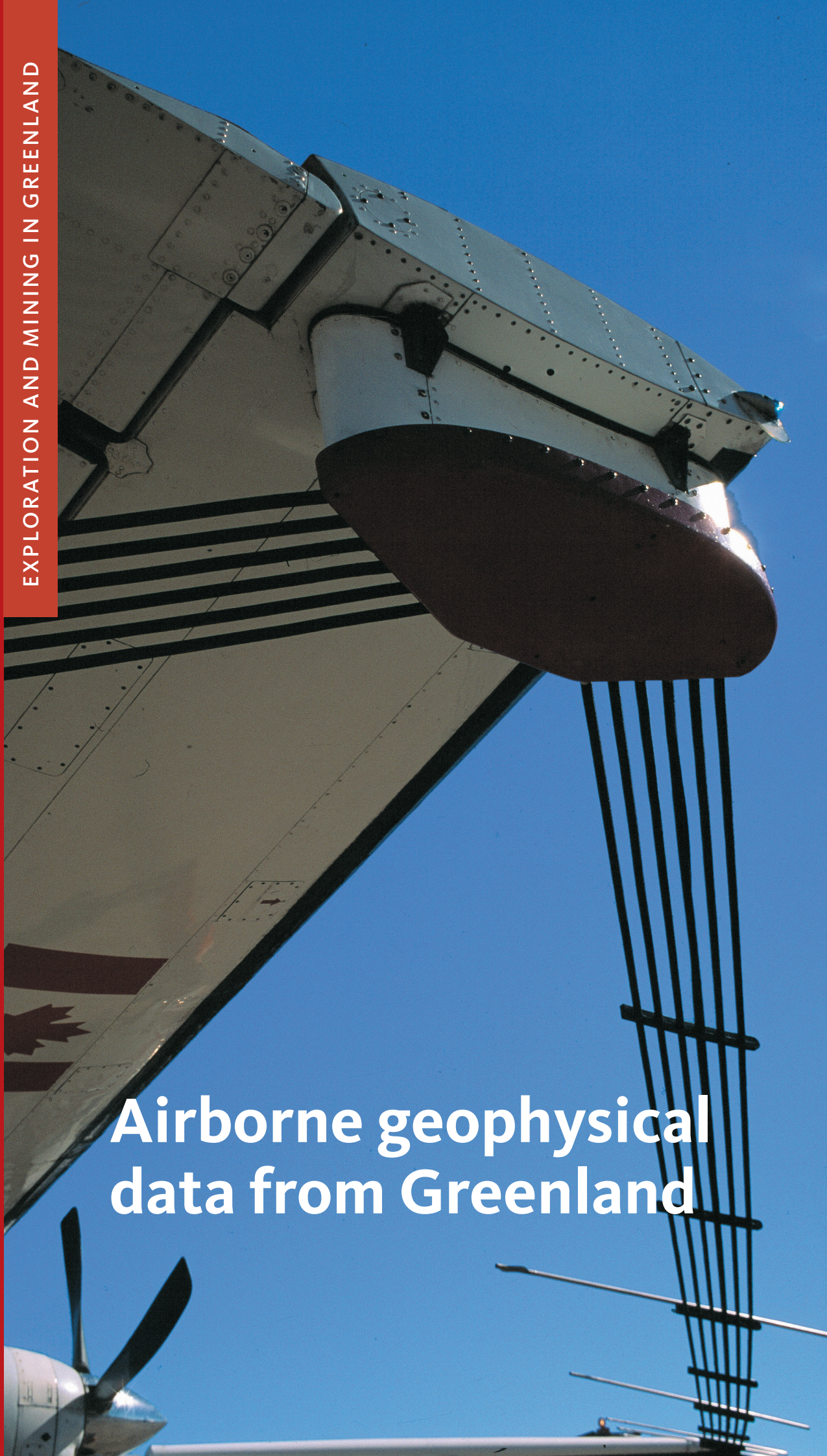
GEOLOGY AND ORE

EXPLORATION AND MINING IN GREENLAND



Airborne geophysical data from Greenland

Airborne geophysical data from Greenland

This issue of Geology and Ore provides a 2024 update on the airborne geophysical and remote sensing surveys from Greenland, previously presented in Geology and Ore no. 22 in 2013.

During the last decade, a series of local hyperspectral surveys and one regional magnetic survey have been acquired on behalf of GEUS and the Greenlandic government as well as many license-specific geophysical datasets from the mineral exploration industry has been released.

Geophysical data is a major source of information on the structure and composition of the Earth. New technological developments with respect to all data acquisition, processing, and interpretation place geophysics as an important key to improved mapping and understanding of the Earth's structures.

Airborne geophysical surveying is a particular efficient tool for systematic investigations of large areas as is the case in Greenland.

Easy access to geophysical data is recognised as being of utmost importance to provide potential users with an overview of publicly available datasets as well as to use these data and reports for their exploration and research activities. In fulfilling this for Greenland, a newly established web-based solution gives access to information and data from both newly acquired surveys and legacy data from older surveys, and presents overview images of airborne geophysical data compilations.

Introduction

Today, the use of airborne geophysical surveys as a fundamental tool in mineral exploration and regional geological mapping has become standard practice. However, Greenland's remoteness, lack of infrastructure, and arctic and alpine conditions make geophysical data acquisition more challenging and expensive than in most other regions, and not all areas have been systematic surveyed yet. The southern, western, and southeastern parts of the ice-free area are now well-covered by regional high-resolution magnetic surveys, but large parts of the northern and northeastern parts still lack systematic regional geophysical surveys of any kind, and future surveying activities are required to fill these gaps. Despite the lack of regional background data, rising exploration activity in the past two decades has led to a large increase of more detailed license specific geophysical datasets and many areas prospective for mineral deposits are well-covered not only with magnetic, but often also electromagnetic, gravity or radiometry data.

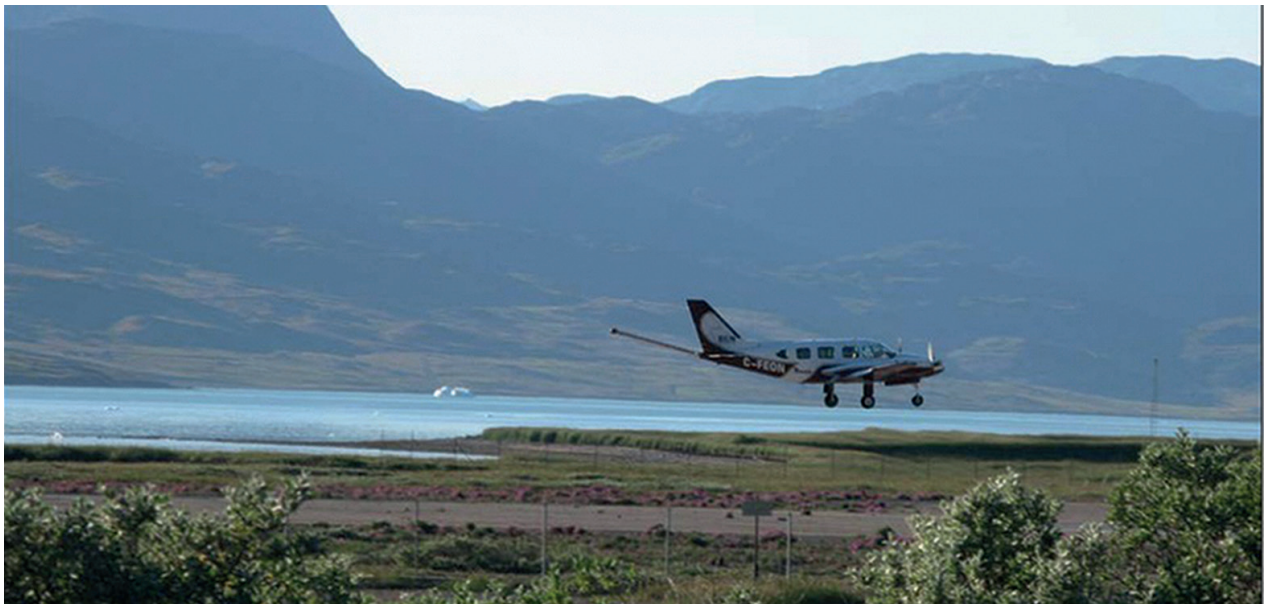
In addition to the classical geophysical methods, hyperspectral imaging techniques have great potential for mapping Greenland's geology due to the excellent rock exposure.

In the early 2000s airborne hyperspectral surveys were introduced and since then several areas have been surveyed by the Geological Survey of Denmark and Greenland – GEUS and on behalf of the Government of Greenland.

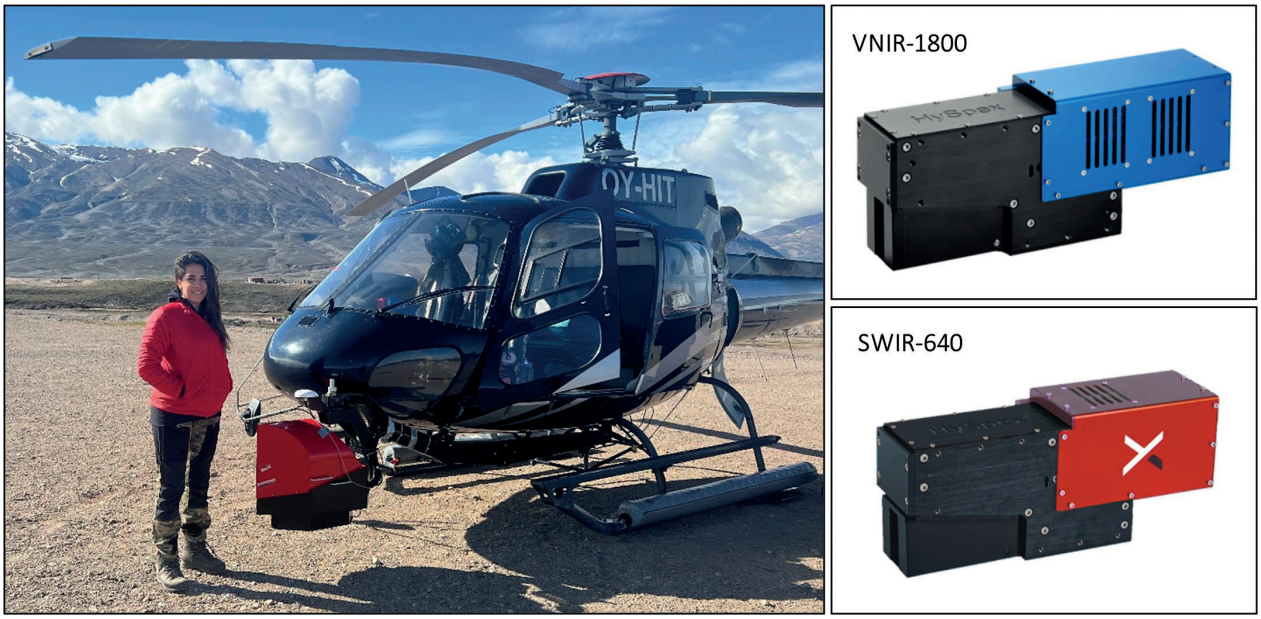
The majority of this data is now publicly available and accessible via the Greenland Mineral Resources Portal at no cost.

History of modern airborne geophysical surveying

In the early nineties the Government of Greenland was seeking new ways to stimulate mineral exploration in Greenland. Among other initiatives, a five-year program, AEM Greenland 1994-1998, of airborne combined electromagnetic and magnetic surveying was proposed. The survey areas were chosen based on the potential for the discovery of economic mineral deposits and to demonstrate the general applicability of airborne methods in the various terrains in Greenland. Simultaneously with the AEM programs, another airborne project, AEROMAG, was soon after started and financed by the authorities, producing a regional coverage of high-quality aeromagnetic data. Management of the publicly funded airborne program, the handling and interpretation of the data were performed by GEUS, while the surveys were flown by commercial



Magnetic surveying. Piper Navajo PA-31 aircraft during take-off from Narsarsuaq Airport, 2012.



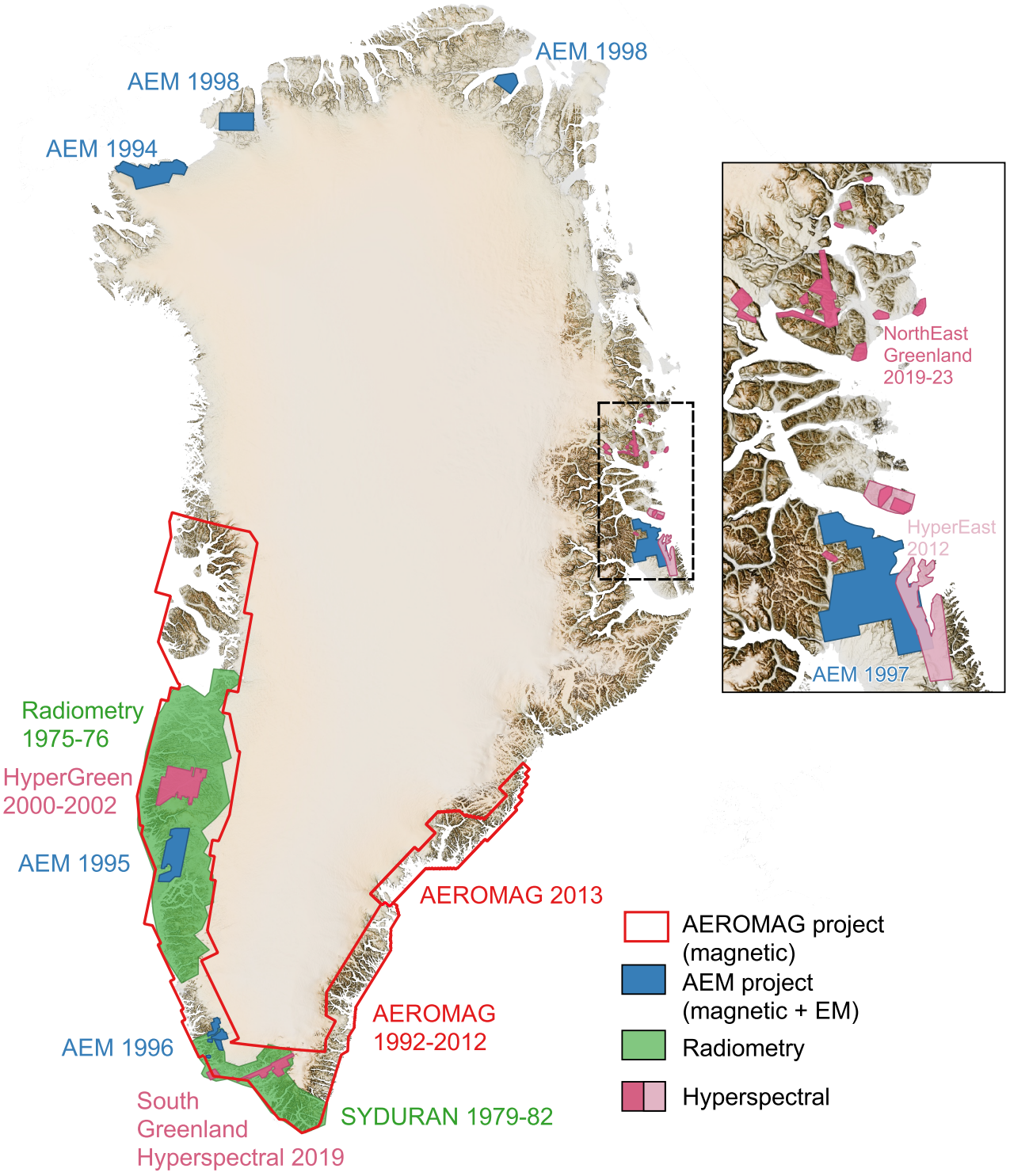
GEUS helicopter-borne hyperspectral survey system. Two HySpex pushbroom scanners operating in the VNIR and SWIR range are mounted on the helicopter allowing both nadir and oblique data acquisition.

geophysical contractors after international tender. In the past decade the surveying activities of GEUS and the Government of Greenland have primarily focussed on acquiring local hyperspectral datasets and applying advanced techniques to integrate these data with 3D topography models from stereo photogrammetry. The areas of all these regional surveys are presented on page 4.

Prospecting companies have frequently utilized airborne geophysical surveying in the search for mineralisations in Greenland in the past decades, and there is a trend towards multi-sensor airborne surveys and use of modern methods as time-domain electro-magnetic and to a lesser extent gravity gradiometry. Many of these surveys are made publicly available for free from the data portal – Greenland Mineral Resources Portal (www.greenmin.gl). The locations of these surveys are shown on the overview maps on pages 7 and 8.

The regional Aeromag surveys

The AEROMAG projects encompassed high-resolution magnetic surveys conducted in 1992, in each of the years from 1995 to 1999, in 2001, 2012 and 2013, producing a total of approximately 633 000 line-kilometres and covering an area of more than 303 000 km^2. The term “high-resolution” applies here to dense sampling along flight lines. The magnetic map obtained from the 2013 survey can be seen on page 5.



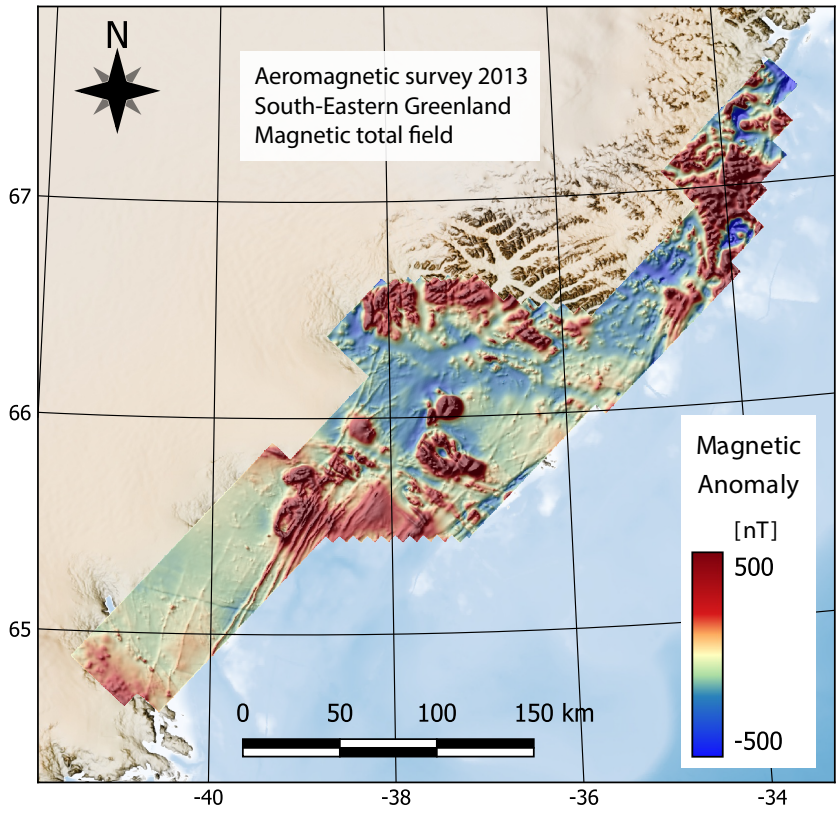
Areas of airborne geophysical and hyperspectral surveys acquired on behalf of GGU/GEUS and the Ministry of Mineral Resources of Greenland.

The AEROMAG surveys provides high quality, high-resolution magnetic data for the total ice-free area of West and Southeast Greenland from the Svartenhuk Halvø in West Greenland and southward and up to just north of Kap Gustav Holm on the south-eastern coast (see page 4).

The AEROMAG surveys were acquired by flying fixed-wing aircrafts (figure at the top of page 3) along a gently draped surface 300 m above the ground and sea level. Rough topography in many areas places some limitations with respect to satisfying a general wish to minimise terrain clearance. Survey lines are with a separation of 500 – 1000 m and tie-lines flown with a separation of 5000 m. Total magnetic field data were recorded with a sampling rate of 0.1 sec, corresponding to a sample distance of 7 m. Aircraft positional data from simultaneous differential GPS measurements were recorded every 1 sec, as well as aircraft altitude was obtained from barometric altimeter and radar recorded every 0.1 sec.

The AEM Greenland surveys

The AEM Greenland detailed surveys with combined electromagnetic and magnetic measurements were carried out in six selected areas of expected high mineral potential. In total, 65 000 line-km covering an area of 23 000 km² were measured in the project. The AEM surveys included either time-domain electromagnetic data (GEOTEM) or a combination of multi-coil frequency domain, radiometric and VLF-data, but magnetic total field measurements were conducted for all surveyed areas. The surveys cover various geological terrains in different regions of Greenland (see page 4).



Magnetic total field data from the regional aeromagnetic survey in 2013 in South-Eastern Greenland.

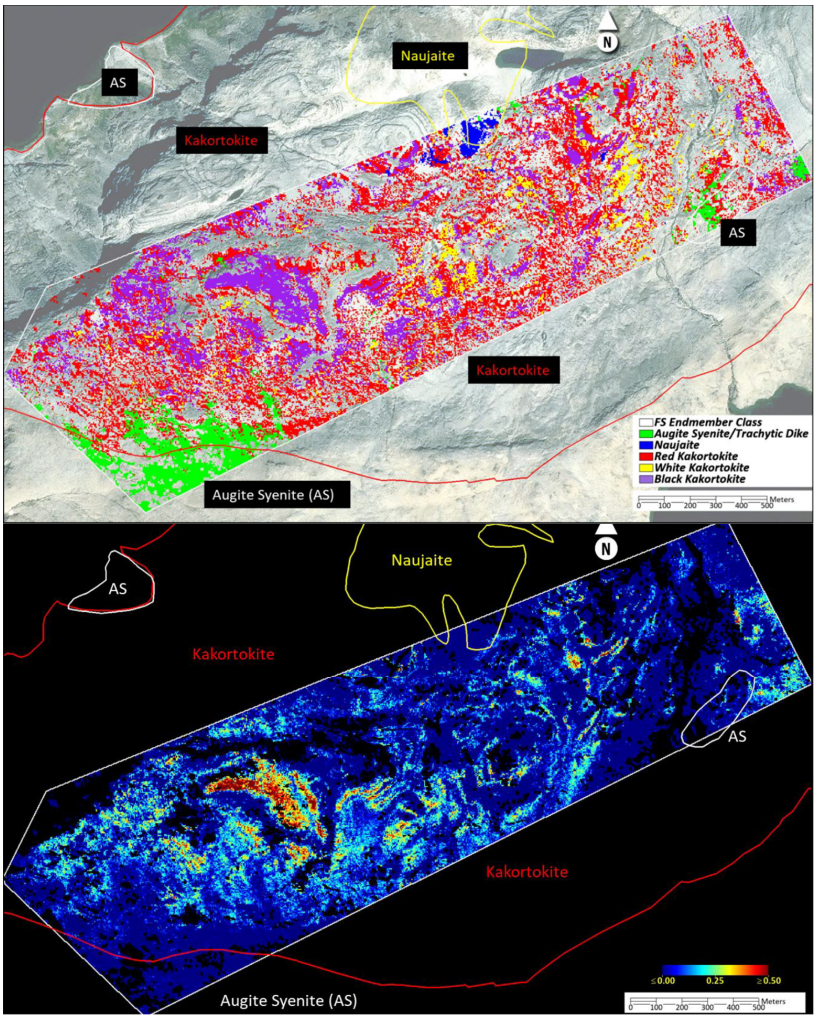
The airborne hyperspectral surveys

Hyperspectral remote sensing techniques offer an efficient means for swiftly collecting data that aids in geological mapping and mineral exploration. Depending on their spatial and spectral resolution, hyperspectral surveys provide opportunities ranging from reconnaissance to detailed studies.

In 2012, the HyperEast 2012 survey was conducted over central East Greenland (see page 4) by the NERC Airborne Research & Survey Facility. The survey was conducted using a Dornier 228-101 research aircraft equipped with Specim AISA Eagle and AISA Hawk sensors, along with a Leica ALS50-II LiDAR and a Leica RCD105 39 mega-pixel camera. The hyperspectral data captured by the hyperspectral sensors have a spatial resolution of 2 meters and encompass 486 spectral bands ranging from 400 to 2500 nm with bandwidths of 3 and 6 nm, respectively.

In 2019, the Government of Greenland and U.S. Department of State collaborated to acquire hyperspectral data over nearly 3000 km² of the Gardar Province in South-west Greenland (see page 6). This data was collected from a fixed-wing platform equipped with three hyperspectral sensors, each with varying spectral ranges: a SpecTIR ASIA DUAL (400-2500 nm), an ITRES CASI 1500 (400-1000 nm) and a Surface Optics SWIR 1700 (950-1700 nm). The U.S. Naval Research Laboratory oversaw the data acquisition and pre-processing, while ASL Environmental Sciences Inc. was tasked with data processing and mineral map generation (results shown on figure on page 6).

In the same year, helicopter-borne hyperspectral data acquisition was undertaken as part of the Clavering Ø project in Northeast Greenland. The primary goal was to test the feasibility of using helicopters as a platform to capture high-resolution spectral and spatial data, aiding geological mapping efforts in Arctic regions with



Top figure shows a classification map of the Gardar Province, based on full spectrum spectral mixture analysis. Used endmembers are associated with an augite syenite/trachytic dike, naujaite, red kakortokite and white kakortokite and black kakortokite. Lower figure shows an unmixing fraction of the above full spectrum data displaying the spatial distribution of black kakortokite variant. Figures are taken from the report of ASL Environmental Sciences (2020).

challenging accessibility. Various surveys were conducted including both nadir and oblique acquisitions.

A pushbroom HySpex Mjolnir VS-620 hyperspectral scanner was deployed covering the full wavelength range from 400 to 2500 nm. It featured a sampling interval of 3 nm in VNIR and 5.1 nm in SWIR resulting in 490 discrete bands and a spatial height of 620 pixels. The system was mounted on a bracket allowing for seamless transition between nadir and side-looking angles to capture data from cliffs.

After the inaugural use of a helicopter for hyperspectral data acquisition in Greenland, the system underwent modifications. This included integrating two new pushbroom hyperspectral systems —HySpex VNIR-1800 (400-1000 nm) and HySpex SWIR-640 (960-2500 nm)— and redesigning the bracket with adjustable angles of 30, 60, and 90 degrees to facilitate various nadir and oblique data acquisition setups (see page 3). From 2022, the Ministry of Mineral Resources and GEUS continued hyperspectral data acquisition in Northeast Greenland using a Eurocopter AS350 helicopter platform (bottom figure on page 3).

In 2019, four areas encompassing Clavering Ø and Wollaston Forland were surveyed in Northeast Greenland. Subsequently, the 2022 survey expanded to six areas that cover a total of 4000 km² and include Malmbjerg, Strindberg Land, Hudson Land, and the southeastern part of Kap Simpson. In 2023, five areas spanning more than 2200 km² were targeted, with surveys conducted over Hudson Land, Gauss Halvø and Hold with Hope.

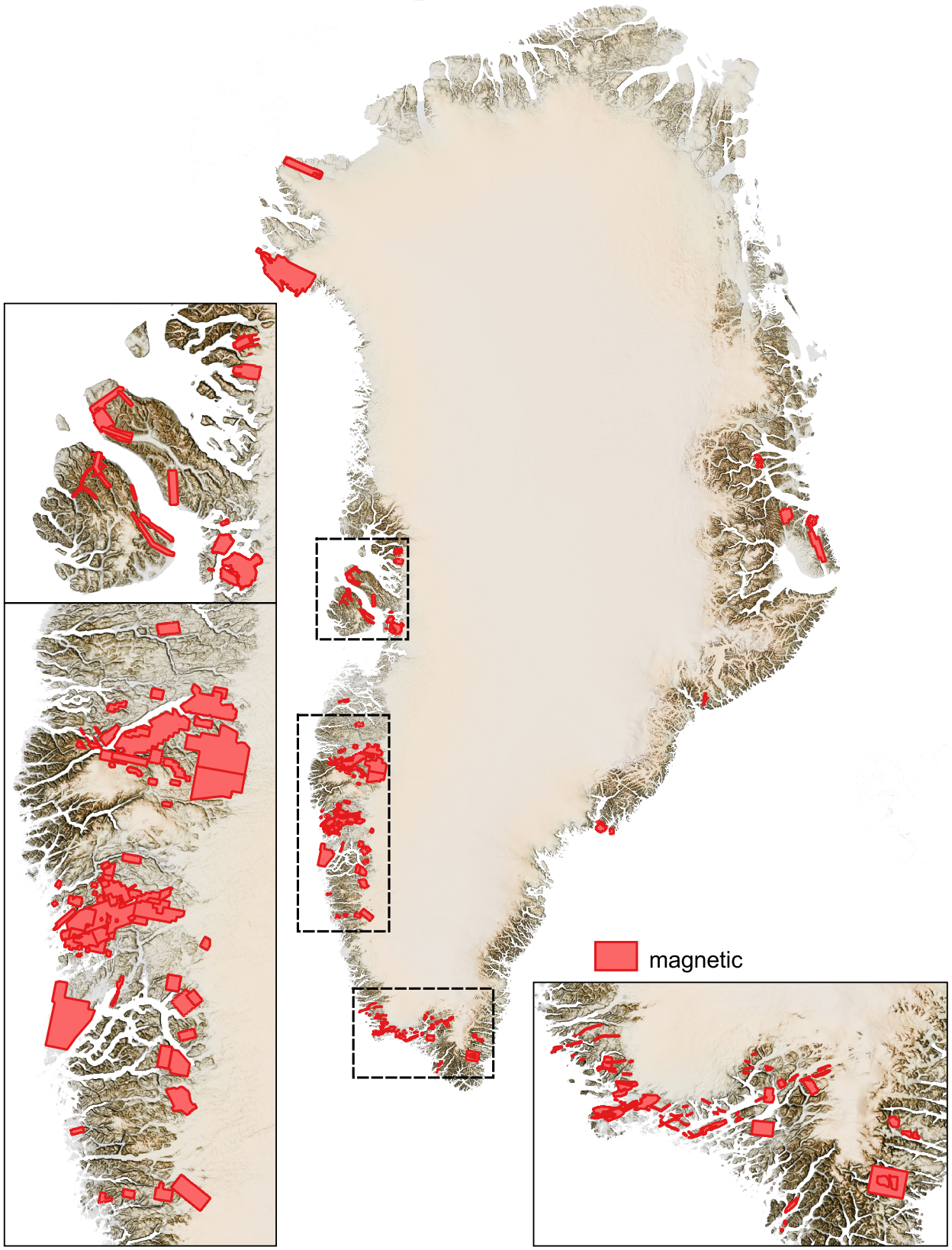
The aeroradiometric surveys

Aeroradiometric data (acquired as gamma ray spectrometry measurements) have been used since the early 1970s to quantify and describe the content of the naturally occurring radioactive elements uranium, thorium, and potassium in rocks in Greenland. The main part of the gamma-ray signal originates in the upper 20–25 cm of surficial rock materials, and therefore the method is primarily used as a tool for geological mapping. Different types of contour maps and combinations of channel ratios are used for the interpretation of geological features.

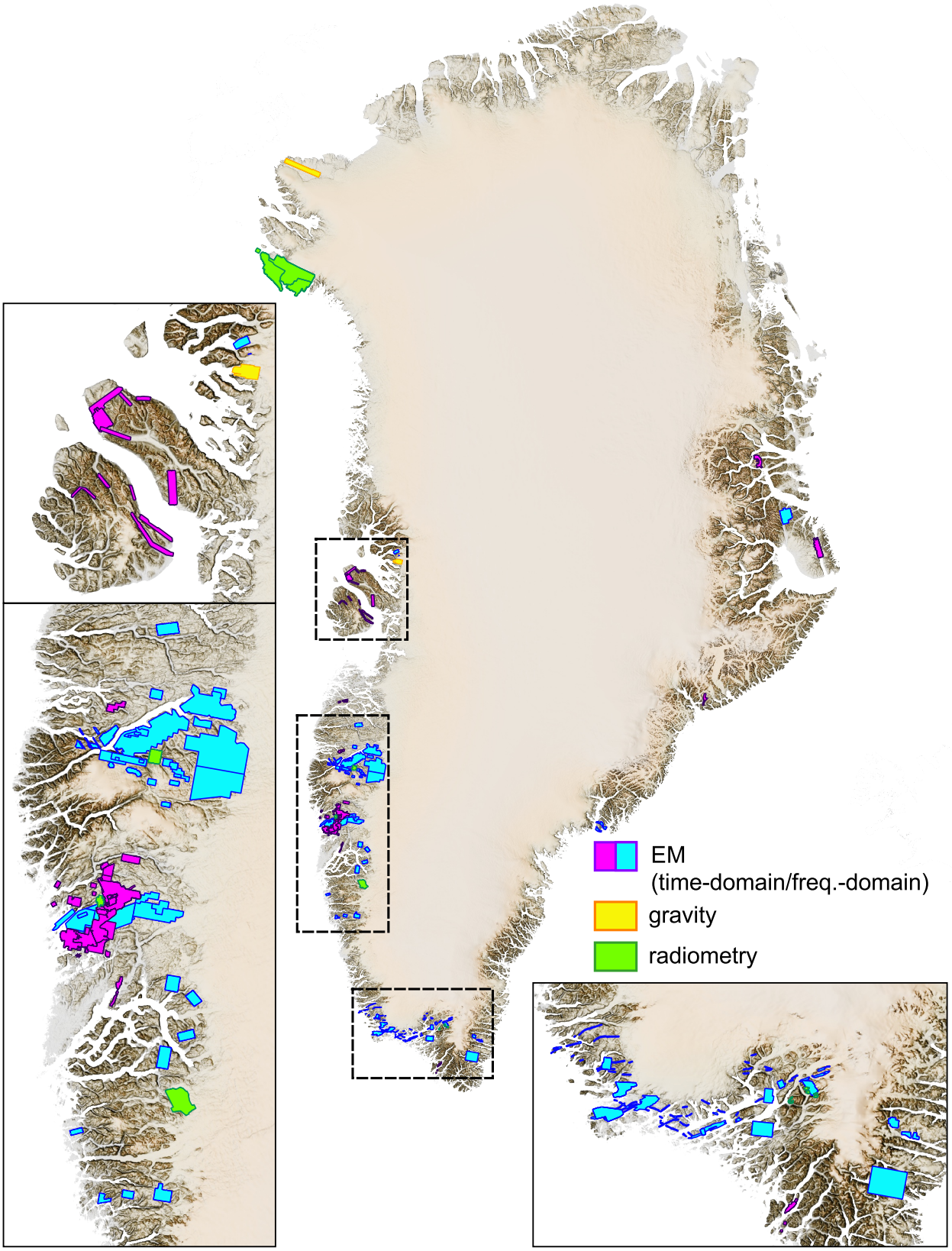
Since regional radiometry data in Greenland were acquired along contour lines following the valleys and fjords, data coverage of these surveys is relatively sparse.

Released license specific surveys

During the last decade, a rise in exploration activity has led to an increase acquisition of license-specific geophysical data. These surveys are typically aimed at mapping deposit scale targets and their areal extents are typically small but have dense line spacing and shallow altitudes resulting in high-resolution data. In early decades, primarily magnetic, radiometry and frequency-domain electromagnetic data were acquired, but in the last decade modern time-domain electromagnetic methods have become common. South Greenland, Disko-Nuussuaq and the regions around Kangerlussuaq and Maniitsoq in West Greenland are



Areas of airborne magnetic surveys that were acquired in licenses of the mineral exploration industry. Only datasets are presented, whose data are freely available on the Greenland Mineral Resources Portal.



Areas of airborne electromagnetic, gravity and radiometry surveys that were acquired in licenses of the mineral exploration industry. Only datasets are presented, whose data are freely available on the Greenland Mineral Resources Portal

Airborne method	Nr. of survey blocks
Magnetic	170
Electromagnetic - Frequency domain - Time-domain	 72 57*
Gravity	2**
Radiometry	6***

* Two of the blocks in Central West Greenland were surveyed with the ZTEM method.
** One block across the Black Angel Mine, Central West Greenland, was surveyed with the full-tensor gravity gradiometry (FTG) method.
*** Additional 5 blocks were gathered on behalf of GGU, the former Geological Survey of Greenland, at Motzfeldt, South Greenland, in 1981

Number of survey blocks from the different airborne geophysical methods that were acquired on behalf of the mineral exploration holders. Only released datasets are listed, whose datasets are publicly accessible on the Greenland Mineral Resources Portal (status: April 2024).

particularly well-covered with license-specific surveys (see page 7 and 8).

The geophysical datasets acquired on behalf of the license holders are submitted together with the annual exploration activity reports to the Ministry of Mineral Resources. These datasets are stored in the databases of GEUS and the Ministry and are made publicly available on the Greenland Mineral Resources Portal once the reports and datasets lose their confidentiality.

A new magnetic compilation

GEUS works in corporation with Kiel University, Germany, on building a new magnetic compilation that incorporates airborne data from the AEROMAG and AEM surveys as well as other regional airborne offshore datasets and data acquired over the Inland ice sheet. The compilation is developed by using modern modelling techniques (equivalent source modelling) that benefits from high-quality data integration of the different datasets. The current version of the compilation covers an area from Maniitsoq in the west and Kulusuk in the east and southward and is presented on a fine 700 x 700 m grid. The compilation can be viewed on the Greenland Mineral Resources Portal (see page 10 bottom right).

The Greenland Mineral Resources Portal

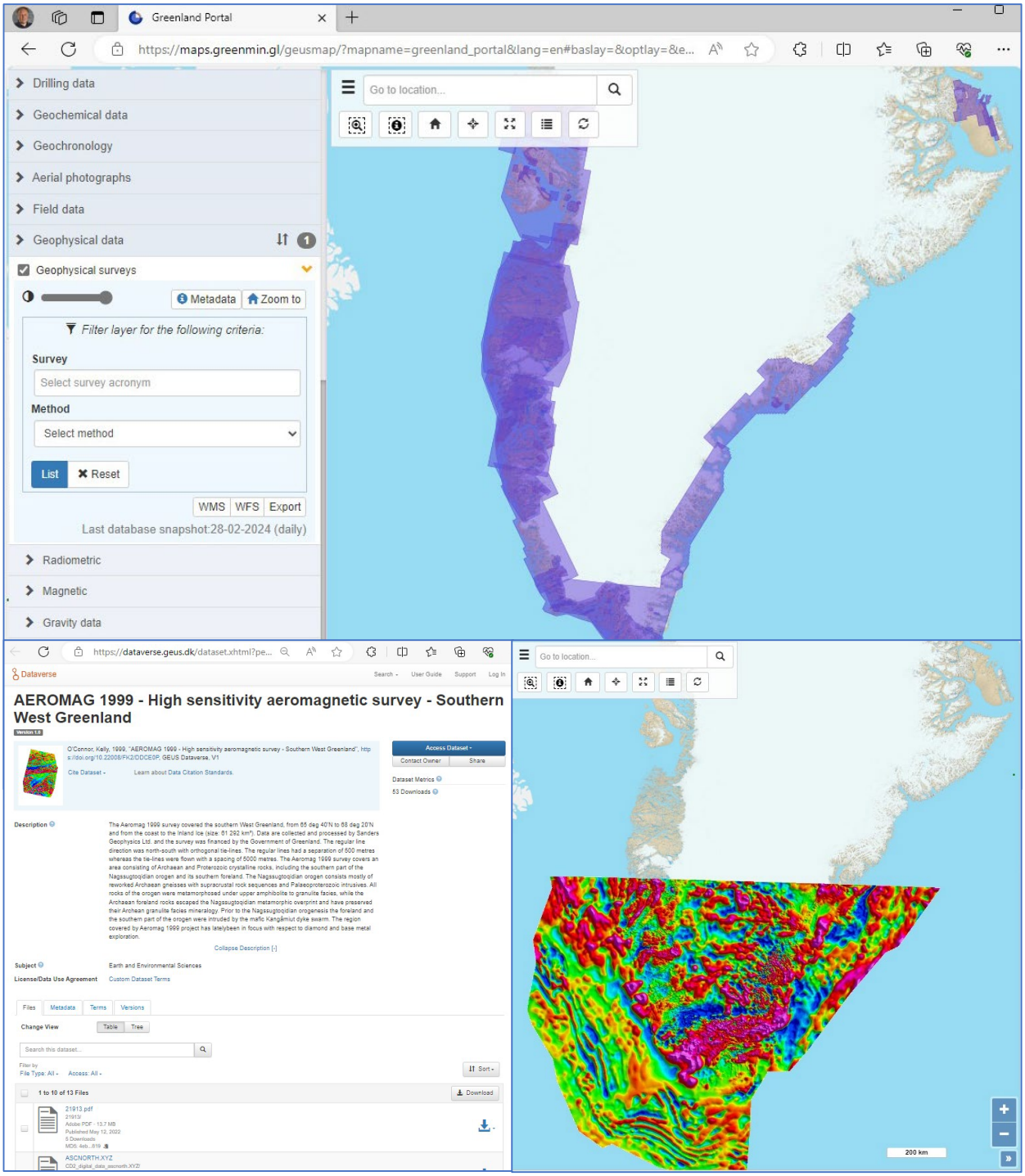
The Greenland Mineral Resources Portal (www.greenmin.gl) makes airborne geophysical surveys acquired by GEUS, the Government of Greenland or the mineral exploration industry available for free (see page 10). The portal includes an interactive map functionality that allows to view the geographical extent of the geophysical surveys and gives access to images of parameter maps and extensive metadata information. From the portal data packages of individual surveys can be downloaded and maps can be linked to a standalone GIS application using WFS and WMS map services.

In addition, physical background maps from different geophysical compilations are accessible on the portal that can be joint visualized with other available geoscience data as e.g., geological or topographical maps, geochemical and rock sample information, or locations of mineral occurrences for an online interpretation. They include e.g. the magnetic anomaly maps from the AEROMAG project and the magnetic compilation of South Greenland, a combined free-air and Bouguer gravity anomaly map of Greenland from the Danish Technical University and several band-ratios mineral index maps from multispectral ASTER satellite data.

Closing remarks

The publicly funded geophysical surveys in Greenland are intended to provide the industry and the geoscientific community with data relevant for exploration for mineral resources. The hyperspectral and geophysical survey programs now comprise more than 800 000 line-kilometers of high-quality measurements of airborne geophysical data.

The airborne geophysical data acquired in Greenland represents international best practice and is comparable with data furnished for regional exploration and mapping by other geological surveys. They are used extensively by the exploration industry and will continue to be valuable for years to come. High-resolution geophysical data are an investment for the future and the industry expects easy access to high-quality geophysical data as these are seen as an essential tool for an effective exploration effort. The Ministry of Mineral Resources and GEUS have therefore made an effort to allow for easy access to geophysical data, both in terms of cost and distribution.



The web map of the Greenland Mineral Resources Portal. The dark blue polygons outline the areas of geophysical datasets, whose data are downloadable free of charge. Bottom left: A data example on the GEUS Dataverse download platform. Bottom right: The total magnetic anomaly map of a new compilation of South Greenland is one of the geophysical background maps that is available on the Greenland Mineral Resources Portal.

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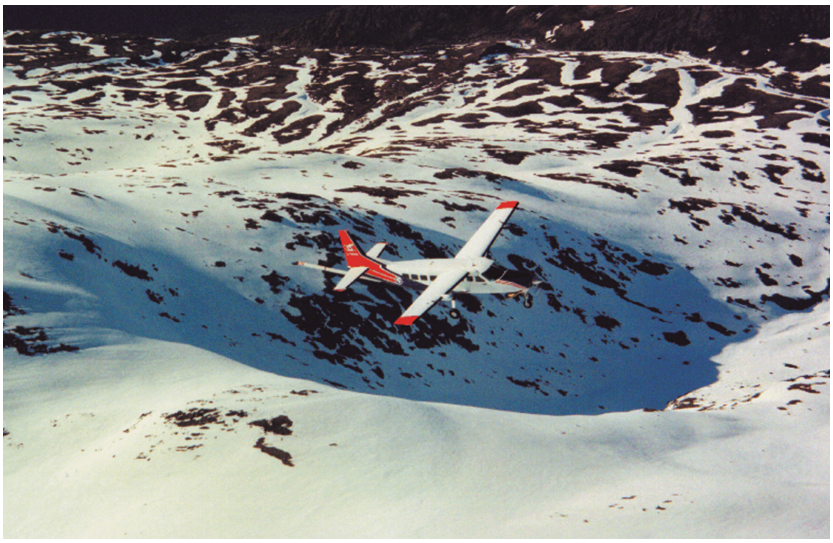

Cessna Grand Caravan from Sander Geophysics Ltd. with tail mounted magnetometer traverses snow-covered terrain at the Nuussuaq peninsula in central West Greenland, Aeromag 1997.

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Front cover photograph
Close up of the electromagnetic transmitter loop fixed to the wings of the Geoterrrex Ltd. Casa aircraft. Thule Airbase 1994.
Photo: Jakob Lautrup, GEUS.

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