DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2009/5

Preparations for a mineral resource assessment programme in South-East Greenland (MRAPSEG)

Leif Thorning (ed.)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

G E U S

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GEUS

Abstract

This report presents the results of preparations for a coming Mineral Resource Assessment Programme of South-East Greenland between approximately 62°N and 67°N (MRAPSEG). The project was initiated and supported financially in 2008 by the Bureau of Minerals and Petroleum (BMP). The new Mineral Strategy for Greenland (December 2008), points to South-East Greenland as a high priority region for publicly supported exploration activities. The choice is based on a wish to encourage industry exploration activities in the practically unexplored region. The region's geological similarities to the Precambrian shield of West Greenland are recognised but modern exploration data are lacking from the region

Based on prior discussions and consensus between BMP and GEUS, the model for MRAPSEG operates with initial airborne geophysics and geochemistry of stream sediments, followed by targeted geological fieldwork in areas that from the new regional surveys and prior geological knowledge can be characterised as economically interesting. The suggestions for MRAPSEG contained in this reports have been adapted to the recent announcements of BMP that funds sufficient for the geochemical surveys would be available in 2009 and 2010, and that it would be attempted to obtain the funds necessary for the airborne geophysical surveying in 2010 and 2011. Thus, main components of the programme are geochemical surveying in 2009 and 2010 and geophysical surveying in 2010 and 2011. To supplement this, remote sensing, geological reconnaissance and dating are suggested to be included in the three years 2009 to 2011, before geological mapping and fieldwork in target areas become the main activities in 2012 an 2013.

The preparatory work carried out during the last half of 2008 encompasses (i), an overview of existing geological and economic geological knowledge of the area, including company activities; (ii) the preparation of a new topographical basis and geological map based on existing 1:500,000 maps; (iii) the creation of a new satellite image map based on Aster data with associated imagery database; (iv) discussions of the regional geochemical and geophysical surveys that are to start the MRAPSEG and (v) initial discussion of additional targeted geological mapping and investigations.

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1. Introduction

Leif Thorning

Over the past many decades, limited attention has been given to South-East Greenland. GEUS has often pointed to the area as worthy of further attention and many have been aware of the potential implied by the geological similarities with the west coast of Greenland, but not proven by fieldwork. There has been a little activity by exploration companies. In 2008, GEUS and BMP decided to carry out some preparatory investigations in a jointly financed project, preparing for a coming mineral assessment programme for the region. This report presents the results of these preparations, including plans and approximate budgets for regional aeromagnetic and geochemical surveys that would be the best start on a mineral resource assessment of the region.

The project has also resulted in a brief review of known knowledge about the region, the completion of new topographical maps of the project area in digital format, and the transference of existing scant geological information to digital formats. Thus, the technical foundation for additional work has been laid.

No fieldwork was carried out during this preparatory project. However, new satellite data was acquired. Based on these, satellite image maps have been produced and an Aster database is now available for further processing and production of interpretational maps of relevance for the geological processes in the region.

All the products of the activities in this project have been compiled in an ArcGIS project in digital form and are now available for GEUS for further work. The information cannot be published or used elsewhere until quality checked as part of the project proper. The plans for regional airborne geophysical and ground geochemical surveys are ready in detailed form to be initiated immediately as the first phase of a full regional mineral resource assessment programme for the region, should financing become available. Preliminary outlines of plans for the subsequent mineral resource assessment programme are only outlined in this report.

Much of the preparatory work presented in this report was done over the summer and early autumn of 2008. In December 2008, the Bureau of Minerals and Petroleum presented the new Mineral Strategy for Greenland, as confirmed by the Joint Commission at its December meeting. This points to SE Greenland as a primary region for BMP supported activities, because the region has attracted the interest of so few companies. At the same time, BMP announced that a budget of 5 million DKK in each of the years 2009 and 2010 would be available for GEUS' execution of a geochemical survey of the region as the first phase of a mineral resource assessment programme over five years. Depending on additional funding becoming available in 2010 and 2011, the next phase would provisionally be envisaged by BMP as a regional aeromagnetic survey, before targeted geological fieldwork would become the main activity in 2011 and 2012. The final reporting of the mineral resource assessment would thus be expected during 2013.

This overall plan is slightly at odds with the assumptions behind GEUS' prepared suggestions, intended for inclusion in this report. In order to adapt to the scenario envisaged by BMP in the new strategy announced December 2008, the publishing of this report was delayed to January 2009. The adaptations called for were mostly in the sequencing of focus areas for the geochemical survey. The original suggestions from GEUS can be read in appendix A; in Chapter 7, the various elements in the Mineral Resource Assessment Programme of SE Greenland have been assembled in a form that fits the expressed requirements of BMP.

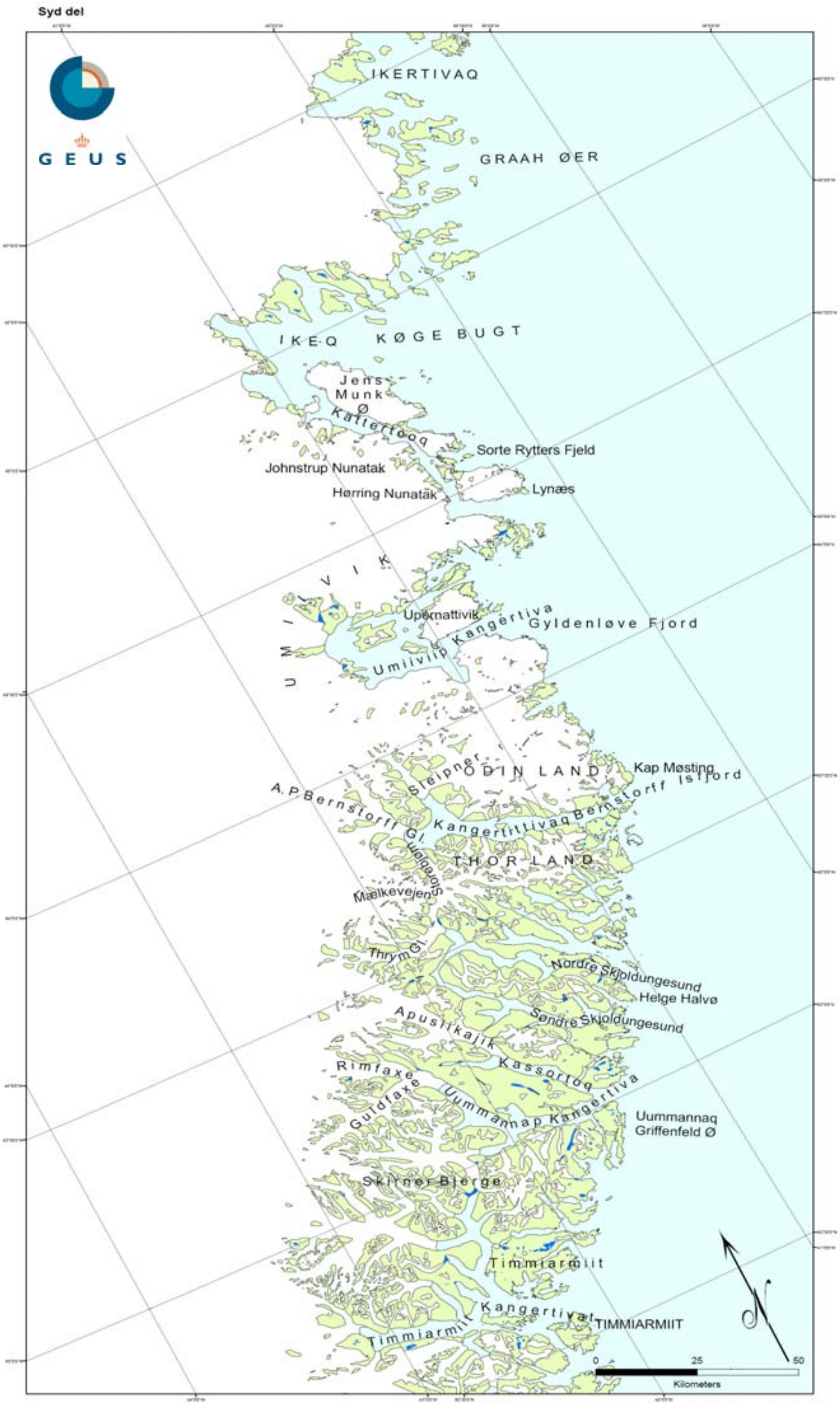

Figure 1. *Topographical map of the intended field area for 2009.*

2. Geological overview of the region

Troels F. D. Nielsen

The areas in South-East Greenland covered by this report encompass the Archaean block in South-East Greenland (62-64°30'N), the Proterozoic Ammassalikian mobile belt (64°30'-66°N) including part of the northern Archaean foreland, and around 66°N a suite of Palaeogene intrusions in the Kialeq (Kialineq) region. The areas south of 62°N are referred to the Ketilidian mobile belt; they have received special attention elsewhere in other previous projects focused at South Greenland.

2.1 Mapping activity by GEUS and university groups

The region between 62° and 67°N in East Greenland is in general under-explored and has not been mapped in detail. Initial investigations in the 1960´es by groups from British Universities were focussed on the regional correlation between the Precambrian of Scotland and Greenland, and North America. Most of the work was carried out from boat along the shores. The British efforts were joined by GEUS (GGU) teams in the late 60´es and early 70´es, again operating from ships along the shores. All these early campaigns resulted in a general geological framework for the Precambrian areas between 67° and 60°N along the East coast of Greenland. But the investigation did not give sufficient area coverage for the production of geological maps. Ship-borne follow-up GEUS (GGU) operations in 1981 and 1982 confirmed that reconnaissance mapping for the 1:500 000 map series could only be obtained with extensive helicopter support.

The regions between 65° and 68°N were covered in 1986 and the areas between 62° and 65°N were covered in 1987, using a combination of helicopters, fixed wing aircrafts, and rubber boats. The main purpose of these operations was the collection of the information necessary for the compilation of the 1:500 000 geological maps (numbers 13 and 14). In addition, a general reconnaissance was made for occurrences of interest for exploration. Map sheets 13 and 14 were published in subsequent years, but no detailed map descriptions have been published.

The 1987 operations were followed up by focused petrologic investigations by University groups related to GEUS.

2.2 Archaean and Proterozoic geology

As on the Southwest coast of Greenland, the region between 62°N and 67°N on the South east coast of Greenland is dominated by Precambrian shield rocks influenced through later events. Both Archaean and Proterozoic terrains are known.

2.2.1 Archaean terrains

The Archaean block in South-East Greenland has received little attention over the years. Early investigations based on coastal surveys (see above) and follow-up investigations in 1981-1982 resulted in an understanding of the general geological framework. Reconnaissance mapping in 1987 supplied the data needed for a reconnaissance map in the scale of 1:500 000 (Map sheet 14).

The Archaean terrains stretch from 62° to 64°30'N and appear divided into a number of tectonic blocks. These blocks are identified based on the occurrences of agmatitic gneiss, supracrustal successions, and structural information. The agmatitic areas are believed to represent deeper parts in the Archaean crust and supracrustal areas more shallow levels in the crust. Abrupt changes from gneiss terrains with abundant supracrustals to agmatitic gneiss terrains with no coherent and continues supracrustal units are taken to illustrate the shift from on crustal block to another. In the following, the general geology of the focus area is described from south to north.

From 62°N and northward, coherent supracrustal belts become increasingly frequent approaching Timmiarmiit Kangertivat. An example is the sulphide-bearing Grydefjeld supracrustal belt. Agmatitic gneiss totally dominates the terrains on the north side of Tingmiarmuit fjord. A major southward dipping and E-W oriented shear zone along the south shore of Timmiarmiit Kangertivat may well be the transition between the southern and central blocks in the Archaean of South-East Greenland.

The agmatitic gneiss terrains north of Tingmiarmiut are massive and continue northward to the Kagssortoq fjord just south of the Skjoldungen (Saqqisikuik) area. In the Kagssortoq area, coherent supracrustal successions can be followed southward under increasing deformation and agmatisation. These relations suggest the surface exposures to represent increasing shallow levels in a rotated block of Archaean crust toward Kagssortoq fjord and the Saqqisikuik area.

The areas just south of Søndre Skjoldungen Sund, on Saqqisikuik and in the inland areas west and northwest of Saqqisikuik are characterized by a large number of syn- to post-tectonic intrusions belonging to the Skjoldungen Alkaline Province (2600-2500 Ma.). The province is suggested to include at least 20 intrusions of variable size, composition, degree of deformation, and equilibrium pressures. The most alkaline complex is the late-tectonic Singertât ijolite-carbonatite intrusion in Kagssortoq fjord, which together with the Ruinnæsset gabbro in inner Nordre Skjoldungen Sund, are the best described intrusions of the province. Areas of syenitic gneiss are common. They are probably early-tectonic intrusions. Mafic rocks are common in the inland areas, and have been interpreted as early- to syn-tectonic plutons related to the Skjoldungen Alkaline Province. A major geophysical anomaly along the south shores of Søndre Skjoldungen Sund, may be indicative of major mafic intrusives at depth and has previously attracted the interest of exploration companies.

Supracrustal belts are common on the north shores of Saqqisikuik (Helges Halvø) and exhibit sulphide mineralisation. Immediately to the north, the Langenæs peninsular is characterized by very garnet-rich rocks. These rocks may represent a metamorphosed boundary between major blocks in the Archaean terrains. Further north, the gneiss terrains include numerous supracrustal belts and may represent a block of shallow level Archaean crust, probably continuing toward the Kangertittivaq/Bernstorff Isfjord area. The supracrustals units are separated by granitic and possibly syenitic gneiss and together the terrain may constitute significant, but very little-know greenstone belt.

Little is exposed between Kangertittivaq/Bernstorff Isfjord and the Umiiviik area, but the exposures at Umiiviik appear to consist of agmatitic gneiss, heavily intruded by an E-W oriented mafic dyke swarm, probably an equivalent to the Kangamiut dyke swarm in West Greenland. These dykes become strongly deformed in the Proterozoic Ammassalik Mobile Belt (equivalent to the Nagssutoqidian orogen in West Greenland), just north of Umiiviik.

2.2.2 Proterozoic terrains

The transition from undisturbed Achaean terrains into the foreland of the Proterozoic Ammassalik Mobile Belt is traditionally located at 64°30'N in Sorte Rytter Fjeld on Jens Munk Ø. As in West Greenland, the transition zone is defined based on deformation of a regional swarm of basaltic dykes.

A proposed E-W suture zone in the Siportôq area WSW of Tassilaq divides the Ammassalikian terrains into a northern and a southern region. South of the suture zone, from 64°30' N to ca. 65° N, the dykes of the regional dyke swarm are intensively folded. The information is limited, but host rocks are believed mainly to be Archaean in age. By analogy to the relations in the foreland zone to the Nagssugtoqidian in West Greenland, the southern region of the Ammassalik Mobile Belt is probably best referred as foreland of the belt.

The approach to the suture zone in the Isertoq area is manifested in the occurrence of supracrustal belts and younger intrusions. The ages of these are not known. The supracrustal including quartzo-feldspatic paragneisses and amphibolites (of extrusive and intrusive origin) may well be Late-Archaean. The age of a large intrusive in the Isertoq area is not known.

Supracrustal successions and intrusives of Proterozoic age are far more common north of the proposed suture zone. The dominant feature is a belt of syn-tectonic norite intrusion from Kulisuk Ø, via Ammassalik Ø, to the areas around Qeetartivatsaap Kangertiva near the Inland Ice. The norite intrusions are in part intruded into an imbricated supracrustal succession of garnet rich paragneisses and amphibolites. The metamorphic temperatures and pressures have been high, and anatexites are common in the surroundings of the norite intrusions. In these supracrustal rocks Ni-Cu-PGE mineralization occurs, probably related to mafic amphibolites. Although the anomalies are weak, the anatexites and the roof zones of the norites may hold a potential for mineralisation, possibly of IOCG-type.

Graphite- and sulphide rich supracrustals, occasionally with related marbles and calc-silicate rocks are common north of the norite belt. Kyanite- and sillimanite-bearing rocks are reported. The supracrustal are interleaved into reworked gneiss, probably of Archaean age. The host rocks often in granulite facies.

The Northern part of the Ammassalik Mobile Belt also hosts a number of mafic and ultramafic intrusion of late-tectonic age (?) to which are related minor sulphide mineralization.

Finally, the northern part of Ammassalik Ø and the main land to the north is intruded by a suite of gabbroic to granitic intrusions. These intrusions are in general undeformed and post-date the regional deformation and metamorphism.

The border zone to the Archaean craton to the north is not mapped in sufficient detail. The reconnaissance investigations carried out 1986 led to the following description (GGU report 146, 66):

> "A re-examination of the northern boundary (of the Ammassalikian mobile belt) shows it to be a diffuse region more than 50 km wide in which retrogression, unrelated to dykes and shear zones, gradually intensifies southwards. Superimposed on this are discrete belts of retrogression associated with dykes and shear zones. The sense of displacement on the latter is compatible with thrusting of the northern Archaean block southwards over the reworked terrain of the mobile belt"

The Archaean region north of the transition zone is in general little known, but includes a swarm of un-deformed late Archaean dykes (equivalent to the dykes south of the Ammassalik Mobile Belt), and enclaves of anorthosite or leucogabbro, and supracrustals in a granulite and/or amphibolite facies multiphase gneiss terrain.

2.3 Palaeogene intrusions

The Palaeogene intrusions in the Kialeq (Kialineq) region are listed Nielsen (2002, GEUS report 2002/113). The report includes summary information and references to all scientific publications as well as all non-confidential company reports.

2.4 Geological field maps

Filed maps and other archive materials from the campaigns prior to 1986 are listed in Open File Report "The Precambrian of SE-Greenland" (Nielsen, T.F.D. 1986). All listed field maps, as well as all field maps from the 1986-1987 campaign can be found in the GEUS map archive.

2.5 Discussion

It is difficult to point to specific economic potentials in the focus areas due to the limited amount of solid geological information. Geochemical and geophysical mapping, followed up by focused mapping and field investigations would undoubtedly lead to a significant increase in the knowledge, area coverage, and potential of the focus area. The combination of geochemical and geophysical mapping, all previous and future field observations, and area coverage using imagery, will provide a much more firm foundation for the geological evaluation of the focus area.

There is a need for more detailed knowledge on the age relations in the Archaean as well as the Proterozoic terrain. A focused dating programme based on zircon from stream sediments and surface samples is advised.

It is obviously difficult to evaluate the economic potential of these Archaean and Proterozoic regions. Nevertheless, the current knowledge does suggest that East Greenland between 62° and 67° N may among others hold potentials for:

- Ni-Cu-PGE mineralizations in the Saqqisikuik region
- Stratabound base metal and PGE mineralization in Archaean as well as Proterozoic supracrust successions
- Sulphide mineralization in Proterozoic gabbro intrusions
- IOCG deposits in relationships to roof zones of norite intrusions and related anatexites
- Graphite in supracrustal successions north of Ammassalik Ø
- The occurrence of Archaean carbonatite in the Sigertât complex and carbonatisation of gneisses in the Tingmiarmiut area may indicate presence of carbonates in the deep lithiospheric mantle and thus the theoretical possibility for kimberlites (diamonds) in the region

Indications are given for all of these and many more are possible based on theoretical considerations. With geochemical maps in hand, a more detailed evaluation of the potential for such mineralisation will be possible.

3. Topographical and geological base maps

Leif Thorning, Mette Svane Jørgensen, Margareta Christoffersen

For the purpose of MRAPSEG, new maps have been created in UTM projection, zone 24N, using WGS1984.

3.1 New topographical base map in scale 1:250 000

The new topographic base has been produced by KMS as a part of their project for the production of G-V250. Further, a similar process to what has been described for the production of topographical maps from North and Northeast Greenland, see

Jepsen, H.F., Mikkelsen, N., Platen-Hallermund, F.v., Schjøth, F. & Weng, W. 2003: Digital Topographic Map of North and Northeast Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2003/8.

In this project, the base maps have been used in scale 1:500 000, produced from the original 1:250 000 material. Only a slight editing of the altitude contours have been carried out in this transformation, and the map seems in most cases detailed enough to be used in scale 1:250 000 if necessary.

3.2 New geological map in scale 1:500 000

The geology is based on three sheets from the GGU/GEUS series Geological map of Greenland 1:500 000:

- *Sheet 13, Kangerdlugssuaq 66º00' - 69º00' N; 25º00 - 36º30' W; J.S. Mayers, P.R. Dawes & T.F.D. Nielsen. 1988.*
- *Sheet 14, Skjuldungen 62º30' – 67º00' N; 35º50' – 43º15'W; J.C. Escher. 1990*
- *Sheet 1, Sydgrønland 59°30' – 62°30´N; 42°00´– 50°30´W; Second edition. A.A. Garde. 2007.*

All geological features have been transferred to the new topographical base described above, using a process described in

Jon Ineson, Hans F. Jepsen, Naja Mikkelsen, Stefan Piasecki, Frants von Platen-Hallermund, Bjørn Thomassen, Frands Schjøth & Willy L. Weng: Thematic maps and data of North and Northeast Greenland: geology, mineral occurrences and hydrocarbons. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2005/28.

3.3 Discussion and comments

Working with the digital versions of the map, the topographic base and the geological maps have been made seamless for the entire area of interest in this project. The legends of the three maps have been correlated and homogenised. For printouts of maps, a special MRAPSEG layout has been created allowing the entire stretch of the SE coast to be shown on the same A0 sheet in scale 1:500,000. The elongated region has been divided into a northern and a southern part, and by rotation of north to the left, the two segments have been placed together on an A0 sheet with room for a legend. A special A4 version of this layout has been used for the illustrations in this report (Figures 3 and 4).

The maps have been compared with the satellite image map created from Aster data and the agreement is almost perfect. According to Hans Jepsen (personal communication), the height contours have only been very slightly smoothed going from the original 1:250 000 scale to 1:500 000 scale. For most parts of the region, it will probably be quit acceptable to work in scale 1:250 000, perhaps even 1:100 000.

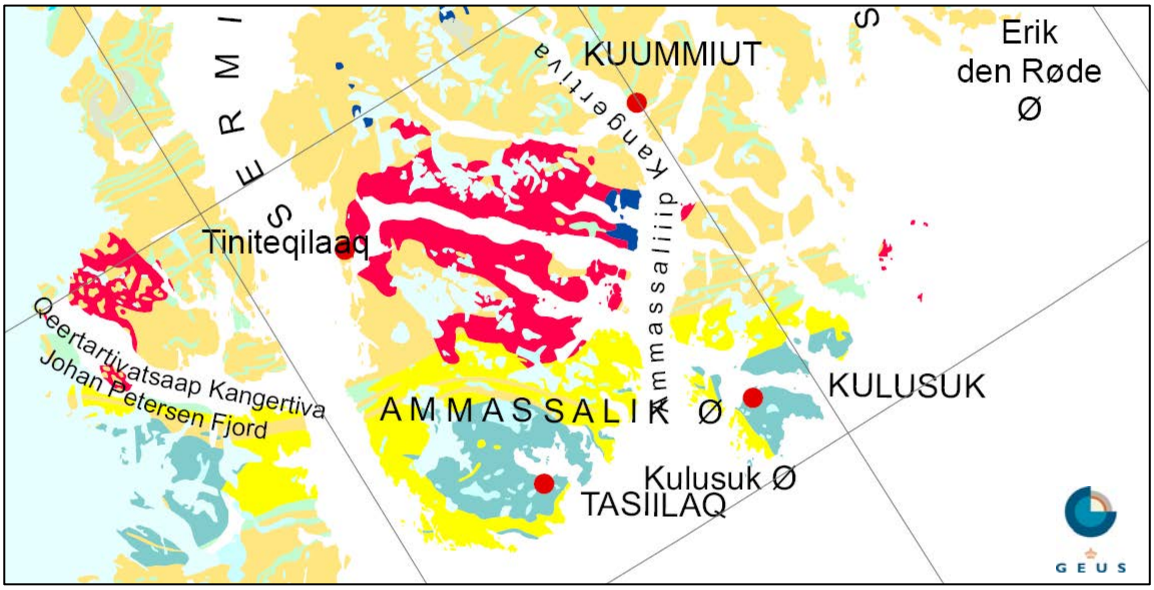

Figure 2. *Example of details in new geological base maps in scale 1:500 000*

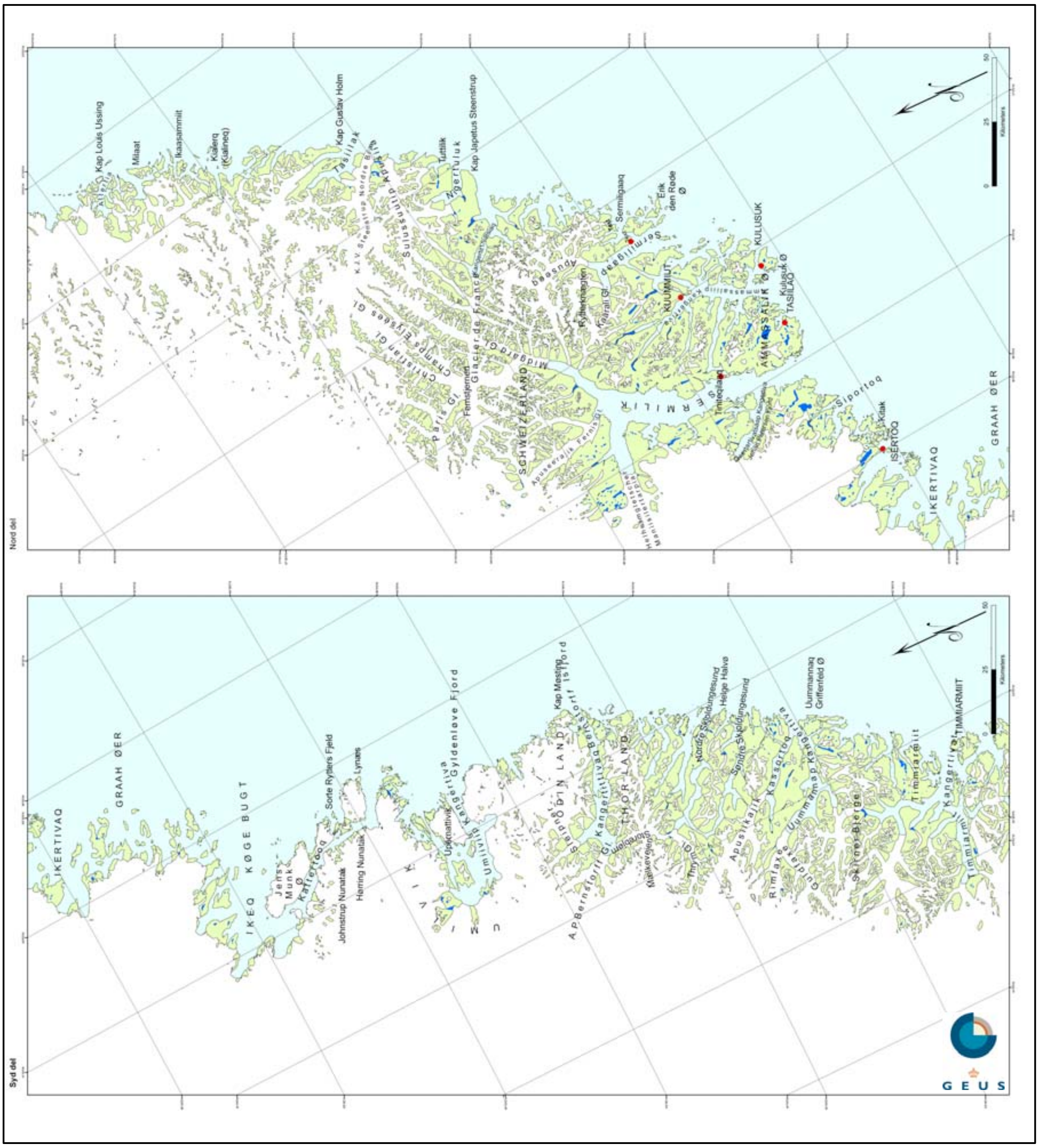

Figure 3. *Topographical base map in 1 : 500 000, MRAPSEG layout. Plotted in 1:500.000 there will be a third segment to the right containing the legend. This has been omitted here because it is still under improvement.*

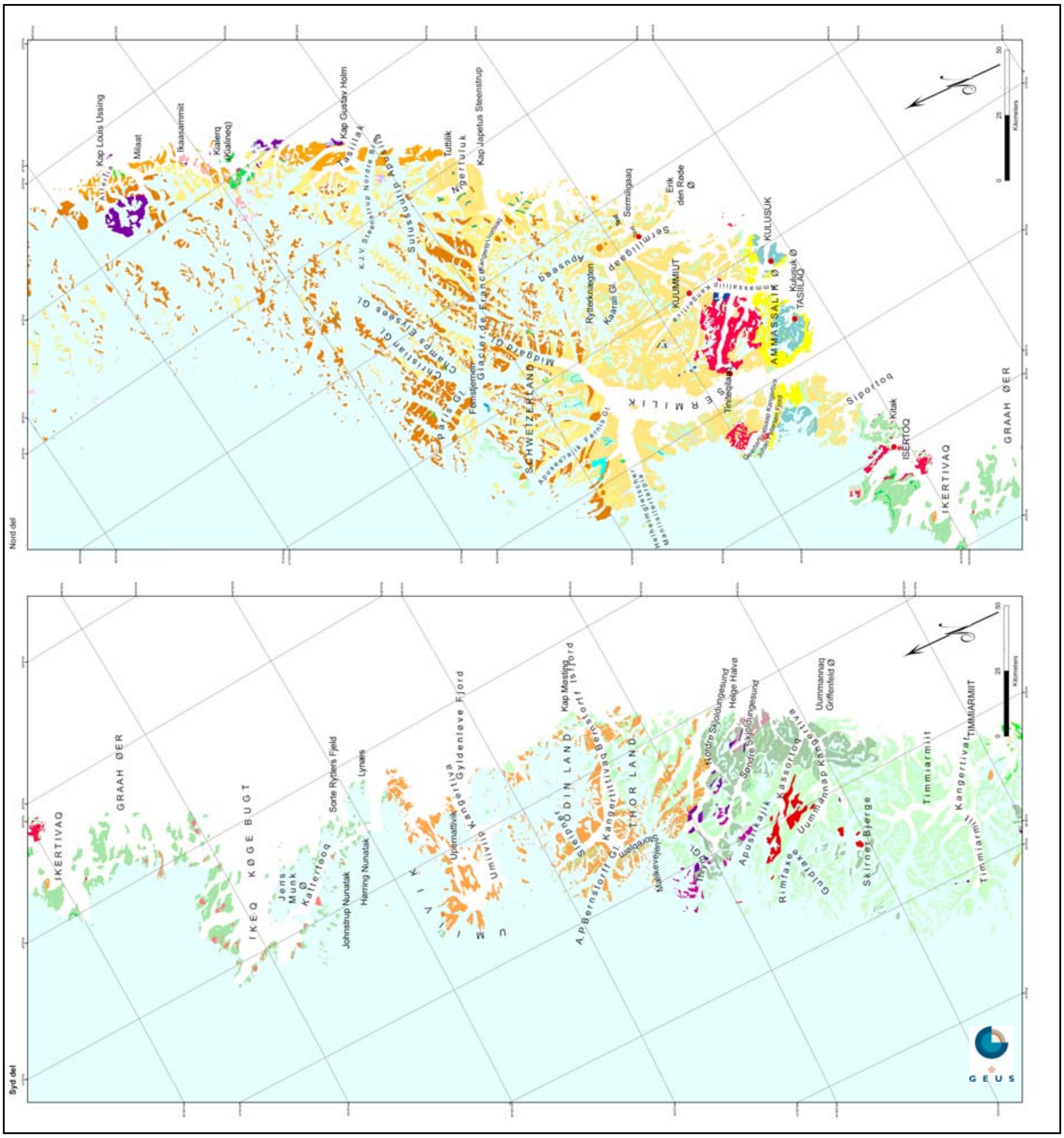

Figure 4. *Geological map based on 1:500 000 map sheets 1, 13, and 14, fitted to the new topographic base. Legend not finalised.*

4. Company activities until 2008

Bjørn Thomassen

Company activities have been limited in the region. The following field investigations are known (GRF refers to GEUS Reference File number; in most cases these are company reports handed in to the authorities by exploration companies according to license regulations.

4.1 Kryolitselskabet Øresund A/S, 1963

Kryolitselskabet Øresund carried out helicopter reconnaissance between Julianehåb and Kap Japetus Steenstrup (66º15’ N), mostly in the form of visual inspection for signs of mineralisation including sampling of promising localities. Unfortunately, the reporting was not completed (GRF no.21241).

4.2. Nordisk Mineselskab A/S, 1971

Nordisk Mineselskab carried out mineral reconnaissance at Kialineq (66º55’ N), but did not obtain any significant results. (GRF no. 20907).

4.3. Ujarassiorit Mineral Hunt Programme, 1989-2008

Several samples anomalous in especially Au-Pt-Pd-Ni-Cu have been submitted from the Ammassalik area. Follow-up work in the Ammassalik area in 1990 showed anomalous Au, As, Se, Ag and base metals.

4.4. Nunaoil A/S, 1996-1998

Nunaoil A/S has been active in the region over three years:

1996: Geochemical exploration was carried out in the Ammassalik area. Au and Ni anomalies were registered (GRF no.21520).

1997: Follow-up exploration in the Ammassalik area indicated Ni-Cu-Au-Co mineralisation (GRF no. 21684).

1998: Follow-up exploration in the Ammassalik area lead to the discovery of Ni-PGE-Au-Cu-mineralisation in ultramafic rocks (GRF no. 21690).

4.5. Major General Resources Ltd., 1999

Major General Resources Ltd carried out diamond exploration in the Saqqisikuik area. The analytical results have not been reported (GRF no. 21722).

4.6. Nunaminerals A/S, 2001-2008

Nunaminerals A/S picked up after Nunaoil in the region:

2001: Additional follow-up exploration was carried out on Ni-PGE-Au-Cu-mineralisation in the Ammassalik area (GRF no. 21794).

2002: Additional reconnaissance and follow-up exploration in the Ammassalik area (GRF no. 21826).

2007: Field work was carried out, no report available at this time.

4.7. Gem Fields Resources Ltd., 2003-04

2003: Field work in the Ammassalik area indicated new Au-PGE-Ni-Cu-mineralised localities (GRF no. 21839).

2004: Continued exploration for Au-PGE-Ni-Cu in the Ammassalik area (GRF no.21916).

4.8. Inco Ltd., 2005

Exploration for Ni-Cu in the Ammassalik area with no conclusive results (GRF 21964)

4.9. Conclusions

The list of scant activities above fully confirms that the mining industry has engaged in very few activities in the region. It is fair to say that outside the Ammassalik area, the region is practically unexplored.

Concerning the Ammassalik area, the most recent statement from an exploration company is this from Nunaminerals' Yearly report 2007:

> "Mineral exploration in the Ammassalik area has led to the discovery of several nickel-copper-bearing structures on the south side of Ammassalik island over a distance of 8–9 km and on the south coast of Qeetartivatsaap Kangertiva c. 40 km to the north-west. The original discovery showing on Ammassalik Island is a 90–100 m long lens, which varies in width from 1 to 8 m. Systematic surface sampling yields an average of 0.77% Ni, 0.34% Cu, 509 ppm Co and 519 ppb combined Au-PGE.
>
> Two mini bulk samples from 2007 returned 1.45% Ni and 0.5% Cu on average with a tenor (converted to 100% sulphides) of 4.7% Ni and 1.6% Cu".

5. Satellite data studies

Tapani Tukiainen and Leif Thorning

The elongated shape of target area for the mineral resource assessment project and the difficult logistical situation makes it an obvious occasion for use of satellite image data. Several sources of data are available, but for a first view of the area, Aster data are convenient. GEUS has acquired 42 Aster scenes providing good coverage of the area.

5.1 Previous satellite data studies

Only sporadic application of remote sensing techniques has been carried out in the target area, mostly in the surroundings of the Tasiilaq by the Nunaoil A/S as a part of their prospecting activity in 2004. This study was based on ASTER-data. The aim of the study was to locate ultrabasic rock units, and determine lithological characteristics and targets of possible gossanous and hydrothermal alteration.

Tukiainen et al (1993)[1] carried a project to assess the application of Spot and Landsat TM images to geological reconnaissance in South-East Greenland, south of the focus area for this report. The study demonstrated that the spectral range of the Spot imagery was insufficient to distinguish with any certainty between the lithologies observed in the field. The acquisition of the spectrally more attractive Landsat TM data was by the time of the project difficult, but the limited available TM-data of sufficient quality convincingly demonstrated the potential of the multispectral VNIR-SWIR data in geological mapping and mineral exploration.

5.2 Available data

Available high/very high-resolution remote sensing data of interest is summarised in Table 1. The Aster and Landsat TM/ETM data have been acquired over a number of years and multitemporal coverages are directly available. The very high resolution GeoEye imagery (spatial resolution is 0.4 m and 1.65 m for the panchromatic mode and the multispectral mode, respectively) can be acquired through data acquisition requests to relevant providers of satellite data. Until now, only very limited Hyperion data is available from the Tasiilaq area, which means that the Hyperion data for this specific region would only become available if new data acquisition were requested at considerable costs and usually also waiting

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[1] *Tapani Tukiainen, Peter Erfurt and Leif Thorning, 1993: Project to assess the application of Spot and Landsat TM imageries to geological reconnaissance, South-East Greenland; Final Report. Grønlands geologiske Undersøgelse, Open Series 93/8*

time. Apart from the very high-resolution GeoEye imagery, similar other products are available via data acquisition requests (Ikonos, QuickBird, Formosat, etc.). In Appendix C, a table of the mostly used satellites has been compiled.

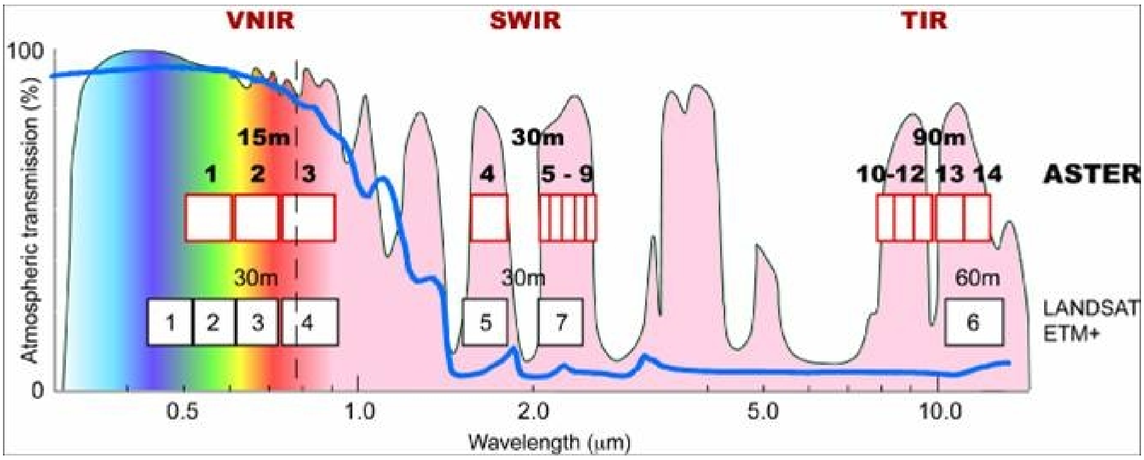


Figure 5. *Channels of the electromagnetic spectrum used in Aster and Landsat ETM+ data. VNIR = Visible and Near Infra-Red, SWIR = Short Wave Infra-Red, and TIR =Thermal Infra-Red. The rainbow colours indicate the position of normal visible light for the human eye.*

5.3 Data used for this study

The better spatial resolution and more extensive spectral capabilities make the ASTER imagery superior to the LANDSAT TM/ETM data as a tool/aid for the mapping and mineral exploration.

The target area is covered by a vast number of ASTER scenes in the USGS Earth Resources Observation and Science (EROS) Center Aster Data archives. Only a fraction of the total data acquisition is of interest because only the cloud free scenes from the data acquisition window July – August are of interest. The snow coverage in July – August is highly variably from year to year. The data search in the EROS data archives resulted in 42 cloud free scenes with minimum snow coverage (Figure 6). These scenes cover more than 99 % of the region of interest and for the most part with extensive overlap between the scenes. All of the 42 selected scenes at processing level L1B (registered radiance at sensor) were acquired for MRAPSEG. The L1B processing level implies that radiometric and geometric coefficients are applied to the data.

The acquired scenes are in UTM projection (Datum WGS1984). The default UTM zone varies from 23N to 25N depending on the scene's central longitude.

The prerequisite for the use of the ASTER data is the application of specific pre-processing routines characteristic for each spectral region of the ASTER data:

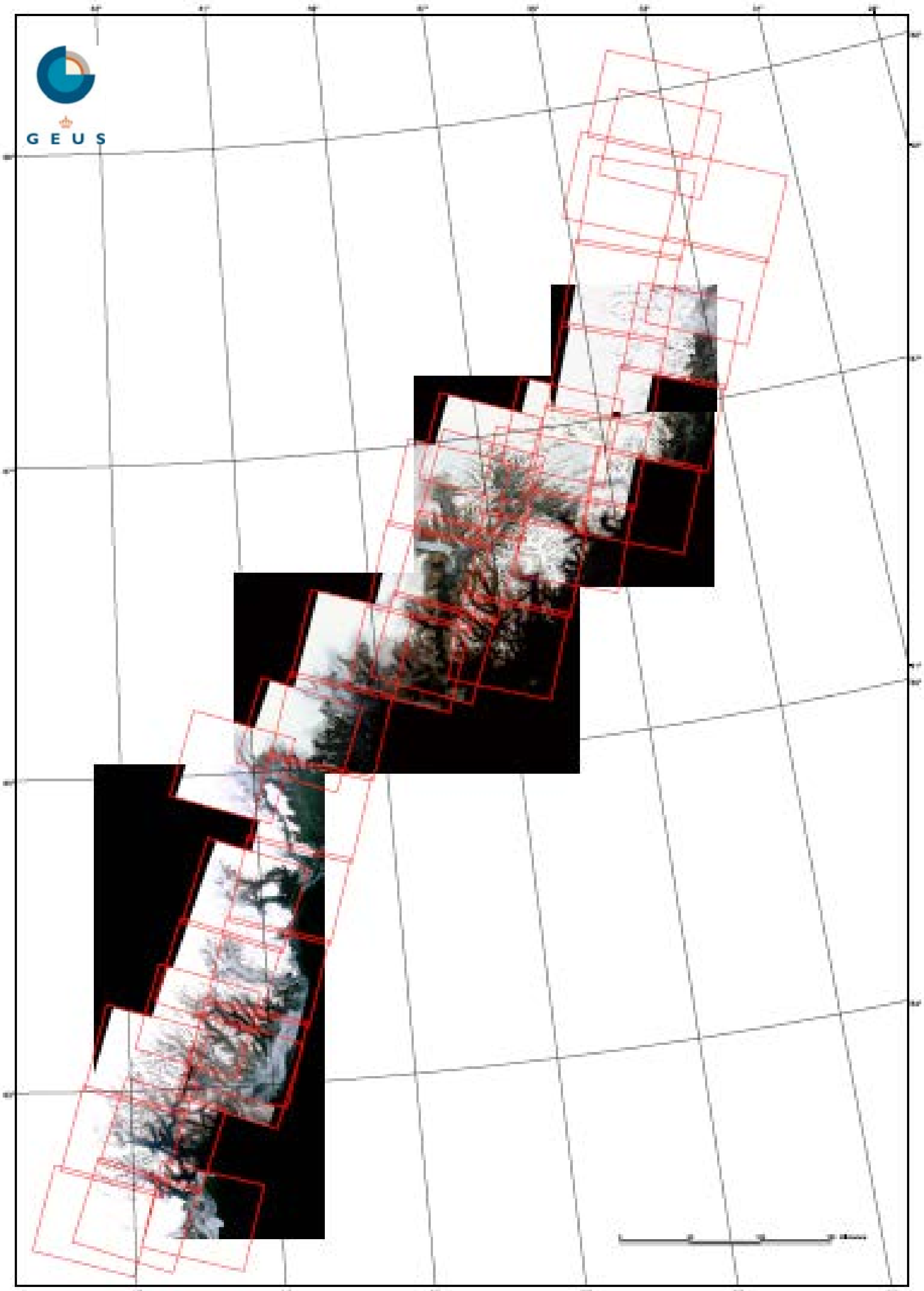


Figure 6: *Index map for Aster scenes used for SE Greenland (labels omitted for clarity). The mosaic has been created using ENVI programs.*

Preprocessing	*Spectral range*
Map projection conversion to UTM Zone 23 (if necessary)	VNIR, SWIR, TIR
Resampling to 15 x 15 resolution	SWIR, TIR
Channel cross talk correction	SWIR
Atmospheric correction (conversion to reflectance)	VNIR, SWIR
Thermal IR Atmospheric correction, de-striping	TIR
Conversion to emissivity	TIR

The Aster data is now stored at GEUS, ready for further interpretational processing.

5.4 Results and maps

The pre-processed VNIR bands of the ASTER scenes were merged into a mosaic to give a first approach to the region. The default geocoding quality of the ASTER data is surprisingly good, as can be seen when comparing with the latest cartographic information from KMS. The coast/ice line information of the KMS-maps registers remarkably well with the geo-coded ASTER data.

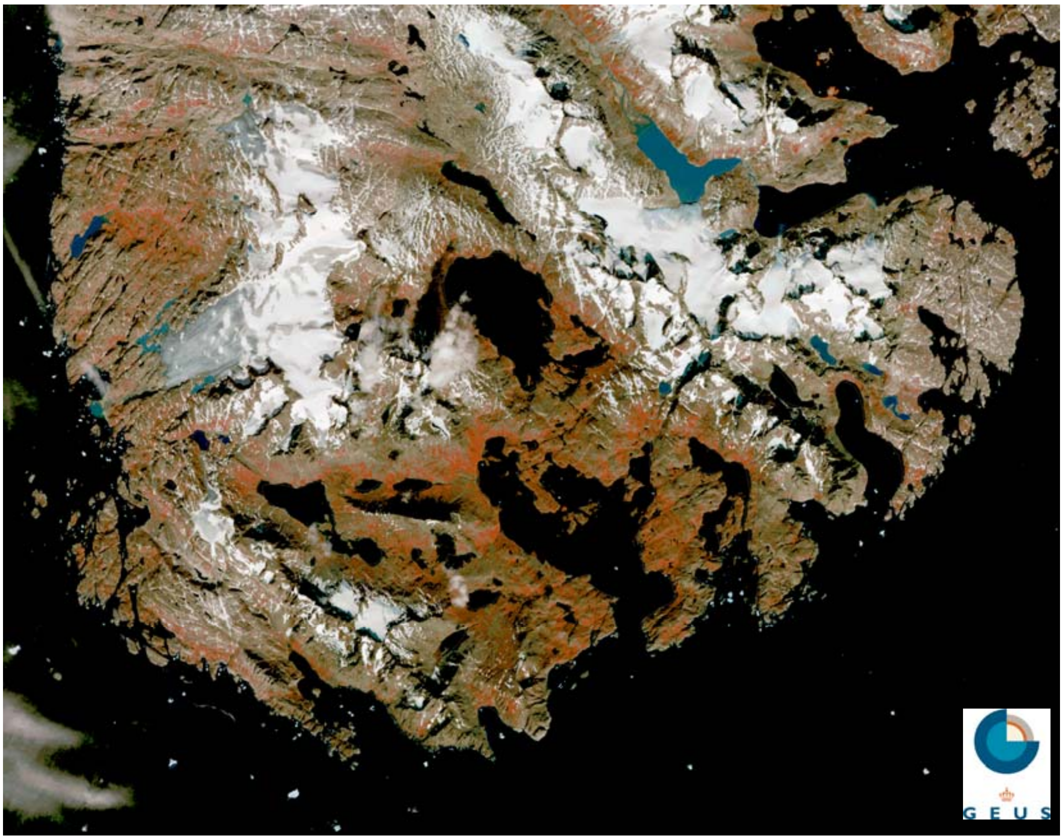


Figure 7. *Example showing the details available from Aster data.*

The preprocessed and geocoded Aster data is a basis for the more advanced spectral analysis involving the SWIR and TIR data to assist the lithological mapping and the mineral exploration in this large and area of difficult access.

By virtue of the backwards looking sensor (band 4), the ASTER imagery has stereoscopic viewing capability of the terrain. Digital Elevation Models (DEM) of a good quality at scales 1:30 000 or better may be extracted from the ASTER L1B data. The ASTER- based DEM could be used as complement to the existing topographic information in selected areas: for instance, as drainage analysis for the planning of the stream sediment sampling programme.

5.5 Discussion

The compiled and pre-processed ASTER imagery is the basis data used to assess the structural and lithological characteristics of the area. The possible use of the very high-resolution data (GeoEye, Ikonos, QuickBird and Hyperion) requires that the data acquisition requests be scheduled for the period of late June – mid August 2009.

The GeoEye sensor, which allows revisiting any area each 1-3 days, makes it possible to acquire data from larger contiguous areas during the short snow free summer period. The revisiting frequency of the Hyperion is 16 days, which implies that only limited ground can be covered during the snow free period.

Considering the geological environments described in Chapter 2 of this report and their theoretical economic geological potentials, it seems of paramount importance for the continued exploration of Greenland to open up this part of the country for further attention by the international mining industry. Continued use of Aster data is advisable, while GoeEye or Hyperion data in practise only can be considered for follow-up use in the autumn or next year.

6. The GIS-model

Leif Thorning, Frands Schjødt, Mette Svane Jørgensen

The initial GIS-model constructed during the preparations for MRAPSEG here in 2008 will be enlarged with new data as they are produced, including all derivative maps, etc. The architecture of the GIS-model will follow the standards for GEUS' mineral resources assessments. The model will be available for internal users throughout the projects and will be published in DVD or web (versioned) at suitable time.

Presently, the MRAPSEG GIS-model contains the following items and issues:

1. Seamless topographic map in scale 1:500 000 with 100 m altitude contours, rivers and lakes, names, in the standard GEUS layout
2. Seamless geological map in scale 1:500 000; a preliminary legend has been constructed – to be improved during the project
3. Special layouts for MRAPSEG in various scales and extents
4. Aster satellite image map with all channels

Additional layers of data will be forthcoming as the project advances. Already the following are being considered and information is in the process of being gathered for some of them:

5. Logistical information concerning old villages, huts, landing strips, suitable locations for fuel depots and camps; these will later be checked and confirmed and supplemented with pictures/photos, etc.
6. Preliminary mineral occurrence map; this will be improved throughout the project.
7. Existing field maps and photos

The separate, but co-ordinated activities applying different methods to the programme will all produce georeferenced data that will be made available in the GIS-model. The GIS model will be the basis for publications of data via DVD or the web at suitable times.

7. An overview of MRAPSEG

Leif Thorning

This chapter contains a proposal for the main elements in a Mineral Resource Assessment Programme for SE Greenland (MRAPSEG). The proposal has been adapted from the original proposal designed early in the autumn into a revised proposal honouring the requirements expressed by BMP early December 2008. The original discussions of the aeromagnetic and geochemical regional surveys have been moved to two appendixes. The various components have then been put together in a slightly different order in this chapter. The overall aim of the programme remains the same.

The MRAPSEG is described here without any consideration of other activities already planned or under consideration for other parts of Greenland.

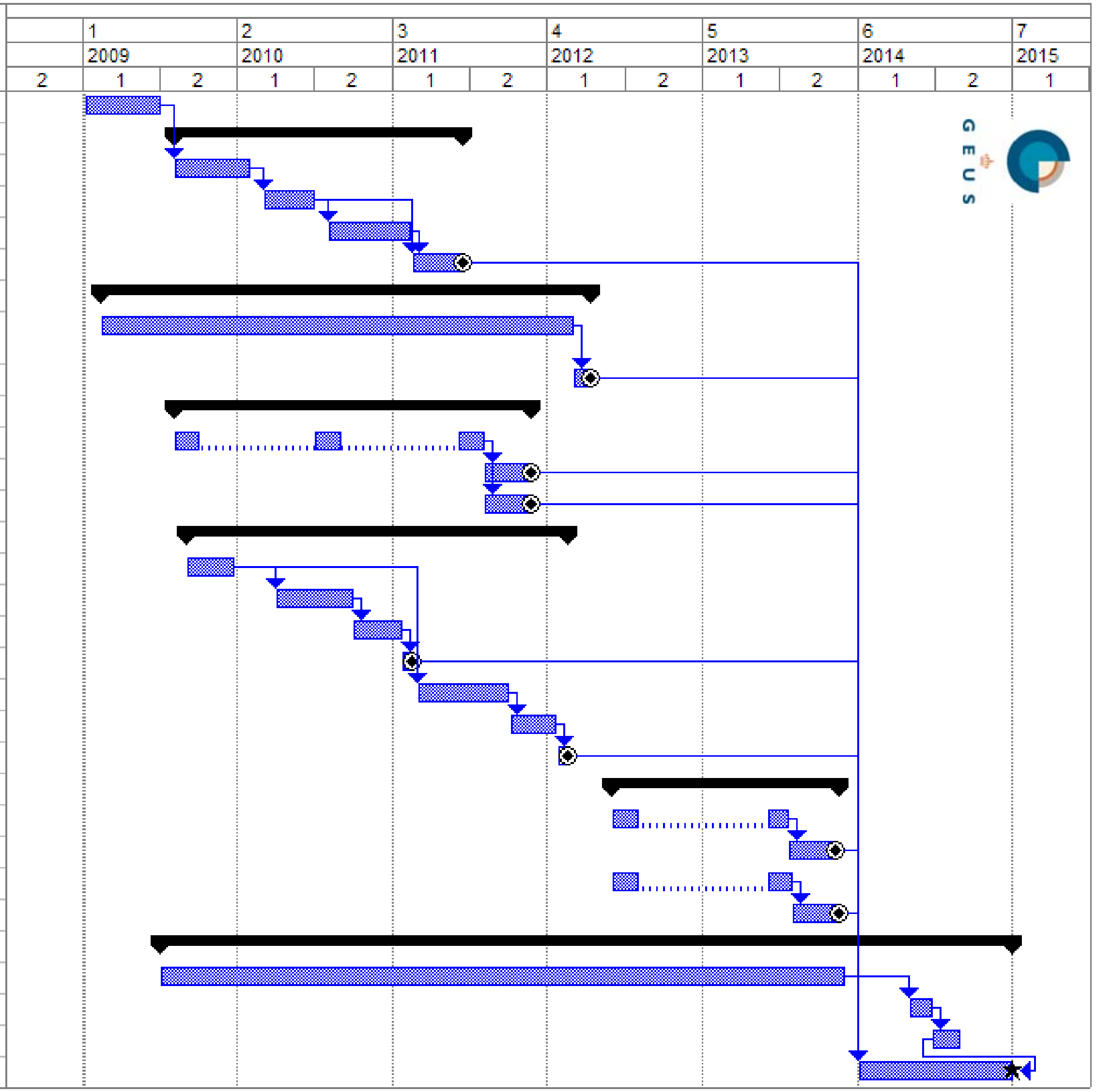
7.1 Main components of the MRAPSEG

In accordance with discussions and talks through the last couple of years and adapted to the most recent specifications and wishes for the programme, the following main components are suggested for the six-year MRAPSEG:

1. Regional geochemical and indicator mineral survey based on stream sediments; field work in 2009 and 2010.
2. Regional aeromagnetic survey in 2010 and 2011, subject to financing becoming available; target areas to be chosen later in 2009, but most likely will be southern part of region corresponding to the first year of geochemical sampling.
3. Aster data interpretation for the identification of main lithologies and important geological processes in 2009; intermittent reprocessing according to results of field follow-up throughout the project period.
4. Reconnaissance geological fieldwork including dating of main lithologies and selected mineral occurrences simultaneously with the geochemical and aeromagnetic surveys in 2009 to 2011.
5. Geological and economic geological fieldwork including geological mapping at relevant scales of target areas for mineralisation in 2012 an 2013; multiparameter, integrated interpretation will be an important part of the continued work to under stand he geological development of the region.

Figure 8 (next page). *Preliminary conceptual overview of the main components in MRAPSEG shown as a simplified Gant-diagram based on <u>approximate calendar time</u> for duration of the activities. In reality, the interaction between activities will be much more widespread in time and detailed in inter-activity influence (produced in Microsoft Project).*

Id	Opgavenavn
1	Inception & detailed logistical planning
2	**Geochemical Surveys**
3	Skjoldungen region, fieldwork and analysis
4	Compilation and interpretation, Skjoldungen
5	Sermilik region, Fieldwork and analysis
6	Final interpretation and report
7	**Aster satellite data interpretation**
8	Processing: lithology and geological processes; catchment basins?
9	Reporting
10	**Geological Reconnaisance**
11	Fieldwork
12	Dating
13	MRA
14	**Aeromagnetic Surveying**
15	Detailed planning and tender process
16	Survey: Skjoldungen
17	Compilation: Skjoldungen
18	Delivery: Skjoldungen
19	Survey: Sermilik
20	Compilation: Sermilik
21	Delivery: Sermilik
22	**Geological Mapping & MRA**
23	Targeted geological mapping
24	Reporting
25	MRA fieldwork
26	Reporting
27	**Final Analysis, MRA, Production and Reporting**
28	Integrated interpretation, MRA, and GIS-model construction
29	Checkup fieldwork
30	Tolkning
31	Final Reporting



6. Ressource assessments and integrated interpretation and reporting/publication of results throughout the project period, with a culmination in 2014. Possibility for brief check-up fieldwork in 2014, if required.

Before commenting on the various components, it is important to emphasise the need for ideally including them all in a mineral resource assessment (MRA) project. The intention is to increase our knowledge of the region significantly through an assessment of the mineral potential. The programme represents a significant investment of labour and funds, and most of the geological issues and methods applied call for work distributed over extended periods. It is a fact that although there are uncertainties in the funding of the aeromagnetic surveys, which therefore may have to be fitted to a much lower budget, the remaining activities are all within realistic limits for funding. Both GEUS and BMP should therefore be committed to carry through with the project over a period of approximately five to six years.

The Microsoft Project overview shown in Figure 8 is conceptual and only meant to illustrate the various, suggested activities. In reality, the picture would be much more complex and there would be many more ties between activities. Although uncertainties in funding obviously will have to be accepted, it is important to commit to the entire programme and accept that omission of some of the activities may decrease the validity and value of the results of the mineral resource assessment, which is the overriding goal of the project. To allow time for a careful consideration and discussion of the logistical parameters, it is suggested to include a brief inception phase in the contract, which will also include the immediate preparations for the first field season. By the end of the inception phase, a clear understanding of the entire project should be shared between BMP and GEUS.

It should also be stressed that because time is very limited for the preparations of the desired geochemical fieldwork in 2009, a contract for the geochemical surveys in 2009 and 2010 should be prepared and signed immediately, e.g. during January 2009. A brief, separate description of these activities will therefore be included among the descriptions of BMP/GEUS projects in 2009 requested by BMP to be delivered on Friday 9 January 2009. Similarly, if it is the intention to go for aeromagnetic surveys in 2010 an 2011, the tender process for this should start November – December 2009.

In the following sections of this chapter, additional comments will be given to the various components, included some on the adaptations from the original proposals in appendices A and B to the combination described in this chapter.

7.2 Regional geochemical surveys

For a detailed description of the stream sediment geochemical survey, see Appendix A.

7.2.1 Brief description and discussion

In Appendix A, principles and methods of the regional geochemical stream sediment survey are described in some detail. In the description, it is assumed that density of sampling, methods of sample acquisition, analysis and compilation will be those well known from previous surveys of other parts of Greenland, supplemented with diamond indicator mineral analysis. Budget estimates are based on 2008 prices as quoted from commercial chemical laboratories and helicopter use is estimated from prior experiences.

In Appendix A, it is suggested to start the geochemical fieldwork in the Sermilik region, i.e. out of Tasiilaq in 2009. This would allow preparing the base camp at Skjoldungen for 2010 (mainly transport of fuel and equipment), while carrying out the actual fieldwork in the region around Tasiilaq. In December 2008, BMP requested that the geochemical survey be started in the Skjoldungen region. This means that the logistics will have to be done differently, probably using a combination of helicopter, rubber dingy and floating base camp (ship) that can carry the required fuel and personnel. BMP is aware of suitable ships that could handle the job, and which are assumed ready for 2009. This will be further investigated during the inception.

This will increase the logistical costs, but at the same time also allow for the inclusion of a geological reconnaissance team that can follow, in a general sense, the geochemical sampling team. The additional team would be responsible for sampling suitable dating material and make the first economic geological observations.

As part of the geochemical project, and increasing the effectiveness of the geochemical sampling, the Aster database compiled during the preparatory project will be used as a planning tool. The Aster digital terrain model (30 by 30 metres) will be used to define catchment basins, if possible. Various processing schemes already applied in SW Greenland, will also be applied in SE Greenland.

The analytical programme is described in Appendix A and will be carried out at commercial laboratories and GEUS as appropriate and possible within the time limits and budget given. In all likelihood, the compilation of results, production of geochemical anomaly maps and interpretational maps will be ready during the first half of 2010, before the next field season in 2010. If a need is indicated by the interpretation of results from 2009 and 2010, it will be possible to do some additional sampling work in 2011.

As an important supplement to the analysis programme described in Appendix A, it is suggested to analyse ca. 50 of the samples collected during the stream sediment geochemical programme for their mineralogical composition and the geochronology (zircon), see Appendix D. The aim of this is to describe variations in the bedrock geology further than possible using geochemical analysis. This will be done using two technologies,namely the CCSEM method and a combination of LA-ICP-MS of zircons. These technologies are well suited for reconnaissance to characterise the geology in a terrain, which is only known in little detail. The cost of the CCSEM analysis and the LA-ICP-MS analysis, respectively, is 2500 DKK and 8000 DKK per sample.

In 2010, the sampling programme will be moved to the Sermilik region, probably out of Tasiilaq; the preparations, fieldwork, and the analytical programme will be similar to the 2009 programme.

The interpretation of the geochemical data will take place throughout the project period; it will be concluded some time in 2011.

7.2.2 Budget considerations

BMP has reserved five million DKK for each of the years 2009 and 2010 for geochemical surveying. This budget should be sufficient to include the initial Aster data interpretation, the geochemical stream sediment sampling and analysis programme, the indicator mineral analysis, the supplementary one team geological reconnaissance effort, and the compilation and interpretation of the data. The great unknown is the cost of the ship-borne platform for the operation, which is not included in the appendix. This will have to be further analysed during the inception phase; in appendix A, the cost of the classical geochemical programme is estimated to just over six million DKK, if the sampling is done over two years. Assuming two times 5 million DKK for the geochemical survey, that leaves about two million for the ship-borne platform and the extra geological reconnaissance team for each of the two years. The costs of the 2010 operation will probably be slightly lower; the 2009 may be slightly higher.

7.3 Regional aeromagnetic surveys

For a more detailed discussion of the aeromagnetic survey options, see appendix B.

7.3.1 Brief description and discussion

The cost of aeromagnetic surveying has increased dramatically since the last Aeromag survey was flown in 2001. However, the recent international developments in the financial and corporate market combined with a possible drop in fuel prices may result in significantly lower prices for large contracts over several years. It is important to try out the market through an international tender according to EU rules; also, joint financing contributions from other sources (mining companies) should be attempted. This means that the preparations for a survey of the Skjoldungen region must start in the autumn of 2009.

The survey parameters for a focused survey over the basically ice-free areas between the Inland Ice and the coast should be similar to those used in the Aeromag surveys 1992 – 2001, i.e. 0.5 km (5 km) spacing, approximately 300 meters over terrain. If surveying the Inland Ice connecting the east and west coasts is considered, the spacing of lines can be increased to 3 km in this region. Ideally, both options should be employed, but the cost of that may be prohibitive.

The airborne geophysical survey activity in Greenland has been considerable in recent years. Apart from the BMP/GEUS run public surveys (the last flown in 2001), the industry has used airborne geophysics intensively in smaller areas onshore and for speculative purposes over large areas offshore. It has been loosely discussed to appeal to mining companies for contributions to the financing of the aeromagnetic surveys discussed in this report. It has been considered to attempt a joint operation with the companies presently engaged in speculative offshore surveys, in other words to carry out a survey covering the onshore areas shown in Figure B1 (A-D) and an area offshore this region. However, this may not be so desirable from a logistical point of view, and good data do already exist for major parts of the offshore area off SE Greenland between 62° and 67°N, data collected in the

GGU/efp/EU supported project Eastmar in 1979 – 1980. Before more, public funds are used on this offshore area, it may be advisable to revisit the existing data and produce new and up-to-date visual presentations of these data[2]. The geological development of this area is fairly well understood. From a geo-scientific point of view, it may be a better investment to cover the Ice Cap with a good, modern quality survey allowing us to study the entire Precambrian block of Southern Greenland, and thus gain a much better understanding of the exposed parts along the coasts of Greenland. This would cause much attention internationally!

7.3.2 Budgetary considerations

If costs were going to be the determining factor, one approach would be just to fly the Skjoldungen region in 2010; this would approximately correspond to area A in appendix B, and if need be, some of the compilation costs could be delayed to 2011. In general, the amount of flying in a given year can be fitted to the budget available, although this would probably, everything else equal, result in a higher per line kilometre price. It is perhaps premature to plan the details in the operational approach, until the budget frame is better known. Considering the international development in prices, it is important to allow sufficient time for an international tender. By describing the aeromagnetic survey as a project over several years, the tender can be for a framework programme, subject to annual funding becoming available. This would also help bring the price down considerably. The model is familiar, having been tested during previous Aeromag projects.

There is a discrepancy between the very preliminary estimates of total coasts attempted in Appendix B and the figure of 5 (?) million DKK preliminarily indicated for each of the years 2010 and 2011 in BMP’s announcement of 9 December 2008. However, the actual prices will almost ceratinly be lower in 2010 due to international market developments, and the tender will help bring the costs further down. What remains will be to fit the area to be flown to the actual budget available, and this is a standard operation used many times in the AEM and Aeromag projects.

Using the option of doing a joint offshore/onshore survey will make it necessary to have a look at the different marketing conditions in the international mining industry and the international hydrocarbon industry. The latter is accustomed to speculative surveys and high prices; the former is dependant on public surveys and moderate to low prices. This has also been the case in Greenland and the whole product and price structure may have to be assessed, unless different prices for the same product are acceptable.

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[2] Actually, as an aside outside the discussion of MRAPSEG, the author would like to suggest that BMP and GEUS carefully assess the possibilities for future co-operation on the coordination, distribution and future use of all airborne geophysics data in Greenland originating from public, speculative and licensed company operations, onshore and offshore; practical, scientific and marketing issues should be considered.

7.4 Geological reconnaissance, mapping and investigation

It is suggested to let one geological team follow in a co-ordinated manner the geochemical sampling team in 2009 and 2010. This will be organised as part of the geochemical project and the objective for the additional team will be to sample for dating of major or critical units known in advance, observed during the fieldwork or worth special attention because of their involvement in mineralisation processes and/or structures. This activity will also serve the purpose of planning the geological investigations in 2012 and 2013. The extra team will also be able to assist with the geological sampling, if needed, and make observations relevant for the mineral resource assessment.

Proper geological mapping will probably not be needed until 2012 and 2013. To understand the geological development in depth, it would probably be necessary to map in scale 1:100 000 or even more detailed in special cases. That will not be possible for the entire region within MRAPSEG because the arregion is so large. Therefore, geological mapping will be focused in the areas of special interest, either for the understanding of the geology or for the detailed mapping of discovered mineralisation.

In an area as unknown and underexplored as SE Greenland there is bound to be many surprises. Some of these will be critical features for the mineral resource assessment programme, and may be the focus of offshoot projects, or they may results in a rethinking of the project activities. It is therefore not feasible to give detailed budgets for such work in 2012 an 2013. It is sufficient to know that because of the large area in question, an early budget of some 4 – 5 million DKK per year would be reasonable to expect to gain significant advances in the geological understanding of the area, not the least through the full investigations and use of all the new data available at that time.

In Appendix D are some suggestions for additional analysis programme that with advantages could be launched at suitable times of the project period. Depending on the budget, some may be employed already during the geochemical project This will be done using two technologies namely the CCSEM method and a combination of LA-ICP-MS of zircons.

7.5 Mineral resource assessment

The mineral resource assessment process will be continues throughout the project, but with varying intensities. Starting with the known sites of interest, the sites will be described and entered into GMOMDB. Early in the process, initial mineral occurrences maps will be constructed; later to be extended with new sites as they appear from one or several of the various activities. When sites are entered into GMOMDB, they will become available for the public at the same time on the GMOM web site. Mineral resource assessment using the USGS method will be applied, if possible. From 2010 and onwards, the methods for integrative, multiparameter statistical analysis will be initiated, working towards prediction/prognosis maps and metallurgic maps. Special studies of relevant mineralisation models will be included. For these interpretational techniques, it will be an advantage that experience from SW Greenland is at hand.

Until sufficient geochemical and aeromagnetic data is available, the initial data compilation will take place in the geochemical project, the aeromagnetic projects, etc. Once the assessment enters into a more intense phase, it may be an advantage to arrange this in an offshoot project, still closely co-ordinated with the main activities.

7.6 Data, reports, maps and publications

The communication of results and data will follow the usual principles for GEUS' mineral resource assessment projects:

- Data and results will be communicated to the international mining industry as soon as possible, subject to GEUS' own quality control
- All avenues will be used: notes, GEUS reports, Geology & Ore, Fact Sheets, international scientific publication, etc.
- Project activity reports will be forthcoming by the end of every year. They will give brief summaries of events, look ahead to the activities of the following year and perhaps discuss suggestions for changes in the programmes.
- Data will be compiled and quality controlled and made accessible via a suitable media, i.e. DVD or web.
- Field reports, documentation of data and observations, acquisition and compilation reports etc. will be published as GEUS reports, if deemed suitable important for external users.
- Scientific results will be published in peer-reviewed papers.
- Results will be presented at conferences and exhibitions; when appropriate, issues of *Geology and Ore* or *Fact Sheets* will be produces for such occasions.

8. Appendix A: Proposal for geochemical survey

Agnete Steenfelt

8.1 Introduction

Geochemical mapping by means of surface samples collected and treated systematically at a density of one sample per 20 to 50 km^2 has been carried out over large parts of Greenland (Figure A1). The data have successfully been used to identify provinces or smaller areas with potential for mineral resources, as clusters of anomalies or during modelling of mineralisation in combination with other data sets. Additionally, the geochemical data exhibit regional scale geochemical variation of interest for the understanding of the architecture of the continental crust in Greenland. A third application of regional geochemical data is in environmental management, as the data provide a documentation of the natural geochemical variation.

Southeast (SE) Greenland is poorly known geologically; reconnaissance scale geological maps at 1:500 000 are the main information, and mineral exploration programmes have been few. The best-known part is the area around Tasiilaq, where NunaMinerals among others have collected samples for exploration of base metals and gold within supracrustal rocks.

There are uncertainties in the correlation of boundaries in West and East Greenland between Archaean and Palaeoproterozoic terranes and lithotectonic units across the Inland Ice. New regional geochemical and geophysical data will greatly improve the basis for making such correlations.

The southern part of SE Greenland is believed to be a continuation of the North Atlantic Craton, which in Southwest Greenland, just across the Inland Ice, hosts several kimberlitic and ultramafic lamprophyre dykes, some of which have proved diamondiferous. The occurrence of such rocks have not been reported from SE Greenland, but similar rocks, the Skjoldungen Alkaline Province, suggest that there is a potential for kimberlites. The identification of kimberlite indicator minerals (KIM) in samples of glacial overburden has lead to many new occurrences of kimberlite dykes in southern West Greenland, and that is also one of the methods used for diamond exploration in the Canadian North.

Indicator minerals for other commodities have been successfully applied in Canada, recently. This includes identification of gold, sulphides, Ni-Cu-PGE oxides in overburden samples.

When designing a geochemical sampling programme for such a poorly known area, there are good reasons for collecting stream sediment samples and overburden samples and undertake chemical and mineralogical analyses that are consistent with those obtained in West Greenland. Overlap with previous sampling in eastern South Greenland is also important. A combined Au-As anomaly on southern Otto Rud Øer is worth checking, while sampling in that southernmost part.

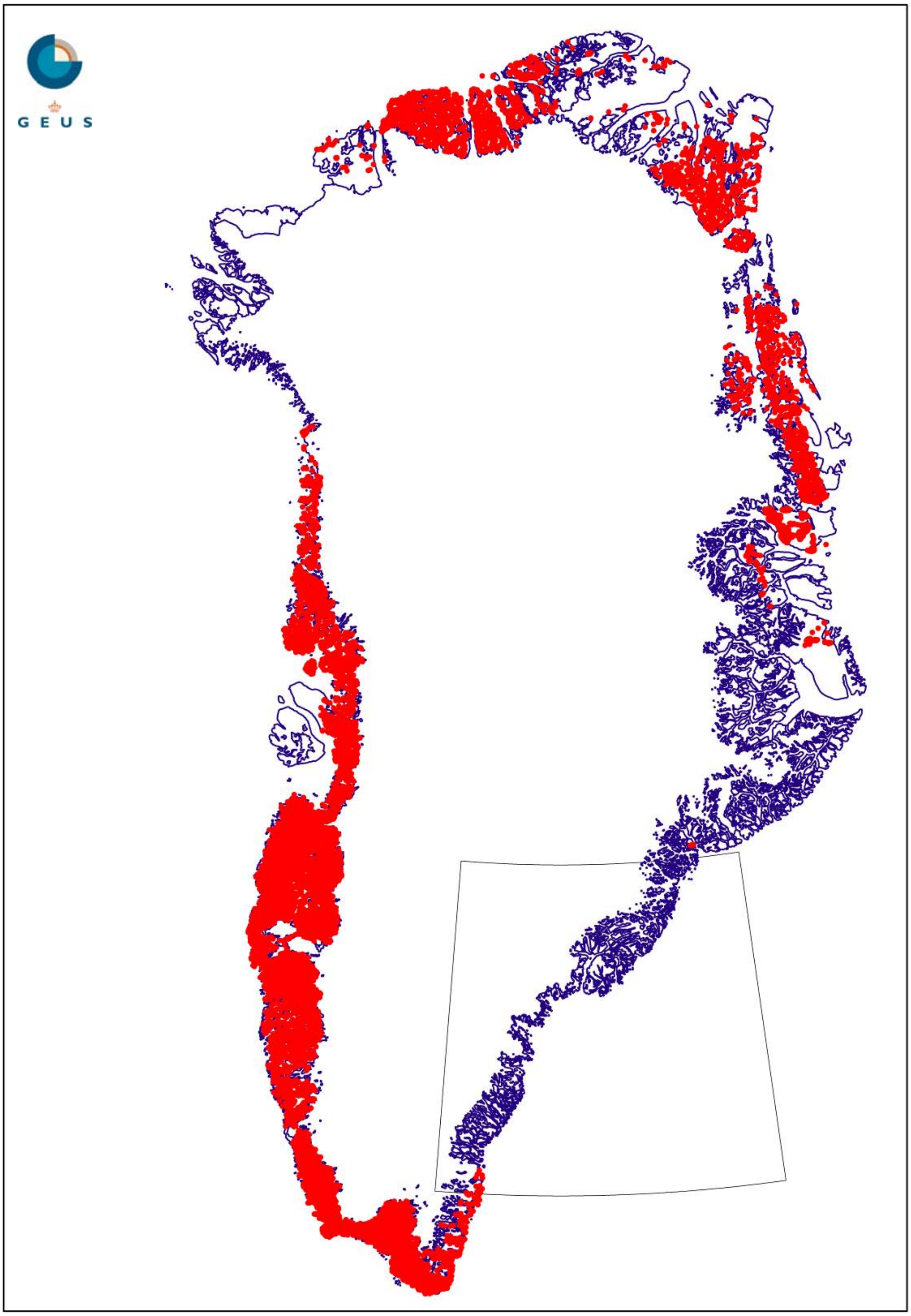

Figure A1. *Stream sediment localities in Greenland (red dots) for existing geochemical surveys and location of the MRAPSEG project area.*

The present proposal contains a description of the study area, requirements for the survey, recommended methods for geochemical sampling and analysis, and a rough cost estimate.

8.2 Objective

The objective of a geochemical survey of SE Greenland from 62° N to 67°30’ N is to map and document the distribution of a long suite of major and trace elements, as well as of indicator minerals (IM). This will enable the identification of districts with mineral potential, and together with aeromagnetic information provide a basis for mineral deposit models/ multi-parameter modelling of mineral deposits. The results will also improve the understanding of the litho-tectonic setting of the rock units in the area.

8.3 Final product

The outcome of the geochemical survey is a report (paper and digital format) with geochemical maps for all elements, minerals and other parameters determined.

8.4 Duration

The entire programme should include at least 2 and preferably 3 field seasons, therefore last 3 to 4 years depending on the progress. It should be initiated at least 4 months before the first field season and can expected to be terminated not earlier than 12 months after the last field season.

8.5 Study region

Southeast Greenland between 62° and 67°30’ northern latitude has an ice-free coastal strip of varying width from nothing to c. 120 km around Tasiilaq. The stretch from Otto Rud Øer (c. 62°N) in the south to Kangerlussuaq fjord (c. 68°N) is c. 850 km long. From a geochemical survey point of view, the widest coastal areas are the most attractive and cost-effective to cover. Thus, there are two coherent regions well suited for geochemical exploration; here termed the Skjoldungen region in the south and Sermilik region in the north (Figure A2). The area in between is regarded to be geologically important, and although sampling and follow-up work will be logistically more demanding, it is not impossible as proven by previous fieldwork in SE Greenland. The vast high-altitude nunatak zone around latitude 67°N, on the other hand, would require so much extra cost both in sampling and follow-up, that it is regarded of low priority in this proposal.

The sizes in terms of geochemical coverage of the two areas have been estimated at 18 000 km^2 for Sermilik (65° to 67°30’ N excluding high altitude nunatak zone) and 20 200 km^2 for Skjoldungen (62° to 65° N).

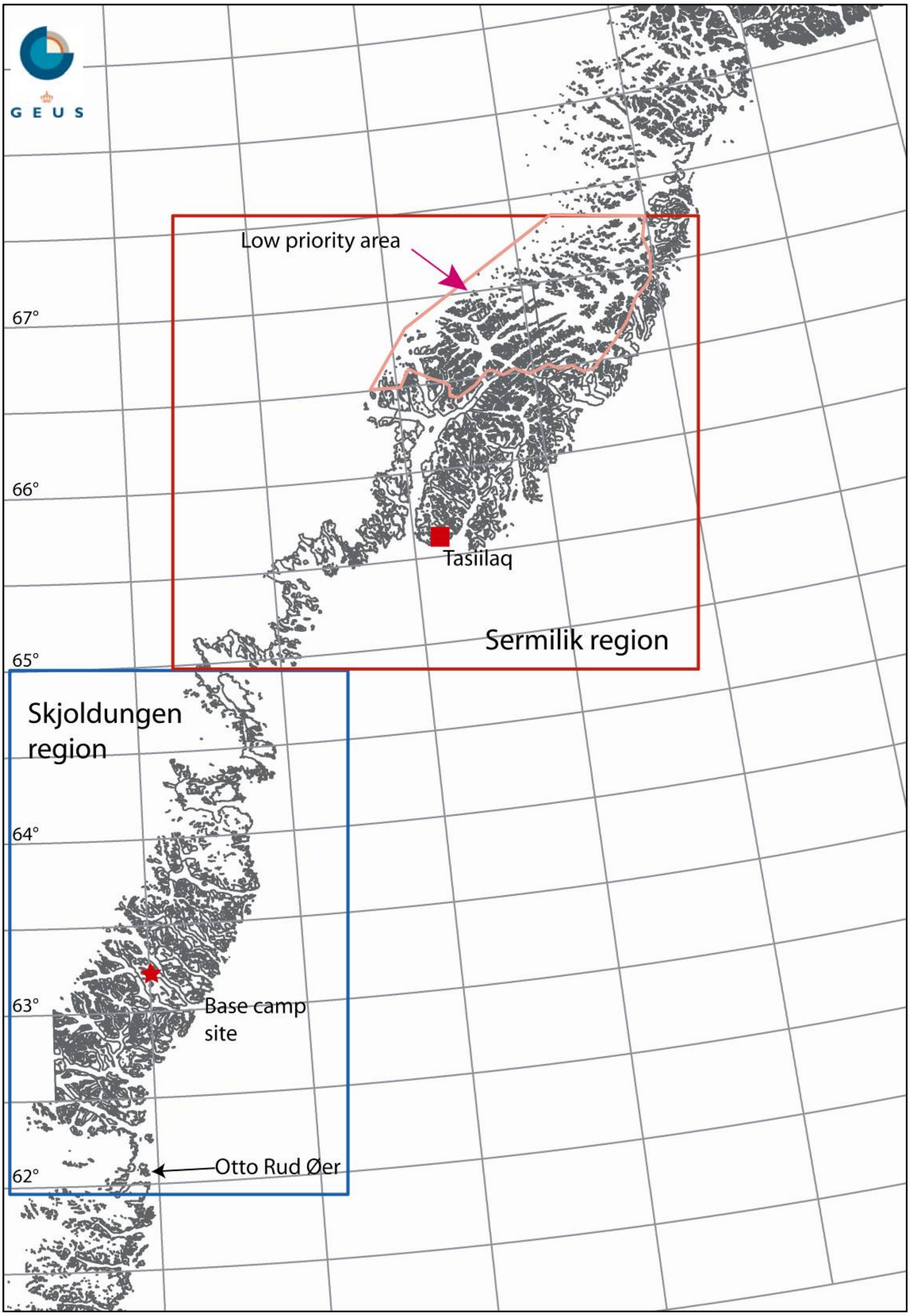

Figure A2. *Subdivision of survey area into a southern part, the Skjoldungen region, and a northern part, the Sermilik region.*

8.6 Logistical framework for field work

Duration. With one field team and one helicopter of type EC120 or AS350, two field seasons are necessary to cover the study area. It is advantageous to limit the sampling period to the warmest period of the year, where most streams are accessible, i.e. mid -July to mid-end August. The assignment of a third field season is recommended to carry out supplementary sampling at selected sites with the purpose of confirming and substantiating identified anomalies.

Transportation. Most of the sampling can be done using helicopter, although a boat may be required to get to certain sites inaccessible for a helicopter, e.g. at steep coastal cliffs. Availability of jet fuel is imperative. The budget assumes that boat expenses can be covered by reduced helicopter expenses.

Field base. Base facilities are required for storing, drying and packing of samples, for storing of boxes, and for electricity for recharging electronic equipment.

Personnel. A team of three samplers is required for the entire sampling period. At least one member of the team must be an experienced geologist.

Progress of coverage. The northern Sermilik area has more infrastructures and should be covered first, i.e. in 2009. The absence of a settlement in the Skjoldungen region has the consequence that a base camp and depot of jet fuel for the helicopter need to be established. That must be arranged during 2009, as equipment and fuel must be shipped to Tasiilaq during 2009 and stored there until the start of the field season 2010.

Sampling media and site recordings. Stream sediment is the preferred media for major and trace element chemical analysis, as it will provide consistency with geochemical mapping elsewhere in Greenland. Because the topography in southeastern Greenland is very rugged, it may become relevant to collect sediment samples from other media such as till, scree or soil as substitute medium, where stream sediment is absent. Lake sediment or soil can be used as substitute medium, where stream sediment is absent. Indicator minerals for gold, kimberlite, PGE etc. can be recovered from stream sediment or soil, whichever medium seems more appropriate at each particular site.

Recording of gamma-radiation is optional but highly recommended. It would result in the recognition of the variation in radiation recorded over individual rock units, thereby providing a basis for a much-improved interpretation of airborne gamma-radiation data.

Sampling density and sample number. An average sampling density of one sample per 30 km2 is recommended and will make the coverage consistent with that in most of West Greenland. The total number of samples required would be 600 for the Sermilik region and 670 for the Skjoldungen region.

8.7 Comparison with previous geochemical mapping campaigns

The Sermilik and Skjoldungen regions cover 15000-20000 km^2 each, depending on how much of the nunatak region is included. Thus, each region is larger than any of the areas covered in West Greenland during a single field season. Comparable topography is found in the Uummannaq district, where the helicopter programme managed to sample 385 sites over 10 000 km^2 in 18 working days (~24 calendar days) using a MD500E helicopter. An additional number of 183 samples were acquired during boat sampling with 9 samples per day on average. The closest comparison in area size is from 1993, where an AS350 helicopter was used to support sampling over three areas in West Greenland totalling 15 900 km^2. During 23 workdays (within 28 calendar days), 70 flying hours were spent to collect 580 samples. In the surveys in West Greenland, samples for IM were not collected.

Allowing a little extra time to collect the overburden samples, the sampling of 670 sites is estimated to last 5 to 6 weeks. (If two helicopter pilots are assigned for the job, the sampling time can be reduced to 4 weeks, weather permitting.)

8.8 Analytical requirements

Sample treatment, chemical analysis, and picking of IM should be done at a commercial laboratory. Analysis should embrace determination of major and as many trace elements as possible – at least as many as have been determined in the mapping of West Greenland (10 major, 35 trace). Picking of IM should comprise gold and KIM as first priority, while other mineral species could be optional. While sampling of overburden should be done systematically, at all sampling sites, the picking and optional analysis of picked grains may be selective and conditional on the presence of stream sediment anomalies indicating the presence of alkaline rocks. In the cost estimate of this proposal, it is envisaged that 100 overburden samples will be processed each year, 2009-2010, and 30 samples during 2011. Sample preparation and chemical analysis typically take 4-5 months after the samples have been received. The budget does not include chemical analyses of mineral grains, which may be preferred to improve the interpretation of the information.

8.9 Data processing, quality control and reporting

This proposal envisages that the final product is a report with all geochemical maps printed as well as on CD or DVD in a GIS environment. Such product requires that all analytical data are quality controlled and data from the two regions are made consistent. The latter requires overlap in sampling and analysis, and possibly some arithmetic data calibration.

8.10 Budget

The budget contains estimates for office work (salary and expenses in connection with sampling preparation, data evaluation and reporting), fieldwork (helicopter, travel, accommodation, salary and allowances, establishment and removal of field base in Skjoldungen region and sample processing (handling, processing, main analysis, and storing). Budget figures for a classical approach have been estimated in 2008 prices and rounded to the nearest 5000 DKK.

Summary of estimated preliminary expenses in 2008-DKK:

	2009	2010	2011	2012
Office work	145,000	105,000	105,000	145,000
Field work	2,005,000	2,435,000	670,000	
Sample processing	465,000	490,000	110,000	
Total	**2,615,000**	**3,035,000**	**885,000**	**145,000**

Note: If sampling in 2011 is not necessary or desired, the expenses in 2011 will be equal to that of 2012 in the table above.

9. Appendix B: On regional aeromagnetic surveys

Thorkild M. Rasmussen and Leif Thorning

9.1 Introduction

The experience from regional aeromagnetic surveying in southern and western Greenland ubiquitously reveals that the structural and lithological information derived from these data significantly improve our ability to understand the geology in the area. The data from southern and western Greenland has been used extensively by both governmental organisations and the mineral industry. Similar measurements are not available from south-eastern Greenland, and we therefore propose an aeromagnetic survey in order to facilitate the understanding of the geology in this region.

At present, only magnetic data from airborne reconnaissance surveys are available from south-eastern Greenland. The experience from the previous surveys in southern and western Greenland shows that measurements at a 500 m line spacing add important details to the map of the magnetic field variation that are not recorded in the reconnaissance data.

9.2 Objective

In addition to the primary results as presented by the digital data and maps from the aeromagnetic survey, the objective of the project is to provide data that complement other geodata with respect to a better interpretation and understanding of the geology of southeastern Greenland. In particular, integration with data from regional geochemical sampling in the area is expected to add valuable information that can be used to guide and focus geological fieldwork. The magnetic data will be useful in delineating and classification of geological domains. Identification and mapping of rock units and structures with anomalous composition is also considered an objective, irrespective that the proposed survey altitude and line-spacing are not optimised for small scale structures.

Combined with magnetic data from previous off-shore surveys, the new magnetic recordings are expected to add valuable information on the relation between on-shore and off-shore geology.

9.3 Final products

The magnetic data and maps will be available in digital format that are readily integrated with other geodata by using standard GIS-platforms. An acquisition and processing report will accompany the digital data archive. A report providing a first order interpretation of the data will be produced and released simultaneous with the digital data.

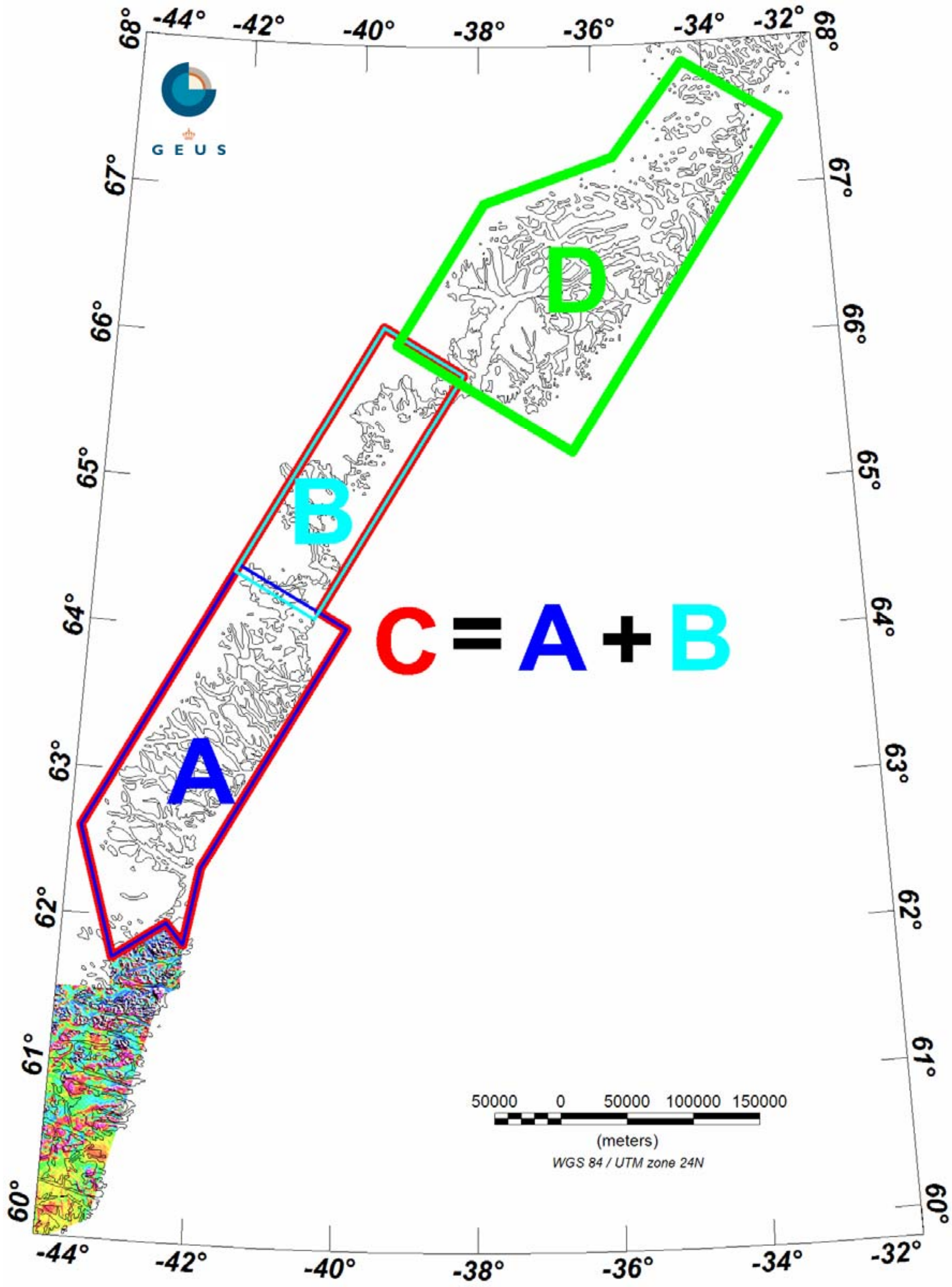

Figure B1. *Outline of boundaries for survey blocks A, B, C & D. The vertical magnetic gradient from the Aeromag 1995 survey is shown.*

9.4 Study region and duration

Figure A1 outlines the areas proposed to be surveyed. The area is divided into separate survey blocks that are dimensioned to allow completion of surveying within one summer period with the use of one aircraft. Survey blocks A and B may possibly be merged into a single Block C and still be flown within one season if surveying starts early. Merging of the two blocks results in a reduction of 1300 line km from the overlap region between A and B. The number of line km for the surveys blocks are summarised in the table below.

9.5 Logistic framework for field work

The data shall be acquired by contracting an experienced geophysical company. Selection of contractor is proposed to follow standard European Union tender procedures. The contractor is responsible for the logistics and data acquisition. The contractor shall report weekly to GEUS about the data acquisition. During surveying, GEUS shall be present at the base of operations at critical times to evaluate and guide the data collection and processing. Any problems and technical matters affecting the data acquisition and data quality shall be reported to GEUS by the contractor, and any deviations from the initial agreement and contract must be negotiated with GEUS.

9.6 Data processing, quality control and reporting

The data processing shall comply with procedures considered industry standard for aeromagnetic surveys. Quality control shall be performed by GEUS.

A description and interpretation of the data shall be provided by GEUS and published in the Geological Survey Report series. The data will be released to the public at the appropriate annual PDAC meetings in Toronto.

9.7 Budget

An investigation of the expected price level for performing aeromagnetic surveys in the area has revealed a considerable higher price level compared to the prices for the previous surveys in 1999 and 2001. A price estimate of approximately 250DKK/km has been mentioned which is about four times more than in 2001! The price per survey block using the above-mentioned price per km gives the following estimates.

Suvey Block	Number of km	Survey cost [DKK]
A	58 000	14 500 000
B	33 000	8 250 000
C	90 000	22 500 000
D	83 000	20 750 000

1, see 9.8	38 000	9 500 000
2, see 9.8	81 000	20 250 000

These costs are high; however, it should be noticed that the estimate of 250 DKK/Km is based on information from a couple of commercial companies, which were very busy at the time because of an inordinate high activity in the sector. The price may become significantly lower in other, less active times after the financing crunch, especially if a contract for several years can be tendered for international competition.

In some previous public airborne surveys in the 1990'ties, supplementary financing of the operation was obtained from mining companies by offering exclusivity to the data within a certain period. A similar agreement may be a possibility if the prices above are thought to be too high for public financing.

In addition to the cost mentioned above, the budget must include the cost for GEUS personnel to perform the following four tasks:

- tendering for geophysical contractor
- quality control during surveying
- interpretation and report writing
- promotion of the data

The table below shows the estimated personnel costs on a yearly basis:

year	Man month	Cost GEUS personnel	travel & allowances	Total DKK
2009	4.5	510 000	35 000	545 000
2010	3.5	390 000	40 000	430 000
2011	3.5	390 000	35 000	425 000

9.8 Supplementary surveying over the Greenland Ice Cap?

An obvious idea is of course to suggest an aeromagnetic survey over the Greenland Inland Ice to enable the correlation of aeromagnetic anomalies of known geological features across Greenland from the west coast to the east coast. The best of previous attempts to survey the Inland Ice (GICAS) operated with 10+ kilometres between N-S lines following lines of longitude, i.e. the distance between them increases to the south. These data clearly showed (i) that the geological features underlying the Inland Ice produces clear and varied anomalies, and (ii) that the flight line distance of 10+ km is to great to allow a reliable correlation of anomalies between lines. Thus, the two areas in Figure B2 (1 and 2), should be surveyed with modern equipment and 3 kilometres between lines. Using this line spacing and slightly different line azimuths in the two areas, the estimated total line kilometres for area 1 and 2 are 38 000 km and 81 000 km, respectively. These figures have been added to the table above for further consideration.

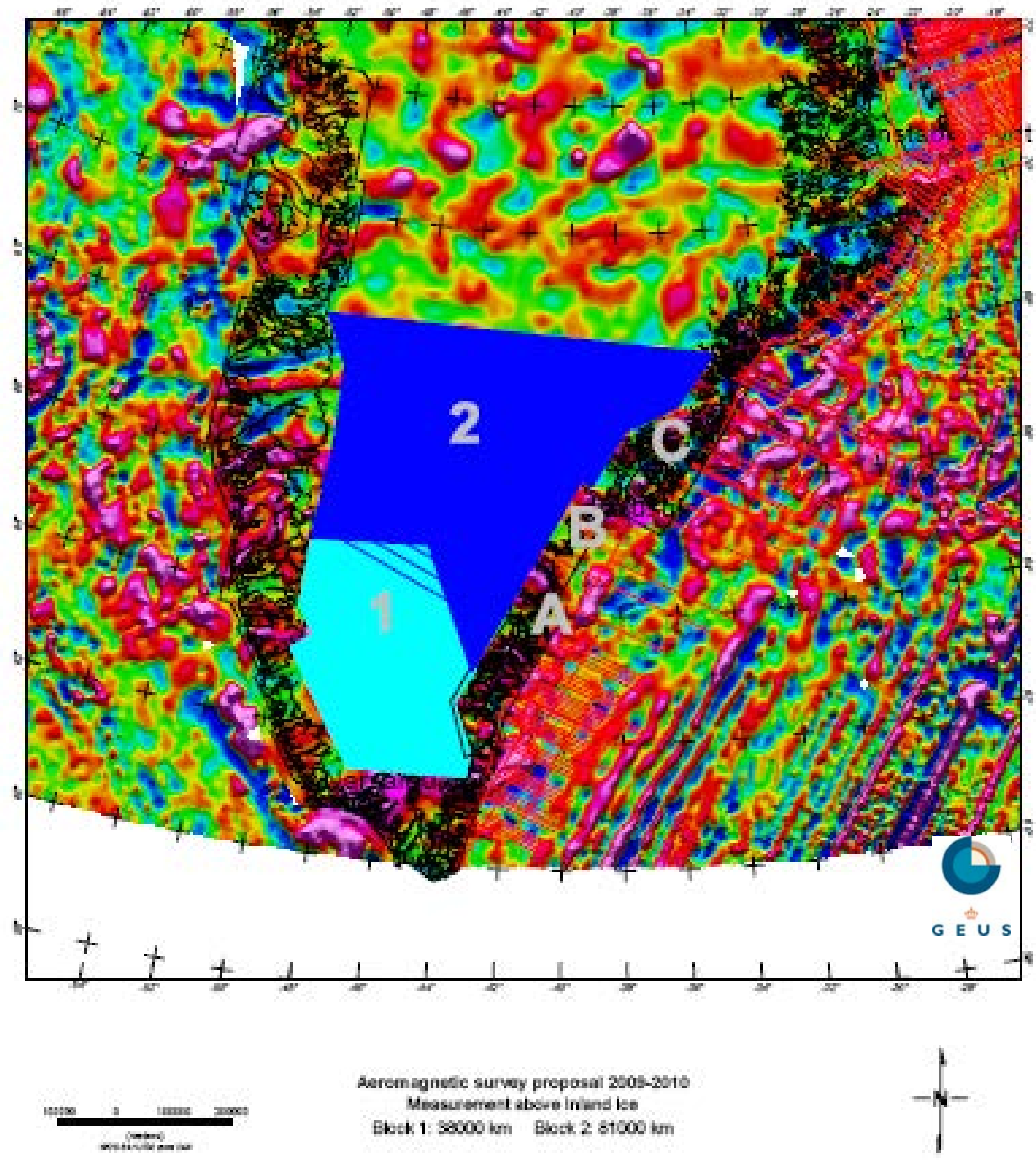

Figure B2. *Compiled aeromagnetic anomaly map of southern Greenland. Offshore flight lines from project Eastmar overlaid to show the coverage of this survey. The two segments of the Greenland Inland Ice numbered 1 and 2 are further discussed in the text.*

10. Appendix C: Table of available satellite systems

The table contains the specifications for data from available spaceborne multi- and hyper-spectral sensors. VNIR – Visible and Near Infra-Red, SWIR – Short-Wave-Infra-Red, TIR – Thermal Infra-Red, St - Sensor type, B – Band, Sre – Spatial resolution (m), Sra – spectral range.

ASTER Swath = 60 km Nominal scene = 60 x 60 km				Landsat TM/ETM Swath = 183 km Nominal sce-ne=170 x 183 km			GeoEye Swath = 15.2 km Nominal scene =245 km^2			Hyperion Swath = 7.5 km Nominal scene=7.5 x 100 km		
Str	B	Sre	Sra	B	Sre	Sra	B	Sre	Sra	B	Sre	Sra
VNIR	1	15	0.52-0.60	1	30	0.45-0.52	1	1.65	0.450-0.510	1	30	0.400
	2		0.63-0.69	2		0.52-0.60	2		0.510-0.580	Hyperspectral data 220 bands 0.400 – 2.500 µm		
	3		0.76-0.86	3		0.63-0.69	3		0.655-0.690			
				4		0.76-0.90	4		0.780-0.920			
SWIR	4	30	1.60-1.70	5		1.55-1.75						
	5		2.145-2.185									
	6		2.185-2.225									
	7		2.235-2.285	7		2.08-2.35				220		2.500
	8		2.295-2.365									
	9		2.360-2.430									
TIR	10	90	8.125-8.475									
	11		8.475-8.825									
	12		8.925-9.275	6	120	10.4-12.5						
	13		10.25-10.95									
	14		10.95-11.65									

11. Appendix D: CCSEM analysis of mineralogy and mineral chemistry and geochronology of stream sediment samples.

Christian Knudsen

It is suggested to analyse ca. 50 of the samples collected during the stream sediment geochemical programme for their mineralogical composition and the geochronology (zircon). The aim of this is to describe variations in the bedrock geology further than is possible using geochemical analysis. This will be done using two technologies namely the CCSEM method and a combination of LA-ICP-MS of zircons. These technologies are well suited for reconnaissance to characterise the geology in a terrain, which is only known in little detail. The methods focus on the fine sand fraction (45 to 500 micron) and they further have the advantage of being unbiased by geologists.

11.1 Mineralogy and mineral chemistry by CCSEM analysis

Computer controlled scanning electron microscopy (CCSEM) combines the advantages of energy dispersive X-ray spectrometry (EDX) with those of digital image analysis of back scattered electron (BSE) micrographs. CCSEM analysis of a wide range of geological or non-geological materials has been introduced at the Geological Survey of Denmark and Greenland (GEUS) as a fast and reliable method to determine both the chemistry of individual grains and of bulk samples. CCSEM has been used in the earth sciences for provenance analysis of ilmenite-bearing beach sands and provenance studies on sandstones in oil-bearing basins, and a large number of stream sediments has been analysed in West and Northeast Greenland using this technique. Sample material consists of a heavy mineral separation of a bulk sample. Approximately 1 g of sample material is mounted in epoxy resin. Commonly, 800–1200 grains are measured and the chemical data are further reduced using a software package connected to a mineral library database for automatic phase recognition and data storage. As can be seen on Figure D1, both abundance and composition of the heavy mineral grains yield indications of the bedrock geology; there is abundant sillimanite/kyanite in the sample to the left, which is from an area with abundant metamorphosed metasediments from the "Krummedal sequence", whereas the sample to the right is north of this area. The prescence of opx. (orthopyroxene) indicates that there are granulite facies rocks in the area, more abundant in area 514116 than in 514115. The compositions of the garnets contain clues concerning the composition of the rocks in which they were formed as well as the metamorphic conditions.

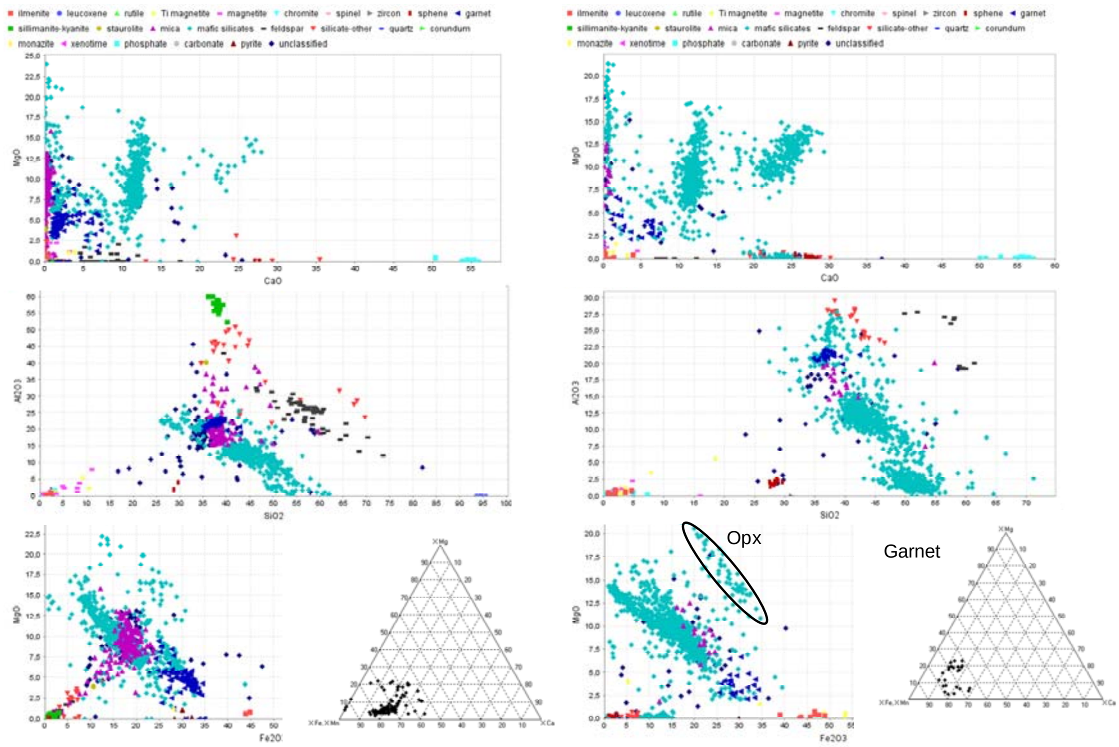

Figure D1. *Examples of CCSEM data from a till samples in North East Greenland. (Sample to the left is 514116 and the one to the right is 514115).*

11.2 Geochronologi by LA-ICP-MS of zircon

GEUS has developed a procedure whereby ca. 200 zircons are separated from each selected stream sediment sample. The zircons are mounted in epoxy, polished and U/Pb ages on single grains were obtained by laser ablation ICP-MS from the polished mineral mounts, employing a Thermo Element 2 sector-field instrument attached with a Nd-YAG ultraviolet laser system at GEUS.

This will give a very good insight into the age structure of the bedrock in the area. This is illustrated on Figure D2, which is also from Northeast Greenland. It is interesting that in the northern part of the Caledonides there are no or very few zircons of Caledonean age. Only in the southern part where there has been melting of the Krummedal sediments and generation of S-type granites we find zircons of Caledonean age.

The experience from West Greenland is, that it is possible to discriminate between the different terranes characterised by their ages using this method. In many cases the rocks in eg. the Nagsugtoqidian orogen are reworked Archaean rocks and accordingly there are many Archaean zircons in the stream sediments. However, there is a characteristic Proterozoic component and there is metamorphic rims of Proterozoic age on the Archaean cores. Using this type of data it will eg. Be possible to locate the boundary between the Archaean Block and the Proterozoic terranes to the north and south of this.

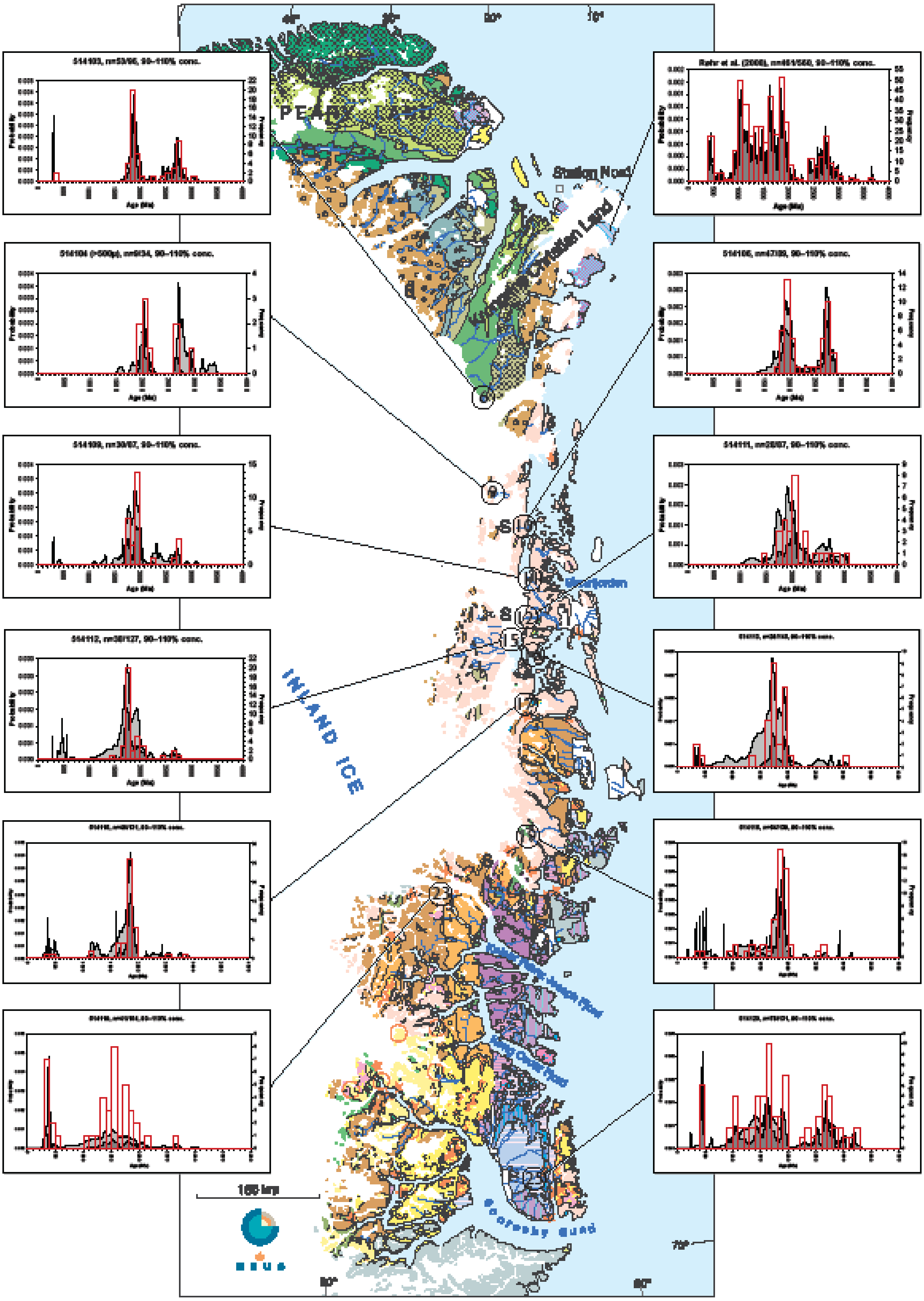

Figure D2. *Geochronology of zircon in till samples from East Greenland (confidential, not published information).*