



Airborne geophysical data from Greenland





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In Greenland, compared to the rest of North America and Europe, the use of airborne geophysical surveys as a basic tool in mineral exploration came fairly late. During the early 1970s the first public airborne surveys were carried out in East Greenland, followed in the mid seventies in West and South Greenland. As for most surveys at the time, the earliest data, magnetic and radiometric, were acquired in digital form but positioned visually by tracking photography. In the eighties, experimental surveys with very wide spacing of lines (10–12 km) were carried out over the southern part of the Inland Ice. Since 1992, systematic digital airborne geophysical programmes have been conducted in many parts of Greenland, now taking advantage of modern positioning techniques, e.g. GPS. At the beginning of the new millennium substantial parts of Greenland have been covered by magnetic, electromagnetic and radiometric surveys using a methodology practical for exploration companies. New methods based on airborne hyperspectral scanning have been introduced and used in selected areas.

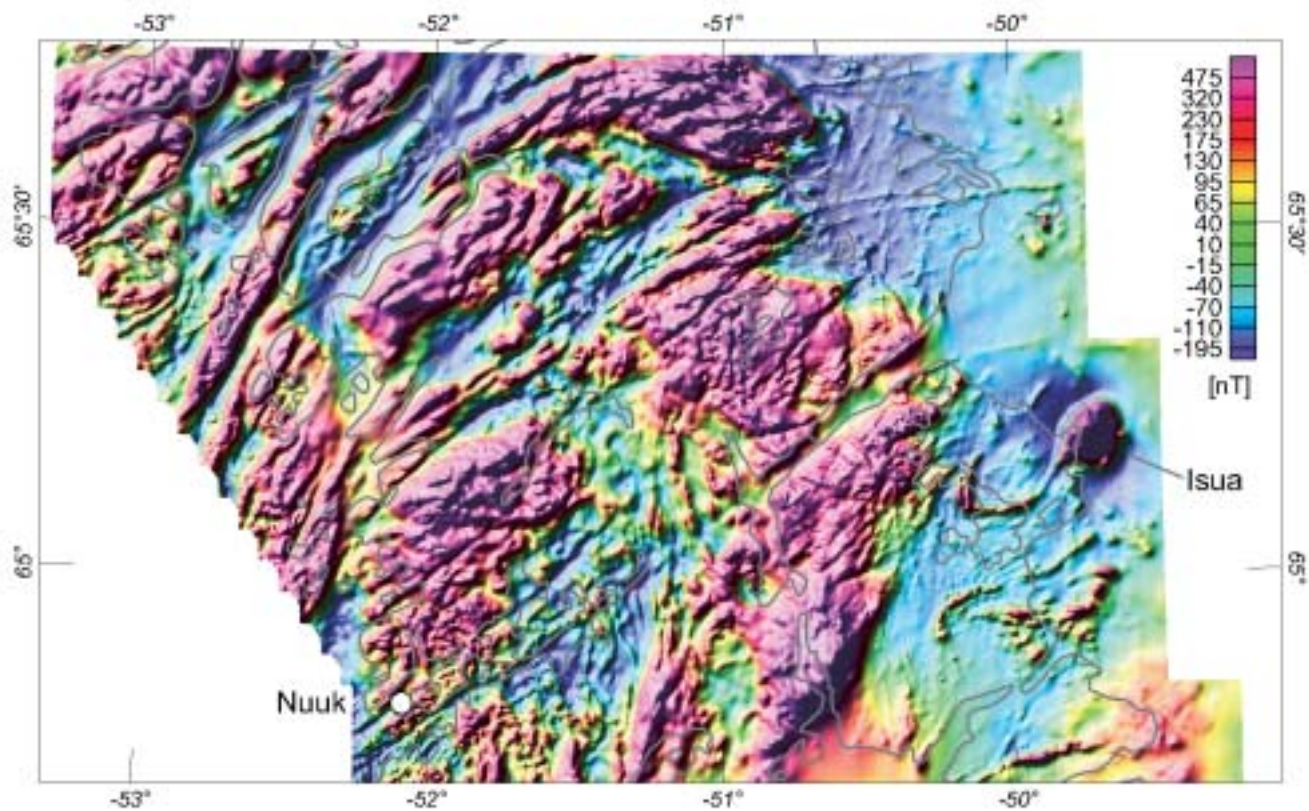
Air Greenland A/S helicopter AS 350 during take-off from Grønnedal in South-West Greenland with its geophysical instrumentation from Aerodat Inc. The lower bird contains the electromagnetic equipment and the upper bird is the magnetometer. During survey the electromagnetic equipment is carried 30 m above the ground.



BN-Islander mounted with tail sensor for aeromagnetic surveying. Kangerlussuaq Airport, 1976.



The electromagnetic (GEOTEM) transmitter loop fixed at the nose of the Geoterrex Ltd. Aircraft (Casa), Nuuk, 1995.



In West Greenland the spectacular 20 000 nT anomaly of the Isua banded iron formation measured at a survey altitude of 300 m can easily be located on the aeromagnetic total field anomaly map (right part) from project Aeromag 1998.

History of modern airborne geophysical programmes

In the early nineties the Government of Greenland was seeking new ways to stimulate mineral exploration in Greenland.

Among other initiatives, a five-year programme, AEM Greenland 1994–1998, of airborne combined electromagnetic and magnetic surveying was proposed by the predecessor of the present day Bureau of Minerals

and Petroleum. The survey areas were to be chosen on the basis of potential for the discovery of economic mineral deposits and to demonstrate the general applicability of airborne methods in the various terrains in



Aircraft (Casa) outfitted for geophysical surveying. The electromagnetic transmitter loop is fixed to the wing tips, tail and nose, Thule Airbase, 1994.



Aircraft (Piper Navajo Chieftain) outfitted for hyperspectral surveying. Kangerlussuaq Airport, 2002.

Areas for acquisition of geophysical data from

A) the programme on airborne magnetic and electromagnetic measurements in Greenland 1992-2001, and

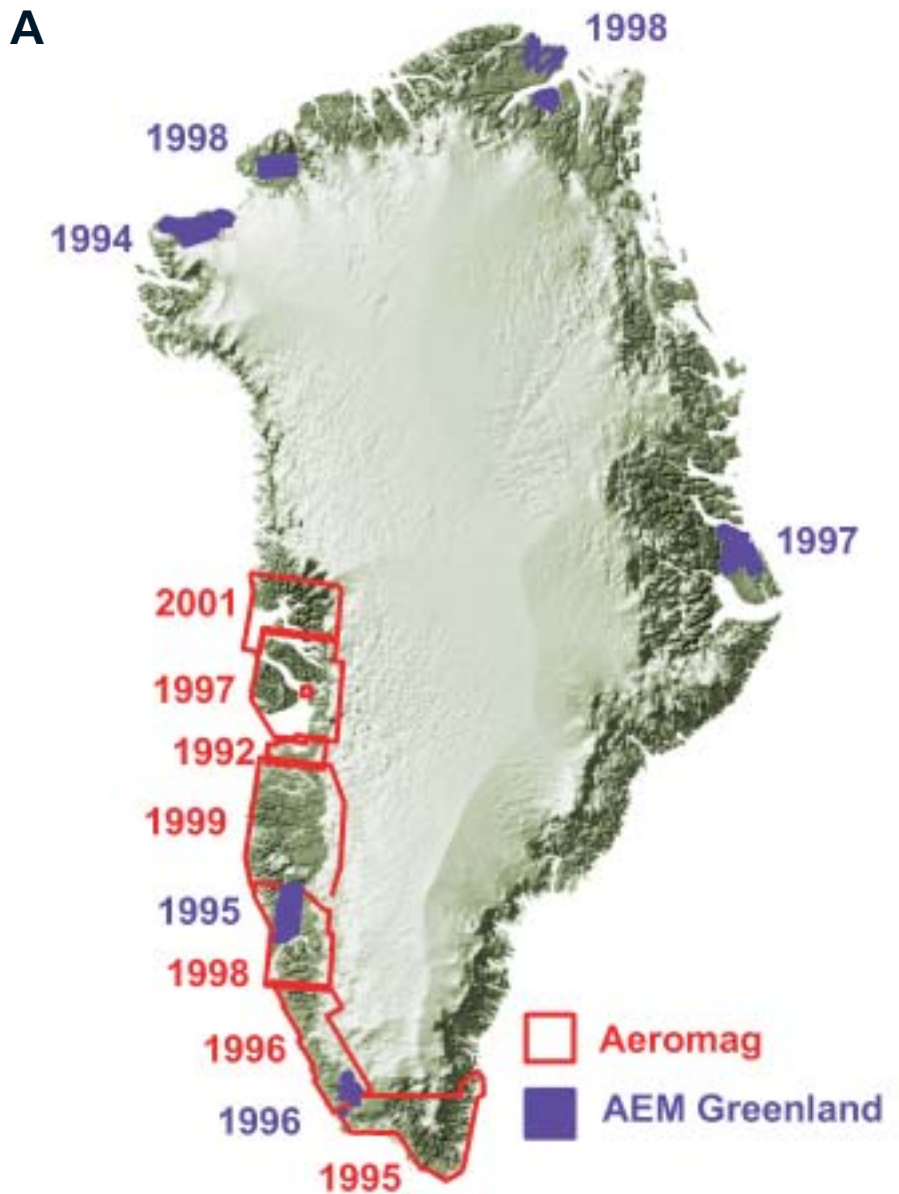
B) survey programmes comprising aeroradiometric and hyperspectral measurements from 1972 to 2002.

Greenland. Simultaneously with the AEM programme, another airborne project, Aeromag, was soon after started and financed by the authorities, producing a regional coverage of high-quality aeromagnetic data. The total coverage of the various airborne methods is shown in a number of index maps. Management of the airborne programme and the handling and interpretation of the data was contracted to the Geological Survey GEUS (formerly GGU), while the surveys were flown by commercial geophysical contractors after international tender.

Major airborne geophysical surveys conducted in Greenland are then:

- Aeromagnetics
- Airborne electromagnetics
- Hyperspectral measurements
- Aeroradiometry

The examples in this issue of 'Geology & Ore' provide an overview of high-resolution geophysical data from the airborne geophysical survey programmes since 1992. The projects 'Aeromag' and 'AEM Greenland 1994-1998' have shown that airborne geophysical methods can be utilised with success under the arctic climatic and logistical conditions in Greenland.



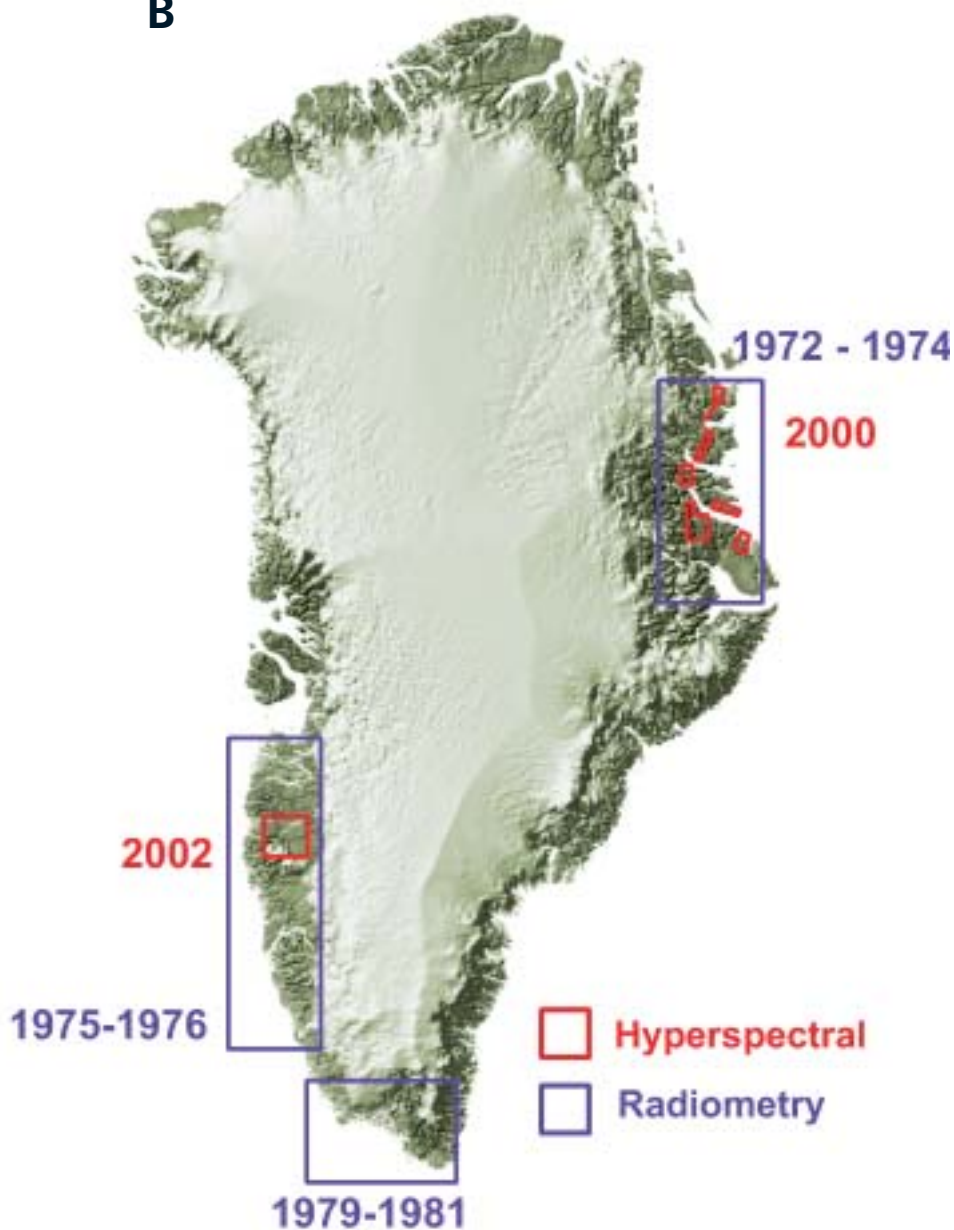
Aim of the modern airborne surveys

In addition to the short-term objective of stimulating mineral exploration, another purpose of the programmes was to provide a lasting database of high quality geophysical data that could give a new dimension to the understanding of the geology of Greenland.

The airborne geophysics initiative did not

The Aeromag surveys				
	Aeromag 1975-76	Aeromag 1992	Aeromag 1995-99	Aeromag 2001
Region	Central West Greenland	Central West Greenland	South and West Greenland	West Greenland
Size of area km²	60 000	8 600	210 000	31 400
Line km	52 000	10 100	440 000	70 000

B



and presented to the mining and exploration community. All the data behind maps are available from the GEUS' databases, and the high quality of the data will ensure their use for many years into the future.

The Aeromag surveys

The Aeromag projects encompass high-resolution magnetic surveys conducted in 1992, each of the years from 1995 to 1999 and in 2001, producing a total of nearly 520 000 line kilometres. Initial measurements were carried out in West Greenland 1975–1976, producing around 50 000 line kilometres, but these data should now be considered to be superseded by the modern data.

High-quality, high-resolution magnetic data are now available for the total ice-free area of West and South Greenland from the southern tip of Greenland to Svartenhuk Peninsula, covering an area of approximately 250 000 km². Most of the yearly surveys have mainly covered onshore areas. However, the survey in 2001 north of Nuussuaq and the survey 1997 in the Disko Bay region, also included significant offshore areas. Approximately one third of the 2001 survey region is offshore, and includes an area well known for its importance in relation to the understanding of the offshore hydrocarbon potential.

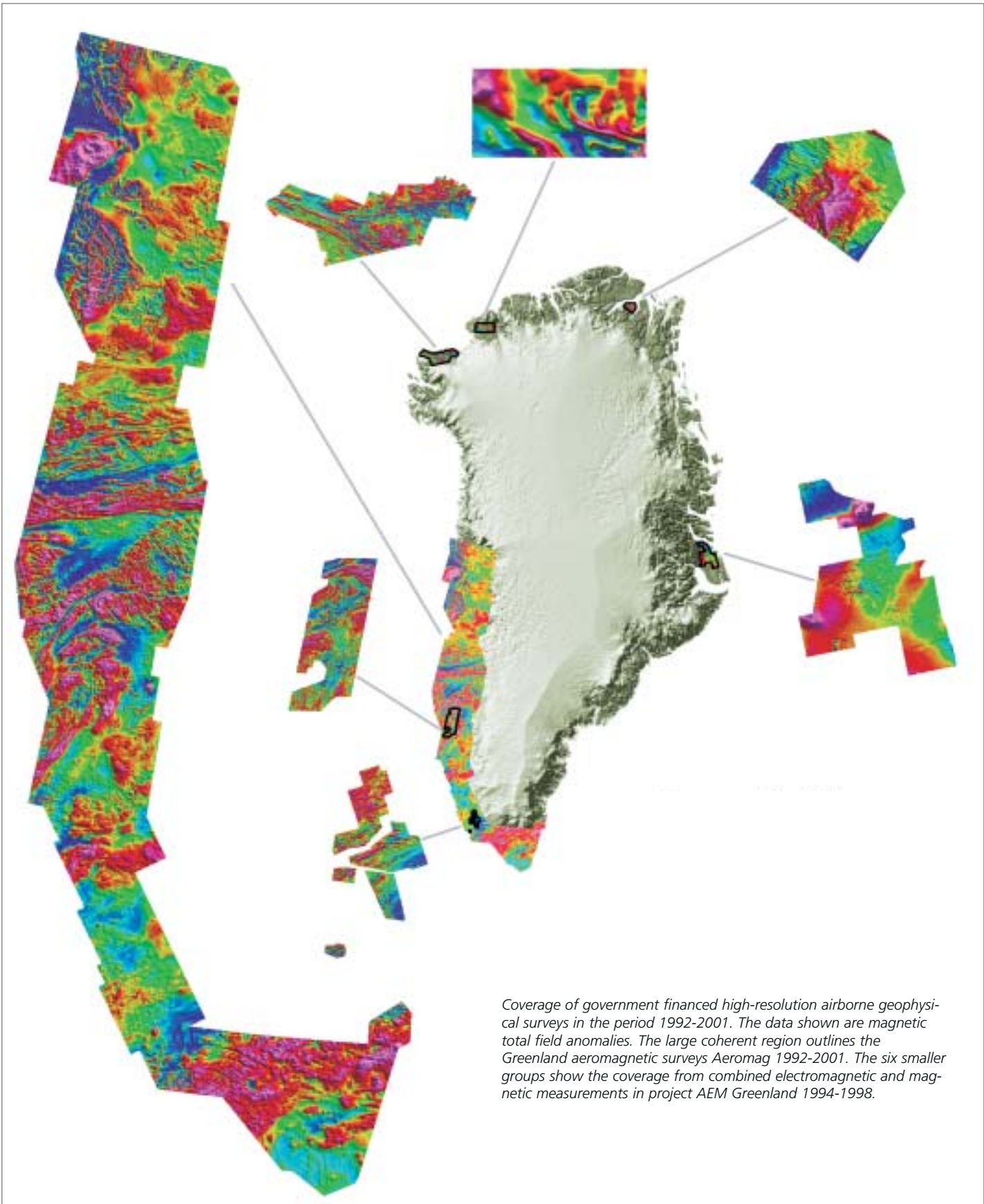
Generally, the Aeromag type of survey is carried out by flying along a gently draped surface 300 m above the ground and sea level. Survey lines are typically aligned in N–S direction with a separation of 500–1000 m. Orthogonal tie-lines are flown with a separation of 5000 m. Total magnetic field data are recorded with a sampling rate of 0.1 sec which corresponds to a sampling distance of 7 m.

stand on its own. The search for minerals was actively supported and promoted by the Government of Greenland in other ways:

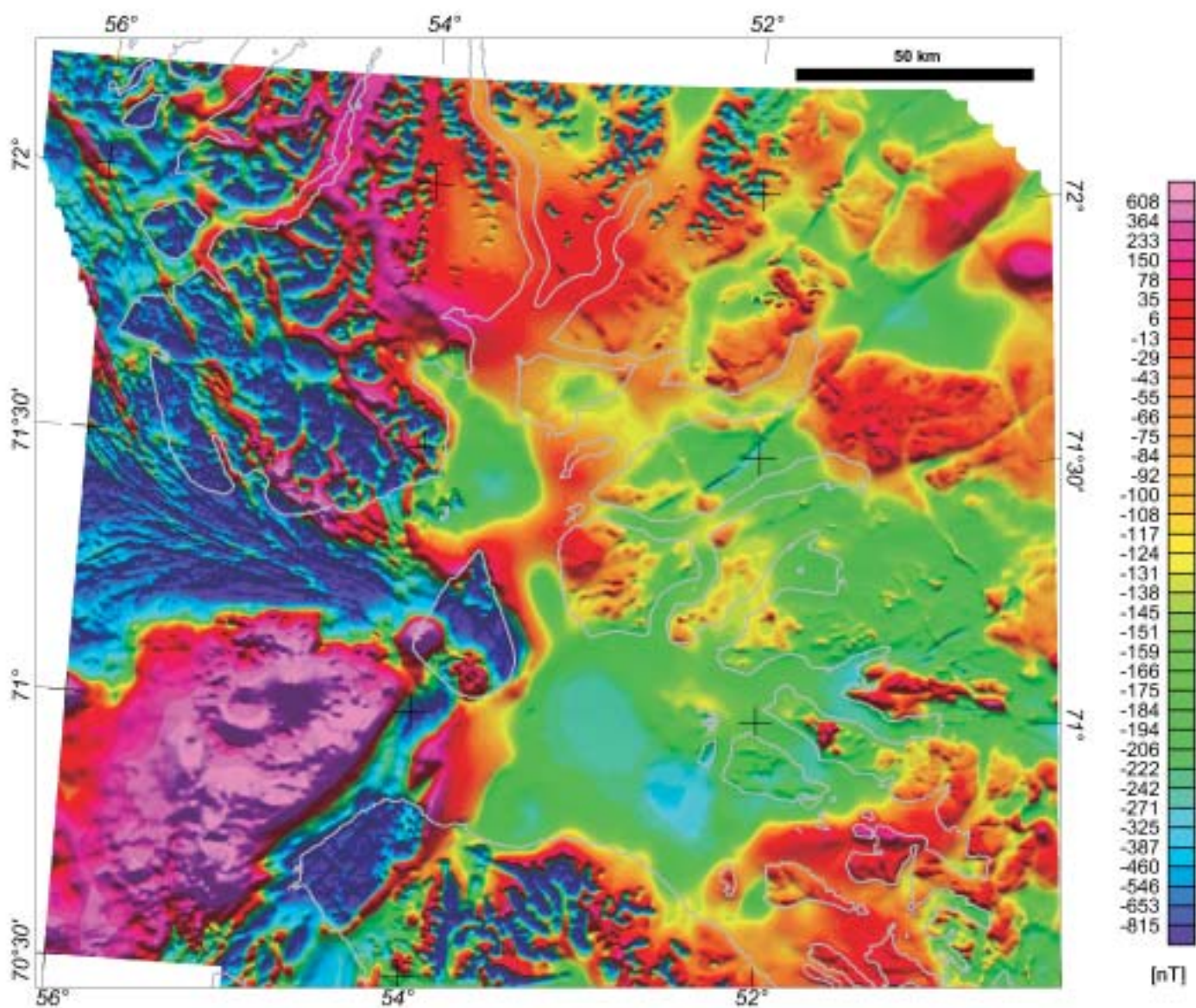
- legal, regulatory and financial incentives
- creation of favourable commercial conditions
- attention to the industry's need for good quality geo-science data
- financing of specific projects carried out by GEUS

After a decade of data acquisition thousands of geophysical maps have been produced

The airborne electromagnetic surveys				
AEM	1994	1995–1996	1997	1998
Region	North-West Greenland	South and West Greenland	Central East Greenland	North Greenland
Size of area km²	6 500	6 800	5 200	4 900
Line km	17 400	29 200	14 000	4 500



Coverage of government financed high-resolution airborne geophysical surveys in the period 1992-2001. The data shown are magnetic total field anomalies. The large coherent region outlines the Greenland aeromagnetic surveys Aeromag 1992-2001. The six smaller groups show the coverage from combined electromagnetic and magnetic measurements in project AEM Greenland 1994-1998.



Map outlining the magnetic total field in an area north of the Nuussuaq peninsula, central West Greenland, Aeromag 2001.

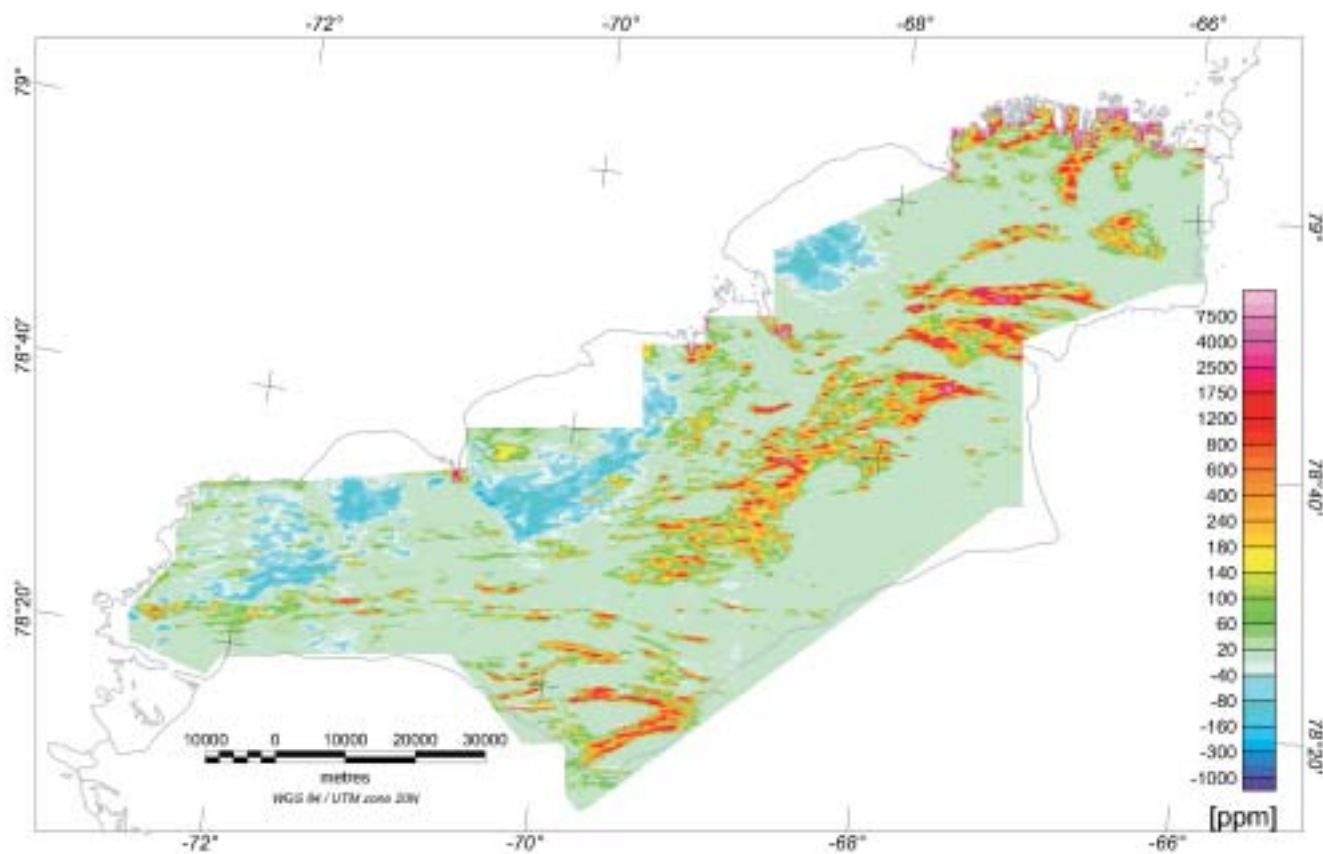
Aircraft positional data from simultaneous GPS (Global Positioning System) measurements, as well as aircraft altitude measurements obtained from barometric altimeter and radar were recorded, and position measurements are presented as digital terrain models.

The airborne electromagnetic surveys

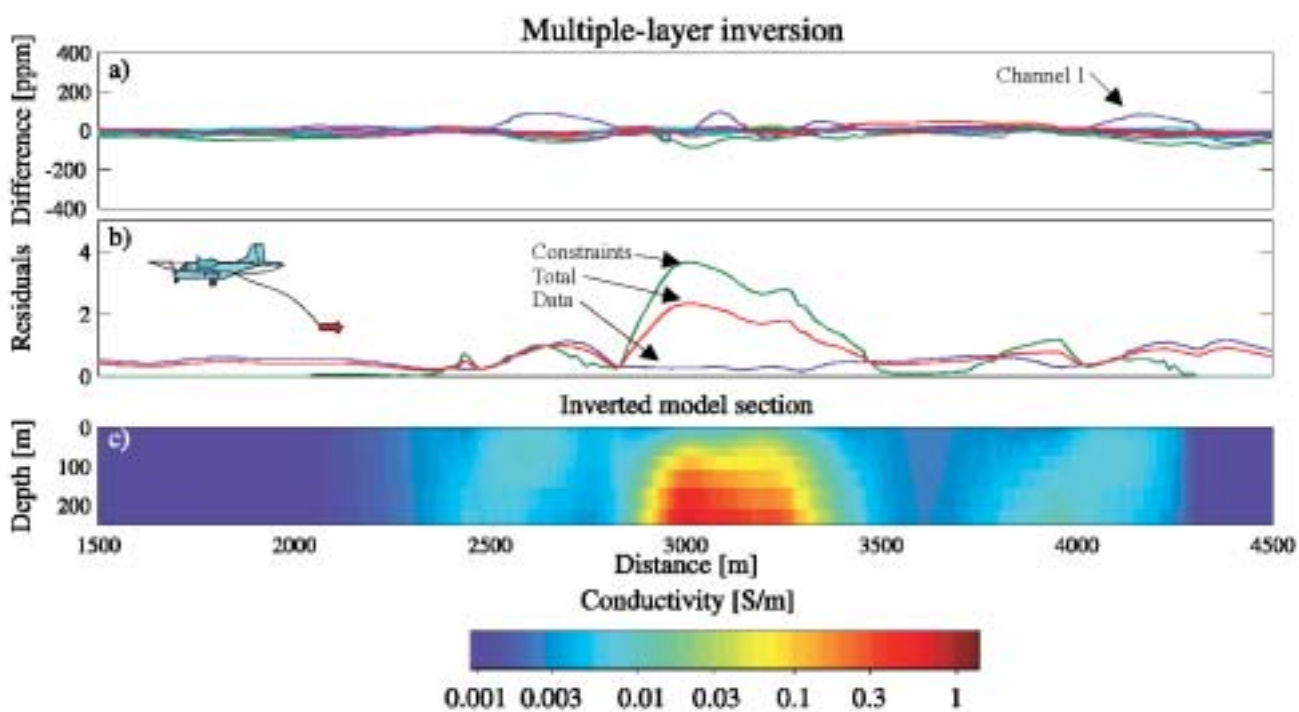
The AEM Greenland 1994–1998 detailed surveys with combined electromagnetic and magnetic measurements were carried out in six selected areas of expected high mineral potential during the project, covering additional 25 000 km².

The AEM surveys include transient electromagnetic data (GEOTEM) and combined multi-coil frequency domain data and VLF-data. Magnetic total field measurements are also available from all surveyed areas.

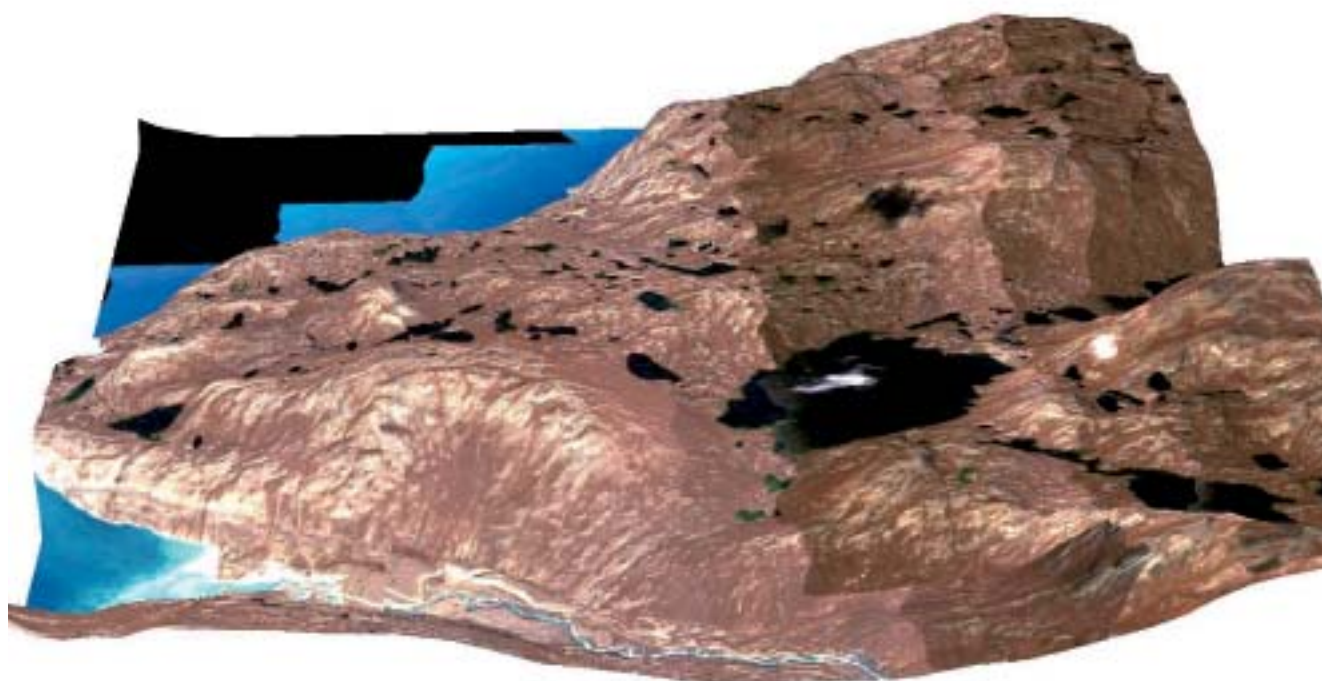
Various terrains have been covered, including Inglefield Land in North-West Greenland, the Maniitsoq–Nuuk region in southern West Greenland, the Grønnedal region in South-



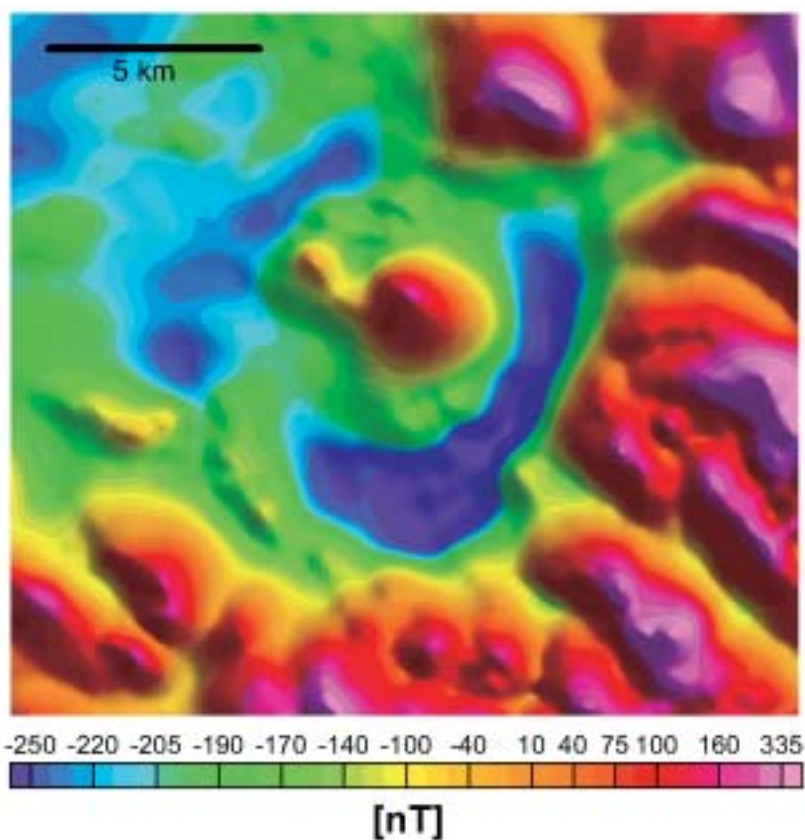
Amplitude of GEOTEM X-coil receiver at 560 microseconds turn-off time of transmitter signal for the AEM Greenland 1994 survey in Inglefield Land, North-West Greenland.



Results of multiple-layer inversion of data from the AEM Greenland 1994 survey in Inglefield Land, North-West Greenland.



3D image of hillside near Kangerlussuaq Airport, West Greenland, created during HyperGreen 2001.

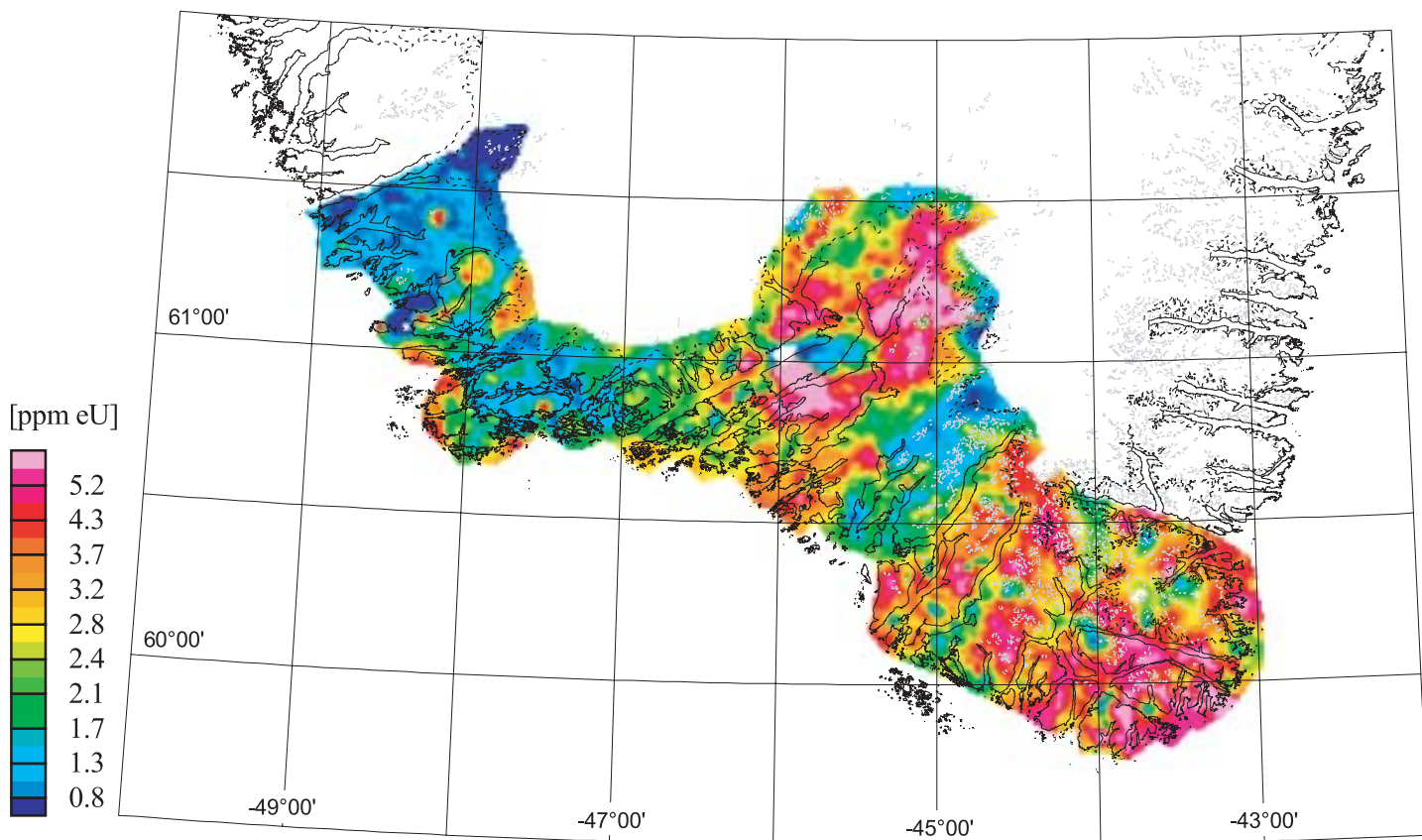


Close-up on the type of magnetic anomaly from the Sarfartoq carbonatite complex, southern West Greenland. The centre of the complex is marked by a high magnetic field caused by the presence of magnetite. The surrounding magnetic low is caused by hydrothermal alteration of the host rocks, Aeromag 1999.

West Greenland, Jameson Land in central East Greenland, Washington Land and Daugaard-Jensen Land in western North Greenland and J. C. Christensen Land in eastern North Greenland. Additional reconnaissance lines were measured adjacent to some of the main survey areas.

In total, 75 000 line km covering an area of 23 000 km² were measured in the project.

The project was initiated and designed to encourage mineral exploration. Thus, at the start of the project all holders of prospecting and exploration licenses in Greenland were contacted to solicit views on possible target areas for the five-year period. The selection of areas was primarily guided by the knowledge of mineral occurrences but also to some extent by a wish to cover different types of geological settings. In addition to the government-financed surveys, several



Equivalent uranium (eU) in South Greenland, based on gamma-spectrometric measurements during the airborne campaign 1980-81.

The hyperspectral survey

HyperGreen	2000–2001	2002
Region	Central East	Central West
	Greenland	Greenland
Size of area km²	2 500	8 000
Line km	2 000	6 000

companies undertook surveys of a similar type, often in adjacent areas to the government-organised activities, exploiting an option in the contract between the Survey and the geophysical contractor whereby the mobilisation costs to and from Greenland could be disregarded for the prospecting company.

The activities sparked a considerable interest from the prospecting companies after the yearly release of data from the 1994–1998 surveys, and it has been confirmed that modern high-resolution geophysical data are of paramount importance in the search for mineral deposits. Although none of the targets located by the surveys and checked have so

far resulted in an occurrence of economic importance, the data contain much valuable information to be used in a continued search for mineral accumulations.

The hyperspectral Surveys

Data acquisition is based on the HyMap™ hyperspectral imaging spectrometer, which collects Hyperspectral data from 126 bands across the reflective solar wavelength region of 0.45–2.5 nm with bandwidths between 15–20 nm, and a signal to noise ratio better than 500:1.

For Greenland, the known mineral occurrences surveyed with this new technique will provide a good reference base for the evalu-

The aeroradiometric survey

Gammascop	1972–1974	1975–1976	1979–1981	1996
Region	<i>Central East Greenland</i>	<i>Central West Greenland</i>	<i>South Greenland</i>	<i>South-West Greenland</i>
Size of area km²	50 000	100 000	35 000	1 600
Line km	10 000	30 000	1 500	9 000

ation and assessment of hyperspectral data processing techniques in mineral exploration and geological mapping in arctic environments. Occurrences associated with hydrothermal alteration, which is hosted by a wide range of igneous and sedimentary lithologies, have a distinct signature in the measured bands. It is expected that the statistical treatment of the data by GEUS will locate new targets with mineralogical characteristics related to the presence of economically interesting mineral accumulations.

The first campaign was carried out in East Greenland 2000–2001 and was concerned with environmental aspects of the former lead–zinc mine at Mestersvig, and known mineral occurrences at various locations in the region. In 2002 a new hyperspectral survey was conducted in central West Greenland under a contract with the Bureau of Minerals and Petroleum. The survey operations were primarily directed towards the kimberlite province in the area. GEUS manages the project and handled the supporting field work and results.

The aeroradiometric survey

Aeroradiometric data (acquired as gamma-ray measurements) have been used to quantify and describe the radioactivity of rocks in Greenland since the early 1970s. The major part of the gamma-ray signal originates in the upper 20–25 cm of surficial rock materials, and therefore the method is a good tool for geological mapping. The gamma-spectrometer is mounted in an aircraft that is flown over an area at low altitude, in the range 30–150 m. Size of the total gamma exposure is estimated by combining the data from the uranium, thorium and potassium data channels. Different types of contour maps of the measurements or ratios of com-

binations of channels are produced and used for the interpretation of geological features.

A large part of the data gathered from Greenland areas (1972–1976), however, are in an analogue form and with irregular tracking lines along terrain contours and thus not suitable for up to date map presentation.

The correlation of early airborne radiometric measurements with the geology has been done visually and typically based on the studying of anomalies from the different channels. Results from that type of comparison have led to recognition of several geological structures and rock associations of relevance to mineral exploration. As examples, some of the promising targets of the present day exploration, e.g. the Sarfartoq carbonatite complex and the Motzfeldt alkaline centre in West and South-West Greenland, were recognised this way.

Closing remarks

The series of publicly funded geophysical surveys in Greenland are intended to provide the industry and the geoscientific community with data relevant for the exploration for mineral resources. The modern survey programme has added more than 600 000 line kilometres of high-quality measurements to the existing database of airborne geophysical data from Greenland. The data have already been used extensively by the exploration industry and will continue to be useful for many years to come. High-resolution geophysical data are certainly an investment for the future.

Access to modern high-quality geophysical data is an essential tool if exploration is to be effective. The airborne geophysical measurements carried out in Greenland represent

data acquisitions up to international best practise, comparable with data furnished for regional exploration and mapping by other national Geological Surveys: the data collected in Greenland since 1992 form an important contribution to the development of mineral exploration.

Maps, digital data on CD-ROM's and accompanying reports are obtainable from GEUS at cost.

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Cessna Grand Caravan from Sander Geophysics Ltd. with tail mounted magnetometer traverses snow-covered terrain at the Nuussuaq peninsula in central West Greenland, Aeromag 1997.

Front cover photograph:

Close up of the electromagnetic transmitter loop fixed to the wings of the Geoterrex Ltd. CASA aircraft. Thule Airbase 1994. Photo: Jakob Laurtrup, GEUS.



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