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Mapping and modelling of glacier drainage in the Pâkitsoq basin, central West Greenland

Henrik Højmark Thomsen

Mapping of surface hydrology and modelling of glacier hydraulics at the margin of the Inland Ice north-east of Jakobshavn have been used for investigating glacier drainage. The work is part of the hydropower investigations at Pâkitsoq in a drainage basin proposed for a local hydropower project. Excluding its Inland Ice sector the basin covers an area of 33.6 km^2 and is situated at about 200–600 m a.s.l. (fig. 1; Thomsen, 1988, fig. 1). The main part of the runoff from the basin is meltwater from the ice sheet draining through three lakes, 326, 233 and 187. Lake 187 and 233 are proposed as two separate reservoirs, with tunnels leading to the fjord north-west of the basin.

Glacier hydrological conditions

Meltwater drainage on the ice itself is complicated. Over large areas meltwater drains through innumerable rivers whose drainage courses are influenced by the surface undulation and different structural features on the ice surface. In most cases the rivers escape down into moulins or crevasses, after which the meltwater drainage is controlled by englacial and subglacial drainage conditions. Delineation of drainage basins requires information about supraglacial and subglacial conditions.

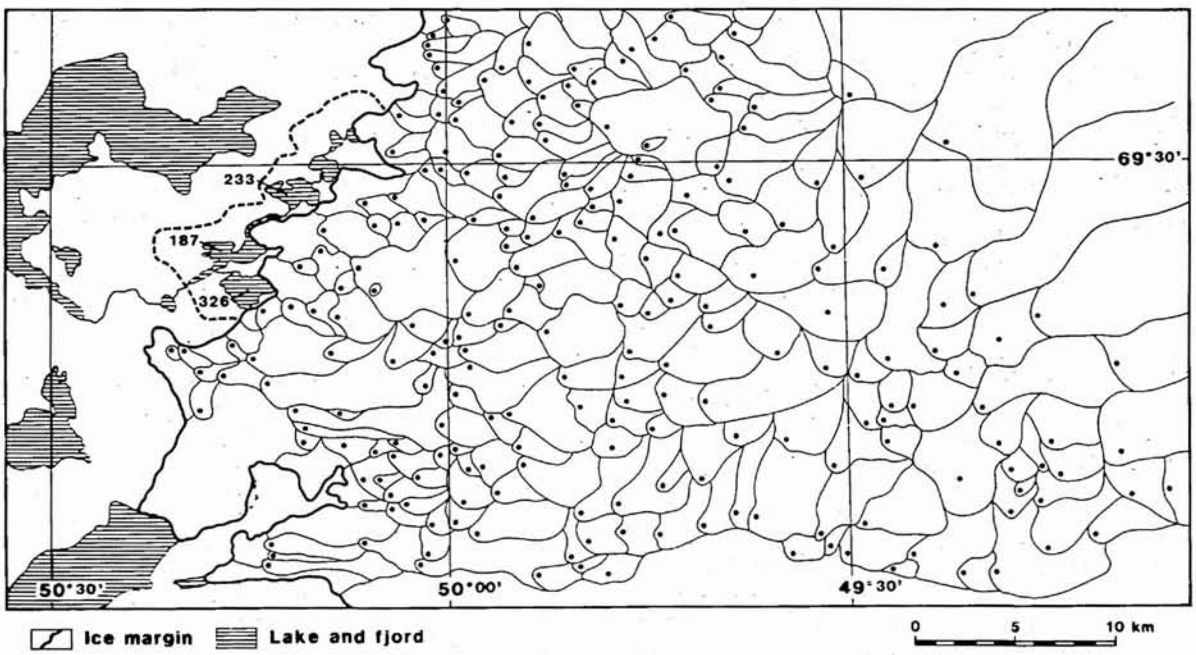

Fig. 1. Drainage cells on the Inland Ice at Pâkitsoq, each draining to a moulin or moulin complex.

Surface topography and drainage

A photogrammetric map on a scale of 1:75 000 was prepared covering the ice-free part of the basin and the adjoining sector of the Inland Ice. The map, based on vertical aerial photographs on the scale 1:150 000 from 10 July 1985, was plotted on a Kern PG-2 stereo plotting instrument connected to a computer system. The map gives physiographic information and surface topography with contour intervals of 50 m in the ice-free area and 20 m on the ice. All possible details have been plotted for the glacier area and trimline zone. This includes features on the ice especially related to surface hydrology such as rivers, lakes and moulins as well as crevasses and lineaments influencing the drainage pattern. The map is supported by observations in the field on foot or from a helicopter.

On the basis of the glacier hydrological map, the ice surface was divided into a number of drainage cells, each draining to a moulin or moulin complex (fig. 1). At the highest elevation, the individual drainage cells have been arbitrarily cut at an elevation of 1100 m a.s.l. The meltwater drainage course from each cell will depend on englacial and subglacial conditions below the point of escape into the ice.

It is reasonable to assume that the drainage pattern on the ice is semi-permanent. It means that drainage takes place in the same valley system on the ice from year to year because the valleys are features of the local topography caused by ice movement over the hilly subglacial terrain. Comparisons with older maps, plotted on vertical aerial photographs from 1959 (Thomsen, 1986) and oblique aerial photographs from 1948 show a stable main drainage pattern with rivers draining in the same valley systems and moulins lying in approximately the same positions. This is despite a mean glacier thinning of 14 m up to an elevation of 500 m a.s.l. in the period 1959–1985.

Englacial and subglacial drainage

Studies of englacial and subglacial water drainage usually deal with drainage in temperate ice conditions. Some water drains through tiny cracks and openings along the single ice crystals (Shreve, 1972), but most water drains in larger channels and conduits starting at moulins and crevasses on the surface. Moulins can reach several hundreds of metres down into the ice, directly to the bottom (Iken, 1972; Meier, 1973). At the bottom of the ice water can drain in a thin water film or in subglacial channels, depending on the regional and local subglacial conditions (Röthlisberger & Lang, 1987).

No direct observations exist about englacial and subglacial drainage from the area at Pâkitsoq. The few ice temperature measurements (see Thomsen, 1988) show slightly negative temperatures in the whole ice body. Observations from White Glacier on Axel Heiberg Island suggest that water escaping down into moulins is

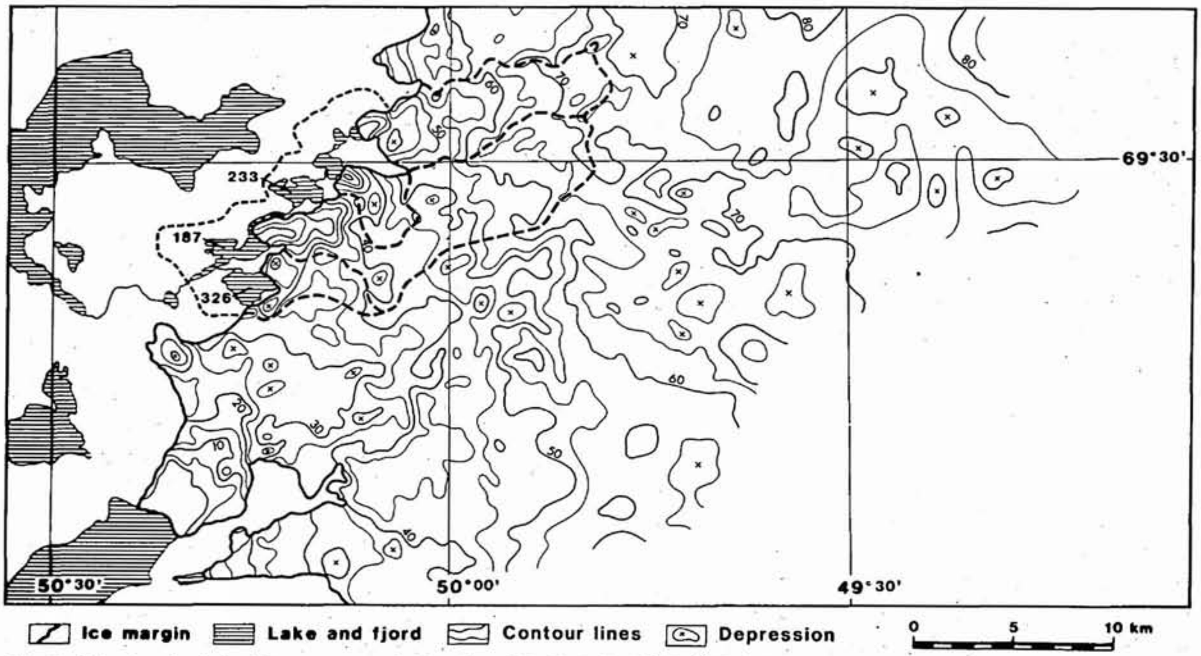

Fig. 2. Calculated subglacial water potential for $k = 0.7$. Units in $10^5 N/m^2$. Subglacial water divides are given by dotted lines.

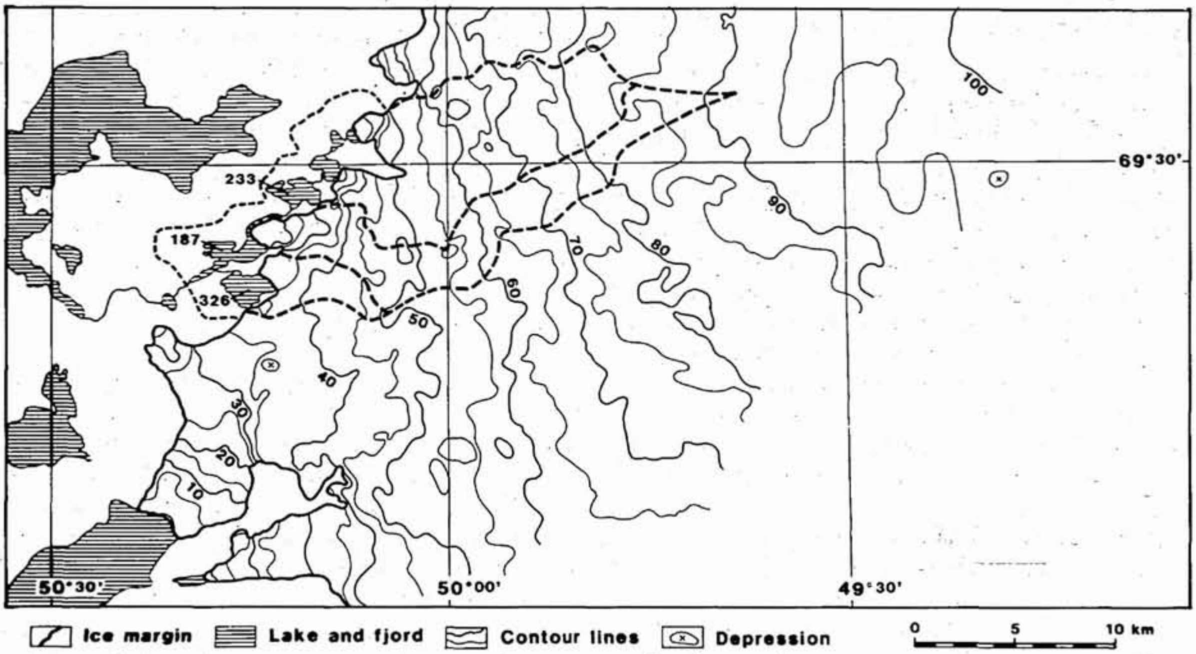

Fig. 3. Calculated subglacial water potential for $k = 1.0$. Units in $10^5 N/m^2$. Subglacial water divides are given by dotted lines

able to reach the bottom of the ice, even under conditions of cold ice (Iken, 1972). From the above it is assumed that surface water at Pâkitsoq which escapes down into the ice through moulins quickly flows to the bottom of the ice and there drains according to the subglacial conditions.

Modelling of subglacial drainage

A model by Björnsson (1982) describing subglacial drainage was used for calculating the drainage at the glacier bed. The model describes water drainage down the gradient at a potential which depends upon both surface and subglacial topopgraphy. Data from the photogrammetric surface mapping and data from radio echo sounding of the bed (Thorning *et al.*, 1986; Thorning & Hansen, 1987) were used as input for the model. The potential is expressed as

$$POT = (r_w - k \cdot r_i) \cdot G \cdot Z_b + k \cdot r_i \cdot G \cdot Z_s$$

r_w and r_i are the density of water and ice, respectively. G is the acceleration due to gravity, Z_b and Z_s are the elevation of glacier bed and surface relative to a horizontal datum, and k is a hydraulic factor expressing the relation between subglacial water pressure and ice overburden pressure. Water flowing in an isotropic basal layer drains perpendicular to the potential lines. The model is a first-order approximation of subglacial drainage and does not describe details in water flow.

In practice the k factor will vary in time and with location in a way which is difficult to describe and will, as a minimum, require extensive measurements of the basal water pressure. Subglacial potentials are therefore calculated for a number of k values from zero to one and are plotted as potential maps, some of which are shown in figs 2 and 3.

The subglacial water divides under conditions of varying k factor were drawn from the potential maps. This includes delineation of sub-basins draining to the three separate lakes, 326, 233 and 187. The results show that subglacial drainage is slightly sensitive to changes in the k factor. The drainage area and the sub-basins are nearly constant for $k = 0$ to $k = 0.5$. For $k = 0.7$ there is a slight increase of drainage area in the north-eastern part of the basin and for $k = 1.0$ this tendency is further reinforced, but with a marked change in configuration of sub-basins (figs 2 and 3). The modelling suggests that changes in the subglacial conditions will not create critical changes in the basin size.

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Electromagnetic reflection survey 1987 in key areas of the Pâkitsoq basin at the margin of the Inland Ice, central West Greenland

Leif Thorning and Egon Hansen

The EMR surveys of previous years (Thorning *et al.*, 1986; Thorning & Hansen, 1987) provided the ice-thickness data necessary for a detailed evaluation of the glaciological-hydrological conditions of the Inland Ice required for planning a hydropower plant at Pâkitsoq (Thomsen *et al.*, 1986). This evaluation also identified some locations where ambiguity in the hydrological interpretation resulted in uncertainties in the estimate of water supply to the Pâkitsoq basin, because the data available did not allow the model to predict the direction of drainage of meltwater. Therefore, further geophysical work was undertaken to provide more detailed information on the subglacial relief of these localities on the ice.

Field work 1987

In May 1987, the helicopter-borne electromagnetic reflection (EMR) survey was continued in the Pâkitsoq area. As in previous years a Bell 206 Jetranger helicopter (Glace, OY-HBF) was used. The antenna (a better version in more durable materials) was mounted between the floats, and a new video recorder (Sony VO-6800PS, U-matic format) was used for the recording of EMR data, navigational check marks and navigator comments. A Del Norte line-of-sight navigation system with four remote stations was used for accurate positioning. The remote stations were placed so as to provide optimal coverage in the area of interest and therefore not at the same positions as in 1986. Flight elevation was 10 m above the ice surface. Operations were carried out from Jakobshavn airport with two or three refuelling stops at the camp at Lake 187, Pâkitsoq, where fuel had been landed by a larger helicopter.

The objective of the measurements was to obtain data from two specific areas where problems in hydrological interpretation existed. Thus, from the outset it was intended to utilize the navigation system for feedback of inflight information to navigator and pilot to make it possible to place lines closely and accurately over the critical areas. For a number of reasons this failed in the field, and instead navigation was visual, based on the combined experience of pilot and navigator, and aimed at a concentration of measurements in the areas of special interest. The navigational data were thus only recorded for later processing and were not used in flight.

Processing of data

The navigational data were processed by Bo Madsen, GTO, and transferred to GGU as calculated positions in UTM coordinates correlated with time. Due to errors in the recording of the data in the field, the positioning is less accurate than in 1986. This prolonged the subsequent processing of EMR data because a number of extra checks and corrections have been necessary.

The EMR data were processed using the same meth-