Polarforschung 69, 25 – 33, 1999 (erschienen 2001)

First Highlights from NOGRAM'98 - Northern Gravity, Radio Echo Sounding and Magnetics

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THEME 2: Aerogeophysics of the Eurasian Shelves: Signatures and Interpretations

Summary: The outline and realization of the airborne survey NOGRAM'98 is presented. Three target areas were covered: (i) northern Fram Strait (aeromagnetics and aerogravity), (ii) northeast Greenland and Morris Jesup Rise (aeromagnetics, partly aerogravity) and (iii) the ice sheet south of Station Nord (radio echo sounding, aeromagnetics, partly aerogravity). Whereas northeast Greenland and the Morris Jesup Rise were flown with a line spacing of 3 km to record the spatial magnetic variations in detail, the two other surveys were flown with a line spacing of about 24 km for geophysical reconaissance. First aeromagnetic data compilations from the area of the Morris Jesup Rise and onshore northeast Greenland are shown. Three profiles covering airborne radio echo sounding and aeromagnetic data from northern Kong Frederik VIII Land are discussed as data examples in more detail.

INTRODUCTION

NOGRAM'98 was the first joint airborne geoscientific research initiative of the Alfred Wegener Institute (AWI) and the Federal Institute for Geosciences and Natural Resources (BGR) in the Arctic. Three major survey areas were defined: the northern Fram Strait, the western Morris Jesup Rise and the northeastern Greenlandic ice cap of northern Kong Frederik VIII Land. The main focus of the collaboration of both institutes was a dense aeromagnetic and gravity profile pattern over the western Morris Jesup Rise. This grid connects as an extension to the easternmost flight area of the German-Canadian PMAP (Polar Margin Aeromagnetic Program) project.

The western flank of the Morris Jesup Rise represents the eastern boundary of the Lincoln Sea. In its continental coastal region a series of dyke and graben structures, roughly parallel to the coastlines, can be followed through northern Greenland. Structures similar in trend and size, visible as high frequency patterns in the PMAP aeromagnetics maps (DAMASKE et al. 1997), are observed on the marine shelf area. Does the Morris Jesup Rise interrupt or terminate these structures and how far south does it reach into the shelf region? Can some of the rare coastal local geology of volcanic origin (i.e. at Kap Washington) be connected to the Morris Jesup Rise? Are there any magnetic lineations overprinted by the Morris Jesup Rise? Can any time constraints be derived from the aeromagnetic data to give some important clues how the complicated setting between Ellesmere Island, northern Greenland and the Fram Basin developed? These questions are connected with the geotectonic puzzle of northern Greenland and the adjacent Arctic Basin and might be answered to a large extent by dense aeromagnetic and aerogravity data sets.

Some large parts of the Arctic puzzle meet each other in one particular area: the northern Fram Strait. Here, the narrow Wandel Sea margin meets the Gakkel Ridge and the Lena Trough. More to the east, the Spitsbergen Fracture Zone and the Yermak Plateau (as a conjugate structure to the Morris Jesup Rise) are connected to them. This remarkable collection of prominent tectonic structures closely grouped together closely is of great interest by itself, but of even higher importance to a thorough investigation because the Gakkel Ridge is a still active midoceanic ridge (KRISTOFFERSEN et al. 1982) and the Lena Trough might be one as well. Therefore, a first step towards a regular flight pattern between Spitsbergen and northern Greenland was taken within the NOGRAM'98 survey and will be continued in future field seasons.

One of the major geological features of northeast Greenland is the Caledonian fold belt. It was mapped throughout the AEROMAG surveys between 1993 and 1996 by AWI aeromagnetics (SCHLINDWEIN 1998). Still missing was a data set that showed its subglacial structure and how it connects to the craton west of it. To get this information and also to collect glaciological knowledge about the ice transport into the Nioghalvfjerdsfjorden Glacier (79.5 °-Glacier) and the Zacharias Glacier a radio echo sounding (RES) survey was carried out.

The NOGRAM'98 flight profiles for all three parts of the survey are shown in Figure 1. This paper discusses some of the first results of the NOGRAM'98 field season. The focus is set on aeromagnetics over the Morris Jesup Rise and aeromagnetics combined with radio echo soundings over the northeastern icecap of Greenland. The flights over the Fram Strait will be discussed in separate papers.

SURVEY SETUP

Logistics

The logistic base for NOGRAM'98 was Longyearbyen Airport on Spitsbergen. Most of the equipment needed for the scientific installations and the aircraft maintenance was shipped there by commercial freight flights. Material that was needed only at Station Nord was flown there with a Hercules C130 of the Danish Air Force from Vaerloese, Denmark. A

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Manucript received 21 January 2000, accepted 23 January 2001

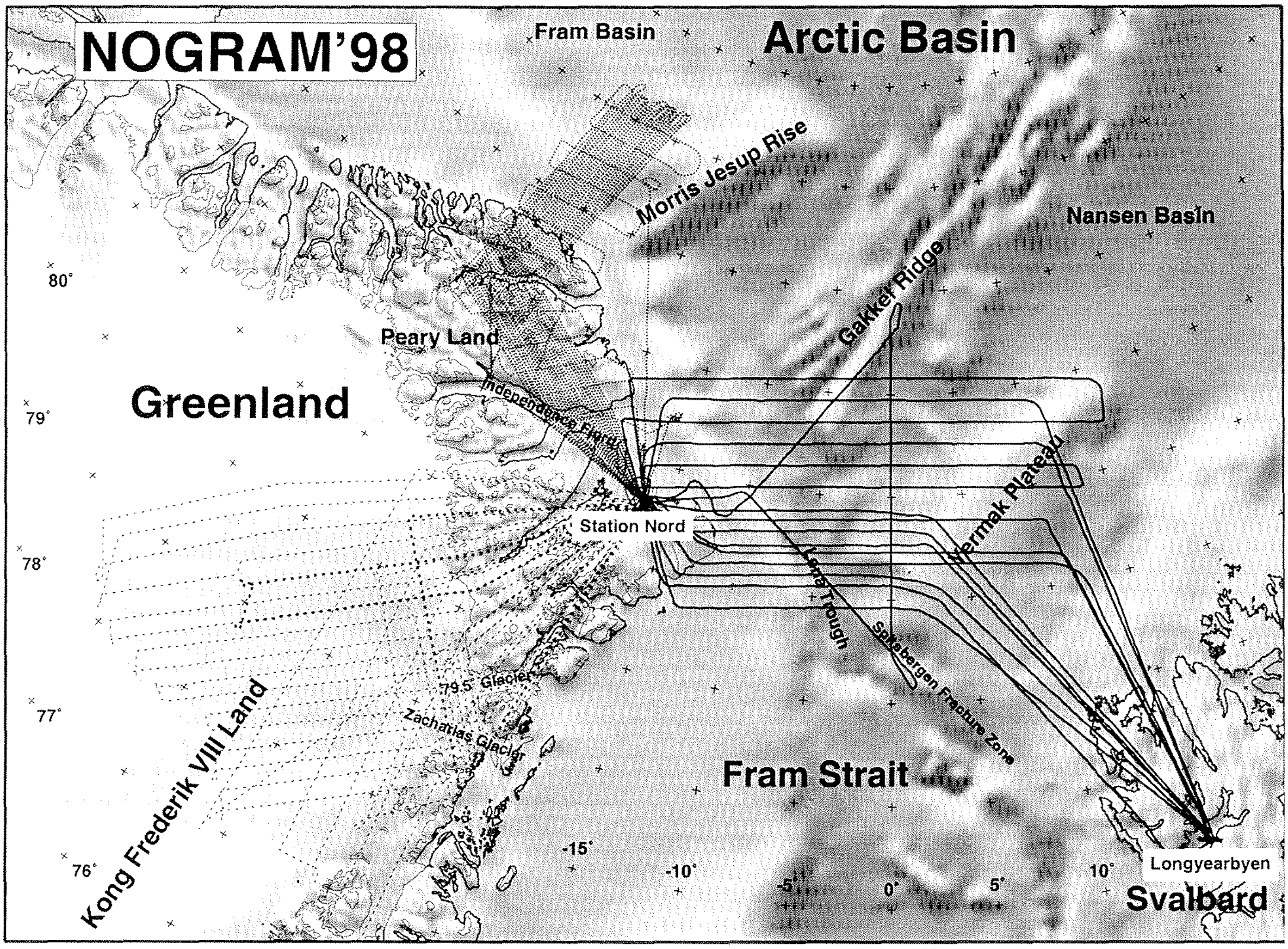

Fig. 1: Map of NOGRAM'98 airborne survey profiles. Solid lines: flight profiles over the northern Fram Strait (aeromagnetics, aerogravity); dotted lines: flight profiles over Peary Land and the western Morris Jesup Rise (aeromagnetics, aerogravity); dashed lines: flight profiles over northern Kong Frederik VIII Land (aeromagnetics, radio echo soundings); bold dashed profiles display lines were the aerogravity system was used. Bathymetry was derived from Gebco Sheet 5.17.

GPS reference station was installed at Ny Alesund, Spitsbergen. Station Nord was the main base of operation for NOGRAM'98.

Station Nord is a Danish Air Force airfield and well suited for this kind of survey as already experienced in former AWI aircraft expeditions. A GPS reference station and a geomagnetic base station were established at Station Nord. The flights over Morris Jesup Rise were planned to overlap the PMAP'97 survey for future data merging. The line spacing was chosen to be 3 km with cross profiles every 30 km. At Station Nord the NOGRAM'98 group met the KMS Twin Otter group, carrying out an airborne gravity survey along the northern Greenland coastline. The KMS Twin Otter flew another set of GPS reference and geomagnetic base stations out to Kap Moltke and brought them back in about four weeks later. Fortunate weather conditions allowed more flights over the Morris Jesup Rise and the Fram Strait than planned. In total, 225 h were flown within NOGRAM'98, including the transits from and to Germany (Tab. 1).

Survey parts etc.	Profile km	Profile h	Area km^2
Fram Strait include transfer flights	12360	53:12	90000
Morris Jesup Rise	13090	57:31	30000
RES on 79.5- and Zacharias Gl. inflow	16340	73:34	80000
(Compensation and tests)	4100	17:50	
(Ferry Germany-Spitsbergen-Germany)	4460	19:25	

Tab. 1: Flight Statistics

Airborne Survey System

The aircraft used for the survey, Polar 2, is a Dornier 228-100 owned by AWI.

The airborne survey system consisted of seven major installations (Fig. 2):

- the basic scientific instrumentation,
- the on-board computer system,
- the GPS units,
- the aerogravity system,

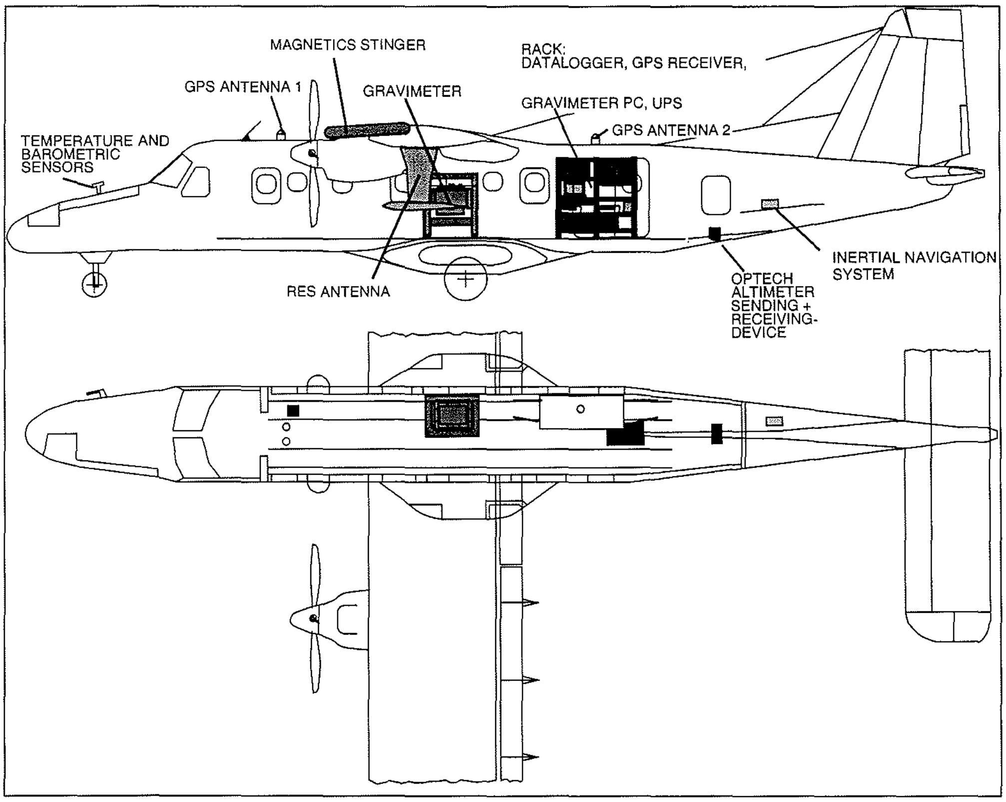

Fig. 2: Scientific instrumentation installed on Polar 2 during NOGRAM'98.

- the laser altimeter unit,
- the aeromagnetics system and
- the radio echo sounding (RES) system.

The basic scientific instrumentation of POLAR 2 includes static and dynamic air pressure sensors as well as a temperature sensor to compute an on-line barometric altitude. It also includes a humidity sensor and wind speed sensing instruments. Honeywell radar altimeter system data is available on the scientific data bus. Moreover, a Honeywell LaserNav II INS (Inertial Navigation System) unit is permanently installed, supplying acceleration, velocity, navigation and attitude data. In the cockpit, a GNS-X navigation management system is installed. This system is able to integrate multiple navigation systems to provide secure guiding information. Optional inputs are GPS, INS, Loran C and VLF Omega. The merged GNS-X navigation data is stored on the on-board computer for on-line and off-line control purposes. The on-board computer system contains two pre-processor units, to sample and digitize data as close to the sensing systems as possible, sending it on transputer links to the main computer unit. The main computer unit also collects serial and analog data of different other sources. It is capable of real-time-processing all data, displaying the data on screen and storing it on Exabyte mass-media storage. A third pre-processor unit is installed in conjunction with the RES system.

Two scientific GPS units (not used for GNS-X) are crucial for exact off-line aircraft positioning. The most recent installation in POLAR 2 is the aerogravity system. A similar system has already been installed on POLAR 4 for the AGMASCO survey over the Skagerrak (TIMMEN et al. 1997). It comprises a LaCoste & Romberg S-56 gravity sensor upgraded for airborne surveys. The gravity data is recorded on laptop and on the on-board computer system. An Optech Rangefinder laser altimeter was installed during the NOGRAM'98 survey.

The aeromagnetics sensing system consists of two He4 optically pumped sensors mounted in wingtip stingers installed on the left and right wing of Polar 2. Data is recorded at a sampling rate of 20 Hz. To reduce the impact of the aircraft remanent magnetic field on the measurements, static compensations were flown. Herein, crossover differences over a fixed point are minimized by current settings for compensation coils. Moreover, dynamic compensations were performed to determine the induced magnetic field components of the aircraft. The present aeromagnetic data set has a mean accuracy of about 3 to 5 nT, depending on ionospheric disturbances and gravity meter induced electromagnetic noise.

The RES system consists of one transmitting and one receiving antenna, installed underneath the left and right wing respectively. A HF signal generator produces a 60 ns or 600 ns burst that is transmitted either in single burst or toggle mode. The mid-frequency of the bursts is 150 MHz. The signal is reflected at layers with a high impedance or permittivity contrast such as the air-ice surface boundary, internal reflectors and the ice-subglacial bed boundary. With the 600 ns pulse ice thicknesses up to 4000 m can be detected with a resolution of 50 m. The 60 ns pulse is able to detect internal structures and bedrock up to 3500 m with a resolution of about 5 m. Further details are given in NIXDORF et al. (1998). For NOGRAM'98 only the 60 ns burst was used.

Ground Reference Systems

Exact navigation solutions are required especially for the 3 km line spacing survey over the Morris Jesup Rise. Therefore three ground based GPS reference stations were installed: at Ny Alesund, Spitsbergen, at Station Nord, Greenland, and temporarily at Kap Morris Jesup, Greenland. Geomagnetic base stations were put out at Station Nord and at Kap Morris Jesup. Unfortunately, the sensor cable and the power supply at the base station at Kap Morris Jesup broke early in the survey period so that no useful data was delivered from this crucial point. At Station Nord data were recorded from a Geometrics G856 and an Elsec 820 proton precession magnetometer system every 10 sec. Gravity ties for the airborne gravity survey flights were measured by connections to documented gravity points by means of a LaCoste & Romberg G877 land gravimeter.

FIRST RESULTS

Aeromagnetic Data Processing

For the present computations the aeromagnetics data were reduced from 20 Hz to 1Hz, cut into profiles and smoothed by a low pass filter (lower filter edge on 30 sec.). The smoothing was necessary due to an internal noise of the magnetics sensors that reached up to 3 nT rms. Due to this relatively high noise level, no dynamic compensation was applied on the data. All data over the Morris Jesup Rise that were not acquired in a flight level of 300 m above sea level were upward / downward continued to match this altitude, using a commercial LCT software package. The data over northern Kong Frederik VIII Land were completely upward continued to 3000 m above sea level.

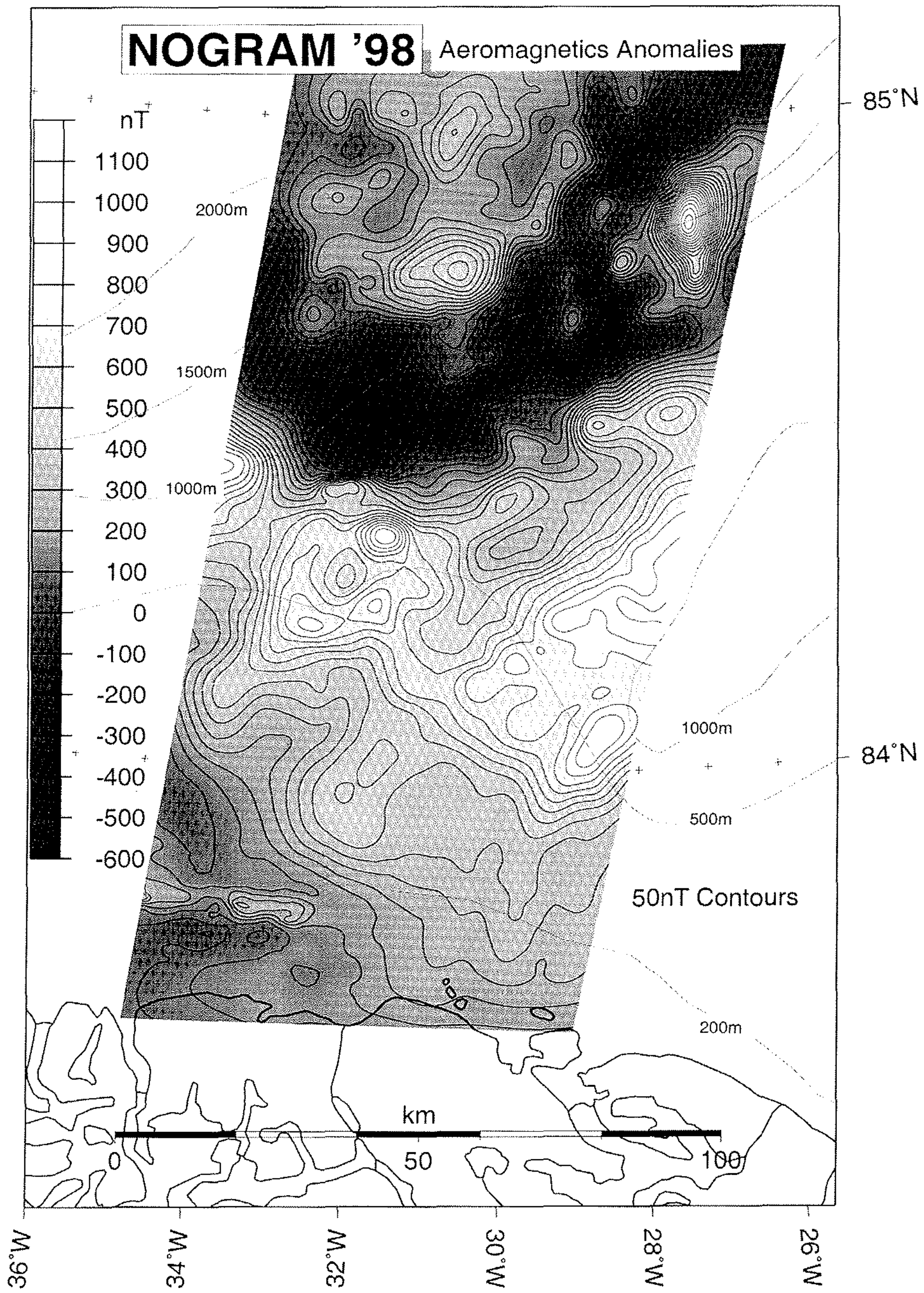

Fig. 3: Aeromagnetic anomaly map of the western Morris Jesup Rise derived from NOGRAM'98 flights. Anomalies are calculated on an altitude level of 300 m above sea level. Grid spacing is 2.5' x 0.25'. Contour line spacing is 50 nT. Overlaid bathymetry contours are derived from Gebco Sheet 5.17.

Aeromagnetic Data over the Morris Jesup Rise

A first compilation of the aeromagnetic data set acquired over the area of the western Morris Jesup Rise is shown in Figure 3. The grid is calculated on a spacing of 2.5' x 0.25'. Bathymetry contours (Gebco sheet 5.17) and the coastlines are overlaid. The grid covers only the western slope of the Morris Jesup Rise and therefore does not represent its complete structure. Another detailed airborne survey covering the complete extend of the Morris Jesup Rise is necessary for interpretation and will be conducted in summer 1999.

The Morris Jesup Rise is a broad plateau-like structure extending about 200 km towards the northeast into the Amundsen Basin. It is assumed to be of oceanic origin formed during the early opening of the Eurasia Basin, presumably as one unit with the Yermak Plateau (DAWES 1990). Both structures were split by seafloor spreading some time prior to anomaly 13 time (KRISTOFFERSEN 1990). The most characteristic feature of Morris Jesup Rise is a conglomerate of large positive anomalies that are now revealed in greater detail.

At the southwestern part of the gridded anomalies a positive, linear structure about 20 km north and parallel of the coastline is visible. It connects directly to the short wavelengths anomalies mapped in PMAP, that follow volcanic formations along the shelf (DAMASKE et al. 1997). From the present data we suggest that these rather complex anomalies are terminated by the southern extent of the Morris Jesup Rise that also magnetically reaches into the shelf region. A model of the interconnection of the different crustal structures in this area will be derived from the aerogravity data set acquired during NOGRAM'98.

In the north, between the 1000 m and 2000 m contour line a distinctive negative anomaly runs along the northern boundary of the Morris Jesup Rise. The Gebco contours display only an imperfect image of the Morris Jesup Rise in this locality, due to the sparse bathymetry data available. Also in this case aerogravity should help to get an improved picture of the Morris Jesup Rise. Within the narrow aeromagnetic survey area of NOGRAM'98, no spreading anomalies north of the Morris Jesup Rise are determined but we assume a more undisturbed oceanic crust in this region from the low magnetic amplitudes compared to the ones within the Morris Jesup Rise.

Aeromagnetic Data over northern Kong Frederik VIII Land

The gridded aeromagnetic data above the northern Kong

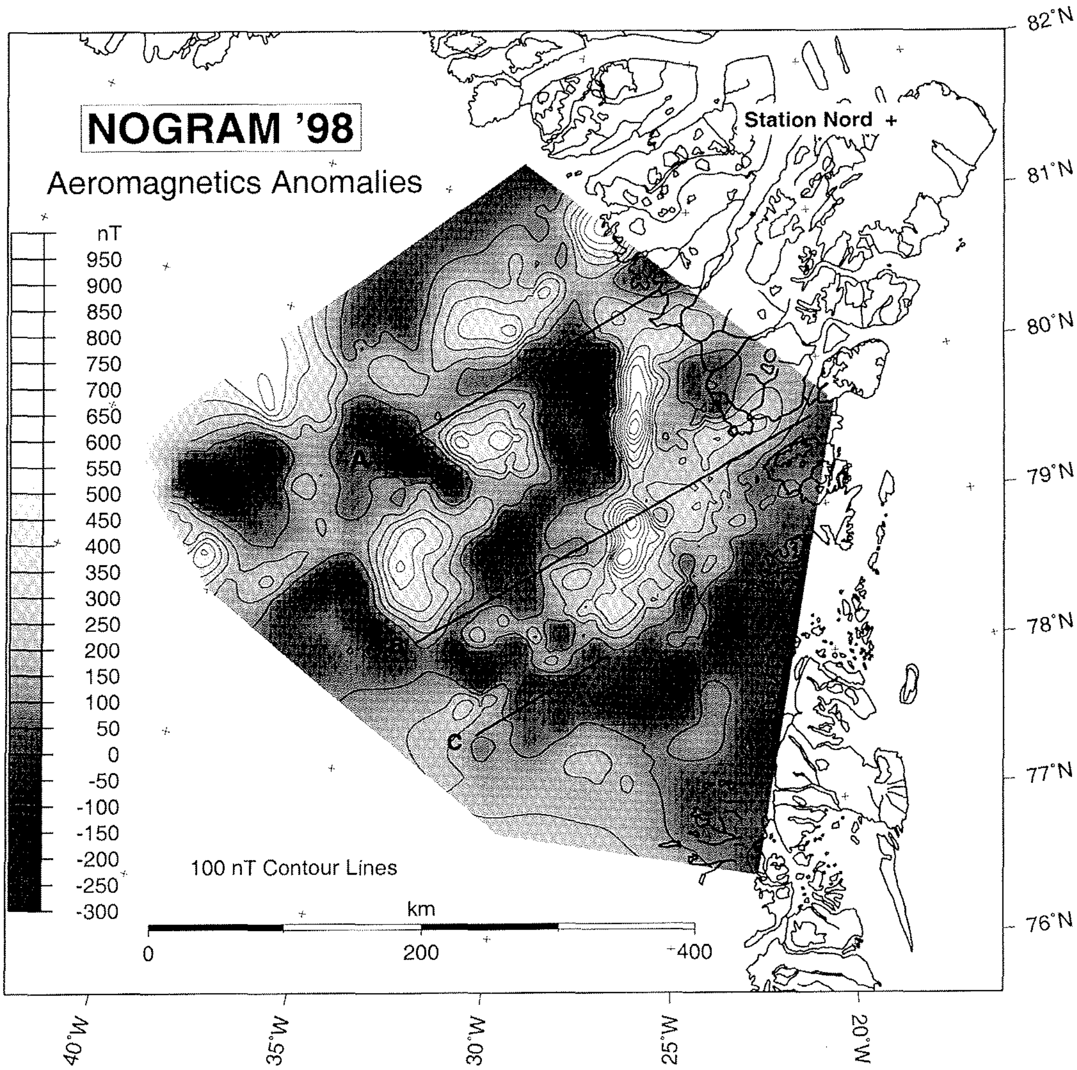

Fig. 4: Aeromagnetic anomaly map of northern Kong Frederik VIII Land derived from NOGRAM'98 flights. Anomalies are calculated on an flight altitude of 3000 m above sea level. Grid spacing is 10' x 2'. Contour line spacing is 100 nT. Profiles A, B and C are shown in Figs. 6 through 8.

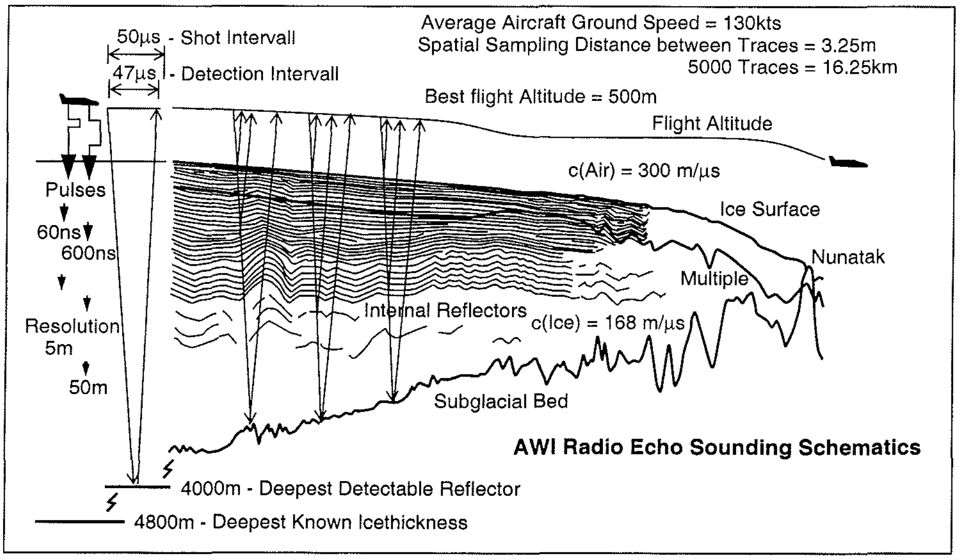

Fig. 5: Schematic overview of the AWI radio echo sounding (RES) measurements.

Frederik VIII Land (grid cell size is 10' x 2') are shown in Figure 4. A first glance at the grid reveals a very patchy structure of positive and negative anomalies. One of the most striking features is a highly positive anomaly running north to

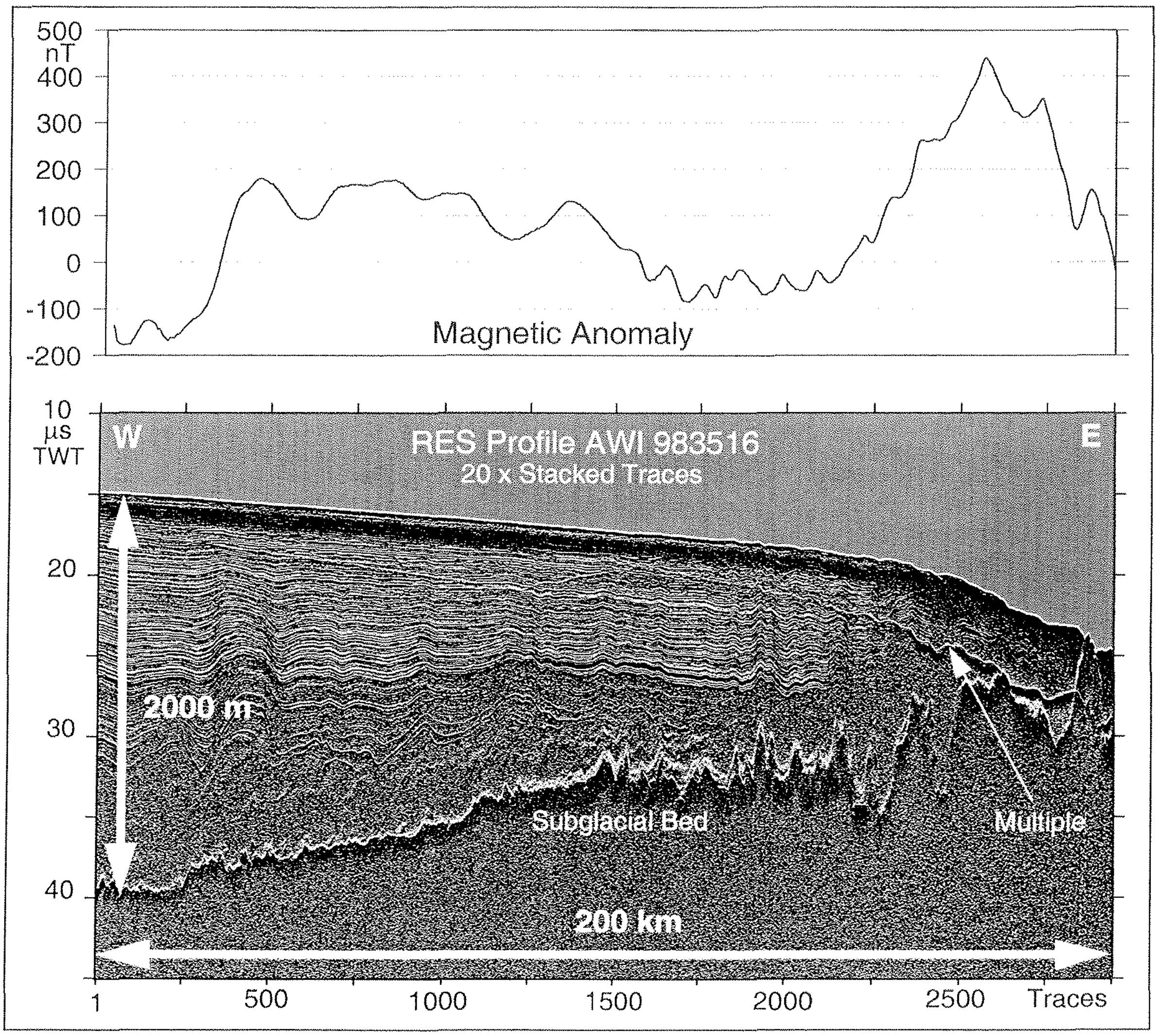

Fig. 6: Aeromagnetic anomaly profile and RES profile A (for location see Fig. 4).

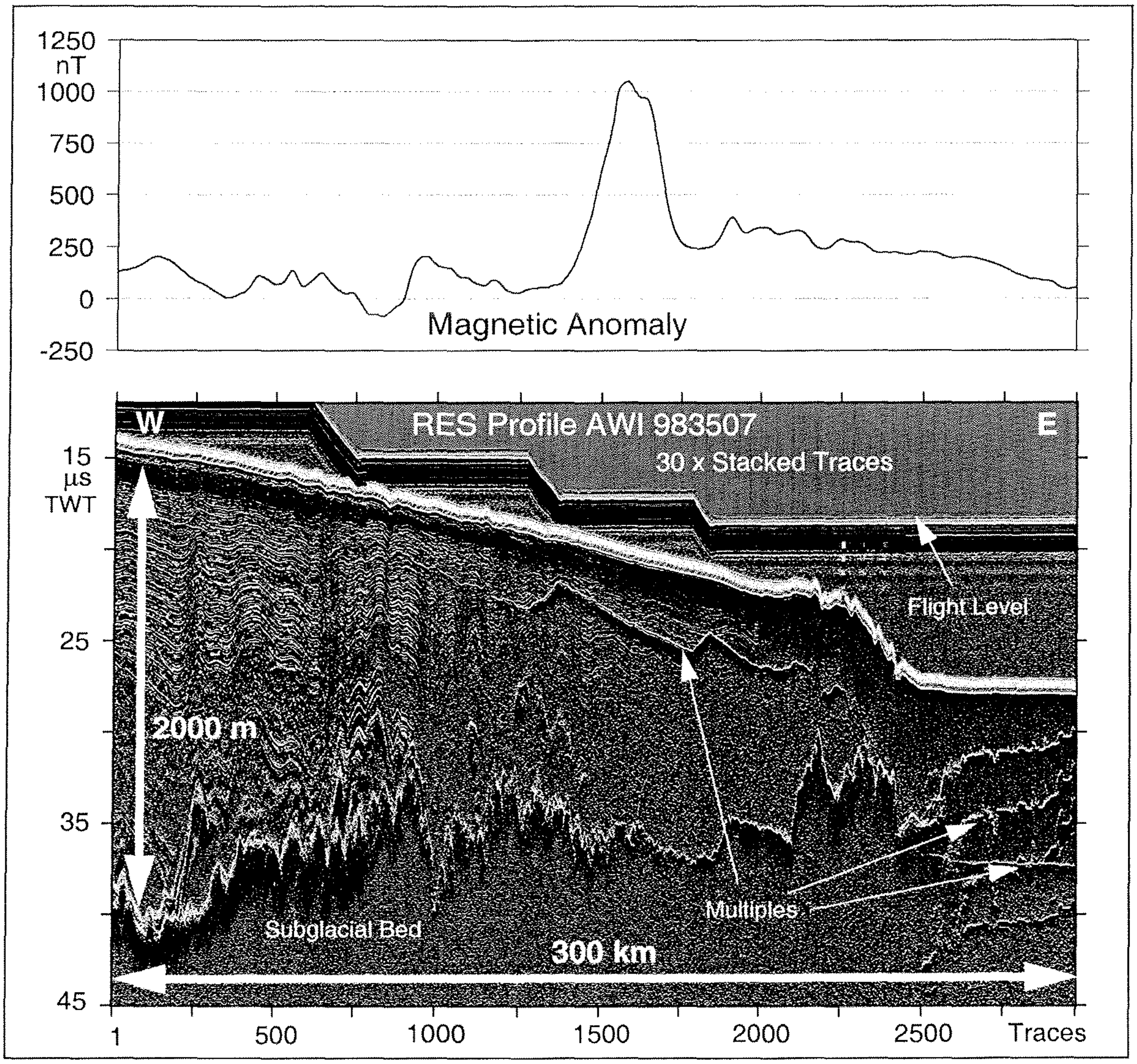

Fig. 7: Aeromagnetic anomaly profile and RES profile B (for location see Fig. 4).

south along about 27 °W with its northern end close to the Danmarks Fjord. This anomaly is not connected to a distinctive subglacial structure as visible in Figure 7, profile B. Looking through all three profiles (Figs. 6, 7, 8) it becomes clear that the aeromagnetic anomalies do not necessarily correspond to the subglacial topography, in fact only few, near coastal anomalies can be related e.g. to the subice terrain or nunataks. Thus, the internal crustal features such as tectonic disturbances and the rock origin and evolution play the major role here. Additional gravity data would a greatly aid the data interpretation. Unfortunately it was only possible to fly aerogravity in conjunction with all other airborne systems on two profiles (Fig.1). Those gravity data are yet not available. SCHLINDWEIN (1998) discusses a variety of possibilities of how the border between the magnetically flat terrain in the southeastern corner of the grid and the highly positive linear anomalies developed. We postulate that it represents the western limit of the caledonian deformation as mapped by HENRIKSEN (1994). At this stage of data processing we have no explanation for the western part of the aeromagnetic grid pattern but we hope for important clues from the few aerogravity profiles.

RES and aeromagnetics profiles

It is problematic to derive ideas about the tectonic setting and evolution of a complex area as northeast Greenland only by means of aeromagnetics. Therefore we aimed to map the subice terrain by radio echo sounding. At the moment, the radio echo sounding data processing is not yet finished but we are able to present a couple of profiles in connection with the aeromagnetic anomalies along the flight track. Figure 5 shows how the radio echo sounding technique basically operates. For the survey only the 60 ns pulse was used, giving an internal resolution of about 5 m. The two way travel time (TWT) in air and ice was used to calculate the depth of the reflectors (for details, see NIXDORF et al. 1998).

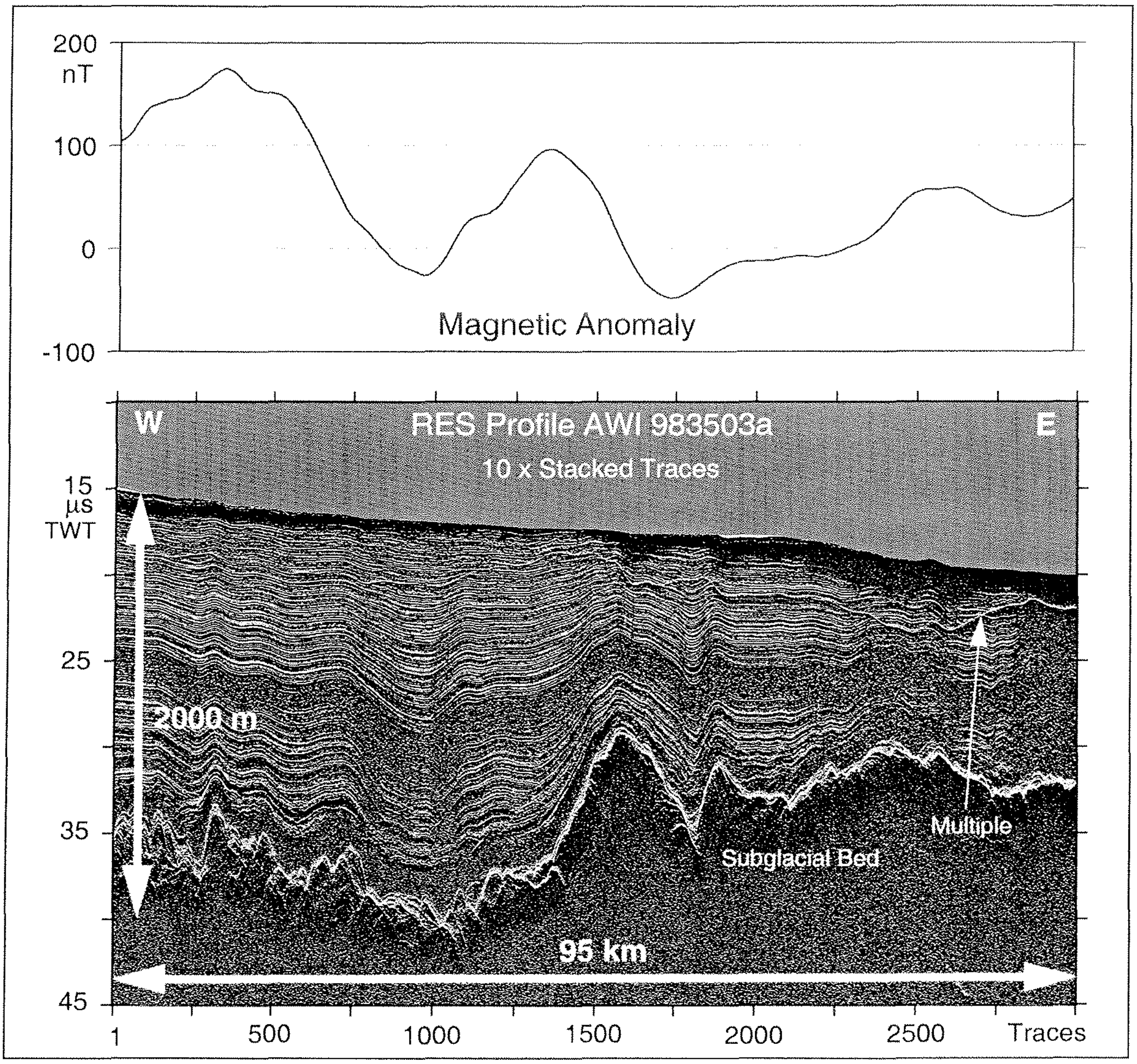

Fig. 8: Aeromagnetic anomaly profile and RES profile C (for location see Fig. 4).

Profile A (AWI 983516)

Profile A (Fig. 6) cuts through the northern part of the survey area (Fig. 4). From west to east, it runs from the inland ice towards the southern tip of the Danmarks Fjord. At its western end (about 79 °N, 35 °W) the ice thickness is about 2000 m. The mean slope of the subglacial bed continuously rises towards the northeast. The profile can be divided into four parts. The westernmost part touches the lower basin, connected with a distinctive negative magnetic anomaly. The subsequent western part of the profile reveals only little disturbances of the subglacial surface connected with positive long wavelengths magnetic anomalies. Gradually, the subglacial terrain gets rougher towards the east. Short wavelengths negative anomalies can be related to a hilly terrain built out of small peaks. The last part of the profile reveals larger mountains connected with high positive anomalies.

Profile B (AWI 983507)

Profile B (Fig. 7) runs directly over the highest positive aeromagnetic data peak of the mapped area. It starts on the inland ice and leads towards the Nioghalvfjerdsfjorden Glacier on the east Greenlandic coast.

From west to east it also starts with an ice thickness of about 2000 m but with a much more disturbed subglacial terrain. On the western flank of the prominent positive magnetic anomaly the bedrock has similar structures and low magnetic signatures as observed in the midst of profile A. The high peak in aeromagnetics is located just west of the near coastal subice mountain chain, but otherwise not connected with an equally prominent subglacial bedrock feature. The easternmost section of the profile packed with multiples in its lower part presents the Nioghalvfjerdsfjorden Glacier.

Profile C (AWI 983503a)

Profile C (Fig. 8) shows one of the few occasions in which a subglacial feature such as a mountain peak can be directly related to a positive magnetic anomaly. The profile is picked from an area that otherwise shows no highly variable magnetic pattern.

Comparison of RES and aeromagnetic data, aerogravity data

As already experienced in the areas of exposed rock, no simple realtionship beween the subglacial bed and aeromagnetics can be determined. It even proves to be difficult to interpret single 2d-profiles. Therefore it is mandatory to compile the best possible map of the subglacial terrain from all available data, to identify subice topographic features, to connect them to surface geology whereever possible and to interpret these then with all available aeromagnetic and gravity data. We will undertake these tasks together with the further necessary data processing in the near future and hopefully will be able to acquire new airborne data over critical elements of the interpretation process.

The aerogravity data flown over the Fram Strait will be processed and interpreted within an PhD-thesis. The other aerogravity data wait further data processing and will be discussed in future papers.

CONCLUSIONS

Until now, about 30 % of the data acquired during NOGRAM'98 are processed. Part of this data is presented here. The Morris Jesup Rise data have to be extended in order to get the complete view of its complex structure. The data onshore data over northern Kong Frederik VIII Land have to be carefully compared with already mapped geological and tectonic features to explain the aeromagnetic and subglacial signatures. The data over the Fram Strait, which are not discussed in this paper will likely reveal equally interesting new features.

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