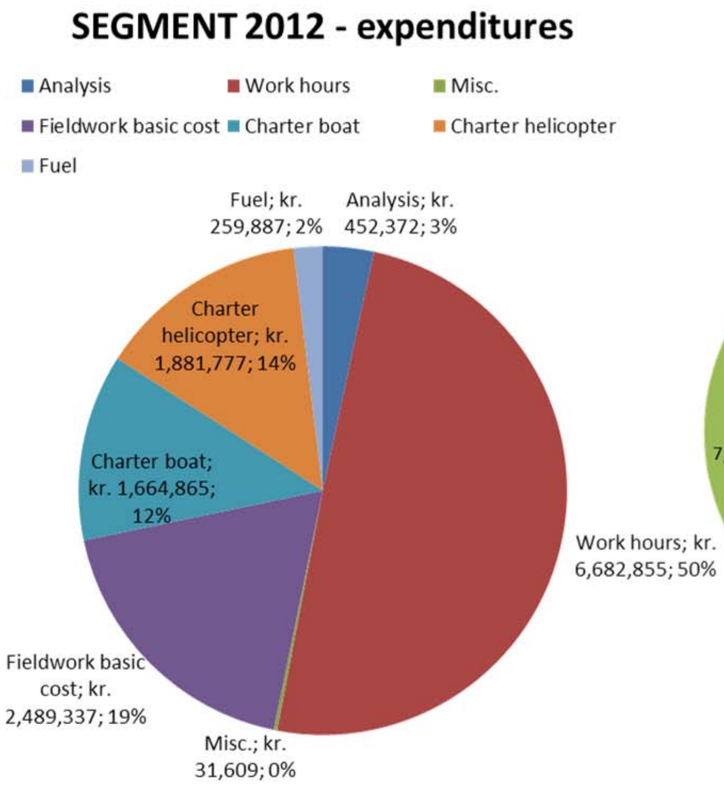
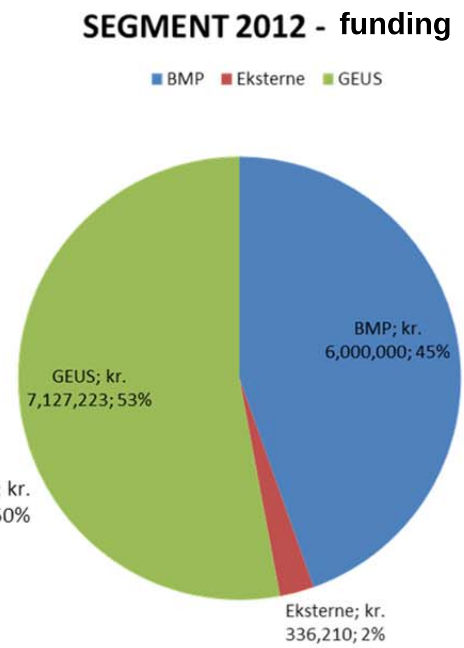


Figure 16. *SEGMENT 2014 expenditures and funding. The 'fieldwork basic cost' covers e.g. expenses such as travel, accommodation, provisions, equipment, allowance, communication, cargo freight*









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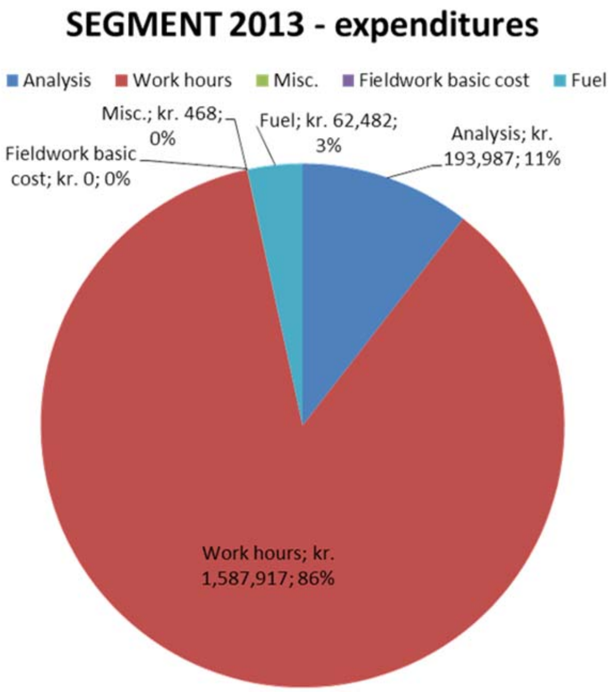

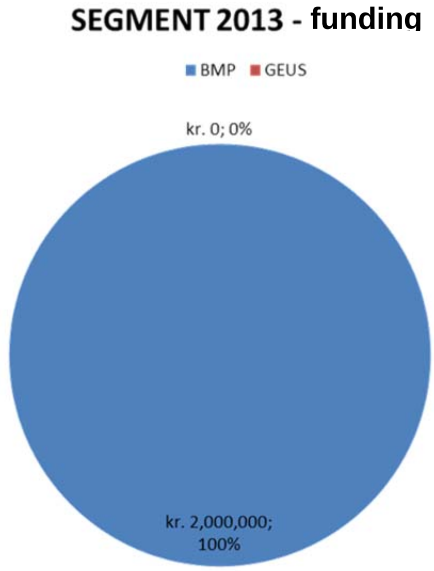

Figure 17. *SEGMENT project years 2011–2013 expenditures and funding (continued from former page).See Figure 16 for explanation of 'Fieldwork basic cost'.*

Future SEGMENT work

The results and observations made during the 2014 fieldwork will be analysed and investigated in the years to come and published in international journals and GEUS reports as well as presented at various geological conferences and mining conventions. The results will also be used for the promotion of the mineral endowment of the underexplored South-East Greenland.

Analytical work, often in close collaboration with external research partners, will be continued through 2015. The work in 2015 will also include a small fieldwork campaign in the vicinity of Tasiilaq and Kulusuk with additional follow-up on the new discovered ruby localities and the associated genetic model, as well as, detailed investigations of the Kulusuk intrusive centre of the Ammassalik Intrusive Complex.

The SEGMENT project as such will continue through 2015 but be officially terminated by the end of the year. By the end 2015/early 2016 will the compiled data be released as a large GIS data package and an updated digital version of the1:500 000 scale geological map (equivalen to map 14 of the 1:500.000 sheet series). These will be accompanied by a comprehensive report presenting an overview of the results obtained during the SEGMENT project, including the recognized mineral endowment for entire South-East Greenland.

Publications

Publications, thesis and presentations on the Skjoldungen and Tasiilaq region, South-East Greenland – SEGMENT 2011-2014 (list also presented in Stensgaard 2014).

<u>Regional Geology, Structural Geology and Geochronology</u>

- Kolb, J. 2014: Structure of the Palaeoproterozoic Nagssugtoqidian Orogen, South-East Greenland: model for the tectonic evolution. Precambrian Research in press, http://dx.doi.org/10.1016/j.precamres.2013.12.015
- Berger, A., Kokfelt, T.F. & Kolb, J. 2014: Exhumation rates in the Archean from pressure-time paths: Example from the Skjoldungen Orogen (SE Greenland). Precambrian Research, in press, http://dx.doi.org/10.1016/j.precamres.2014.04.011
- Kolb, J., Thrane, K. & Bagas, L. 2013: Field relationship of high-grade Neo- to Mesoarchaean rocks of South-East Greenland: Tectonometamorphic and magmatic evolution. Gondwana Research 23, 471-492, http://dx.doi.org/10.1016/j.gr.2012.02.018
- Bagas, L., Næraa, T., Kolb, J. & Reno, B.L., Fiorentini, M.L. 2013: Partial melting of the Archaean Thrym Complex of southeastern Greenland. Lithos 160-161, 164-182.
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Appendix A – missing abstracts from 2014 workshop abstract volume

Intrusions of the Archaean Skjoldungen Alkaline Province, South East Greenland: Observations from the 2011-2012 field seasons and preliminary geochemical results

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Background

The Skjoldungen Alkaline Province (SAP), situated at ca. 63º30'N in South East Greenland, is part of the Archaean North Atlantic Craton. The SAP is one of the oldest alkaline provinces in the world and as such offers a rare opportunity to study alkaline magmatism in the early Earth system. The province constitutes a number of mainly mildly alkaline intrusions of mafic/ultramafic to intermediate and evolved compositions, but also includes a late stage of more strongly alkaline character, the nephelinitic-carbonatitic Singertât Complex. The SAP was emplaced syn- to post-tectonically during the 2750-2700 Ma Skjoldungen Orogeny (Kolb et al. 2013), into a basement of felsic agmatitic gneisses containing dismembered supracrustal rock units of Meso- to Neoarchaean age. Geographically the far majority of SAP intrusions occur within a ca 30 km wide by 80 km long NW-SE trending strip stretching from the Atlantic coast onto the inland ice cap, however, syenitic intrusions of early SAP age is located further to the south down to Skirner Bjerge (Fig. 1). During the Skjoldungen Orogeny peak metamorphism at granulite facies conditions was reached at ca 2740-2750 Ma, followed by exhumation at modern comparable rates to shallow crustal levels at ca 2700 Ma (Berger et al. 2014). Several SAP intrusions show accordingly variable signs of syn-tectonic deformation, both on outcrop scale and in thin section. Deformation in such intrusions is particularly pronounced towards lithological boundaries and consist in foliated fabrics, bended crystals etc. Other intrusions show pristine magmatic textures, including igneous layering, cross bedding, drop stone structures and intrusive contacts. The extent of deformation in each intrusion likely reflects the timing of emplacement in relation to the Skjoldungen orogenic event, as well as depth of emplacement.

The first age determinations on SAP intrusions were based on zircon U/Pb TIMS dating (Nutman and Rosing, 1994) and Sm-Nd whole rock isochrons (Blichert-Toft et al. 1995), both indicating intrusion ages of around 2720 to 2700 Ma. Our new SE Greenland age database at GEUS (N > 50, still growing) consisting of zircon LA-ICPMS U-Pb ages on a variety of SAP intrusions (including cross-cutting felsic dykes) now indicates that the age range for the SAP is larger, from 2750 to 2630 Ma, but with the main magmatism between 2750 and 2690 Ma. The new SAP age database furthermore suggests that magmatism initiated in the south and progressed generally northwards with time. Magmatism within the SAP also seems to have migrated E-W within the central Skjoldungen area over a 30 Myr time period (see also Næraa *et al.* 2014).

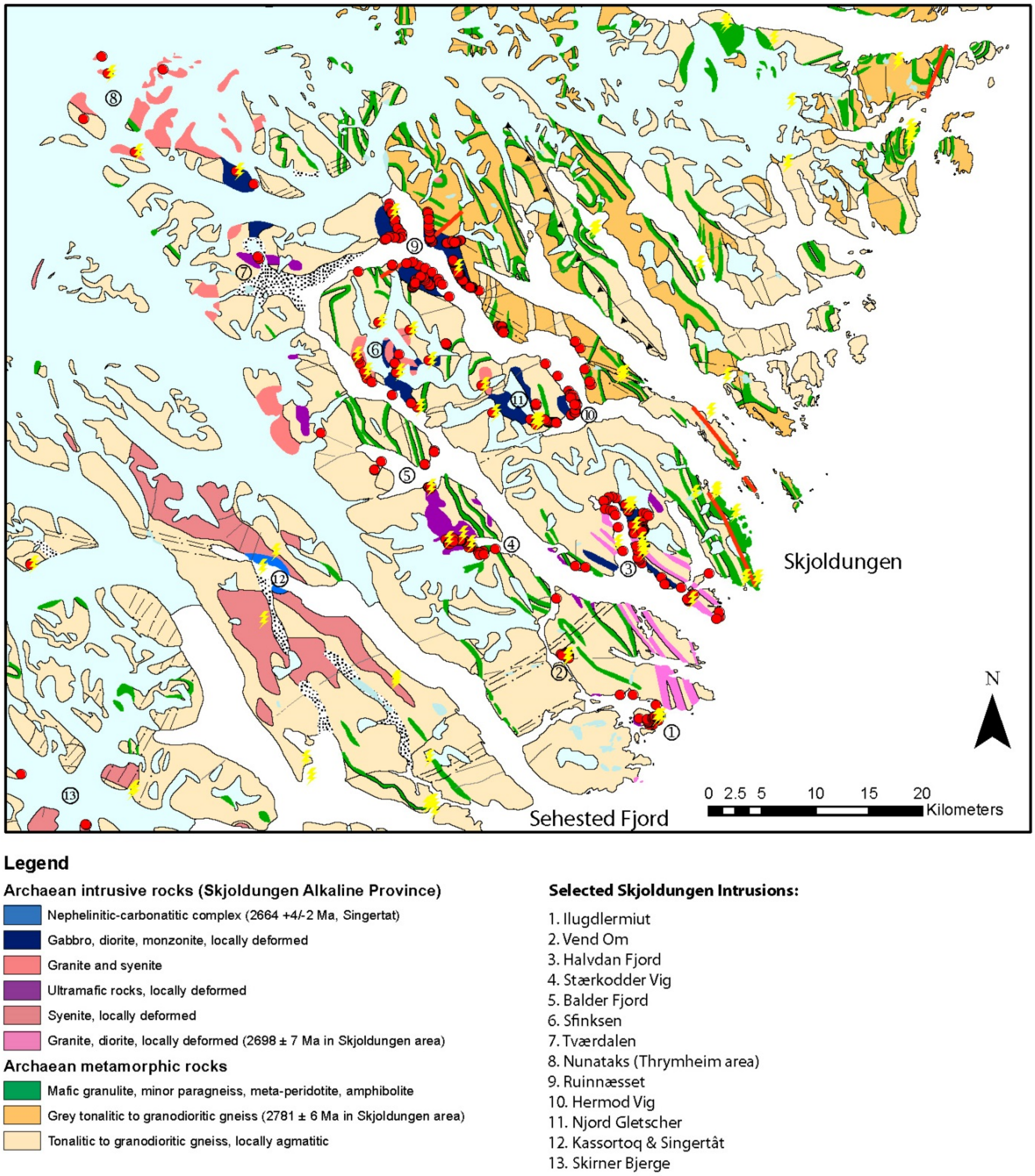


Figure 1. *Geological map of the Skjoldungen area (redrawn by J. Kolb after Escher (1990)). Red circles indicate localities visited during the 2011 and 2012 field seasons (N = 696). Encircled numbers mark selected intrusions/areas that were targeted during the 2011-12 GEUS field work.*

Geological mapping of the Skjoldungen area was done by GGU, mainly at a reconaissance scale, in the late 1980's and early 1990's, resulting in the map compilation in scale 1:500 000 of Escher (1990). One aim of the renewed field work by GEUS was to carry out more detailed work in selected key areas in order to develop a better understanding of the overall petrogenesis of the SAP, as well as to evaluate the economic potential of the area. Specific key questions set out included: (1) constrain the geographical extent of the SAP through more reconnaissance and detailed mapping (see below), (2) identify any temporal evolution within the SAP from new zircon U/Pb age dates (see Næraa et al. this volume), (3) characterize the parental magma types for the SAP magmatism using geochemistry and isotope analytical work (see below), (4) evaluate the geotectonic setting for the emplacement of the SAP (see below and see Kolb et al. 2013), and (5) identify any economic potential of the SAP (see also Rosa et al.; Árting et al., both in this volume).

New field observations from 2011 and 2012

The field work was carried out in four weeks in July-August 2011 and 2012 and resulted in ca 700 stations and 600 samples, of which ca 500 samples were (or are currently being) analysed for whole rock geochemistry and 200 were prepared for petrological thin sections. The rock types collected include mafic and ultramafic intrusive rocks (mela- leucogabbro and pyroxenite), to intermediate and felsic rock types (diorite, monzonite, syenite and granite), as well as, a number of SAP related dykes and sheets of intermediate to primitive composition.

For the authors of this abstract 11 SAP intrusions, or main areas of interest, were targeted for detailed field work around the Skjoldungen island, whereas reconnaissance work was done in a number of other areas (during recos or drop-offs). The main areas of interest include (clockwise order, see Fig. 1): (1) Ilugdlermiut, (2) Vend Om, (3) Halvdan Fjord area, (4) Stærk Odder Vig, (5) Balder Fjord, (6) Sfinksen, (7) Tværdalen, (8) Nunatak area, (9) Ruinnæsset, (10) Hermod Vig, (11) Njord Gletscher. In addition other teams worked in detail on the SAP intrusions further to the south; (12) the syenitic gneisses and the alkaline Singertât Complex in the Kassortoq region and (13) syenititic intrusions in Skirner Bjerge.
It should be noted that the Skjoldungen region was initially described and mapped out by Nielsen and Rosing (1990), who reported 24 different SAP intrusions, which they arranged into six different categories according to extent of deformation (as expressed by foliation in the rocks) and composition: (1) syenitic gneisses, (2) foliated gabbros and diorites, (3) ultramafic, gabbroic, and dioritic complexes, (4) dioritic to syenitic complexes, (5) felsic complexes, and (6) strongly alkaline complexes. Their list offered a good framework and check list for our work in the area, and mostly all 24 intrusions were checked in 2011-2012. We found that some modification to the list was required, but mostly at a fairly detailed level, such as revising the areal extents of intrusions, or modifying the naming of main rock types encountered. However, we also discovered a couple of new intrusions not mapped out before, including a mafic lopolith intrusion in Balder Fjord and a gabbro intrusion on the island of Ilugdlermiut and a possible southern extension of the Ruinnæsset intrusion (Fig. 1). We also note in relation to the produced 1:500 000 scale map by Escher (1990), that several intrusions appearing on the map are either grossly exaggerated in size, or in some cases non-existent (being mistaken for older amphibolites).

Here a brief description of some of the new and most important findings made during 2011-12 field seasons.

Vend Om Gabbro, Ilugdlermiut Gabbro and Njord Gletscher Gabbro

In the SE part of the Skjoldungen area a number of fairly small, relatively undeformed mafic intrusions, Vend Om Gabbro, Ilugdlermiut Gabbro and Njord Gletscher Gabbro were studied in detail (Fig. 2). These intrusions include gabbros, gabbronorites and norites that show a pronounced magmatic layering, as well as, notable occurrences of concordant semi-massive oxide (magnetite/ilmentite) layers, typically 20 cm in thickness, but in some cases up to 1-2 m. All three intrusions have now been U/Pb dated indirectly from felsic back-veins at their contacts to be ca 2690-2700 Ma (Kokfelt, unpublished data), i.e. late to postorogenic, explaining their relatively pristine appearance. The best investigated of these intrusions is the Vend Om Gabbro that measures ca 250×450 m and is made up of a 30-70 m wide marginal zone of coarse-grained hornblende-bearing melagabbro, surrounding a central sequence with pronounced steeply inclined magmatic layering (Fig. 2). The Vend Om was targeted for detailed sampling and analytical work (see Maarupgaard et al., this volume). The newly discovered intrusion on Ilugdlermiut island closely resembles Vend Om, with coarse grained hbl-bearing melagabbro at the margin and layered gabbros towards the centre. This intrusion was studied and sampled during 1.5 days reco/drop-off, collecting some 40 samples from the island. It should be noted that an additional and considerably more disturbed mafic intrusion occur on the south coast of Ilugdlermiut (dated to 2710 ± 5 Ma; Kokfelt et al. unpublished data); we suspect that this intrusion could be the so-called ‘Uivaq Diorite’ of Nielsen & Rosing (1990), which however, is unclear from their map.

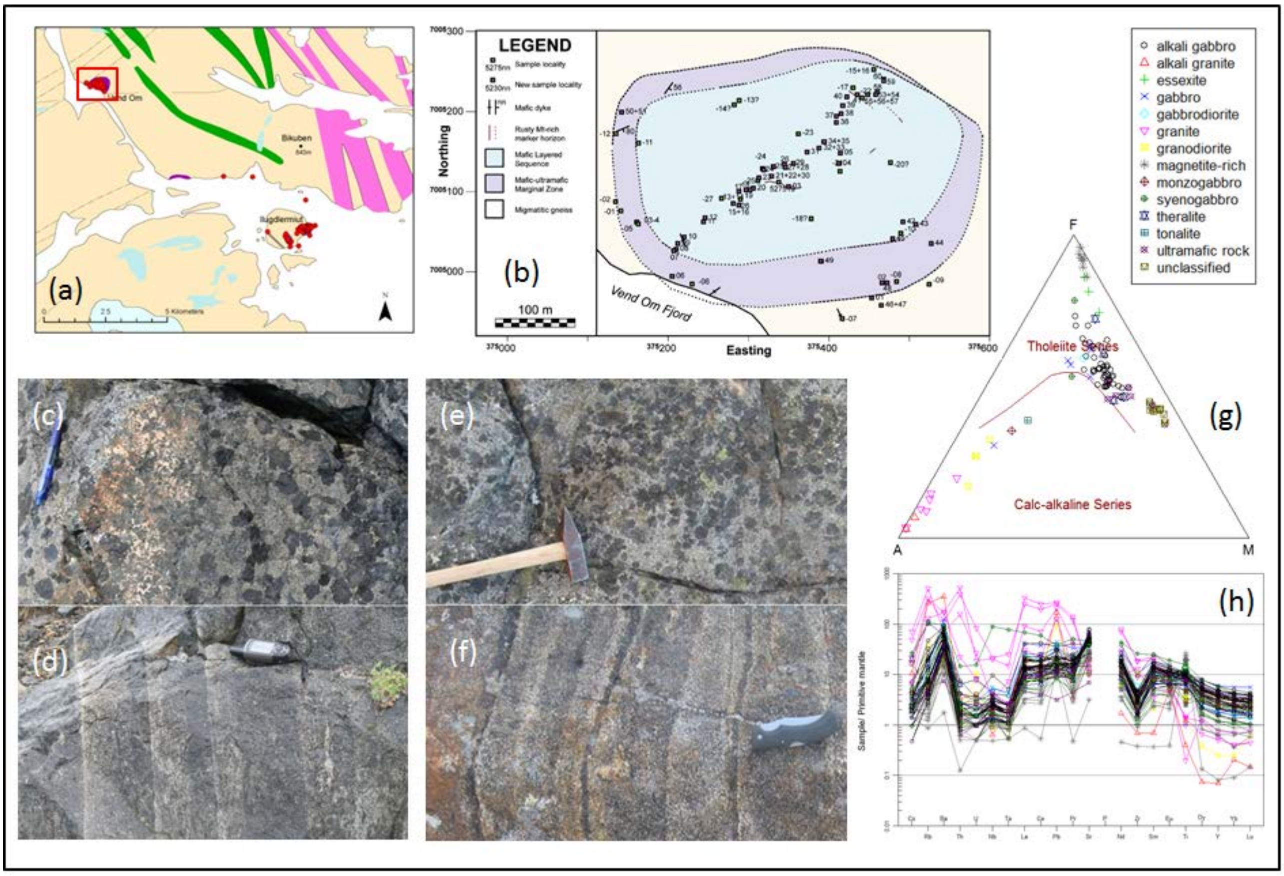


Figure 2. *(a) Geological map of the Vend Om – Ilugdlermiut area (provisionally revised) with stations indicated (red circles); (b) Geological map of Vend Om Gabbro with the sample locations indicated, (c)-(d) and (e)-(f) field photos from Vend Om and Ilugdlermiut, respectively, of marginal hbl melagabbro ((c) and (e)), and interior layered sequence ((d) and (f)). There is a*

very strong resemblance between the two intrusions, in terms of the lithologies, and the architecture of the intrusions. (g) AFM diagram plotting all available data for Vend Om Gabbro; In the AFM diagram the Vend Om Gabbro defines a trend of cumulate rocks that show extreme FeO-enrichment. Our working hypothesis is that this trend reflects accumulation of early crystallizing magnetite in the intrusion, consistent with the occurrence of concordant semi-massive magnetite/ilmenite horizons.

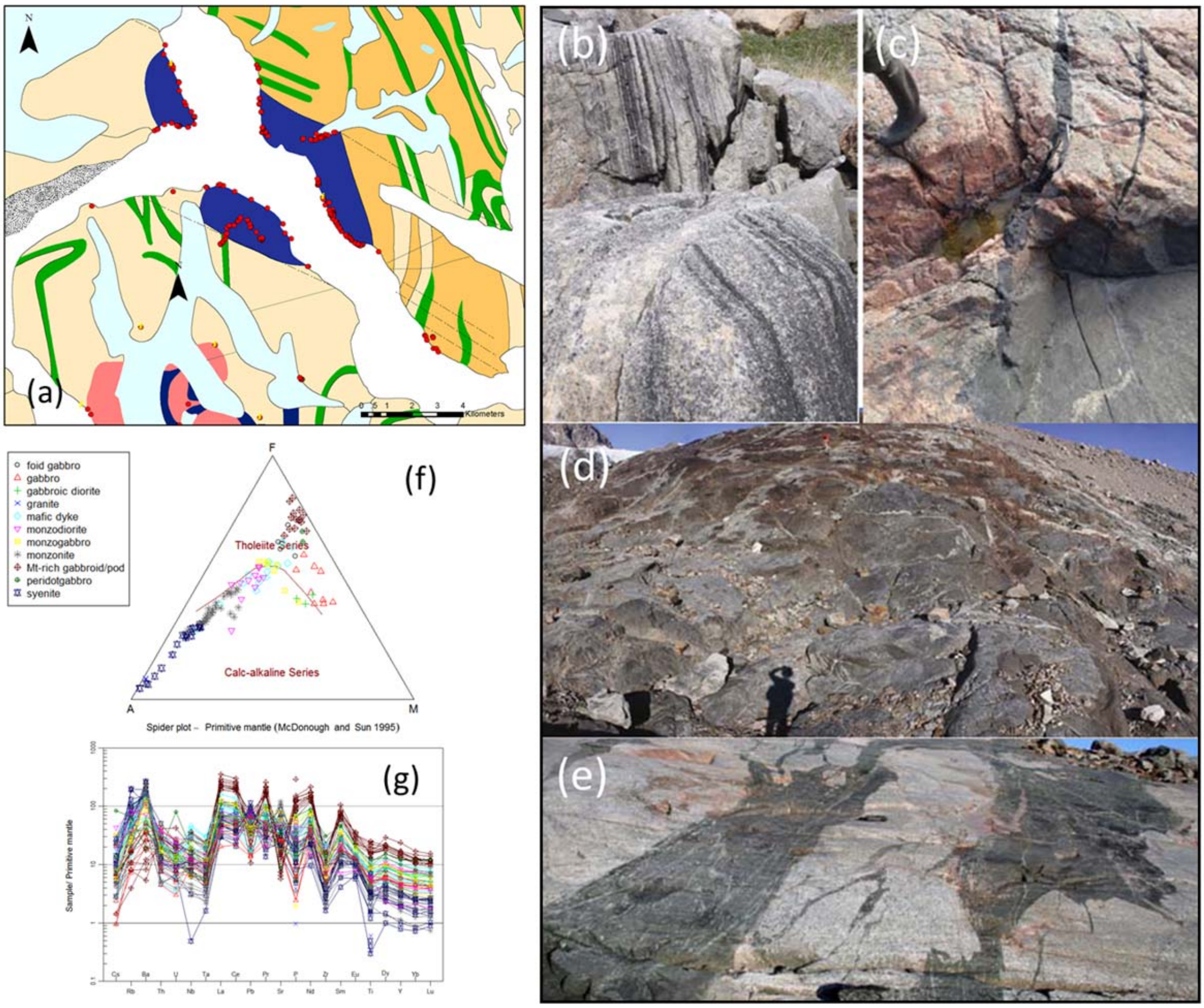
The Njord Gletscher Gabbro (former "Hermod Vig diorite 2", cf. Nielsen & Rosing (1990)) is somewhat larger than Vend Om and Ilugdlermiut intrusions, but also contains a layered series of gabbros that in the lower part includes concordant oxide-rich layers (see also abstract by Árting *et al.* this volume). We note that part of what was previously mapped out as a larger "Hermod Vig diorite 2" (cf. Nielsen & Rosing, 1990), was mistaken supracrustal units embedded within the agmatitic gness basement, meaning that the actual mafic intrusion is much smaller than indicated on the 1:500 000 map. Apart from the oxide rich layers, the upper part of the intrusion contains coarse grained gabbronorites that in places contain miarolitic cavities. Such cavities provide important constraints on the maximum depth of intrusion (to less than 3-4 km), and have also been found in the contemporaneous 2.7 Ga Ruinnæsset intrusion (Berger *et al.* 2014).

Ruinnæsset – revisited

The Ruinnæsset intrusion defines a c. 3×3 km large, well-preserved, rhomb-shaped intrusion dominated by coarse grained syenite that shows variable modal layering (Fig. 3). There is a systematic distribution of rock types within the intrusion, with the western part mainly being comprised of syenites and monzonites, whereas the eastern part also comprises more mafic lithologies, such as pyroxenites, gabbros and diorites, which occur as xenolithic domains or rafts in the syenite host (Fig. 5d). The main lithology is constituted by coarse grained syenite that commonly shows rhytmical layering as defined from c. 5-20 cm thick modally distinct layers rich in hornblende, pyroxene and Fe-Ti oxides. The intrusion is cut by multiple generations of late dykes, sheets and leucocratic pegmatites. Some of these late intrusions outcrop as irregular bodies that appear to intrude at a late magmatic phase into a semi-ductile (mush?) rock of syenite. Irregularly mafic bands rich in magnetite and apatite are observed to intrude the bulk lithologies, suggesting either these either represent late stage interstitial residual liquids that were squeezed out, or alternatively represent liquid immiscibility at a late stage of the magmatic evolution. The 2012 field work resulted in many additional samples taken along profiles (Fig. 3). Future work in the Ruinnæsset intrusion will encompass a detailed petrological, mineral chemical and geochemical work in order to constrain the petrogenetic models and to evaluate the economic potentials.

Overall, the Ruinnæsset rocks define an alkaline evolutionary trend (suite) towards enrichment in K_2O with increasing SiO_2 that likely reflects crystal fractionation processes exerting a main control on the chemical differentiation. The silicate rock samples show moderate to strong LREE enrichments (typically ~100-200 x chondrite) relative to the HREE (~10 x chondrite). The magnetite-rich samples are high in FeOt and generally enriched in REE's and P_2O_5, presumably reflecting variable modal abundance of apatite in these mafic layers.

Figure 3 (next page). *(a) Geological map (sketch) of the syenitic Ruinnæsset intrusion with sample localities indicated. The occurrence of more mafic and ultramafic rocks seems to be confined to the eastern part of the intrusion. (b) Nearly vertical layering in coarse grained syenite, cut by a felsic pegmatite vein. (c) Late magnetite-apatite-rich nelsonites as mafic bands intruding into a host of syenite, possibly reflecting either extraction of interstitial residual melt or liquid immiscibility. (d) Xenoliths of metamorphosed and partly brecciated melanocratic rocks (melagabbroic to pyroxenitic rocks intruded by syenite) occur within a zone some hundreds of meters from the exposed eastern margin of the intrusion. (e) Intrusion of feldspar porphyritic monzonite into syenite; the irregular lobate boundary indicates intrusion into a semi-ductile host rock. (f) AFM diagram showing 124 samples defining a semi-coherent differentiation trend across the diagram bordering the calc-alkaline and tholeiitic transition; note group of Fe-rich (nelsonites) corresponding to late mafic bands in (c). (g) Mantle-normalised multi-element diagram showing characteristic 'saw-tooth' pattern with high LIL/HFS element ratios.*



Geochemistry of the SAP

Based on the initial geochemical characterization of the SAP intrusions, Blichert-Toft et al. (1995) suggested derivation from shoshonitic (high-K) parental melts, which most commonly are found along active margins. They also found that high Mg# and high LILE/HFSE ratios of the most primitive SAP compositions would be consistent with hydrous melting of a mantle wedge source that had been metasomatized by hydrous fluids from a subducting oceanic slab. New chemical and isotopic data (in progress) on SAP rocks will be used to further: (1) identify and characterize the parental melt composition to the SAP magmatism, (2) make detailed sampling (including in profiles) of some of the best preserved, pristine intrusions, and (3) to evaluate roles of crustal reworking relative to pristine mantle input using Hf isotopes in zircon and Lu-Hf on whole rocks.

With respect to identifying the parental SAP melt(s), we will focus future work on the abundant syntectonic mafic dykes that dissect the larger Skjoldungen area. In the merit of being finer grained than the SAP intrusion counterparts, these dykes should be better representatives of melt compositions used by Blichert-Toft et al. (1995) to address the issue of parental melts. This work was laid out in a Ph.D. project set up in SA, however, is currently on stand-by, as the student left the project. With regard to detailed work on selected intrusions, work is now undertaken on some of the least disturbed SAP intrusions, such as the Vend Om Gabbro and the Ruinnæsset Intrusion. For both these intrusions, stratigraphic sections were taken for detailed micro probe and geochemistry work. For several other intrusions data are available for future student projects (at BSc or MSc level). New isotopic data are currently being produced (by Tomas Næraa in collaboration with Axel Gerdes, Frankfurt). Six samples with zircon crystallization ages between 2.75 and 2.70 Ga will be characterised in terms of their Hf isotope ratios, which will enable us to unravel the relative proportions of input from the mantle vs. the crust at different stages of SAP magmatism.

SAP dykes (‘deformed dykes’)

Mafic to intermediate dykes, usually up to 1 meter wide, occur throughout the larger Skjoldungen area, all the way from Halvdan Fjord to the Nunatak area (Thrymheim area), and were sampled at various places for geochemical and structural investigations. The dykes generally strike NW-SE and have characteristic blurred contacts to the host rock, giving rise to the field term ‘deformed dykes’ (Fig. 3). We consider these dykes to be intruded syntectonically as part of the SAP magmatism.

In order to characterize the parental melts to the SAP magmatism these dykes are considered the best candidates, as they presumably were less affected by magma chamber process than many of the intrusive complexes. Figure 4a-b shows the typical outcrop morphology of the SAP dykes, dissecting the gneiss basement as a sub-parallel swarm and with semi-regular spacing with blurred irregular contacts. The SAP dykes are invariably alkaline in composition and have the characteristic SAP signature of LIL-enrichment and HFSE-depletion. Compositions vary a great deal from basic to intermediate, indicating that many dykes are fed from differentiated magmas at deeper level.

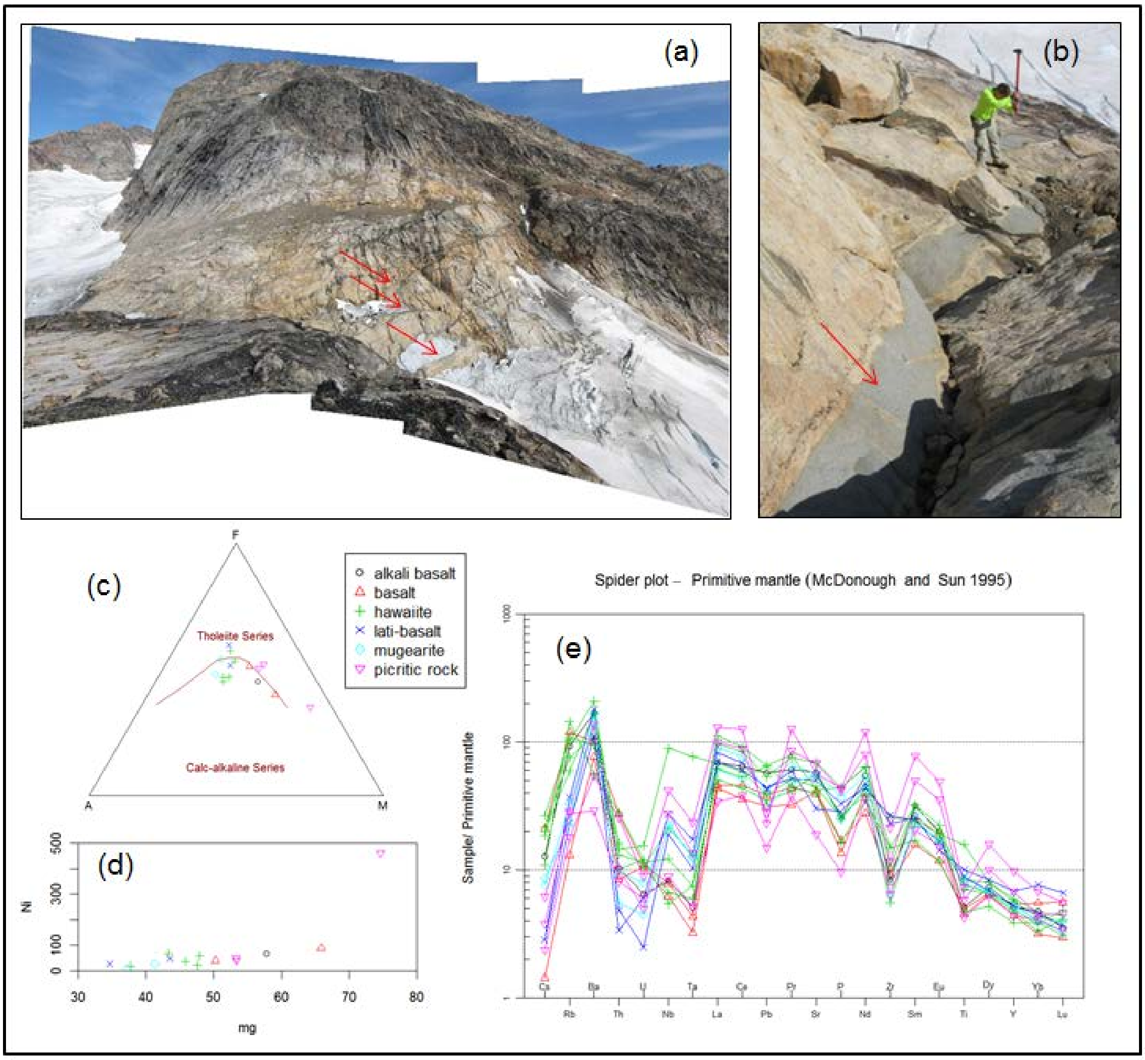


Figure 4. *(a) Several sub-parallel SAP dykes intruding into agmatitic gneiss basement of the central Skjoldungen area (red arrows). (b) Sampling of a 1 m wide inclined dyke; note the lobate contact to surrounding host rock, indicating intrusion under semi-ductile (synorogenic) conditions. (c)-(d): Geochemistry of selected SAP dykes with rock names applied from the R1-R2 classification scheme of De La Roche et al. (1980); (c) In the AFM diagram the dykes lie on the division line between calc-alkaline and tholeiitic series; (d) mg# vs. Ni follows a typical fractionation trend (control by olivine and/or opx), two samples have high mg# and Ni consistent with them being relatively unfractionated mantle derived melts; (e) Mantle normalized spider-diagram show a 'saw-tooth' pattern with generally high LIL/HFS element ratios typical for many subduction related magmas.*

Syenitic and granitic intrusive complexes

Syenitic and granitic intrusive complexes dominate in the western part of the SAP, including Sfinksen and the Nunatak area (Thrymheim area) (Figure 1). In these regions coarse grained varieties of granites, syenites (+/- qtz) and monzonites dominate with smaller proportions of mafic lithologies. When comparing our preliminary geochemical data from these areas with unpublished data of T.F. Nielsen, two evolutionary trends can be distinguished, one granitic and one syenitic, the latter being characterized by higher alkalies and higher K_2O/Na_2O ratios.

A number of SAP syenites have been U/Pb dated by LA-ICPMS and give intrusion ages between 2710 and 2730 Ma, with a prevalence of the former age in the Nunatak area and the latter in the Sfinksen area. Some samples have small populations of inherited zircons up to 3.2 Ga in age (see Næraa et al., this volume). The age difference suggests a temporal westwards shift of the evolved magmatism within the SAP over ca 20 Ma. The occurrence of inherited zircons suggests that crustal contamination, at least to some extent, was important in the differentiation of the evolve SAP melts. A possible explanation for the two differentiation trends (granites vs. syenites) could hinge on the extent of crustal assimilation in the two series. New Hf isotope data in zircon will help to resolve this issue further.

Note on the economic potential of the Skjoldungen Alkaline Province

The greatest potential for an economic deposit in the SAP seems to be related to the semi-massive oxide layers within some of the gabbroic intrusions at Vend Om, Ilugdlermiut and Njord Gletscher. Magnetite seems to be the dominant oxide phase in all of these intrusions, followed by ilmenite, and such occurrences are elsewhere in the world, such as Bushveld in South Africa, being mined for V. Preliminary microprobe analysis across a magnetite/ilmenite layer in Njord Gletscher (in the middle part of the intrusion) indicate ca 0.75 wt%V_2O_5 in magnetite. Our current best estimate is that the occurrences are not of economic importance, mainly due to too small tonnages.

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Reactivation of Proterozoic structures along the South-East Greenland margin (Skjoldungen)

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The Archaean basement of Skjoldungen in South-East Greenland is cross-cut by brittle structures consisting of dike swarms of Proterozoic age and faults. Pseudotachylites sampled along brittle faults, related to injection veins with irregular orientation, show coherent Paleoproterozoic age (1900-2000 Ma) with large errors due to the old age and to the presence of excess Ar that differs from the age of the country rock by 600 Ma.

In this area pronounced ENE-WSW and NE-SW trends are visible from the aerial photographs and digital elevation models. The more than 50 km-long morphological lineaments parallel Proterozoic dike systems. Structural mapping along these structures revealed the presence of strike-slip deformation overprinting and reactivating the former dike trends. Paleostress analysis of fault-slip data, combined with the pseudotachylites analysis and cross-cutting relationships with dikes allowed separating five distinct tectonic events where three of them are characterized by extension and dike intrusions and two by strike-slip brittle faulting. The youngest strike-slip event is interpreted as Paleocene and related to the Northeast Atlantic rifting. The estimated left-lateral offset along the major structure is about 15 km and its offshore prolongation cut through the Tertiary basalts encountered by the ODP Leg 152 along the SE Greenland shelf.

The multiple brittle deformations in the craton together with the cross-cutting relationships between faults and dikes show the potential of reactivation of pre-existing structures in particular during rifting processes addressing the problem to combine structural data of different age into a single data set.