Projects *MINEO* and *HyperGreen*: airborne hyperspectral data acquisition in East Greenland for environmental monitoring and mineral exploration

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In remote sensing terminology the word 'hyperspectral' is used to distinguish sensors with several tens or hundreds of bands from the traditional 'multispectral' sensors such as Landsat TM or Landsat MSS. The success of hyperspectral techniques relies on the detection of subtle variations in the spectral properties of one or more of the components being imaged. The advances of worldwide research and development in sensor technology to achieve higher signal to noise ratios, good operational stability and improved levels of spectral and radiometric calibration have provided the instrumental basis for the deployment of this advanced technique to a number of earth resource and environmental mapping and monitoring tasks. The analysis and interpretation of hyperspectral data are extensively based on the use of spectral libraries covering a wide range of inorganic and organic natural materials and comparison of data between different areas and sensor systems.

Airborne hyperspectral data acquisition in Greenland in the summer of 2000 was carried out as part of the project *MINEO* (monitoring the environmental impact of mining activities in Europe using advanced observation techniques). This is a collaborative venture by nine European research organisations and two mining companies, with financial support from the European Community, to operate a commercial, high-quality, airborne hyperspectral scanner system (Fig. 1) for acquisition of hyperspectral data from six mining areas in Europe and Greenland (Tukiainen 2000). The area of the former lead mine in Mestersvig in central East Greenland (72°N) was selected to represent arctic environmental aspects in the *MINEO* project. The objectives of *MINEO* are to assess the application of hyperspectral techniques for pollution detection and monitoring in a wide range of mining environments.

The hyperspectral data acquisition mission in Greenland was extended to acquire data for project *HyperGreen*, a mineral exploration programme of the Geological Survey of Denmark and Greenland (GEUS), financed by the Bureau of Minerals and Petroleum, Greenland. The objectives of *HyperGreen* are to assess the applicability of high spectral resolution imaging spectroscopy as a mineral exploration tool. The *HyperGreen* project also included a target flown for the National Environmental Research Institute, Denmark (DMU). The original survey targets of project *HyperGreen* were located in West Greenland, but were cancelled due to weather constraints and the limited availability of the HyMap™ system (Cocks *et al.* 1998). Six alternative areas in central East and North-East Greenland with a variety of known mineral occurrences (Harpøth *et al.* 1986) and potential for new occurrences were therefore surveyed (Fig. 2).

Airborne hyperspectral imaging system

HyVista Corporation, Australia, was selected as the contractor for the airborne hyperspectral data acquisition. A Dornier 228 aircraft, operated by Deutsches Zentrum

Fig. 1. HyMap™ imaging spectrometer installed on a Dornier 228 aircraft.

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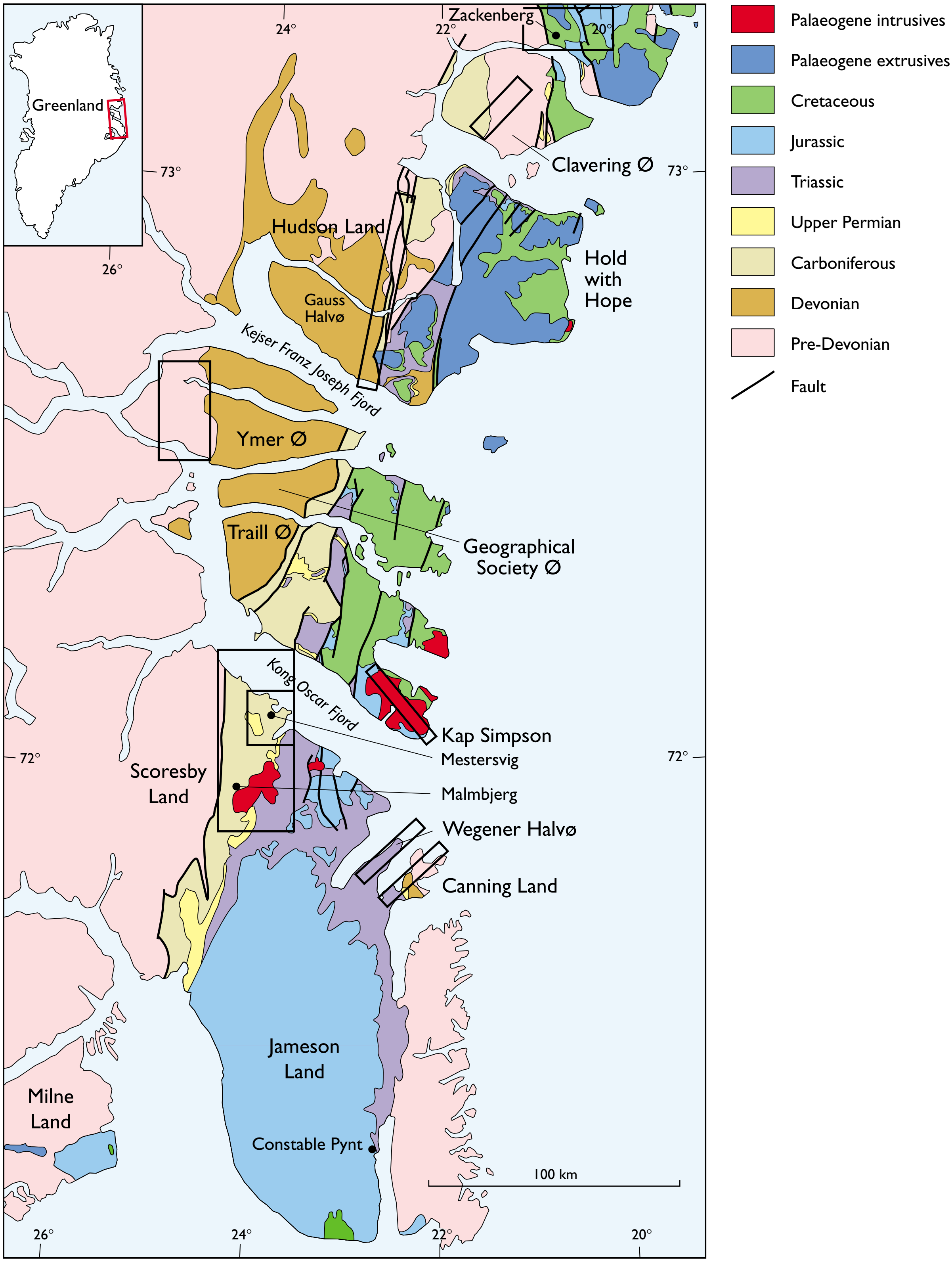


Fig. 2. Simplified geological map of central East and North-East Greenland. Modified from Stemmerik *et al.* (1997). The areas where airborne hyperspectral data were acquired are indicated by **black frames**.

Table 1. Spatial and spectral characteristics of HyMap™ sensor

Spatial configuration			
Instant field of view (IFOV)	2.5 mr along track 2.0 mr across track		
Field of view (FOV)	60 degrees (512 pixels) Swath 2.3 km at 5 m IFOV (along track) 4.6 km at 10 m IFOV (along track)		
Spectral configuration			
Module	Spectral range	Average spectral sampling interval	Number of bands
VIS	450–890 nm	16 nm	30
NIR	890–1350 nm	13 nm	32
SWIR1	1400–1800 nm	12 nm	32
SWIR2	1950–2480 nm	16 nm	32

mr = milliradian
nm = nanometre

Table 2. Summary of hyperspectral data acquisition programme in central East and North-East Greenland

Survey area	Project	Number of flight lines	Line km
Canning Land	*HyperGreen*	5	165
Mestersvig	*MINEO*	10	197
Malmbjerg	*HyperGreen*	15	695
Ymer Ø	*HyperGreen*	6	186
Hudson Land	*HyperGreen*	5	232
Clavering Ø	*HyperGreen*	1	25
Zackenberg	DMU/*HyperGreen*	12	360
Kap Simpson	*HyperGreen*	2	64

für Luft und Raumfart, e.V., Germany, provided the platform for the HyMap™ hyperspectral imaging spectrometer (Fig. 2) and a Zeiss RMK A 15/23 aerial camera; the latter was used for simultaneous aerial photography to obtain stereoscopic coverage for the production of digital terrain models.

The HyMap™ hyperspectral scanner manufactured by Integrated Spectronics Pty Ltd., Australia, has four spectrometers covering the interval from 450 to 2450 nanometres (nm), excluding the two major water absorption windows (Table 1; Cocks *et al.* 1998). The sensor operates in a 3-axis gyro-stabilised platform to minimise image distortion due to aircraft motion. The signal/noise ratio measured outside the aircraft with a sun angle of 30° and 50% reflectance standard is more than 500/1, except near the major atmospheric water absorption bands.

Geo-location (longitude, latitude and altitude) and scanner attitude (roll, pitch and true heading) data to provide the necessary information for image geo-coding were acquired with a differential GPS satellite navigation system (DGPS) and an integrated inertial monitoring unit. The scanner operations required that the three detectors for the near infrared (NIR) and shortwave infrared region (SWIR1, SWIR2) had to be cooled to 77°K using liquid nitrogen. Approximately ten litres of liquid nitrogen were consumed for each full day of data collection.

Survey areas

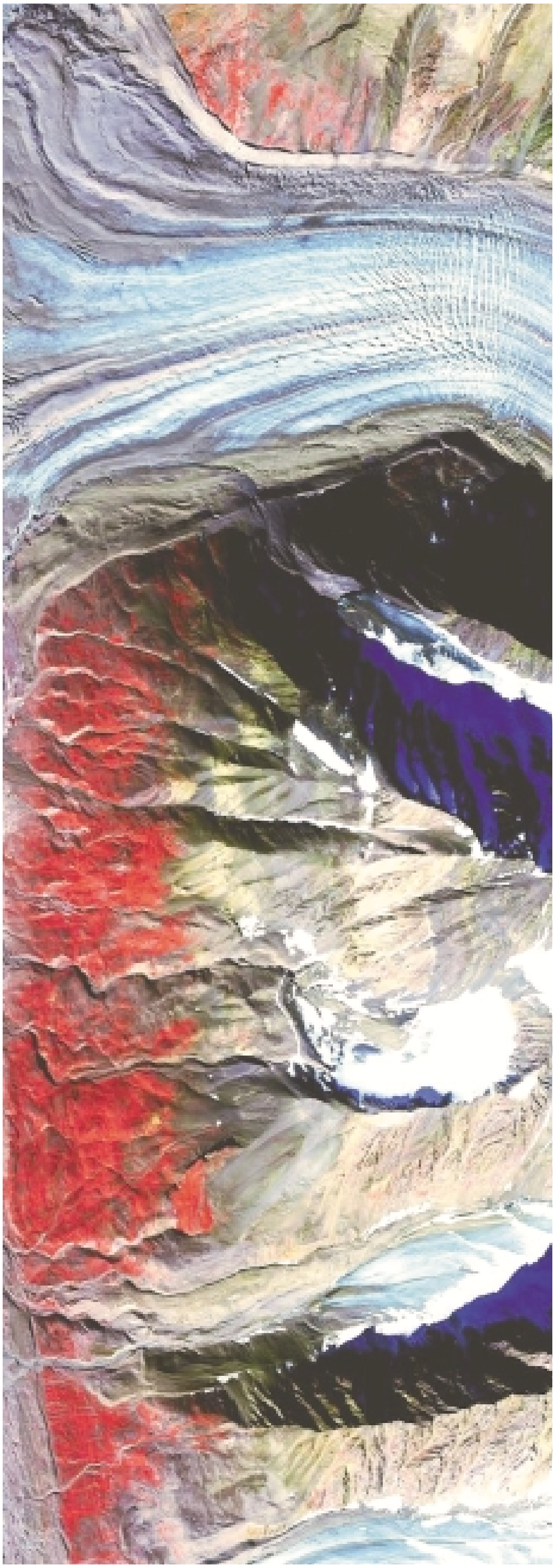
Flight operations in Greenland in 2000 commenced on 5 August and were completed on 11 August. Eight target areas reached from airfields at Mestersvig and Constable Pynt (Fig. 2; Table 2) were surveyed with the following survey specifications:

IFOV ('pixel size')	5 m
Overlap per line	20%
Approximate ground speed	150 knots (277 km/h)

For the HyMap™ instrument the instant field of view (IFOV) of 5 m corresponds to a flight altitude of 2500 m (8200 ft) at which the scanner's swath width (the area to be imaged across the flight track) is approximately 2.3 km (Fig. 3). For the more mountainous areas, the flight altitude was determined from the local topographic baselevel.

Data processing and analysis

By the end of the year 2000 the contractor had delivered flight line radiance data ('at sensor radiance'), spectral and radiometric calibration data for the HyMap™ sensor and the geo-location and scanner attitude data. The data will be subjected to atmospheric and geometric corrections to provide the basis for detailed analysis. The final processing of the data to extract spectral end members ('mineral mapping', vegetation types and vegetation stress) and map their locations and abundances will be based on advanced algorithms developed for the analysis of hyperspectral data (Goetz *et al.* 1985; Boardman & Kruse 1994).



The large volume and complexity of the data generated by the hyperspectral sensors mean that the classification techniques to analyse the multispectral data, based on euclidean distance between groups of data (classes), are computationally cumbersome. A variety of interpretation techniques have therefore been developed in the last ten years. The most popular of these is the selection of 'end members' from hyperspectral data. This technique is based on the assumption that the imagery is composed of mixed pixels ('mixels'), each pixel resulting from an integrated measurement over a multicomponent pixel to form a composite spectrum. A composite spectrum is formed by linear combinations of individual spectra ('pure' or single component spectra). The extraction of spectral end members will be undertaken using a variety of 'spectral unmixing' algorithms.

Conclusions and outline of future work

High-quality airborne hyperspectral data totalling 1924 line km were acquired from eight localities in central East and North-East Greenland, using an advanced hyperspectral imaging spectrometer with 126 narrow bands covering the spectral range from 450 nm to 2480 nm. The hyperspectral data will be used to assess the application of hyperspectral techniques to environmental monitoring and mineral exploration.

Field follow-up will be carried out for both *MINEO* and *HyperGreen* projects in the summer of 2001, and will be concentrated on selected areas considered representative for the assessment of the objectives of the two projects.

An international team from the *MINEO* consortium will undertake follow-up and baseline studies on environmental indications emerging from the processing of the *MINEO* data by GEUS and the *MINEO* partners. The final results and conclusions will be included in the final report of the *MINEO* project which is planned for the end of 2002.

Fig. 3. False colour 'quicklook' of HyMap^{TM} data from a flight line at the west edge of the Mestersvig survey block. The striped lithologies are sediments of the Neoproterozoic Eleonore Bay Supergroup. Bright red colours are vegetation-rich areas. The N–S strip (top to bottom) covered by the flight line is about 2.3 km wide.

For the *HyperGreen* project, the known mineral occurrences, some associated with spectacular hydrothermal alteration hosted by a wide range of igneous and sedimentary lithologies (e.g. Malmbjerg molybdenum deposit, Fig. 2), will provide a good reference base for the evaluation and assessment of hyperspectral data processing techniques in mineral exploration and geological mapping in arctic environments.

It is expected that the statistical treatment of the *HyperGreen* data by GEUS will locate new targets with mineralogical characteristics (in terms of specific rock alteration phenomena or direct detection of ore minerals) related to the presence of potentially economically interesting mineral occurrences.

In order to assess the discriminative power of this novel technique, follow-up ground spectroradiometric measurements will be carried out on known and new targets. These will be chosen to represent a wide range of mineralisation types and rock lithologies. The results of this work are expected to be available during 2002.

References

Boardman, J.W. & Kruse, F.A. 1994: Automated spectral analysis: a geological example using AVIRIS data, northern Grapeville Mountains, Nevada. Tenth Thematic conference, Geological Remote Sensing, 9–12 May 1994, San Antonio, Texas, Environmental Research Institute of Michigan (ERIM), Ann Arbor, MI. Proceedings, 407 p. & 418 p.

Cocks, T., Jenssen, R., Stewart, A., Wilson, I. & Shields, T. 1998: The HyMap™ airborne hyperspectral sensor: the system, calibration and performance, 7 pp. Unpublished report, Integrated Spectronics Pty Ltd, Baulkham Hills, NSW, Australia.

Goetz, A.F.H., Vane, G., Solomon, J.E. & Rock, B.N. 1985: Imaging spectrometry for earth remote sensing. Science **228**, 1147–1153.

Harpøth, O., Pedersen, J.L., Schønwandt, H.K. & Thomassen, B. 1986: The mineral occurrences of central East Greenland. Meddelelser om Grønland Geoscience **17**, 139 pp.

Stemmerik, L., Clausen, O.R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. Geology of Greenland Survey Bulletin **176**, 29–38.

Tukiainen, T. 2000: Assessing and monitoring the environmental impact of mining activities in Europe using advanced Earth observation techniques. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/104**, 24 pp.

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