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Geophysical investigations at the Inland Ice margin of the Pâkitsoq basin, central West Greenland

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In recent years much effort has been directed towards investigation of the margin of the Inland Ice in connection with possible development of hydropower. The thickness of the ice and thus the subglacial relief has been difficult to determine. Electromagnetic reflection (EMR) techniques have been used over large parts of the Inland Ice with considerable success, but have so far not produced good results in the marginal areas of the Inland Ice. This note reports the successful application of EMR techniques to an area of the Inland Ice adjacent to the Pâkitsoq basin near Jakobshavn, central West Greenland, together with a ground magnetic survey over a smaller part of the area. The field areas are shown in fig 1. The field work was carried out by LT and EH during a five week period in July–August 1985.

Helicopter-borne EMR survey

The original plans for the summer's EMR work called for a number of experiments to be carried out by a group from the University of Münster, West Germany, and were designed to explain why previous EMR measurements at the ice margin did not give good results. The Münster group were unable to come to Greenland, and in the spring of 1985 an alternative programme was decided upon to be carried out by GGU. The instrumentation used in 1984 without obtaining any results (Thomsen & Madsen, 1985) was improved by the use of a new antenna, a two element fed cylindrical parabola installed in a helicopter rather than a fixed-wing aircraft. The construction of this antenna was carried out at the Electromagnetics Institute, Technical University of Denmark. The characteristics of the instrumentation are given in Table 1.

The instruments could easily be installed in the back of the helicopter while still leaving room for a technician. The antenna was suspended between the floats of the helicopter (fig. 2). Plans to use another 60 Mhz antenna were abandoned for flight safety reasons.

The first experimental tests of the improved radar equipment were so encouraging that it was decided to carry out a proper survey, and subsequently the lines shown in fig. 3 were acquired. The helicopter was a Glace Jet Ranger (OY-HBF) with floats, manned with a navigator (LT) and a technician (EH). The tests had shown the altitude above the ice surface to be a decisive factor for the penetration of the radar, and thus the measurements were carried

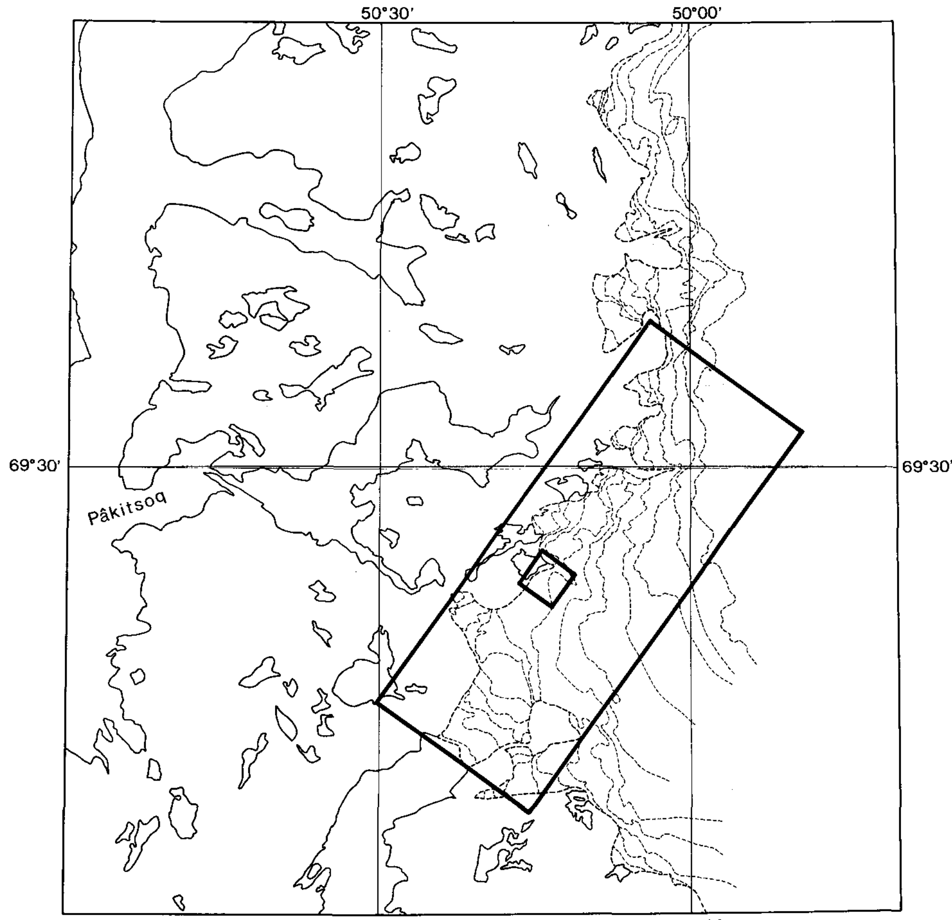


Fig. 1. Index map of the survey areas. Large area: helicopter-borne EMR survey. Smaller area: ground magnetic survey.

Table 1. Details of the instrumentation used in the electromagnetic reflection survey at Påkitsoq

Frequency	300 Mhz
Pulse effect	800 W
Repetition	0-15.5 kHz
Pulse length	0.25 microsec
Range resolution	24 m
Effect	max 1100 W
Weight	*c.* 70 kg

Fig. 2. The helicopter used for the airborne EMR survey. The antenna visible below the helicopter between the floats. (Photo HHT.)

out approximately 10 m over the surface at an airspeed of 80–90 knots. The only means of navigation was visual sighting supported by standard flight instrumentation. This, together with the low altitude, severely limited the size of the area that could be surveyed and constrained the possible configurations of the lines, which is the reason for the rather unusual pattern of lines that can be seen in fig 3. Altogether 21 flight hours were used including time for transport of fuel into the area. A further two hours were used over the ice stream of Jakobshavn Isbræ flying for the Polar Ice Coring Office (PICO).

The operation turned out to be very successful. Good reflections were obtained along most lines, although difficulties were encountered over water-logged areas, large crevasses, and the most broken up glaciers. Even there, further processing of the EMR data may give meaningful data, and it will probably be possible to compile an ice thickness map, and subsequently a map of the subglacial relief, for most of the surveyed area. In fig. 4 an example of data from line 58 is given. The upper part of the figure shows the *a* trace with the reflections annotated, in the lower part the corresponding *i* trace shows the picture of the bedrock re-

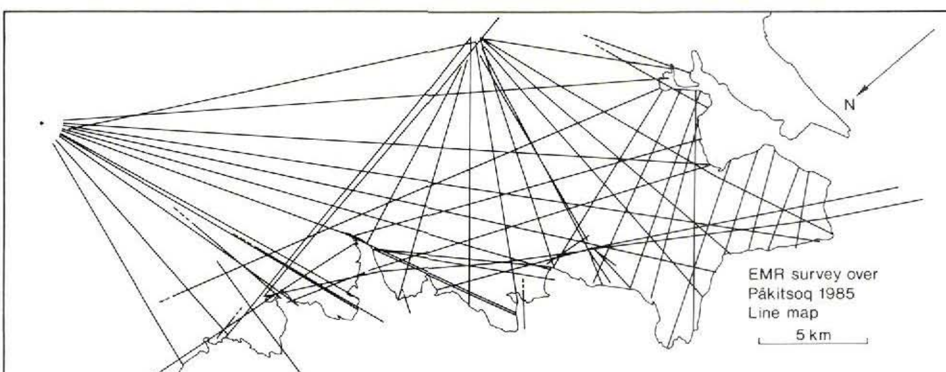
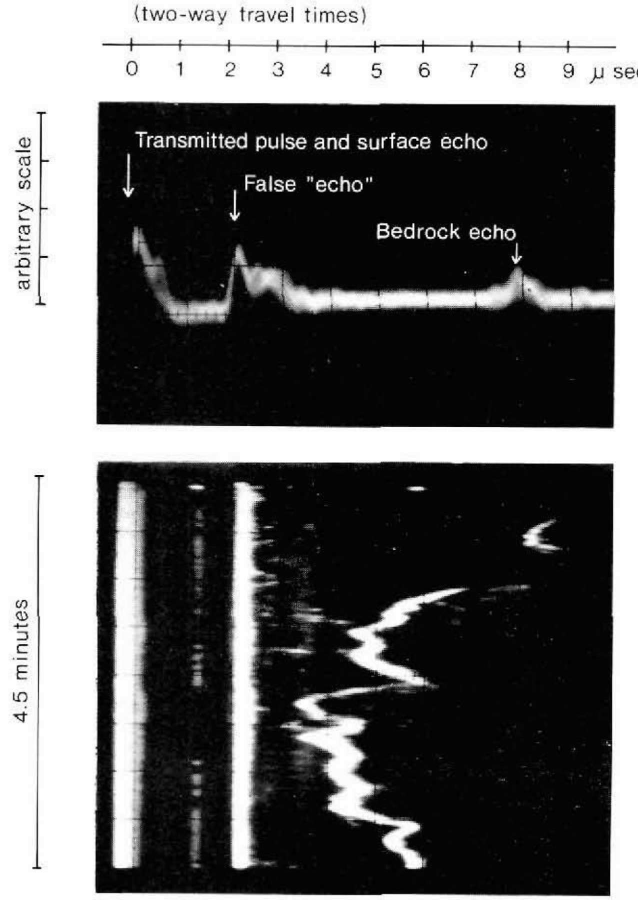


Fig. 3. Line map of EMR profiles flown. The map is provisional, awaiting a new topographic map of the area. Not all lines in the area are shown.

Fig. 4. Example of EMR data (profile 58). The upper part shows an amplitude plot of reflected energy from the ice surface and the bedrock low. There are also indications of internal echoes. The lower part shows the corresponding intensity plot of part of profile 58 with the same reflectors indicated, and some typical dispersed echoes from what presumably is a crevassed area.



flection that is obtained by stacking the data. Note that the transmitted pulse and the returned echo from the surface of the ice merge because of the low altitude of the helicopter. The deepest part of this profile is approximately 4 μsec, equal to 680 m assuming a constant velocity of light in ice of 169 m/μsec. On the profile over Jakobshavn Isbræ good echoes were returned from depths of approximately 1200 m.

In the field the EMR data were recorded on videotape to be replayed later for production of plots like those shown in fig. 4 (polaroid). An improved data replay facility is being constructed at GGU using a microcomputer for control and a film with higher resolution. Some computer processing of digitized information from these hard copies is anticipated in areas where multiple or weak reflections are encountered, or where migration of the EMR data may be necessary.

Ground magnetic survey

In 1984 a test was carried out at Nordbogletscher in South Greenland where magnetic profiling was used to calculate ice thickness (Thorning, 1985). The results of this experiment

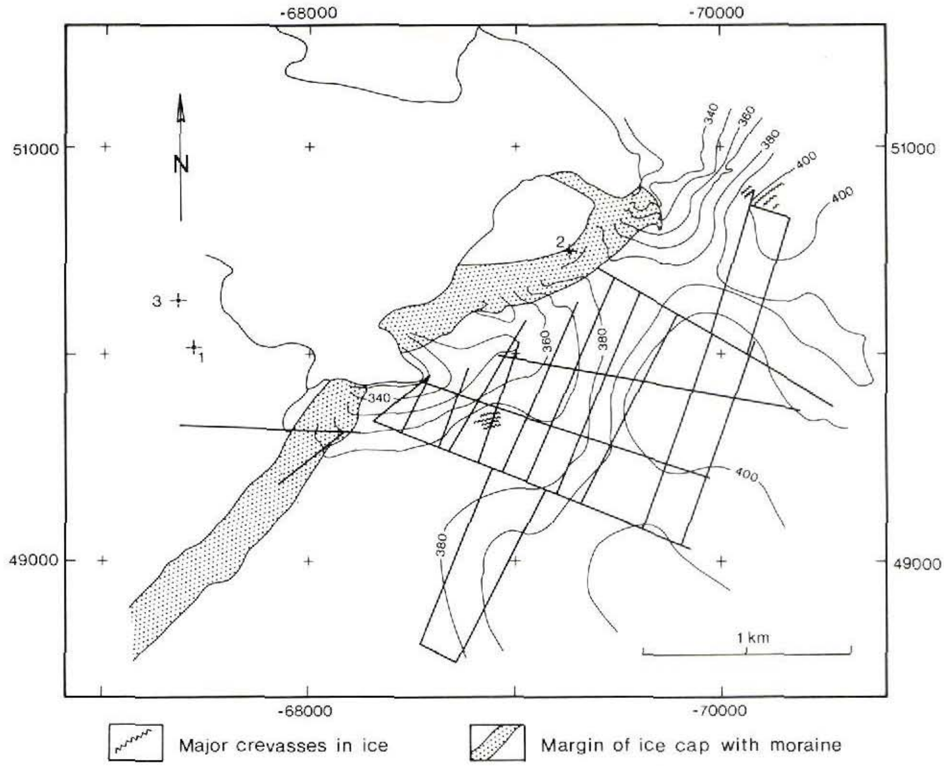


Fig. 5. Line map for the detailed ground magnetic survey near lake 326 (upper right corner).

were encouraging and thus in 1985 a detailed survey was carried out over the part of the ice margin directly adjacent to lake 326 in the Pâkitsoq basin from a tent camp at the margin of the ice. The glaciological model, based on the regional division of the ice cap into sectors, predicts greater variations in the water level of this lake than the very small variations observed. Thus the existence of topographical thresholds under the ice might be suspected, diminishing the area of the ice cap which drains to lake 326. The magnetic survey was designed to test this hypothesis. In fig. 5 the lines acquired are shown. Geometrics G856 proton precession magnetometers were used for both the base station recording at 15 sec intervals and the profile recording at 10 m intervals. The sensitivity of these instruments is 0.1 nT and the correction for diurnal variations can be made very accurately (fig. 6), which is a prerequisite for the use of magnetic data for this purpose. The NW–SE lines were laid out with a theodolite from known points on land and the remaining lines were measured by tape over the ice surface. Some 19 km of lines were acquired. Measurements with a mono-pulse radar (borrowed from PICO for two days) gave good results on one line indicating ice thicknesses of 200–300 m, but results from another line were very difficult to use because of multiple reflections interfering with each other. The magnetic susceptibility of the underlying rocks has been evaluated from approximately 600 measurements at 40 localities in the field (average 0.76×10^{-3} cgs) and found to be exactly the same as the measured average susceptibility of blocks of the marginal moraine.

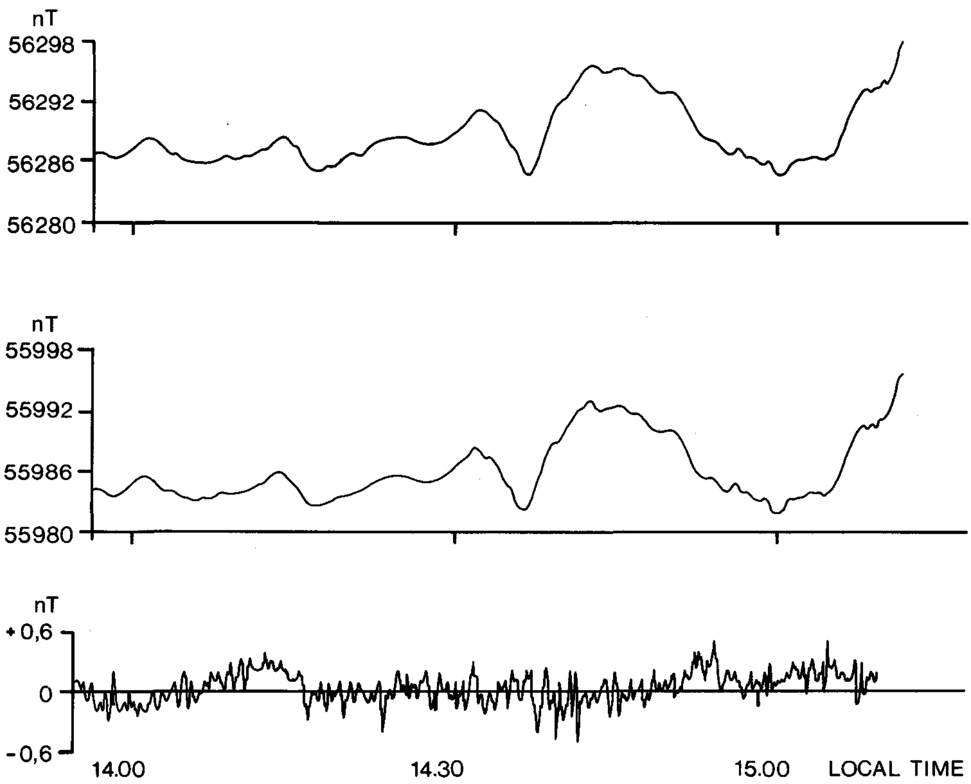


Fig. 6. Correction of stationary measurements in the profile area (middle curve) using the base station recordings (upper curve) give 'errors' of maximum 0.5 nT (lower curve).

The corrected magnetic field in the survey area shows very smooth variations of fairly large wave lengths. In fig. 7 a contour map of the magnetic anomaly map is shown. The susceptibility measurements mentioned above clearly showed the underlying rocks and moraine to be magnetically quite homogeneous and similar, and thus the magnetic anomalies reflect mainly the variations in ice thickness. The dominant trend in the map of fig. 6 is a clear decrease in the magnetic field towards the south-east, and some local maxima towards the north-west where lake 326 is situated. Qualitatively this can be interpreted to show increasing ice thickness towards the south-east and the existence of topographic thresholds below the ice indicated by the magnetic maxima. Modelling will further refine this interpretation and compensate for the undulations of the surface of the ice; but the results certainly confirm the hypothesis put forward above. Most of the meltwater can be expected to flow away to the south.

General discussion

The results of the geophysical investigations briefly described above seem to represent a breakthrough in the mapping of the subglacial topography of the margin of the ice cap.

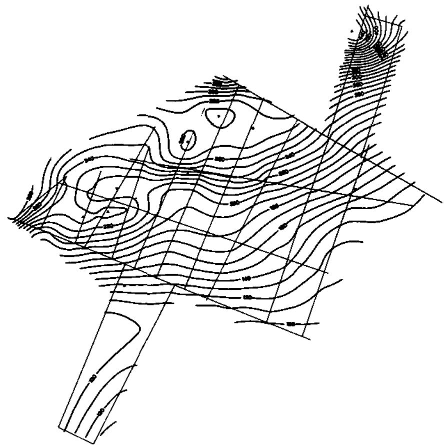


Fig. 7. Magnetic anomaly contour map based on corrected data from profiles shown in fig 5. Contour interval is 10 nT.

EMR instrumentation and techniques have been developed which will presumably give equally good results in other areas and, as predicted in Thorning (1985), the magnetic method has proved to be a possible way to map variations in ice thickness. A combination of the two methods into one airborne survey is tempting, but may be impractical. The low altitude necessary for good EMR data inhibits the use of a magnetic sensor in a bird, and an onboard sensor demands the use of an effective and costly magnetic compensation system. The implementation of such a combined system could only be defended if large-scale systematic coverage was intended. In the immediate future separate EMR and magnetic surveys seem adequate.

The post-field processing of EMR data can and will be improved. The first step is a better reproduction of the hard copies of the data, and improvements have been made. Further, development or acquisition of suitable software for processing of EMR data is contemplated. As a minimum this should include facilities for digitizing and re-scaling reflection data, and possibly also methods for the correction of the data in ways used in seismic data processing. This is especially important in the marginal areas of the ice cap, where the variations in the subsurface relief can be considerable over short distances, and where the reflection cannot always be assumed to have its source immediately below the point of measurement.

The effectiveness and safety of the airborne EMR operations can be significantly improved by the use of a larger, twin-engine helicopter with greater range, and the introduction of a navigation system, preferably giving both horizontal and vertical positions with sufficient accuracy, as this would circumvent the difficulties arising from poor maps of the surface of the ice cap in relation to which all ice thicknesses have to be calculated. Finally, the survey should be carried out earlier in the year when water is less abundant, in and on the ice.

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Fourth year of glaciological field work at Tasersiaq and Qapiarfiup sermia, West Greenland

Ole B. Olesen

As part of the GGU programme for the regional mapping of the hydroelectric potential of West Greenland, glaciological and climatological investigations were continued at 'Amitsulôq' ice cap in 1985, while only glaciological measurements were made at Qapiarfiup sermia. The field programme at Qapiarfiup sermia was originally started in March 1981, whereas the permanent field station near 'Amitsulôq' ice cap (fig. 1) was first established in August of the same year. Brief reports of the work have been given by Olesen (1982), Olesen & Andreasen (1983), and Olesen (1985).

Glaciological field work

The field work in 1985 started with measurements of the winter snow accumulations on Qapiarfiup sermia on 22nd May. As the winter of 1984–85 was very mild in West Greenland and spring came early, melting had already set in. As a result it was only at the uppermost snow pits that the 0°C horizon had not yet penetrated to the bottom of the snow pack. Based on the state of the snow pack (density and wetness) and the trends of accumulation curves for former years, it is believed that only insignificant amounts of snow had disappeared by this time. Qapiarfiup sermia was visited again on 3rd September when the summer balance was measured.

At 'Amitsulôq' ice cap winter balance measurements started on 28th May. On the lower parts of the ice cap it was evident that some runoff had already taken place so that unfortunately the winter balance for this year is incomplete for some areas. On the small glacier tongue near the field station (location 951 on fig. 1) a 'stake farm' consisting of five stakes positioned at the corners and centre of an approximately 14 m square was erected. During the summer stake readings were taken every day at all five stakes. The remainder of the stakes on the ice cap were visited at irregular intervals for determination of transient balances and possible redrillings. Positions of some of the stakes were measured by intersection from fixed points on bedrock on 14th July and as in previous years the position of the glacier tongue near the camp was tape measured from markers in front of it.