DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2005/28

Thematic maps and data of North and Northeast Greenland: geology, mineral occurrences and hydrocarbons

Naja Mikkelsen, Hans F. Jepsen, Jon R. Ineson, Stefan Piasecki,
Frants von Platen-Hallermund, Frands Schjøth,
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(Project Group)

(1 DVD included)

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

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1. Abstract

In August 2002, the Greenland Government endorsed a Strategy plan for the National Park in North and Northeast Greenland and the Scoresby Sund area (Grønlands Hjemmestyre 2004). The data compilation for this plan required a reliable and homogenous digital topographic map, as well as data on geology, biology and archaeology compiled in thematic maps. A project was therefore launched in the spring of 2004 to compile the latter data.

The present report outlines the various thematic subjects that have been compiled, and examples of these elements are shown in the report. The thematic subjects include a presentation of a geological map at a scale of 1: 250 000, a description of geological sites of special scientific interest, selected hydrocarbon-related sites, selected mineral occurrences, and geophysical and geochemical data. The actual data files for the various thematic subjects are compiled on the enclosed DVD.

The DVD is for users with an ArcView GIS and/or MapInfo software licence.

It should be noted that the aim of the present project has been to identify specific geological sites or localities that have particular scientific or economic significance, or at least are representative of a suite of localities, or a swathe of countryside, that are noteworthy for economic or scientific reasons. The project has therefore focused on compiling and presenting data on a selected and representative part of known occurrences of geologically interesting localities in the National Park and the Scoresby Sund area. Thorough and detailed work has been done to compile and homogenise existing data – but it should nevertheless be stressed that future field and reconnaissance studies in the vast area of the National Park may provide new information on hitherto unknown occurrences of geological, mineralogical and hydrocarbon significance.

2. Introduction

In August 2002, the Greenland Government endorsed a Strategy plan for the National Park in North and Northeast Greenland and the Scoresby Sund area (Grønlands Hjemmestyre 2004). This plan, which was published in 2004, outlined the need for a reliable and homogenous digital topographic map, as well as a database containing data on geology, biology and archaeology compiled in thematic maps. A project was therefore launched in the spring of 2004 to compile the dataset for this map and the project was financed by by the Danish Co-operation for Environment in the Arctic, Ministry of the Environment (DANCEA)

The data compilation for this plan required a reliable and homogenous digital topographic map as well as data on geology, biology and archaeology presented in thematic maps. A project financed by the Danish Co-operation for Environment in the Arctic, Ministry of the Environment (DANCEA), was therefore launched in the spring of 2004 to first compile the data set for the topographic map.

This report outlines the work undertaken to compile and homogenise existing geological data into themes, and examples of these are shown in the report. The thematic subjects include a presentation of a geological map at a scale of 1: 250 000, descriptions of geological sites of special scientific interest, selected hydrocarbon-related sites, selected mineral occurrences, and geophysical and geochemical data. It should be noted that the emphasis in this project has been on data compilation and as such no recommendations are made herein with respect to whether/which sites should be protected. The actual data on the various thematic subjects are compiled on the enclosed DVD. The DVD is for users with an ArcView GIS and/or MapInfo software licence.

2.1 Geographical area

The project covers an area from 80°N on Greenland's northwest coast extending eastwards to the northernmost point of Greenland and south to 70°N on the east coast; this comprises roughly half of Greenland's ice-free land area (Fig. 2.1). Additional data have been included from Washington Land at the north-western extremity of the study area. It should be noted that for simplicity the area concerned is referred to as North and Northeast Greenland in this report, although spanning North, North-East and central East Greenland as formally adopted in Survey publications and maps.

The area for which a wide array of geological data has been compiled during the present project covers *c*. 220 000 km^2 and includes the National Park of North and Northeast Greenland and the area around Scoresby Sund. The sites and localities included in the GIS presentation under the present project are based on published literature, data files and unpublished reports from the archives of the Geological Survey of Denmark and Greenland, and the localities are described in standardised datasheets.

Fig. 2.1. *Map of North and Northeast Greenland showing the study area relative to the National Park area.*

2.2 Limitations

The aim of the project was to compile and present a selected and representative part of known occurrences of geologically and mineralogically interesting localities in the National Park and the Scoresby Sund area. Thorough and detailed work has been done to compile and homogenise existing data. It should nevertheless be stressed that future field and reconnaissance studies in the vast area of the National Park may well provide new information on hitherto unknown occurrences of geological, mineralogical and hydrocarbon significance. For this reason, the compilation presented here should not be regarded as complete. Furthermore, relative 'ranking' of sites is not attempted as in most cases final judgement of the value of sites would demand more focussed and detailed study.

3. Digital topographic data

3.1 Introduction

The 2002 strategy plan for the National Park in North and Northeast Greenland and the Scoresby Sund area outlined the need for compilation of a wide array of data. In order to provide the framework, a homogeneous digital topographic dataset based on modern photogrammetry was needed. As a forerunner to the current geological project, the Danish Cooperation for Environment in the Arctic, Ministry of the Environment (DANCEA) therefore initiated a project to compile a digital topographic dataset. The production of the topographic data was undertaken by the Geological Survey of Denmark and Greenland (GEUS) and is described in Jepsen *et al.* (2003). The text below is a summary of that report.

3.2 History

The history of the topographic mapping of North and Northeast Greenland is described in Dawes (2003) and Nielsen *et al.* (1995). Maps covering the area prior to 1970 were compiled at 1:300 000 for North Greenland by Koch (1932, 1940), part of Northeast Greenland at 1:250 000 in the 1930s by the Geodetic Institute, and the entire region at 1:250 000 by the American Army Map Services in the 1950s.

Modern geodetic work in the present project area started in the 1970s, when modern technologies and funding became available (Madsen 1984) and planimetric errors up to 20 km in the existing mapping were discovered and documented (Lillestrand & Johnson 1971).

Modern techniques (available from the mid-1970s) included: (1) Satellite based geodetic ground control, (2) High altitude super-wide angle photography, (3) Computation of large least squares bundle adjustment, and (4) Digital registration from photogrammetric stereo plotters.

At the same time, the Geological Survey of Greenland (GGU) needed modern topographic maps for compiling geological data at a map scale of 1:100 000 and 1:500 000. In 1977, GGU established a Laboratory for Geological Applied Photogrammetry applying the new methods of high precision digital photogrammetry to the study of aerial photographs of Greenland (Hougaard *et al.* 1991).

In 1995, the Geological Survey of Greenland (GGU) and the Geological Survey of Denmark (DGU) merged into the Geological Survey of Denmark and Greenland (GEUS), and GEUS has continued the high precision mapping of areas in Greenland where geological mapping was undertaken.

3.3 Coverage, origin and description of topographic data

The data covers an area from latitude 80°N on Greenland's northwest coast across North Greenland and down to latitude 70°N on the east coast; it comprises an area of *c*. 220 000 km^2 i.e. roughly half of Greenland's ice-free land area.

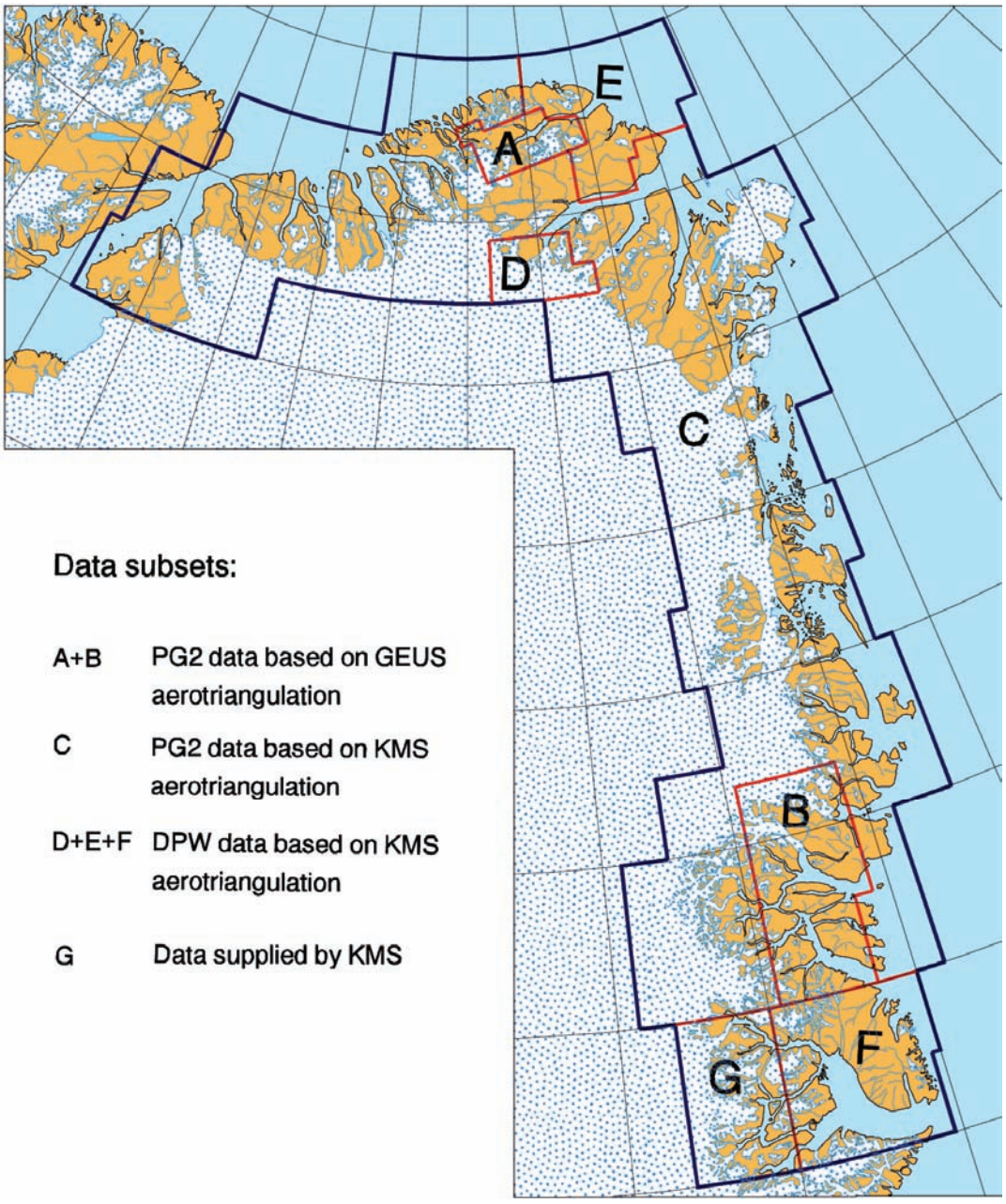

Fig. 3.1. *Index map showing different data subsets.*

At the project start, digital topographic maps covering *c*. 80% of the area already existed. Of these, 70% were produced by the GGU/GEUS laboratory and 10% were supplied by the National Survey and Cadastre (KMS). The remaining 20% were produced by GEUS during the project period. The present topographic dataset covering the National Park and Scoresby Sund areas has thus been produced over a period of more than 25 years.

Reflecting the technological evolution in that period, photogrammetric methods and the quality of ground control have changed over the years, and the dataset can therefore be described with reference to several subsets corresponding to this evolution (Fig. 3.1).

Aerial photographs at a scale of 1:150 000 and photographed from *c*. 14 km altitude with super-wide angle 9-inch photogrammetric cameras form the basis for all data. The aerial photo campaigns were carried out by KMS over a 10-year period from 1978 to 1987 (Bengtson 1983). Ground control was established by KMS (Madsen 1984). From 1976, the TRANSIT satellites and Doppler measurements were used at a large number of geodetic control points with a spacing of about 50–60 km. The Doppler observations were supplemented with traditional trigonometric measurements, barometric observations and gravity and geoid determinations.

Most of the area has been aerotriangulated by KMS. In each aerial photograph, 10+ points are measured, each of which are measured in 2–4 different overlapping photographs. The locations of the geodetic ground control were visually transferred to the photographs and included in the point measurements. The observations were computed in a least squares adjustment (Poder 1982), with each photo treated as a free bundle of rays. The adjusted xyz-ground coordinates have rms. errors below 10 m.

The time-consuming measurement of the many photos covering all of Greenland extended over some 20 years. Prioritisation of the different areas being measured was planned in close co-operation with GGU. Approximately 15% of the area was, however, aerotriangulated by the GGU laboratory and it was done using photogrammetric model coordinates as computational units. The resulting GGU generated ground coordinates have xy-rms. errors of about 30 m and z-rms. errors of about 10 m.

From 1978 to 1999, a mechanical-optical 2nd order stereorestitution instrument of the type KERN PG2 produced the topographic data from the GEUS laboratory. The instrument utilised transparent photographic copies of the aerial photographs. Both the hydrographic themes (coastlines, lakes, rivers, ice margins) and the contour lines were generated manually. In the period up to mid-1988, the PG2 instrument was equipped with a slow prototype xyz-digitiser which periodically would skip one or two vertices when the stereooperator was drawing at high speed.

Since 2000, topographic data has been produced by a digital photogrammetric workstation (DPW) from LH-Systems using digital scanned copies of the aerial photographs. The hydrographic themes are still generated manually whereas the contour lines are generated from an automatically extracted digital terrain model (DTM). Breaklines including the hydrographic themes are included during the DTM generation.

KAMPSAX A/S (now part of COWI A/S) produces the data supplied by KMS on a digital photogrammetric workstation using digital scanned copies of the aerial photographs.

The data produced by GEUS and the data supplied by KMS are summarised as follow:

Data produced by GEUS:

Target map scale:	1:100 000
Topographic themes:	hydrography and 100 m equidistant contour lines both on ice-free land and on parts of the ice
Area coverage:	*c.* 90% of the target area
Subareas:	PG2 data based on GEUS aerotriangulation.
	PG2 data based on KMS aerotriangulation
	DPW data based on KMS aerotriangulation

Data supplied by KMS:

Target map scale:	1:250 000
Topographic themes:	hydrography and 100 m equidistant contour lines on ice-free land
Area coverage:	*c*. 10% of the target area. The area is located on the east coast, west of 27^{o}W between 70^{o}N and 72^{o}N

The attributes DATE, SOURCE_ID and SO_DATAID can be used to distinguish between the different data subsets.

The themes included in the topographic data set are illustrated on Figure 3.2. It should be noted that as a general rule no man-made objects are included in the present dataset.

The raw 3D photogrammetric data were imported to the Esri ArcInfo GIS-platform as 2D data. Topology was validated (i.e. polygons are closed) and attribute data were added. In a semi-automatic procedure, the 1:100 000 data were generalised to a 1:250 000 version using line smoothing, elimination of small areas and minor rivers. In the 1:250 000 dataset, consistency of the contour lines was further validated and place names added. Data at the two target scales are each unified into seamless datasets.

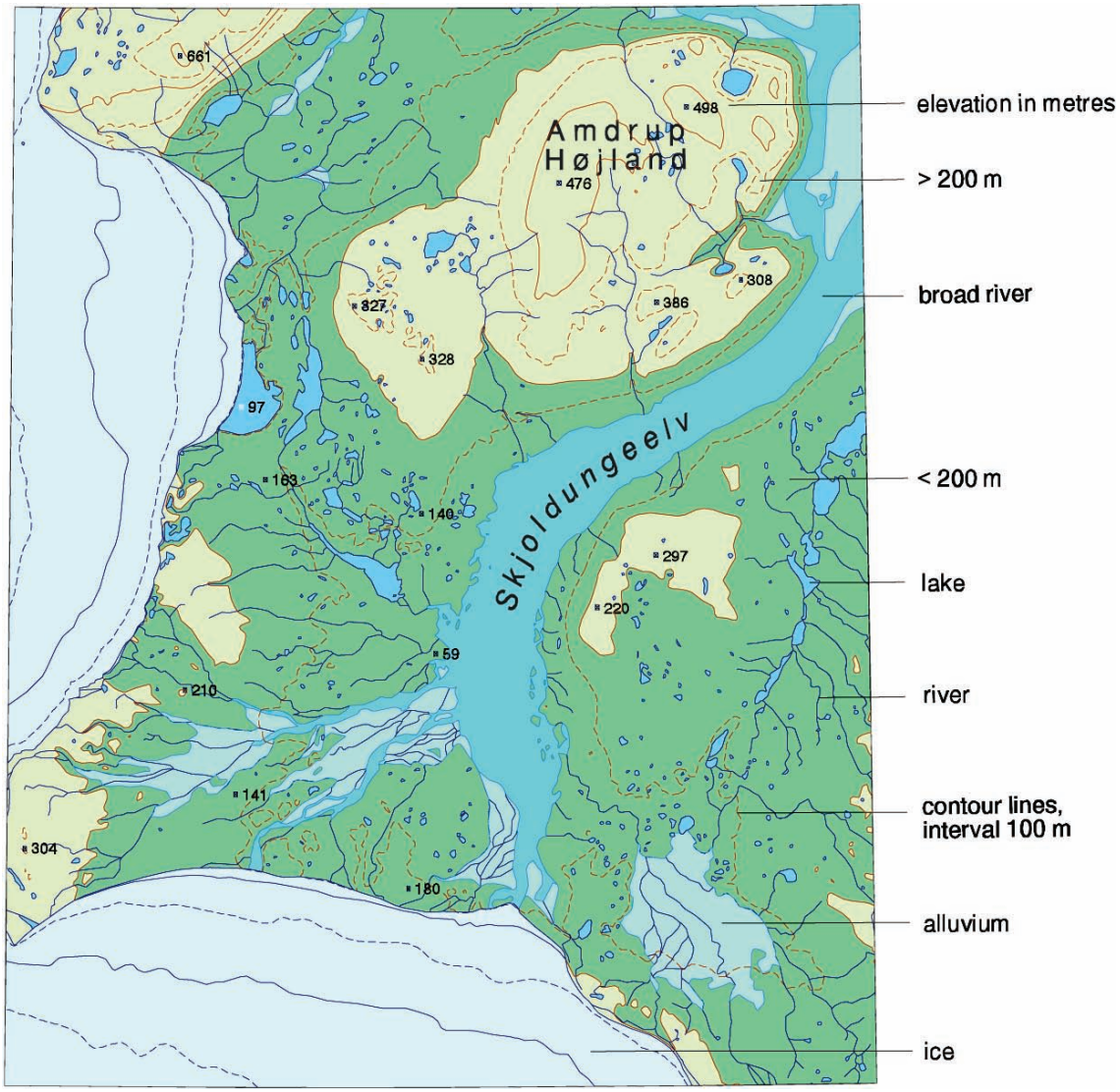

Fig. 3.2. *1:250 000 map sample with themes available in the digital dataset.*

3.4 Place names

Place names are an important key to geographic information and the present map compilation therefore includes place names. In North and Northeast Greenland, most place names are European. However where Greenlandic names exist, both forms are used. In the project area, several thousand names are authorised. Of these *c*. 1700 names are used in the 1:250 000 dataset. Five different sources have been used:

- Laursen (1972)
- Higgins (in press)
- The Place Name Register (developed by KMS)
- Reference maps of The Place Name Register
- Various maps produced by GEUS over the years

Oqaasileriffik, The Greenland Place Name Committee, Nuuk have kindly checked the place name theme.

4. Digital geological maps

4.1 Data sources

Geological mapping of North and Northeast Greenland at a scale of 1:500 000 was completed by the Geological Survey of Denmark and Greenland in 1999. The resulting 7 geological map sheets were published over a period of 20 years between 1984 and 2004 (Fig. 4.1 and list below). In order to establish a common geological reference map for the 3 themes of this project (geology, mineral occurrences and hydrocarbons), the 7 map sheets have been compiled into a single digital map at a target scale of 1:250 000. The progressive development of the geological understanding of the area over the last two decades has been incorporated into the dataset, and the nomenclature of map units has been made consistent across the original map boundaries. The digital topographic base map for the compilation was established with the best possible precision prior to this project (see section 3, above).

4.2 Map at target scale of 1:250 000

Four of the seven map sheets (7, 8, 10 and 12) were originally produced as hand-drawn (scribed peel-coats) print originals; they thus had to be vectorised manually and transferred to the Survey's ESRI ArcInfo GIS database. During this process, line- and polygon topology has been validated and attribute data added. The geometrical precision of three of the maps was satisfactory and adjustment to the new topographic base was fairly straightforward. In contrast, the fourth map sheet (12 Scoresby Sund) showed a very low degree of geometrical precision, and vectorising has involved a great amount of adjustment with consequent loss of precision with respect to the positioning of geological boundaries and structures.

The remaining three map sheets (6, 9 and 11) were originally compiled as digital datasets on an ArcInfo GIS platform. Map sheet 6 (Humboldt Gletscher) was compiled at a target scale of 1:500 000 and has (with minor attribute changes) been transferred to the 1:250 000 database. Map sheet 9 (Lambert Land) were originally compiled at a target scale of 1:100 000. It has been generalised and transferred to the 1:250 000 database. Map sheet 11 (Kong Oscar Fjord) was already compiled at a target scale of 1:250 000. Its attribute tables have been brought into conformity with the rest of the 1:250 000 dataset and a few structural lines have been modified to fit the adjoining map sheets.

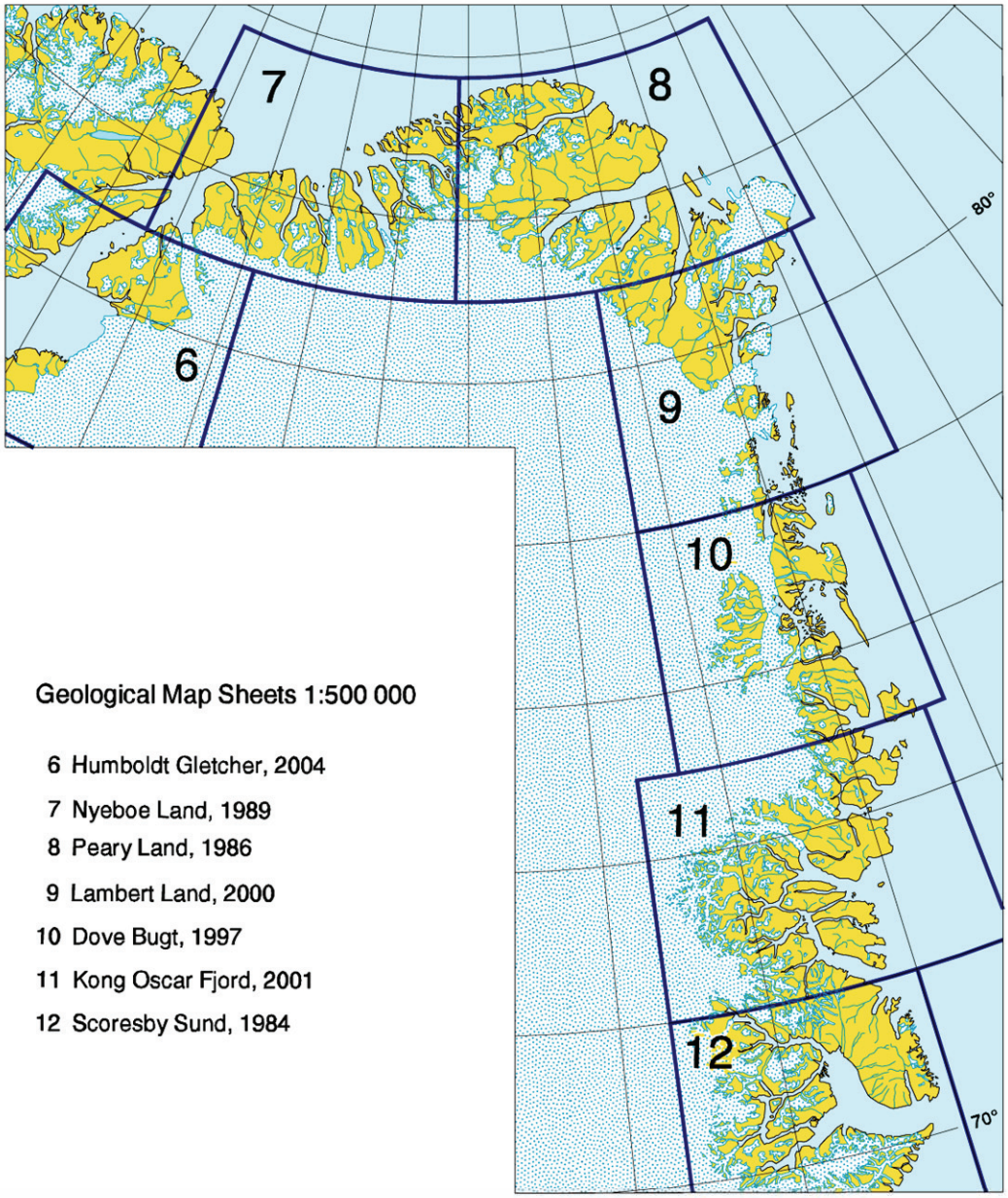

Fig. 4.1. *Index of Geological map sheets of Greenland, 1:500 000. Year of publication.*

The project area stretching from 80°N on the north-west coast through North and Northeast Greenland to 70°N on the east coast is now covered by a seamless and homogeneous dataset which can be accessed as GIS-intelligent data (see section 10, below). The amount of detail reflects the information on the published map sheets at a scale of 1:500 000 with the exception of areas covered by map sheets 9 and 11 where the dataset includes additional details from maps originally compiled at a scale of 1:100 000 and 1:250 000, respectively. Although concerted efforts have been made to quality-check the conversion from paper to digital form, errors are clearly unavoidable in such a comprehensive dataset; we thus encourage the user to bring such potential problems to our attention so that ongoing refinement of this digital geological archive can be undertaken.

4.3 Synoptic maps

Two map sheets at a target scale of 1:5 000 000 have been compiled, summarising the structural framework, sedimentary basins and basement complexes (Figs 4.2 and 4.3).

These maps can also be accessed through GIS applications.

4.4 Source maps

The following seven 1:500 000 scale maps form the basis geological data source for the integrated digital geological dataset (Fig. 3.1).

Bengaard, H.-J. & Henriksen, N. 1984: Geological map of Greenland, 1:500 000, Scoresby Sund, sheet 12. Copenhagen: Geological Survey of Greenland.

Bengaard, H.-J. & Henriksen, N. 1986: Geological map of Greenland, 1:500 000, Peary Land, sheet 8. Copenhagen: Geological Survey of Greenland.

Dawes, P.R. & Garde, A.A. 2004: Geological map of Greenland, 1:500 000, Humboldt Gletscher, sheet 6. Copenhagen: Geological Survey of Denmark and Greenland.

Escher, J.C. 2001: Geological map of Greenland, 1:500 000, Kong Oscar Fjord, sheet 11. Copenhagen: Geological Survey of Denmark and Greenland.

Henriksen, N. 1989: Geological map of Greenland, 1:500 000, Nyeboe Land, sheet 7. Copenhagen: Geological Survey of Greenland.

Henriksen, N. 1997: Geological map of Greenland, 1:500 000, Dove Bugt, sheet 10. Copenhagen: Geological Survey of Denmark and Greenland.

Jepsen, H.F. 2000: Geological map of Greenland, 1:500 000, Lambert Land, sheet 9. Copenhagen: Geological Survey of Denmark and Greenland.

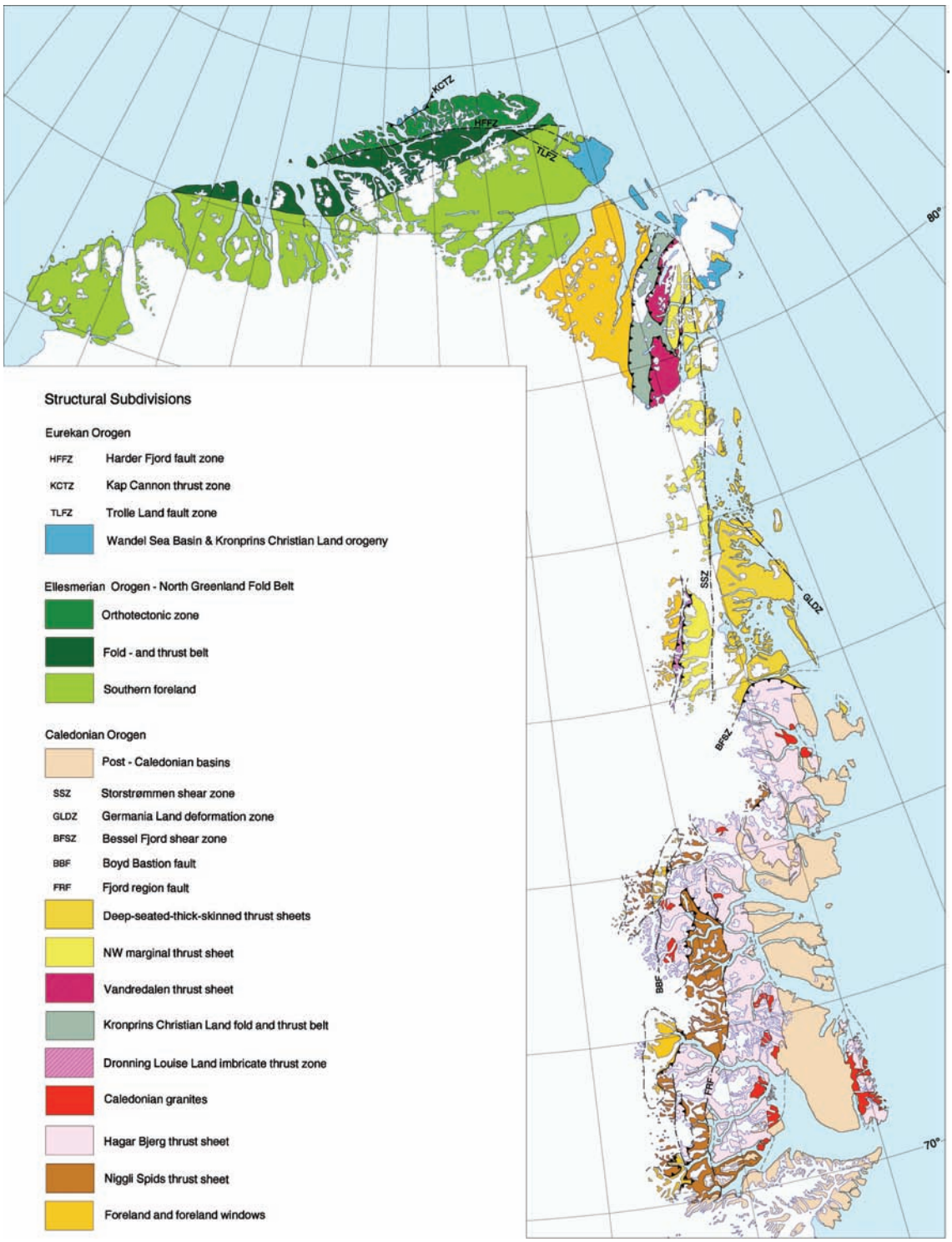

Fig. 4.2. *Synoptic map – Structures.*

Fig. 4.3. *Synoptic map – Sedimentary basins and basement complexes.*

4.5 Datasheet presentation

The geological maps presented on the DVD are linked to a comprehensive stratigraphic lexicon that provides summary information on all lithostratigraphic units utilised in the project area; an example of the information available on the individual stratigraphic datasheets is given in Figure 4.4.

Geological Map Unit

Print date: 15-Jun-2005

Stratigraphic unit **Kap Holbæk Formation** S829

Legend code **KH**

Period Cambrian

Authors
Adams & Cowie (1953, p.12), revised (Hurst & McKerrow 1981a, p.17; Hurst & McKerrow 1981b, p.53), Clemmensen & Jepsen (1992, p.22), removed from Hagen Fjord Group (Smith et al. 2004a, p.10)

Synonomy
Kap Holbæk Sandstone (Adams & Cowie 1953, p.12), Kap Holbæk Sandsteine (Fränkl 1955a, p.18).

Type locality / area
Locality: Kap Holbæk, head of Danmark Fjord, eastern North Greenland.

Distribution
Inner part of Danmark Fjord and in northern Kronprins Christian Land.

Thickness
C. 150 m at type locality.

Lithology
Initiated by 5 m of variegated mudstone and thin sandstone beds. The overlying part is composed of fine to medium grained sandstone associated with coarse grained sandstone and mudstone. Glauconite common in the uppermost deposits. Degree of cementation variable with the tightest cemented forming cliffs (= Quartzite units of Adams & Cowie 1953). In the lower part the sandstone and associated lithologies are randomly interbedded but form one well developed, coarsening upwards sequence near the top of the formation.

Boundary, upper
A sharp, very low angle, erosional unconformity beneath a dark, cherty dolostone cliff belonging to the Danmark Fjord Member of the Wandel Valley Formation.

Boundary, lower
Overlies stromatolitic dolostone of the Fyns Sø Formation with a well defined but in detail, obscured contact.

Age
Early Cambrian (Jepsen 2000,1:500 000, Sheet 9); Tommotian (Smith et al. 2004a, p.11).

-- end of Kap Holbæk Formation

Fig. 4.4. *A representative datasheet illustrating the standard layout used in the GIS platform.*

5. Mineral occurrences

5.1 Introduction

North and Northeast Greenland host a wide range of mineral occurrences of a large diversity with respect to geological age and type. To date, only one occurrence, the Blyklippen lead-zinc deposit at Mesters Vig, has been mined but some of the others have been investigated in great detail. In particular, the Malmbjerg molybdenum and the Citronen Fjord zinc-lead deposits, presently under licence, are well known, and the former is being drilled and assessed with a view to feasibilty studies. The majority of occurrences have only been superficially investigated, however, and their economic significance remains uncertain. Due to its remote location, the region as a whole is highly under-explored and its mineral potential remains largely untested. However, in the light of the region's diversified and complex geological environments, the potential seems promising.

The central East Greenland region, corresponding roughly to the areas of geological maps 11 and 12 in Figure 4.2, represents that area in all of Greenland which displays the greatest variety and density of mineralisation. Each mineralised locality represents a zone in which geological processes have combined to create a concentration of economically important elements i.e. the geological environment in which the mineralisation occurs is able to "house" mineralisation at a scale large enough to be economically important. In this connection, it is worth noting that, for a wide range of types of mineralisation, economically-viable deposits are ringed by an aureole of small uneconomic mineralisations.

The mineral occurrences have been placed in the following three groups, subdivided on the basis of the level of investigation (in the datasheets, termed 'significance').

1. Mines: past and present producers.
2. Prospects: occurrences deemed to be of sufficient economic importance to be drilled or bulk sampled.
3. Showings: little known or economically insignificant occurrences, judged on present knowledge.

An estimated 200–250 mineralised localities are known from the project region. Due to time constraints, only 104 of these have been selected for the present GIS presentation (Fig. 5.1). These split into: all mines (1) and prospects (16), and 87 showings. In selecting the latter, the author has aimed at maximal diversity of deposit type, geological environment, age, and geographical dispersion, as the best way to illustrate the potential of the region.

It should be stressed, however, that the distribution of data illustrated here is based on present-day knowledge and should not be considered to necessarily reflect the real potential of the region. Parts of the region remain unexplored, or only investigated at a reconnaissance level, and further work may reveal significant mineral potential in areas that presently show few data points.

5.2 Mineral exploration

Most of the known mineral occurrences have been found by commercial companies operating under exploration licenses issued by Danish/Greenlandic authorities. Important players have been Nordisk Mineselskab A/S, who operated the Blyklippen lead-zinc mine (1956–1962) and explored the surrounding region in Northeast Greenland (documented in Harpøth *et al.* 1986), and Platinova A/S who investigated the Citronen Fjord zinc-lead deposit in North Greenland 1993–1997 (van der Stijl & Mosher 1998). In general terms, the number of known mineral occurrences is a function of the geology and the time spent on mineral exploration. Thus, the geologically diverse region 70° – 74°30´N, the former Nordisk Mineselskab concession area that was explored by the company in the period between 1952 and 1984, hosts some 170 mineralised localities, of which 73 are included in the present study. The region 74°30´ – 80°N has seen no commercial activity to date; 20 mineral occurrences are known from this region, of which 12 are included in the project. North of 80°N, where only very limited mineral exploration has been carried out, mainly by the Greenarctic Consortium (1969–1971) and Platinova A/S (1992–1999), about 30 mineral occurrences are known, 19 of which are included in the project (Lind *et al*. 1993).

5.3 Data sources

The mineral occurrence data presented in this project have been extracted mainly from company reports but also from GEUS' reports and scientific publications, and then entered into the GREENMIN data base. This is the normal procedure for safe-keeping knowledge from commercial and governmental activities. Subsequently, a part of these data has been extracted from the database and presented in an edited version for this project (see DVD).

GREENMIN (GREENland MINeralisation database) is the GEUS database for systematic registration of information concerning raw materials in Greenland (Lind *et al.* 1994; Thorning *et al*. 2000). The Department of Economic Geology is responsible for GREENMIN. The database contains geoscientific, technical, administrative and bibliographic information on significant mineral occurrences encountered by GEUS, exploration companies and others. The database resides on a Unix workstation (in an OpenIngres RDBMS).

The order in which information becomes available to GEUS, as well as the many different approaches applied by companies active in Greenland, makes it difficult to adhere to a strict definition of the professional terms attached to exploration work. Thus, sensible ways of grouping mineralised localities into a case will vary from year to year, from area to area, and may change through time.

The identification of a mineral occurrence consists of two numbers (separated by a slash) designating case and sub-case. The critical concept is the sub-case, which defines the physical placing in nature (latitude, longitude, altitude), name and/or exploration campaign, and other attributes. The case concept has been adapted to facilitate grouping of sub-cases with common characteristics. It is primarily intended as a help to organise data at the compilation stage. A few examples may illustrate the rationale behind this. Many reports describing an exploration campaign have the form of a case study, where this campaign

can be used as the GREENMIN case designator and the individual localities will then become the sub-cases. When a number of showings within an area have been subject to several exploration passes, assigning a separate case to each campaign will provide an exploration history. Also, the individual campaign may focus on different aspects of the same mineralised locality, thus making it difficult to combine all data for one locality into a single coherent database entry.

GREENMIN records based on an industry mineral assessment report are confidential for a given time. This period of confidentiality is stipulated in the licence text according to the Mineral Resources Act of June 3, 1998, with affiliated standard terms and rules. GREENMIN keeps track of the confidentiality of company data. All data in the present study have been released for public access.

5.4 Datasheet presentation

The selected mineral occurrences are presented as PDF datasheets, which can be accessed interactively from the GIS platform (see DVD). The datasheets have a standard construction (see Fig. 5.2), with the following thirteen subheadings. When no information exists for a subheading, the subheading is absent.

Designation and *name or campaign*: This gives the identification number of a mineralised locality. The main number or case number designates a group of mineral occurrences with common geological, geographical or exploration characteristics. The sub-number or sub-case number names the individual locality and/or the exploration campaign, concerning derivation of the data. If a mineral occurrence has been investigated in more than one year, there may be more than one number reflecting the exploration history.

Location: The geographical locality defined by coordinates and altitude.

Commodities: Metals or minerals of potential economic significance.

Summary: A brief description of the mineral occurrence.

Investigations: A summary of the geological, geophysical, geochemical, technical and special investigation work carried out at the mineralised locality and the name of the investigator (company or institution).

Geological setting: Geological description of the wall rocks or host rocks of the mineral occurrence.

Deposit type: Classification of the occurrence with regard to geology and level of investigation – mine, prospect or showing (termed ‘significance’ on the datasheets).

Deposit form: Gives the estimated geometry of the occurrence.

Ore minerals: Lists the minerals of economic interest and the valueless gangue minerals.

Analytical data: This table presents a statistical summary of selected chemical analyses.

Reserves: This table lists the ore reserves and ore production.

References: Reports and publications from where the data have been extracted; key references of a more general character may also be included.

The various occurrences are related to the geological evolution of the area and placed in the most probable of seven major geological periods when mineralisation took place (see DVD). Naturally, the age grouping of the various occurrences is tentative. It is to a high degree based on host-rock age and thus mostly indicates maximum ages. The seven periods are:

Tertiary
Mesozoic
Upper Palaeozoic
Lower Palaeozoic
Neoproterozoic
Mesoproterozoic
Archaean–Palaeoproterozoic

For each period, occurrence descriptions are presented broadly from south to north. The big spread in the number of mineral occurrences of the different periods is of course a result of varying mineralisation intensity, but also reflects the unevenness in exploration due to the remoteness and inaccessibility of some of the areas.

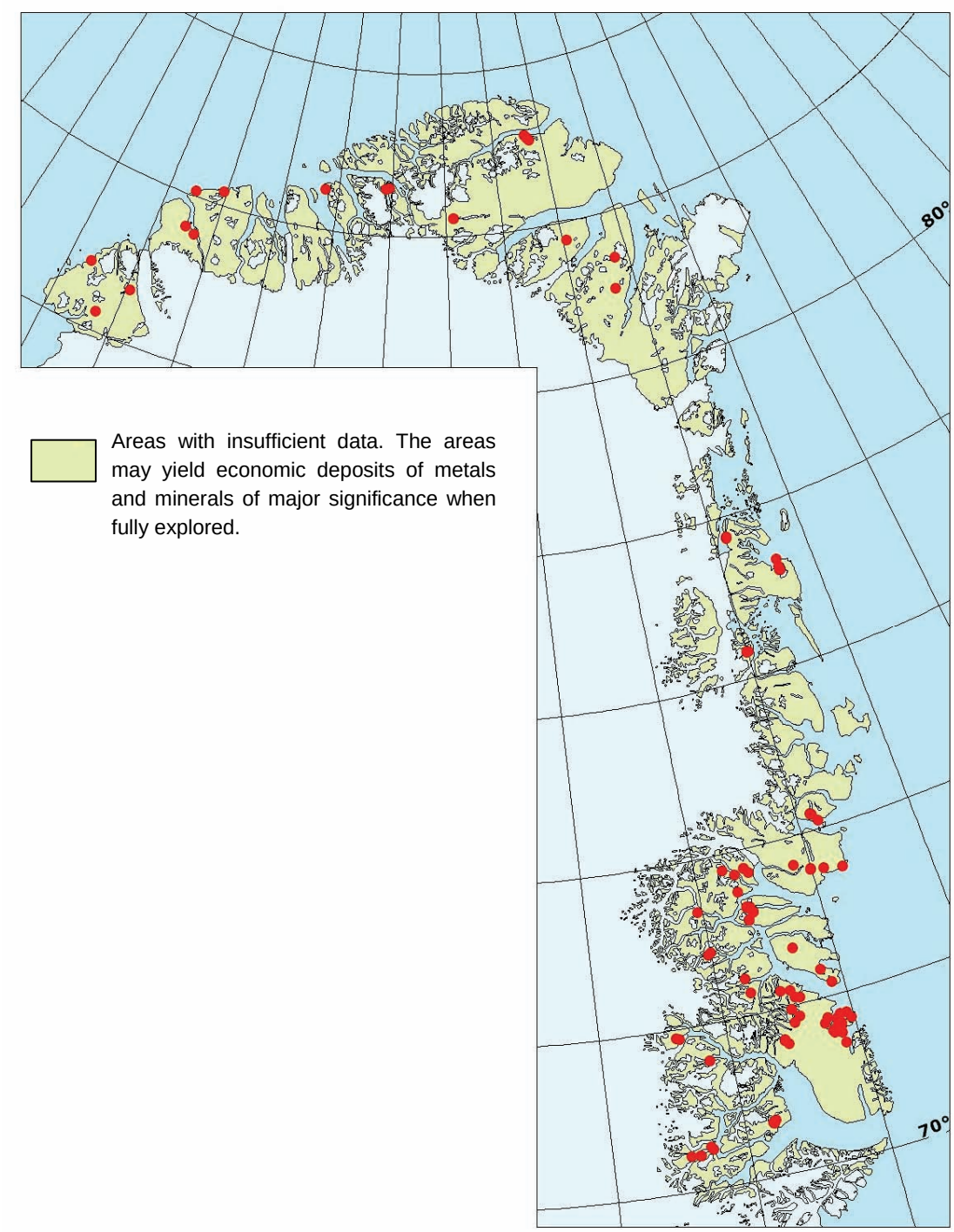

Fig. 5.1. *Map of North and Northeast Greenland showing the distribution of selected mineral occurrences.* ***It is emphasised that areas showing few data points should not be considered as necessarily possessing lower potential since the distribution of known localities also reflects the degree of investigation in the area****.*

Mineral occurrence

Print date: 25-May-2005

Designation M 285/1 Upper Permian, Traill Ø: stratabound Cu
Name or campaign Rubjerg Knude
Location 73°40.81'N 23°36.77'W. Altitude: 700 m
Commodities Copper

Summary

Stratabound copper mineralisation with minor lead and silver occurs in Upper Permian conglomerates on central Traill Ø. Metal distribution is controlled by palaeochannels, and metal concentrations of 0.26% Cu, 5 ppm Ag and 148 ppm Pb have been indicated by chip sampling.

Investigations

Geological
Name of investigator: Nordisk Mineselskab A/S
Period: 1981
List of investigations: Profile
Petrology
Field-check

Geophysical
Name of investigator: Nordisk Mineselskab A/S
Period: 1975
List of investigations: Ground radiometric

Geochemical
Name of investigator: Nordisk Mineselskab A/S
Period: 1975
List of investigations: Sample medium: Heavy mineral

Geological setting

Host rocks
Importance: 1
Rock name: Conglomerate
Relative age: Upper Permian
Member: Conglomerate Member
Formation: Huledal
Group: Foldvik Creek

Deposit type

Sulphide minerals
Descriptive type: Stratabound - Disseminated
Genetic type: Diagenetic
Significance: Showing

Deposit form

Shape: Tabular
Length: 2500.0 m
Width: 200.0 m
Thickness: 10.0 m
Outcrop size: 1000 m²
Inferred continuity in:
Length direction: Yes
Width direction: No
Thickness direction: No

Ore minerals

Economic minerals: 1 Chalcocite
2 Bornite
3 Galena
4 Pyrite
5 Rutile
Gangue minerals: 1 Quartz
2 Feldspar
Texture/structure: 1 Disseminated
2 Blebs

Fig. 5.2a. *Example of a datasheet illustrating the standard layout used in the GIS platform.*

Mineral occurrence

Print date: 25-May-2005

Analytical data

Element/ mineral	Unit	No. of anal.	Sample type	Quantity	Min.	Max.	Med.	Arith. Avg.	Weigh. avg.	Width avg. m
Silver	ppm	11	Chip	64.0 m	-2.00	20.00			5.00	5.80
Copper	%	11	Chip	64.0 m	0.04	0.63			0.26	5.80
Lead	ppm	11	Chip	64.0 m	15.00	390.00			148.00	5.80
Zinc	ppm	11	Chip	64.0 m	20.00	900.00			348.00	5.80

Reserves

Element/ mineral	Grade	No. of bodies	Reserve category	Reserve	Production	Until
Silver	5.00 ppm	1	Speculative	5000000 t	0 t	6-Dec-2004
Copper	0.30 %	1	Speculative	5000000 t	0 t	6-Dec-2004

References

Baumgartner, W., 1976: 10/75. Montangeologischer Bericht Nordmine 1975. Über die Gebiete Skjoldungebrae - Linné Gletscher und zentraler Teil der Traill Ö. Internal report, Nordisk Mineselskab A/S, 37 pp. (In archives of Geological Survey of Denmark and Greenland, GEUS Report File 20776).

Harpøth, O., 1982: 3/81. Prospecting report. Prospecting in Karstryggen, central Traill Ø, Broget Dal, Bersærkerbræ and Canning Land, central East Greenland. Internal report, Nordisk Mineselskab A/S, 76 pp., 1 app., 2 plates, 35 photos. (In archives of Geological Survey of Denmark and Greenland, GEUS Report File 20723).

Harpøth, O., Pedersen, J. L., Schønwandt, H. K. & Thomassen, B., 1986: The mineral occurrences of central East Greenland. Meddr Grønland Geosci. 17, 138 pp., 1 plate.

Putallaz, J., 1961: Géologie de la partie médiane de Traill Ø (Groenland Oriental). Meddr Grønland 164, 2, 84 pp.

Tower, D., Bay, K., Leythaeuser, D., Jones, J., Wise, J., Alewine, J., Oforsagd, M., McNeal, R., Simpson, H. & Dial, J., 1972: SP1/72. Report on Arco Greenland Inc. 1972 East Greenland field party. Internal report, Nordisk Mineselskab A/S, 108 pp., 40 photos. (In archives of Geological Survey of Denmark and Greenland, GEUS Report File 20767).

Fig. 5.2b. *Example of a datasheet illustrating the standard layout used in the GIS platform.*

6. Geochemical data

Chemical data from systematically collected samples of material derived from the surface environment such as stream sediment and soil provide information on the chemical variation in the underlying rock complexes including their potential as hosts of mineral occurrences. On a local scale, stream sediment samples reveal where streams carry material from mineral occurrences within their drainage basins. On a regional scale, zones or provinces with characteristic metal concentrations in the surface samples can outline environments favourable to ore formation. In addition, systematically acquired geochemical data document the chemical background variation in the surface environment, which is important information for environmental issues such as plant and animal nutrition and pollution control. Some examples of the available data are included here to illustrate the variability of the geochemical signatures over such a large area.

6.1 Data sources

A large number of chemical data from stream sediment and soil samples have been acquired from the project area by GGU/GEUS. These comprise regional-scale surveys using the fine grain-size fraction for analysis and local investigations often using other grain-size fractions or heavy mineral concentrates. The regional surveys using the fine fraction have provided data suitable for documenting the geochemical variation over the National Park area. Altogether around 3600 samples have been collected and analysed in the period 1974 to 1999 during a number of individual sampling campaigns or surveys for geochemical exploration and mapping purposes. The sampling density has varied and a systematic coverage has been acquired over most of the area, except for Washington Land at the north-western extremity of the project area, Peary Land and the area south of 73°N, where samples are scarce and irregularly distributed. This is illustrated by Figure 6.1 showing the location of stream sediment samples stored in the GEUS database 'GeusGreen'. Non-systematic geochemical surveys carried out by mining companies are not dealt with in this study (e.g. Harpøth *et al.* 1986).

Samples from individual surveys have been analysed by different analytical methods for different suites of elements according to the availability of analytical methods and budget at the time of the campaigns. X-ray fluorescence spectrometry and instrumental neutron activation are the preferred methods; they both render total concentrations of elements. The quality of the analytical data is very variable and some, particularly older data, are of poor quality (Jensen 1995).

The results of each survey have usually been reported at the end of the campaign. Some data, however, have not been published. Compilation of chemical data derived from several individual surveys has rarely been undertaken.

Geochemical data from a large area in West and South Greenland have been quality controlled, calibrated and compiled into a consistent data set, which enabled the production of a geochemical atlas (Steenfelt 2001). The atlas documents the existence of geochemical

provinces in Greenland, some of which have been proved to host mineral occurrences such as the gold province in South Greenland hosting the Nalunaq gold mine. The samples collected in North and Northeast Greenland could form the basis for the production of a geochemical atlas of the National Park area. However, thorough quality control and evaluation of the present data, together with considerable extra analytical work and correction routines, would be required to obtain a consistent and reliable data set suitable for the production of a geochemical atlas.

A few of the chemical elements have been determined in most samples and a preliminary evaluation has shown that the values are consistent. A compilation of two of these elements gives an example of the geochemical variation over the project area (Fig. 6.2), and indicate the value of the geochemical data. The distribution of calcium oxide (CaO), shown as a contoured grid, reflects the character of the rocks. High values of CaO are seen in Hall Land, Warming Land and Wulff Land, and they mark rocks of the Early Palaeozoic platform, rich in calcium carbonate. The distribution of zinc (Zn), shown as dots sized proportionally to the concentration in the sample, show the trend of zinc mineralisation across North Greenland, which at the western end includes the zinc-lead occurrence at Cass Fjord, Washington Land (outside the present study area) and at the eastern end includes the Citronen Fjord zinc-lead occurrence, Peary Land.

The geochemical data presented on the accompanying DVD represents the result of a rough compilation of selected data. In a preliminary evaluation of all geochemical data, those selected were found to be the most consistent. Elements reflecting regional lithological variation (CaO, K_2O, Ba and U) are presented as contoured grids, while the distribution of Au and Zn are presented as dots, sized proportionally to the measured concentrations. The presence of higher concentrations in certain areas does not necessarily indicate an economic potential although it does make it more likely that mineralisations may later be found in these areas.

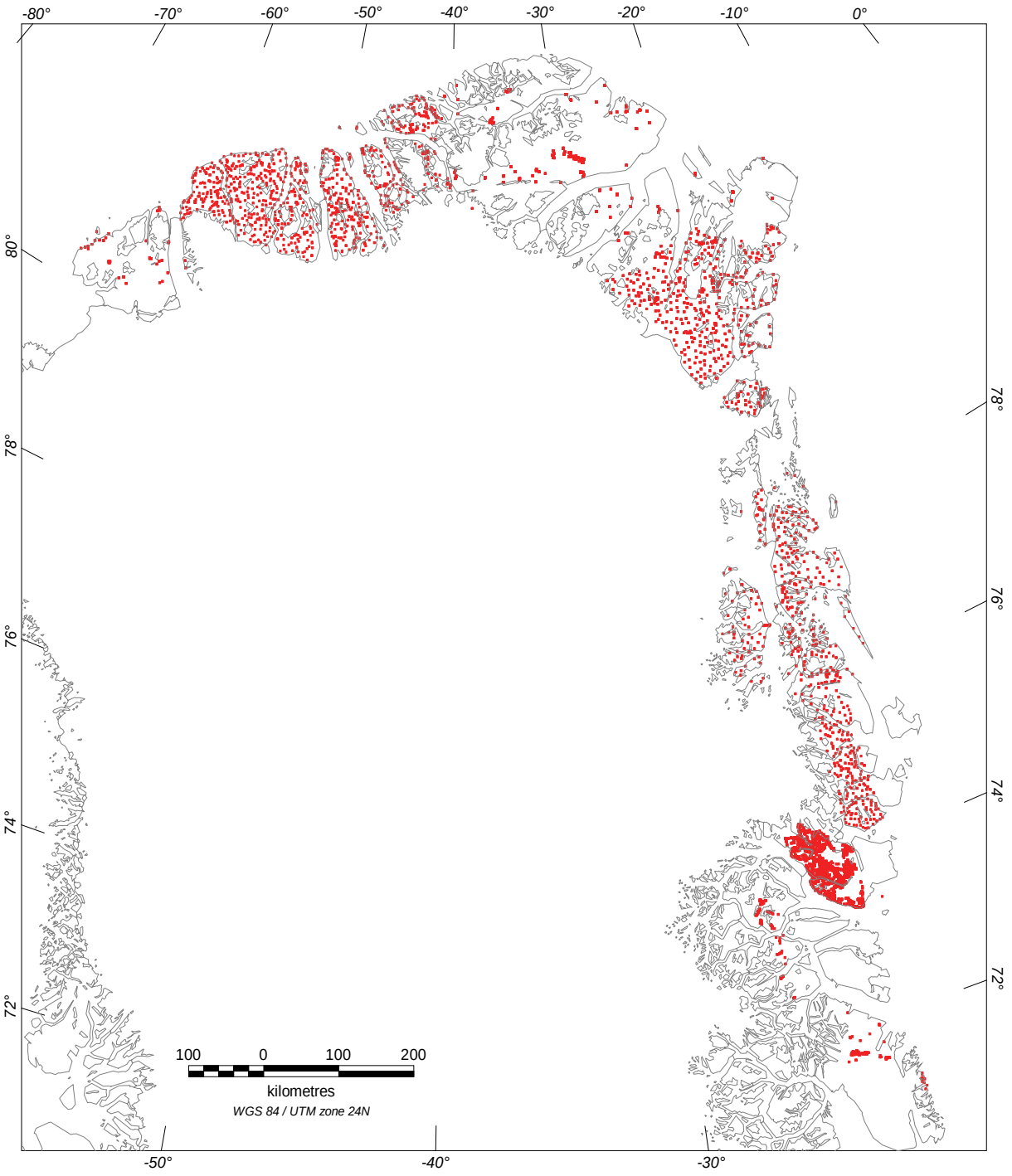

Fig. 6.1. *Location of chemically analysed samples of stream sediment in North and North-east Greenland*.

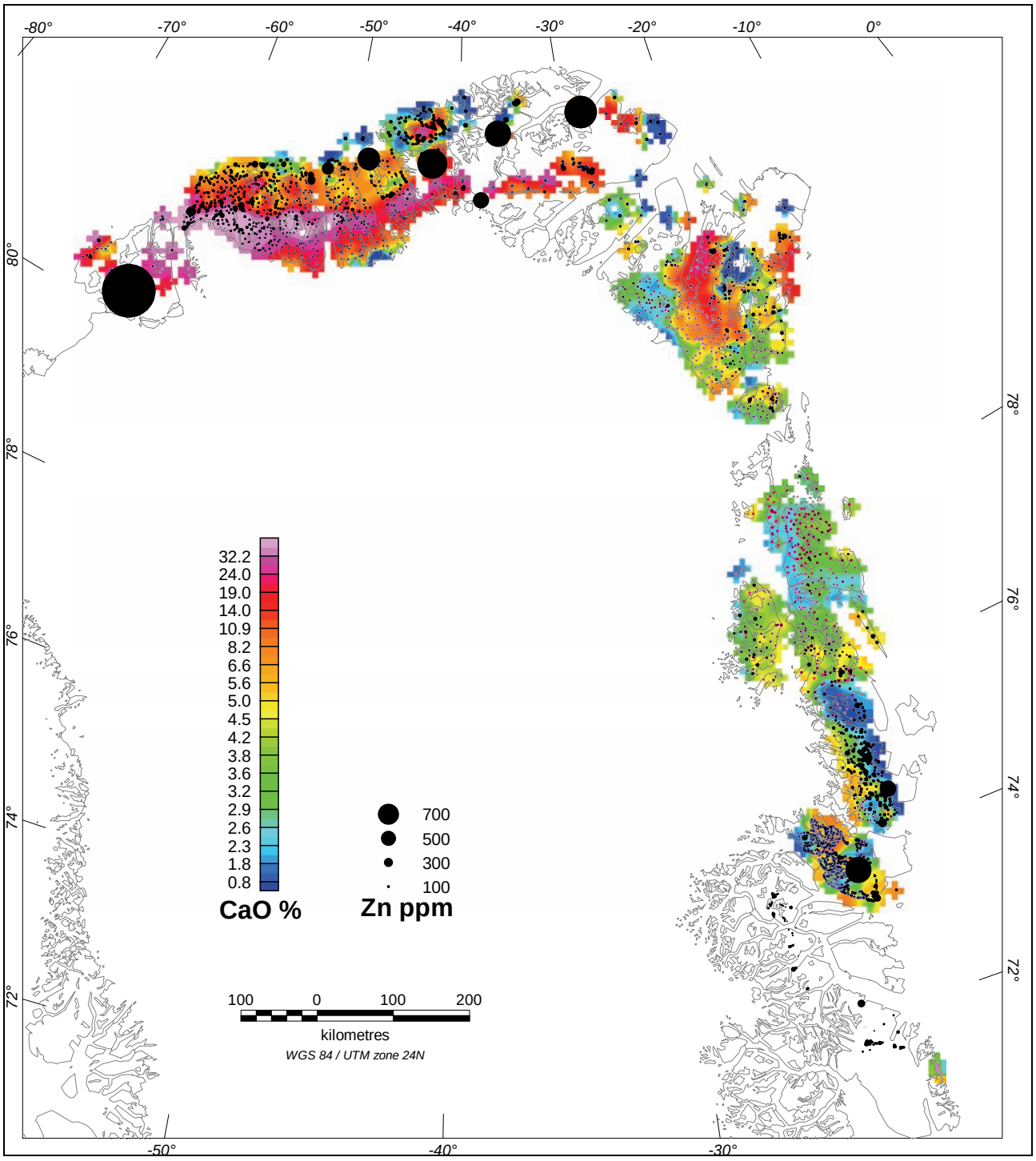

Fig. 6.2. *Geochemical map of North and Northeast Greenland showing calcium oxide distribution as a colour-coded contoured grid and zinc concentrations as black dots sized proportionally with the measured value.*

7. Geophysical data

7.1 Introduction

The geophysical data presented in this report include observations of the Earth's natural magnetic and gravimetric field and observations of electromagnetic responses from controlled source methods. All magnetic surveys have been carried out from aircraft or ships. The gravimetric data are from observations at land stations and from airborne and shipborne surveys. The electromagnetic (EM) data are from airborne surveys. Hyperspectral data are available from airborne surveys carried out in 2000, but only the flight lines are outlined in this report. Seismic data are not included.

Most of the data are presented as grids; i.e. equidistantly spaced values on a surface that are presented as images or maps with colours representing the data values. The grids are created from interpolation of the original or processed data obtained at non-equidistant sampling locations. The variations horizontally of the fields are referred to as anomalies; i.e. in this treatment of the data as deviations from a predefined reference level.

The amount of detail (the spatial resolution) that can be observed is related to both the survey altitude and the initial sampling density. The amplitudes of potential field anomalies attenuate exponentially with increased survey altitude and anomalies with restricted areal extent are attenuated more than anomalies with larger spatial extent. This implies that surveys carried out at low altitudes must sample the field more densely than a survey at high altitude in order fully to describe the actual field variations. Insufficient spatial density of the sampling locations with respect to the actual variations of the field measured may result in artefacts in the representation provided by the grid. Thus, the variations often appear smoother than the actual field variations. Although the applied interpolation techniques include requirement about smooth results, the opposite may also occur. Therefore, the choice of sampling density is one of the most important parameters in the design of a survey. The significance of the sampling density and survey altitude can be studied by comparing the included results of the magnetic field variations in areas where data exist from both detailed and reconnaissance surveys.

Some of the grids presented in this report are constructed from processing and merging of data from surveys that differ in terms of sampling density, survey altitude, equipment etc. Although much effort has been invested with respect to correcting for these differences in order to obtain a uniform representation, the differences may contribute to deviations of the results from the actual field variations. Details about the applied techniques and estimates of errors are found in the referenced publications for each of the images presented below.

The data included on the DVD are (coverage shown in Fig. 7.1):

- Compilation of gravimetric data from airborne, shipborne and satellite surveys
- Compilation of magnetic field variations from reconnaissance surveys
- Detailed combined electromagnetic and magnetic airborne data from Jameson Land with reconnaissance lines from Traill Ø

- Detailed combined electromagnetic and magnetic airborne data from Washington Land/Daugaard Jensen Land
- Detailed combined electromagnetic and magnetic airborne data from J.C. Christensen Land and with reconnaissance lines from eastern Peary Land
- Outline of hyperspectral coverage

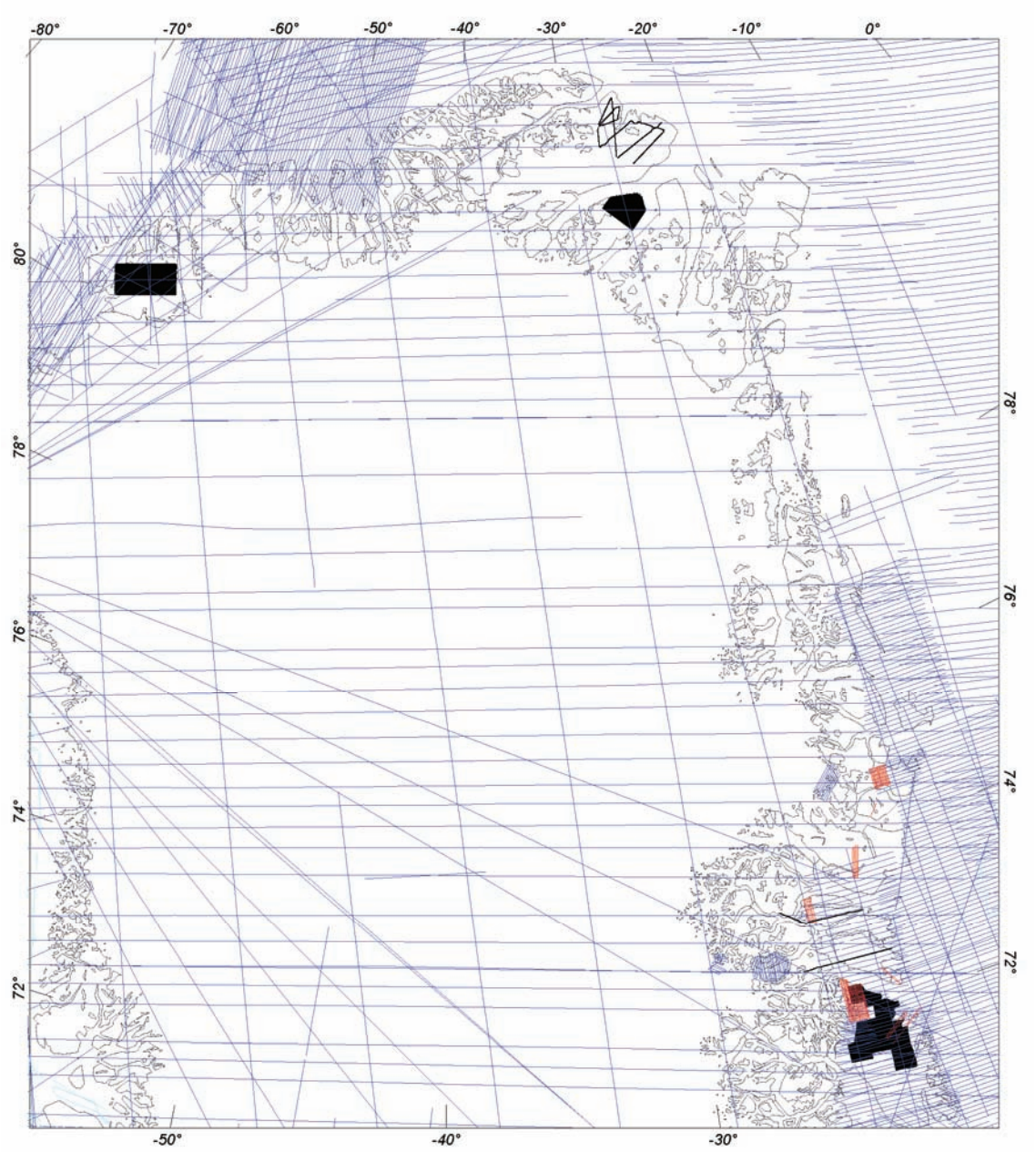

***Fig. 7.1**. Areas with combined magnetic and electromagnetic surveys are indicated by the black areas. The black lines show the location of associated reconnaissance lines in eastern Peary Land and on Traill Ø. The lines in blue and light blue colours indicate flight lines and ship tracks for the magnetic surveys included in the compilation of magnetic data by GSC (Verhoef et al. 1996). The red lines show the location of hyperspectral surveys.*

7.2 Gravimetric data

The gravimetric data are provided by the Danish Space Center, which in January 2005 took over responsibility for the national gravimetric database from the National Survey and Cadastre (KMS). Details of the survey parameters and processing techniques are given in Strykowski & Forsberg (1998), Kenyon & Forsberg (2000), Andersen *et al.* (2001) and Forsberg (2002). The grid image on the enclosed DVD shows Bouguer gravity field values onshore and free-air anomalies offshore. The grid was produced by merging the gravity grid for the interior of Greenland provided by the ArcGP project with gravity data from coastal and offshore areas that includes the most recent surveys (Fig. 7.2).

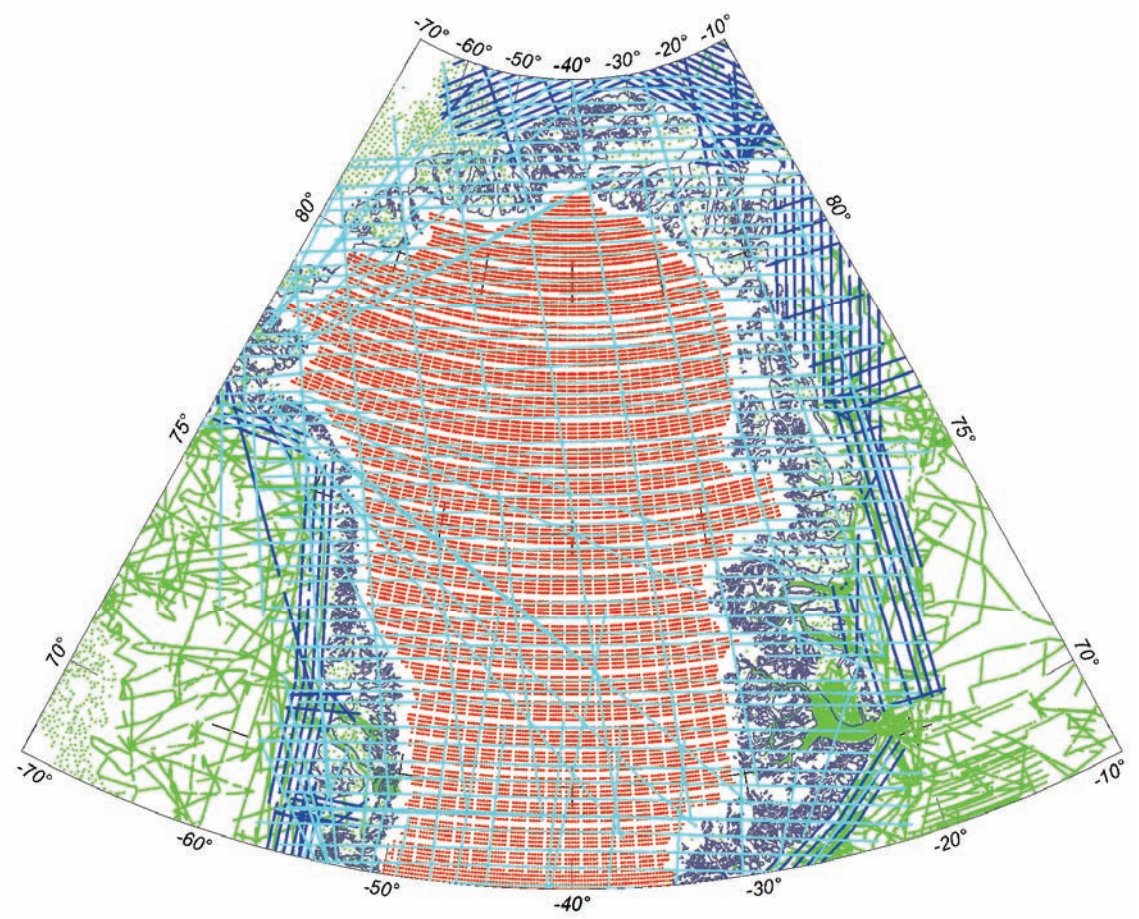

***Fig. 7.2**. Location of gravity stations (green, blue and light blue dots) and grid locations (red dots) for the grid from the ArcGP-project used for the construction of the grid included on the enclosed DVD. Marine measurements and land stations are shown by the green dots, airborne data by blue dots. The airborne survey data used for the ArcGP grid is shown by light blue dots.*

7.3 Magnetic data from reconnaissance surveys

Magnetic data from Greenland are included in a compilation of data covering the entire Arctic and North Atlantic Ocean and adjacent land areas (Verhoef *et al.*1996). Both airborne and shipborne data are included. The survey parameters vary considerably between

individual surveys. The majority of the surveys were carried out with distances between survey lines of more than 5 km. The airborne surveys were carried out with altitudes of 300 m or more above ground. Flight lines and ship tracks are shown in Figure 7.1

The images included are the magnetic total field and the calculated vertical derivative. Ship and flight tracks are included as a separate theme. The included images cover the entire co-ordinate frame used in the representation.

7.4 Magnetic and electromagnetic surveys from combined surveys

Jameson Land and Traill Ø
The survey area covers northern Jameson Land (including eastern Scoresby Land), central East Greenland and was flown by Geoterrex-Dighem Ltd during the period from July 7th to 24th August, 1997. The survey includes electromagnetic (GEOTEM) and magnetic total field measurements. Reconnaissance lines were flown over Traill Ø, north of the main area.

The survey lines were oriented east–west at 400 m intervals with north–south directed tie-lines spaced at four km intervals. Nominal flight altitude was 120 m over terrain with the total field magnetic sensor and electromagnetic sensor 75 m and 70 m above ground, respectively. The size of the survey area is 5194 km^2.

Detailed information on the equipment and processing can be found in Geoterrex-Dighem Ltd. (1997a, b). Results from the survey are presented in a report by Stemp (1998).

The enclosed DVD contains the following grid images:

- Amplitude of the GEOTEM X-coil channel 12
- Conductance calculated from the GEOTEM Z-coil data
- Magnetic total field anomaly
- Calculated vertical gradient of magnetic total field anomaly
- Digital elevation model calculated form GPS and radar measurements

The two images of EM parameters are based on interpolated data corrected for system asymmetry (de-herringboned).

Washington Land / Daugaard-Jensen Land
The survey area in Washington Land and Daugaard-Jensen Land in western North Greenland was flown by Geoterrex-Dighem Ltd. from May 29th to June 24th, 1998. The survey includes electromagnetic (GEOTEM) and magnetic total field measurements.

A total of 9321 line-km were flown. The survey is divided into a main part flown with a line distance of 400 m and a detailed part within the main area with a distance between the lines of 200 m. Line direction for the main area is N156.5°E, and N66.5°E in the detailed part. The objective of the detailed survey was to provide a better coverage of an area with a known Zn-Pb-Ag occurrence (Jensen & Schønwandt 1998) for which a flight line direction

of N66.5°E was most favourable with respect to topographic conditions. Tie lines were directed N66.5°E with a distance of 4000 m between lines.

Nominal flight altitude was 120 m over terrain with the total field magnetic sensor and electromagnetic sensor of 75 m and 70 m above ground, respectively. The size of the area is 3220 km^2.

Detailed information on the equipment and processing can be found in a report by Geoterrex-Dighem Ltd. (1998a). Furthermore, the data and interpretations are presented in Rasmussen (1999a).

The enclosed DVD contains the following grid images:

- Apparent conductance
- Z-coil channel 10 amplitude
- Total magnetic intensity
- Calculated vertical magnetic gradient
- Digital elevation model

The maps of EM parameters are based on interpolated data corrected for system asymmetry (de-herringboned).

J. C. Christensen Land and eastern Peary Land

The survey in J.C. Christensen Land with additional reconnaissance lines in eastern Peary Land, eastern North Greenland was flown from May 29th to June 24th, 1998. The survey includes electromagnetic (GEOTEM) and magnetic total field measurements.

The survey in J.C. Christensen Land was flown with lines directed along NE45.8^{o} and distance between lines of 400 m. Orthogonal tie-lines were flown with a line separation of 4000 m. A total of 4492 line-km were collected. In total, 485 line-km were flown in eastern Peary Land as reconnaissance lines.

Nominal flight altitude is 120 m over terrain with the total field magnetic sensor and electromagnetic sensor 75 m and 70 m above ground, respectively. The size of the survey area is 1603 km^2.

The measuring system was identical to the one described above for the survey in Washington Land and Daugaard-Jensen Land.

Detailed information on the equipment and processing can be found in a report by Geoterrex-Dighem Ltd. (1998b). In addition, the data and interpretations are presented in Rasmussen (1999b).

The enclosed DVD contains the following grid images:

- Apparent conductance from the main survey
- Z-coil channel 10 amplitude from the main survey
- Total magnetic intensity from the main survey
- Calculated vertical magnetic gradient from the main survey
- Digital elevation model

The maps of EM parameters are based on interpolated data corrected for system asymmetry (de-herringboned).

7.5 Hyperspectral data

Hyperspectral data were collected in 2000 in three separate projects that used the same survey platform and instrumentation. The European Union financed the MINEO project (monitoring the environmental impact of mining activities in Europe using advanced observation techniques) with a survey in the area around Mestersvig. The HyperGreen project financed by the BMP surveyed Canning Land, Malmbjerg, Ymer Ø, Hudson Land and Kap Simpson. A survey at Zackenberg was financed jointly by The National Environmental Research Institute, Denmark (DMU) and BMP. The instrumentation used was the HyMap™ sensor scanning the spectral range from 450 nm to 2480 nm with a swath width (distance across track) of approximately 2.3 km. More details on instrumentation and survey parameters can be found in Tukiainen (2001). Only flight tracks are included on the enclosed DVD.

8. Selected hydrocarbon-related sites

8.1 Introduction

To date, the hydrocarbon potential of most sedimentary basins in, and adjacent to, the National Park in North and Northeast Greenland (Fig. 8.1) has been only evaluated in a generalised, preliminary fashion. Furthermore, many of these earlier evaluations are not up-to-date, and in some cases integration of the most recent research results in a new comprehensive basin assessment would lead to a re-evaluation of the potential of the basin, most often a positive direction.

It should also be emphasised that nearly all these evaluations are based on surface (outcrop) data and that seismic data from the region is extremely limited whilst borehole data deeper than c. 100 m is not available.

It is thus difficult, at any realistic level, to identify either areas that lack potential or areas that may have the greatest chance of yielding hydrocarbons. Experience from West Greenland in recent years has shown that areas that previously had been assumed to lack hydrocarbon potential can subsequently become of significant interest on the basis of new data. One example of this is Nuussuaq, an area that prior to the discovery of oil seeps and the recognition of thick sedimentary successions on seismic was not deemed of interest in an exploration context. Similarly, large offshore areas that had been inferred to be ocean crust were thus down-graded with respect to hydrocarbon potential until new high-resolution data revealed the presence of deep sedimentary basins.

Furthermore, in relation to the discussion of zoning of the National Park, it is important to ensure that corridors are retained for transport, installations etc, and also to recognise that in many cases identifying the optimum location of such zones necessitates comprehensive technical and environmental evaluations. This relates not only to possible exploration and production onshore but also to potential hydrocarbon activities in adjacent offshore areas. In the World Petroleum Assessment presented by the United States Geological Survey in 2001, offshore Northeast Greenland was named as one of the frontier areas in the world in which there is the greatest possibility of significant hydrocarbon discoveries.

It is stressed that the distribution of hydrocarbon-related sites presented here reflects, to a large degree, variation in the intensity of field investigations across the area. A scarcity of sites within a region thus does not necessarily reflect a lack of hydrocarbon potential but rather a limited knowledge of that region.

The selected sites comprise localities with exposures of importance for the evaluation of the regional petroleum potential and localities of general importance for petroleum science and interpretation of specific types of hydrocarbon fields. Site sensitivity is not specifically evaluated and stated because none of the sites included here are sensitive to any normal activity beyond large-scale mining.

8.2 Data sources

The sites were selected on the basis of discussions with colleagues in GEUS and from published literature and internal GEUS Reports. The applied literature is listed under “References” in each datasheet and further literature with respect to stratigraphic units, nomenclature and hierarchical status can be obtained directly through the GIS interface.

8.3 Site selection

The practical selection of the sites was relatively easy due to the limited dataset for this region. The criteria for the selection focused on two aspects, the importance and significance for the regional petroleum systems and/or the scientific importance for interpretation of petroleum systems in general.

1) Several regionally extensive, potential source rocks have been located both in East and North Greenland and are exemplified by selected localities with good exposures. Some of these potential source rocks occur in a depositional and tectonic framework that allow interpretation of regional hydrocarbon potential whereas the available data concerning other potential source rocks are too limited to allow such an interpretation. In addition, localities with liquid or solid, migrated hydrocarbons are very important indicators of past or present generation of hydrocarbons in on- or offshore sedimentary basins.

2) The terrain of East and North Greenland provides steep cliffs and deep valleys with excellent exposures of thick successions extending laterally over tens of kilometres. Several of the most important British or Norwegian offshore hydrocarbon fields have geological counterparts exposed onshore in East Greenland at “seismic scale”, which can be studied and analysed at a level of detail not available in traditional seismic records. These Greenland exposures are thus extremely important for analogue studies.

8.4 Datasheet presentation

The datasheets concerning hydrocarbon-related sites in the GIS platform (Fig. 8.2 and DVD) are presented under two headings: ‘Hydrocarbon-related locality …’ and ‘Hydrocarbon-related strata …’. This distinction is utilised to differentiate between sites (localities) that present features of localised extent (e.g. restricted oil-seeps, reservoir analogue exposures etc.) and sites that display representative sections through extensive stratal units (strata) of hydrocarbon interest (e.g. source rock or reservoir units). Although the latter are indicated as a point that typifies the unit, the areal distribution of these units can be obtained from the GIS platform utilising the geological map and stratigraphic unit functions.

The datasheets are organised into the following categories:

Designation: Locality numbers (H01–H18) together with the name of the unit and locality or the geological type of site.

Justification: The justification for inclusion of the locality in the list.

Location: The locality defined by name (if present) and by geographical co-ordinates (latitude/longitude) from the GIS platform.

Geological/stratigraphic setting: Concise description of the geology, stratigraphy and age of the relevant succession.

Description of locality: Topography and location of the exposure with additional comments.

Features of special hydrocarbon interest: Summary of the specific features of interest.

References: Key references with analytical data and comprehensive reference lists, which provide a link to more specialised studies.

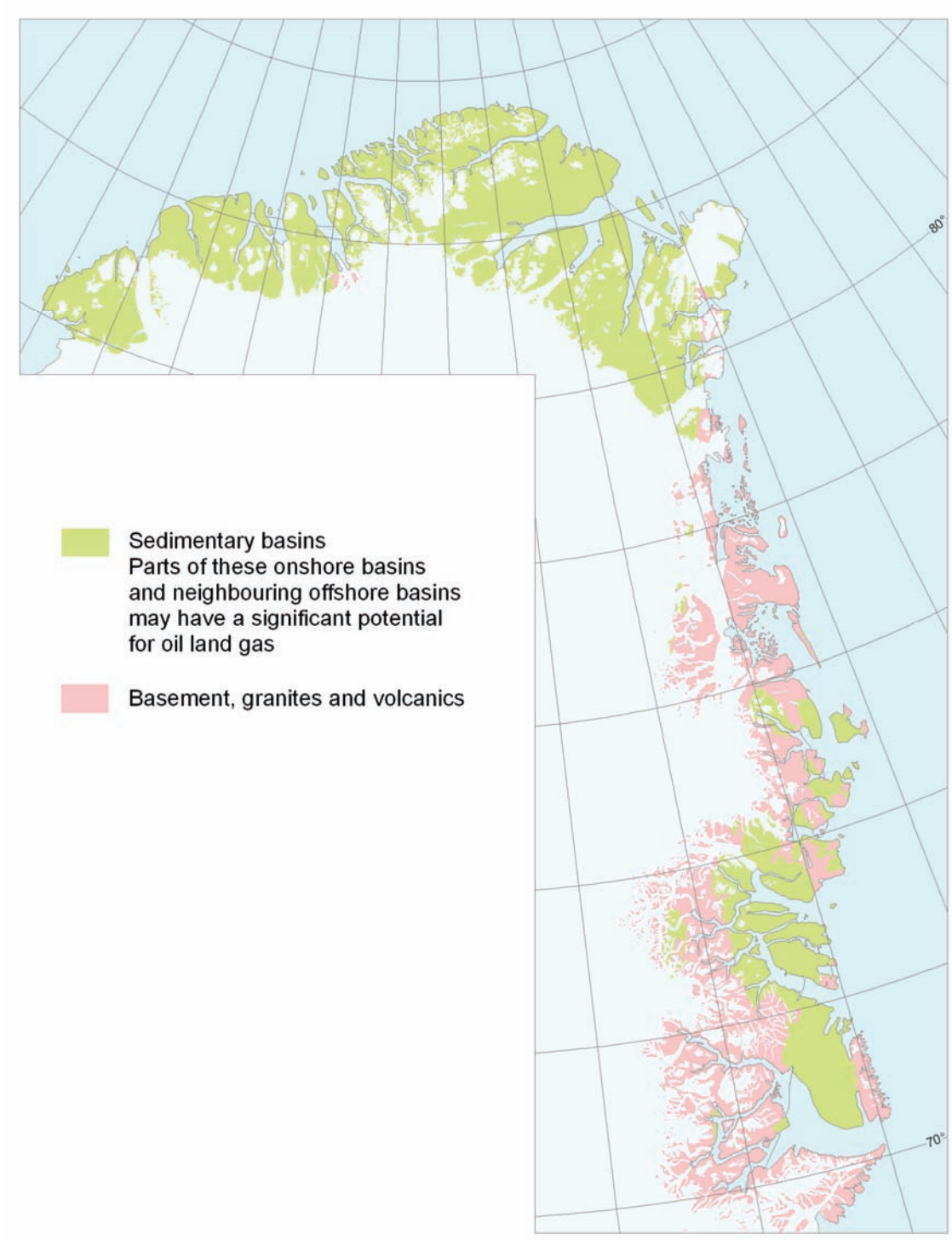

Fig. 8.1. *Map of North and Northeast Greenland showing the generalised distribution of sedimentary basins.*

Hydrocarbon related locality

Designation **H15** Palaeo oil field in carbonate buildup, Wulff Land.

Location

Wulff Land – Victoria Fjord, North Greenland.

81° 59' 50,63" N, 47° 27'

Justification

This palaeo oil field has significance for the modelling of hydrocarbon generation in North Greenland.

Setting

In North Greenland, Silurian carbonate buildups (Washington Land Group) are located in an 800 km long belt from Kronprins Christian Land to Washington Land. The outer shelf deepened in Early Silurian and the shelf margin retreated in western North Greenland. The relevant buildup is situated in an upper slope position 5 km north of the Lower Silurian carbonate platform margin and draped by shales and turbidites of the Peary Land Group.

Description

The carbonate buildup is exposed in eastern Wulff Land in the steep cliff along Victoria Fjord. The buildup is more than 260 meters high and extends for approximately 1200 m along the north–south-trending fjord. Shales and turbidites drape the buildup.

Features

The analysed oil is well preserved and the geochemical data indicate active replenishment of the reservoir in contrast to previous models suggesting pre-Devonian migration and entrapment. All available pore space is filled with bitumen in the upper 120 m of the buildup. The porosity is estimated at 10–20%. The fact that only the upper buildup is filled suggests limited drainage area in a basinward direction (i.e. short distance migration of 5–10 km) or that other source rock parameters result in lower generation potential than earlier estimated.

References

Christiansen, F.G. 1989: Quantitative aspects and economic implication. In: Christiansen, F.G. (ed.): Petroleum geology of North Greenland. Grønlands geologiske Undersøgelse Bulletin 158, 78–84.

Stemmerik, L., Sønderholm, M. & Bojesen-Kofoed, J.A. 1997: Palaeo-oil field in a Silurian carbonate buildup, Wulff Land, North Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. Geology of Greenland Survey Bulletin 176, 24–28.

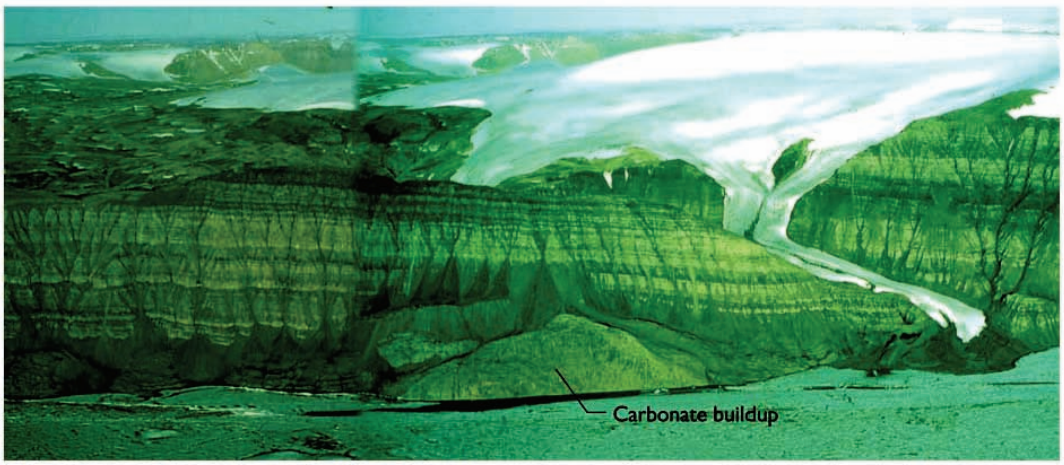

Fig. 8.2. *A representative datasheet illustrating the standard layout used in the GIS platform.*

9. Geological sites of special scientific interest

9.1 Introduction

The National Park and contiguous areas in North and Northeast Greenland include geological features that rival anything to be found elsewhere in the world, both in terms of scientific importance and with respect to the scale and degree of exposure. Indeed, some of the extensive fjord-wall geological sections to be found in East and North Greenland are unparalleled elsewhere and provide unique analogues for subsurface/poorly exposed geological provinces. Evidence of the continued attraction of this “geological paradise” is provided by the flux of international researchers to study the geology of Greenland.

In some respects, then, to highlight individual localities may seem an irrelevance since broad tracts of the area could be collectively defined as being of exceptional value and interest to the international scientific community – and thus worthy of protection in a broad sense. As outlined below, however, the aim of this endeavour was to identify specific sites or localities that have particular scientific significance, or at least are representative of a suite of localities or a swathe of countryside that is noteworthy for scientific reasons.

The sites identified here (thirty-nine in all; Fig. 9.1) should not be considered as directly comparable with formal Geosites or Sites of Scientific Interest, as defined in Europe, which represent the end-result of a more structured process of research, documentation and prioritisation. The localities compiled here should rather be considered as a preliminary, and not necessarily exclusive, list of candidate localities that may be up for consideration should such a formal process be undertaken in the future.

It is emphasised that the distribution of scientifically-significant sites presented here is clearly dependant to a large degree on the intensity of investigation in this ‘frontier’ region. A scarcity of sites in certain regions should not therefore be understood to necessarily indicate an area of lesser scientific importance – such areas may yield geological sites of major significance when fully explored.

9.2 Data sources

The sites included in the GIS presentation are based primarily on published literature i.e. articles in international geological journals, bulletins etc. The localities were identified and described in the datasheets under the present project and thus do not rely on any previous databases. The key references on the basis of which the sites were identified and described are given in the respective datasheets. Further source literature with respect to stratigraphic nomenclature and status can be obtained directly through the GIS interface.

9.3 Site selection

Selection of sites of special scientific interest is problematic. Firstly, a degree of subjectivity is unavoidable in defining what is of ”interest” to the scientific community – this is a general problem, not restricted to Greenland, and can be combated by the involvement of a broad suite of geoscientists and by a well-constructed, consistent evaluation process. A second problem relates more to the nature of the terrain and the intensity/homogeneity of research in the area. Much of the National Park region is, in comparison to Northwest Europe, known only at a reconnaissance level so that the degree of geological knowledge (and hence publication) is highly variable – to some extent controlled by ease of access. As a result of both these factors, the list of sites given here represents a guide to the scientifically important sites known to us at present but should be regarded as a provisional list of candidates should a more formal definition process be envisaged in the future.

In selecting the thirty-nine sites included here, the subproject group (J.R. Ineson, A.K. Higgins, O. Bennike) – all of whom have geological experience from different disciplines within the National Park area – produced a preliminary list that was supplemented after discussions both within the wider DANCEA project group and with other geologists with experience in the area in GEUS and the Geological Institute (KU). In addition, site suggestions were solicited from members of DGF (Geological Society of Denmark), via the Society’s electronic membership list. The latter avenue was not highly productive and the most constructive proposals arose through direct discussion with individuals with experience in the area. Clearly, should more formal definition of Geosites become a priority in the National Park, a formal accreditation procedure should be established involving a broader spectrum of the Greenland geological community.

In practice, selection of the sites focussed particularly on those geological localities that have awakened interest within the wider geological community via international publication. This criterion accounts for probably the most important palaeontological sites – G06 Sirius Passet and G23 Celsius Bjerg – and outstanding sedimentological localities such as G04 Navarana Fjord and G19 Wollaston Forland. In other cases, a site was included as being representative of a well-documented and important geological feature (e.g. a sedimentary basin or a tectonic surface/lineament) although the site itself may not be prominent in the published literature. Examples of this are G05 J. P. Koch Fjord and G13 Keglen.

A preliminary evaluation of site sensitivity is included (see below). Within the framework of this project, a refined sensitivity rating is deemed inappropriate since formal criteria are presently unavailable. The sites are thus broadly ranked in terms of sensitivity as ‘High’ or ‘Low’; five palaeontological sites are attributed ‘High’ status, given the importance of the faunas/floras and the potential for lasting damage at these sites. The remainder of the sites are not considered sensitive since they typically represent extensive rock formations exposed in cliffs, mountainsides or fjord walls. It should be noted that although the important palaeontological sites may benefit from protection from excessive, irresponsible collecting, it is equally important given the scientific importance of these sites that access for *bona fide* scientific study is not inhibited.

In selecting the sites included here, a number of spectacular geological localities were ultimately excluded since it was also considered important to include a broad spectrum of features so as to reflect the geological diversity of the region. Thus, the thirty-nine sites span the region both geographically, from western Hall Land in North Greenland to southern Jameson Land in East Greenland (Fig. 9.1), and geologically, including sites from the Palaeoproterozoic to the Holocene covering geological processes from the deep crust to the glaciers of the last Ice Age.

9.4 Datasheet presentation

The Geological Sites of Special Scientific Interest are presented as PDF datasheets accessed from the GIS platform (see DVD). Cross-referencing to the mineral occurrences and hydrocarbon localities is included where relevant. The sites are numbered G01–G39, broadly from north-west (Hall Land) to south-east (Jameson Land).

The datasheets have a standard construction (see Fig. 9.2), with eight subheadings:

Designation: This gives a locality number (G01–G39) together with a name that typically links the geological feature with a geographical locality.

Location: The geographical locality defined by name and precise position (latitude/longitude) from the GIS platform.

Justification: The basis for inclusion of the locality in the list.

Geological/stratigraphical setting: A brief description of the broad geological setting and age, together with the lithostratigraphical status, where relevant.

Description of locality: A general description of the nature of the locality, ease of access etc. In the case of sites deemed highly sensitive (see below), the approximate dimensions of the locality are indicated.

Features of special scientific interest: Description of the features that justify inclusion in the list. This section may be illustrated further by photos or diagrams.

Site sensitivity. Only two categories of sensitivity are utilised: low and high. The vast majority of sites involve extensive, often mountain-scale exposures and are considered unlikely to be affected by intensive geological interest. Five palaeontological sites are, however, deemed to be potentially sensitive and are thus given a “high” evaluation.

References: Key references are listed, particularly singling out review articles that contain comprehensive reference lists concerning the site and thus provide a link to more detailed, specialised studies.

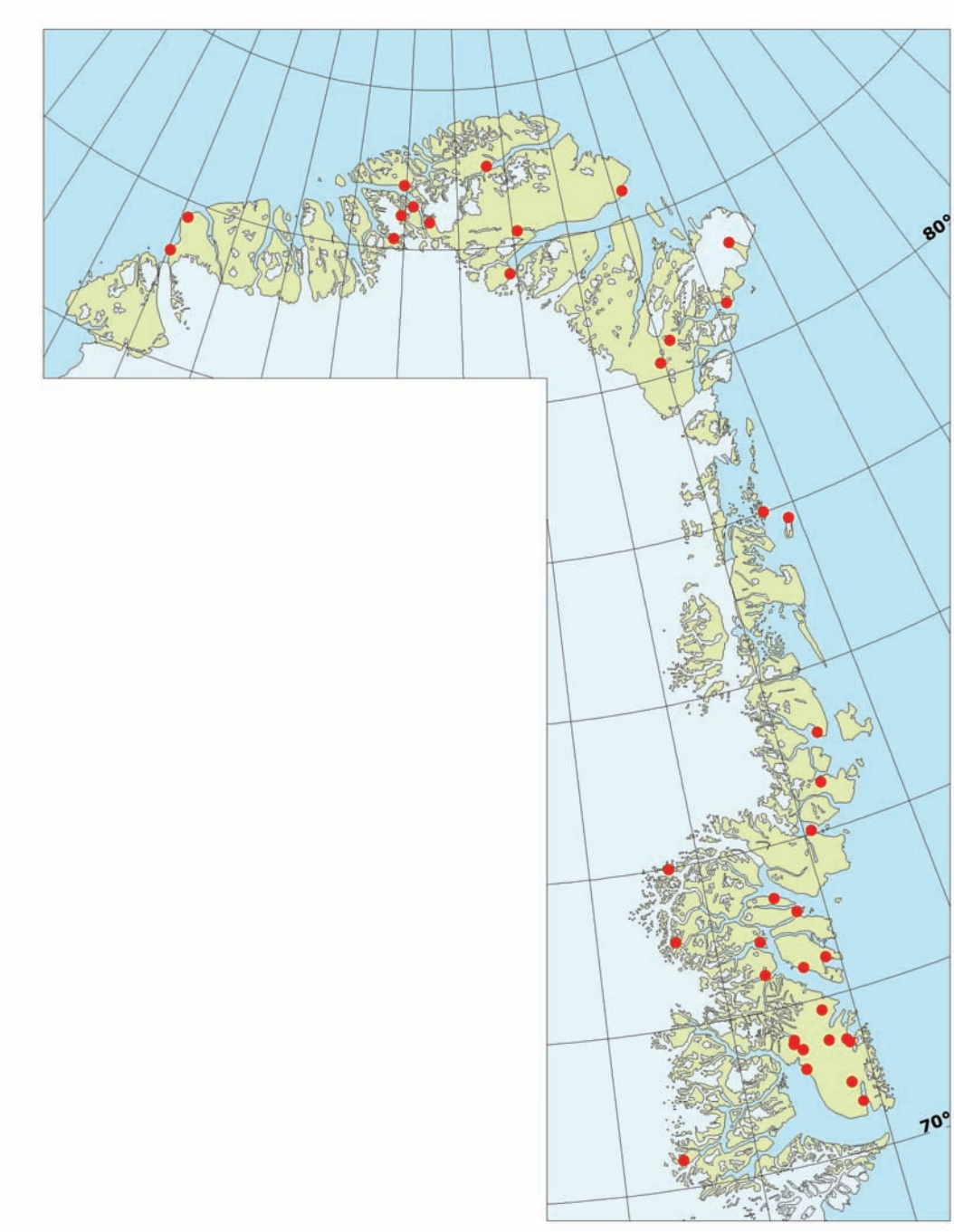

Fig. 9.1. *Overview map of the National Park region showing the distribution of Geological Sites of Special Scientific Interest.* ***Note that the distribution of sites displayed here to some extent displays the intensity of geological investigation, given that some areas are known only at reconnaissance level.***

Geological site of special scientific interest

Designation **G33** Middle Jurassic shallow marine sandstones

Location

Pelion, a mountain in Jameson Land, central East Greenland.

71° 27' 48.45" N, 23° 19'

Justification

The geology of the Middle Jurassic of Jameson Land has considerable implications for understanding of analoguous deposits in the subsurface of the Norwegian shelf. The Pelion Formation is particularly well-known in this respect.

Setting

The Mesozoic Jameson Land Basin forms part of the Late Palaeozoic – Mesozoic East Greenland rift complex – the westernmost portion of the major N–S rift system between Greenland and Norway. The Jameson Land Basin subsided broadly symmetrically in the mid-Jurassic and the basin geometry was a gentle ramp. The sedimentary rocks exposed on the mountain of Pelion are referred to the Pelion, Fossilbjerget and lower Olympen Formations of the Vardekløft Group.

Description

The Pelion, Fossilbjerget and lower Olympen Formations are exposed on the upper slopes of mount Pelion, which is 1200 m high at its summit.

Features

The Pelion and Olympen Formations are marine sand-rich formations exposed widely in Jameson Land and have been studied in considerable detail. Their depositional facies and their overall and internal architecture are well-known and provide important and popular analogues for reservoir sandstones in the subsurface of the Norwegian shelf and the North Sea.

Sensitivity

Low

References

Surlyk. F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 659–722.

Engkilde, M. & Surlyk, F. 2003: Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 813–863.

Larsen, M. & Surlyk, F. 2003: Shelf-edge delta and slope deposition in the Upper Callovian – Middle Oxfordian Olympen Formation, East Greenland. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 931–948.

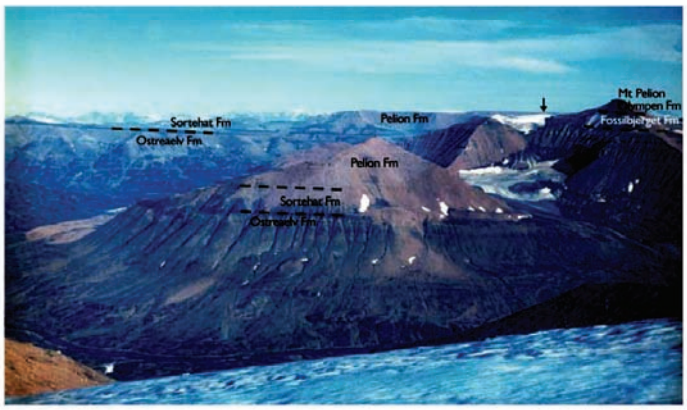

Fig. 9.2. *A representative datasheet (G33) illustrating the standard layout used in the GIS platform.*

10. Data specifications and GIS application

10.1 DVD contents

On the enclosed DVD, all necessary files for the GIS-applications are collected. The top-level directory has the following content:

Name	Content
Readme.txt	Brief instructions for use of the DVD
Instructions_for_use.pdf	More elaborate documentation of contents and use of the DVD
ArcView	Directory with ArcView project file and associated shape files
MapInfo	Directory with MapInfo workspace file and associated TAB files (empty in first version of DVD - will be included in second version)
Report	Directory which includes a PDF-version of this report as well as special versions of the datasheets, where all datasheets from each subject are assembled into one PDF-document suitable for printing

Please check the document “Instructions for use.pdf” for any changes made to the setup of the DVD after this text was written.

10.2 Data

All data collected in this project are accessible from a GIS application. For this use, data is divided into two **levels**:

1) Summary information, often based on codes, is put directly into the GIS-dataset (shapefile in ArcView, TABfile in MapInfo). The GIS-application can then be used for visualization, custom symbolization and for searching and selecting specific localities based on coordinates and summary information.

2) The full documentation is available in PDF-files, which can be opened directly from the GIS-application. In the PDF-files, full text-searches can by made within the Acrobat-application (but not directly from the GIS-application.)

The collected data also falls into two **types**:

1) All localities in the categories "Mineral occurrences", "Hydrocarbons", "Geological sites of special scientific interest" are represented as points. In reality, these sites can have an extent from a few metres to several kilometres, but often with an unclear boundary. To make the material more homogeneous and the location easy to map at all scales, all are shown as a point placed in the centre of the area.

2) The geological map is represented as polygons covering the total area of land. As on any geological map, the boundaries may also be gradational in reality. This map has its preferred viewing scale at 1:250 000.

As a supplement most of the datasets mentioned in section 6 (Geochemical data) and section 7 (Geophysical data) are included on the DVD. Please refer to these sections for further description. Many of these datasets are raster-based.

Table 10.1 lists all GIS-datasets included in the main application on the DVD. A detailed description of their attribute fields can be found as Excel-files in the directories ArcView and Mapinfo.

All GIS-datasets are delivered in UTM zone 24, WGS 84. The user may project them into other zones or datums if desired.

Name in ArcView	Contents	Filename
Geological sites	Geological sites of special scientific interest	geological_sites\special_interest.shp
Hydrocarbon	Hydrocarbon-related sites	hydrocarbon\hydrocarbon.shp
Mineral occurrences	Mineral occurrence sites	mineral_occurrences\mineral_occurrences.shp
Names as text	Placenames as text	topography\250k_map\names
Names as points	Placenames as points	topography\250k_map\namepoints.shp
Grid Lat:15' Long 1°	Dense geographical grid	topography\250k_map\grid_small.shp
Grid Lat:1° Long:5°	Coarse geographical grid	topography\250k_map\grid_big.shp
Mapsheets	Mapsheet borders for geological maps	topography\250k_map\mapsheets.shp
Grid + frame	Custom grid with frame	topography\250k_map\grid_plus_frame.shp
Projectarea boundary	Projectarea boundary	topography\250k_map\projectareabound.shp
Natpark boundary	National park boundary	topography\250k_map\natparkbound.shp
Points	Topographical points	topography\250k_map\points.shp
Contours	Contours	topography\250k_map\contours_line.shp
Rivers	Rivers	topography\250k_map\rivers.shp
Geology text	Text annotation for geological map	geology\geopointanno
Geology point	Markers for geological map	geology\geopoint.shp
Geology trends	Separate lines for geological map	geology\trends.shp
Geology line	Polygon borders for geological map	geology\geology_line.shp
Geology poly	Geological map polygons	geology\geology_poly.shp
Areas line	Lines for topographical map	topography\250k_map\areas_line.shp
Areas poly	Topographical map polygons	topography\250k_map\areas_poly.shp
Structures text	Text for synoptic structural map	geology\structures_text.shp
Structures line	Lines for synoptic structural map	geology\structures_line.shp
Structures poly	Polygons for synoptic structural map	geology\structures_poly.shp
Basins text	Text for synoptic sediment map	geology\basins_text.shp
Basins line	Lines for synoptic sediment map	geology\basins_line.shp
Basins poly	Polygons for synoptic sediment map	geology\basins_poly.shp
Overview lines	Lines for simplified topographical map	topography\250k_map\overview_line.shp
Overview polys	Polygons for simplified topgraphical map	topography\250k_map\overview_poly.shp

Table 10.1. GIS-datasets on DVD

10.3 GIS-application

The GIS-application is produced in two versions: ArcView (version 3.2a) and MapInfo (version 7.5). For each of these platforms, a project/workspace is defined which includes all the above mentioned data together with the general topographic map, which was produced in an earlier phase of this project. For each dataset, an appropriate symbology has been chosen. It is possible for the user of the application to define alternative symbologies based on any attribute of the data.

No extra functionality has been added to the application. However, the (hot)link tool has been activated and must be used to access the PDF-documents. In ArcView it is important to remember, that an active theme must be chosen to guide the hyperlink tool to the correct document. From the GIS-application each datasheet is available as a single document of 1-3 pages. In the folder “report” on the DVD exists another version where all datasheets from each subject are assembled into one PDF-document - suitable for printing.

When using the GIS-application, the user has the option of using either the general topographic map or the geological map as background for the rest of the map-themes. Please note however, that the topographic map at this time (june 2005) is not yet declassified for free distribution (see also section 11).

In order to provide an overview of the content of the geological map, a special "legend-map" or interactive legend is included. Each of the geological units is presented here in a stratigraphical context showing a box with the colour and code for the unit and a short description. By clicking on this "legend-map" with the link tool, the PDF-document with the full description is presented.

11. Conclusions and recommendations

The Dancea project reported here has compiled and homogenised a wide array of geological and geophysical data from the National Park in North and Northeast Greenland and the Scoresby Sund area. The project has also focused on compiling and presenting data on a selected, representative proportion of known localities in the area that are significant for both economic and scientific reasons.

The project has resulted in:

- A seamless and homogeneous digital geological map, accessible as GIS-intelligent data, that stretches from 80°N on the north-west coast through North and Northeast Greenland to 70°N on the east coast. This dataset is linked to the complete digital topographic coverage of the area created by GEUS under an earlier project.
- A digital platform that is ideally suited to compilation of a wide spectrum of existing and future datasets.
- Selection and presentation of 104 mineralised localities on the GIS platform that illustrate the known mineral prospectivity of the region. Regional geochemical and geophysical data covering the project area are also included.
- 18 selected hydrocarbon-related sites and 39 geological sites of special scientific interest are presented via the GIS platform. The hydrocarbon sites include both localities significant for evaluation of the regional petroleum potental, as known to date, and localities of importance for understanding petroleum systems in general. The sites of special scientific interest were chosen on scientific merit but also reflect the geological diversity of the region, including sites from the Palaeoproterozoic to the Holocene covering geological processes from the deep crust to the glaciers of the last Ice Age.

Thorough and detailed work has been done to compile and homogenise existing data to provide an accurate and up-to-date summary of the present-day knowledge of the geology of the region.

It should be stressed, however, that future field studies in the vast area of the National Park may provide new information on hitherto unknown occurrences of geological, hydrocarbon and mineralogical significance.

Recommendations

On the basis of experience gained in the course of the project, the following recommendations are proposed:

- The digital geological and topographical map data should be subject to ongoing revision and refinement. For example, a useful addition to the maps would be the location of logistic features – landing strips, emergency field huts, safe coastal access points, natural harbours etc. Users of this data-package are thus encouraged to provide feedback concerning problems/errors encountered.

- The mineral occurrences presented here on the GIS platform are a representative selection of known occurrences. It is recommended that the remaining known sites are incorporated, together with new discoveries, to maintain a comprehensive and up-to-date database.

- The geological sites of special scientific interest presented here represent a preliminary list of candidate localities. Should more formal definition of Geosites become a priority in the National Park, a more rigorous accreditation procedure should be established involving a broader spectrum of the Greenland geological community.

- Although the National Park, by definition, excludes offshore areas beyond the coastal zone, economic exploitation of potential offshore resources (e.g. off Northeast Greenland) would clearly have consequences for the onshore region. It is recommended therefore that the geology of offshore regions, albeit poorly understood at present, is included in future considerations.

- The digital dataset, presented here as a confidential report and DVD, should be de-classified and made available to the wider public.

- The digital dataset, once publically available, should be made available on the internet, e.g. via the GEUS website. The database represents an important resource and should be maintained and updated continuously.

12. Acknowledgements

The present project has received financial support form the Danish Environmental Protection Agency as part of the support program Dancea – Danish Cooperation for Environment in the Arctic. The results and conclusions presented in the report do not necessarily reflect the position of the Danish Environmental Protection Agency.

The active co-operation of the members of the Project Steering Committee is gratefully acknowledged. These members include Mette-Astrid Jessen and Jørgen Søholm, Department of Environment and Nature, Nuuk; Hans Chr. Schønwandt, Jette Blomsterberg and Heidi Nexø, Bureau of Mineral Resources, Nuuk; Anders Dalgaard, Asiaq, Nuuk; and Peter Aastrup, National Environmental Institute, Roskilde.

Gabriel Strykowski from the Danish Space Center is thanked for providing the gravity data.

In addition to the core Project Group, a number of GEUS employees provided valuable assistance that we gratefully acknowledge:

Ole Bennike, for contributing to the selection of geological sites.

Margareta Christoffersen, for a critical contribution to the digital geological map conversion.

A.K. Higgins, for providing the tectonostratigraphic review of the region, proof-reading the maps and contributing to the selection of geological sites.

Thorkild M. Rasmussen, for reviewing the geophysical data and contributing the geophysical section in this report.

Agnete Steenfelt, for reviewing the geochemical data and contributing the geochemical section in this report.

Stuart Watt, for making a comprehensive Greenland lithostratigraphic database available and compatible.

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14. Availability

The present report including DVD is classified as ‘confidential’ due to restrictions on the digital topographic dataset that forms the framework for this data compilation.

Comments or corrections to the digital dataset are welcomed, and can be sent to the following email address: geus@geus.dk with the following subject: “Thematic maps – GEUS 2005/28”.