Continued glaciological investigations with respect to hydropower and ice-climate relationships, at Pâkitsoq, Jakobshavn, West Greenland

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Hot-water drilling and mass-balance measurements were carried out on the Inland Ice at Pâkitsoq north-east of Jakobshavn. Observations of water level fluctuations in the drill holes indicate a high subglacial water pressure close to the ice overburden pressure. Mapping the occurrence of Wisconsinan ice along the ice margin, by sampling of surface ice, was continued and observations were made around an unexpected tapping of an ice dammed lake.

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Glaciological investigations for planning hydropower have been carried out since 1982 at the Inland Ice margin at Pâkitsoq north-east of Jakobshavn (Thomsen, 1986). The main emphasis has been on description and understanding of the meltwater drainage on, in and below the ice for delineation of drainage basins on the Inland Ice. Surface topographical and ice-thickness data have been used for modelling meltwater drainage below the ice (Thomsen *et al.*, 1988) and mass balance data have been collected over the seven year period. In the modelling of meltwater drainage at the base of the ice assumptions on ice temperatures and subglacial water pressures were made. To test these assumptions hot-water drill holes were made through the ice in 1987 (Olesen & Clausen, 1988).

A programme for ice surface sampling was started in 1985 to evaluate stable-isotope methods for studying the hydrology and dynamics of the marginal zone at Pâkitsoq (Reeh & Thomsen, 1986). The investigation shows that oxygen isotopes can be used as natural tracers for the meltwater runoff from the ice sheet margin and have applications in the delineation of drainage basins (Reeh & Thomsen, 1989). The isotope studies have also documented that ice deposited in the central regions of the ice sheet during the last ice age is now exposed at the surface of the ice sheet as a band roughly 600 m wide near the ice margin (Reeh *et al.*, 1987). The palaeoclimatic and ice-dynamic implications of this discovery are significant, and since this observation stable-isotope investigations have been made together with the glacier-hydrological studies. The work has been carried out in close cooperation with the Alfred Wegener Institute for Polar and Marine Research (AWI) in West Germany (Reeh *et al.*, 1989).

The aim of the 1989 field programme was to extend and confirm assumptions in the previous work.

As in previous years the expedition included guests from other countries, this year from Switzerland, engaged in reconnaissance for possible future studies of the 'greenhouse effect' in cooperation with GGU (Braithwaite, 1990).

Logistics and participation

The field work in 1989 was carried out from a base camp located on the glacier tongue leading to lake 326 (fig. 1), about 600 m upstream from the ice margin. The work was supported by a helicopter shared with the GGU Disko Bugt project based at Atâ (Kalsbeek, 1990). Four persons took part in the work: L. Lund, O. B. Olesen, H. H. Thomsen (all GGU) and T. Konzelmann (Swiss Federal Institute of Technology), who worked as a GGU field assistant during the stay.

Mass-balance measurements

The stakes (fig. 1) established for mass-balance measurements in earlier years were visited by helicopter on 12 May and 14 August. The winter snow cover on the ice was very patchy and confined mainly to drifts in

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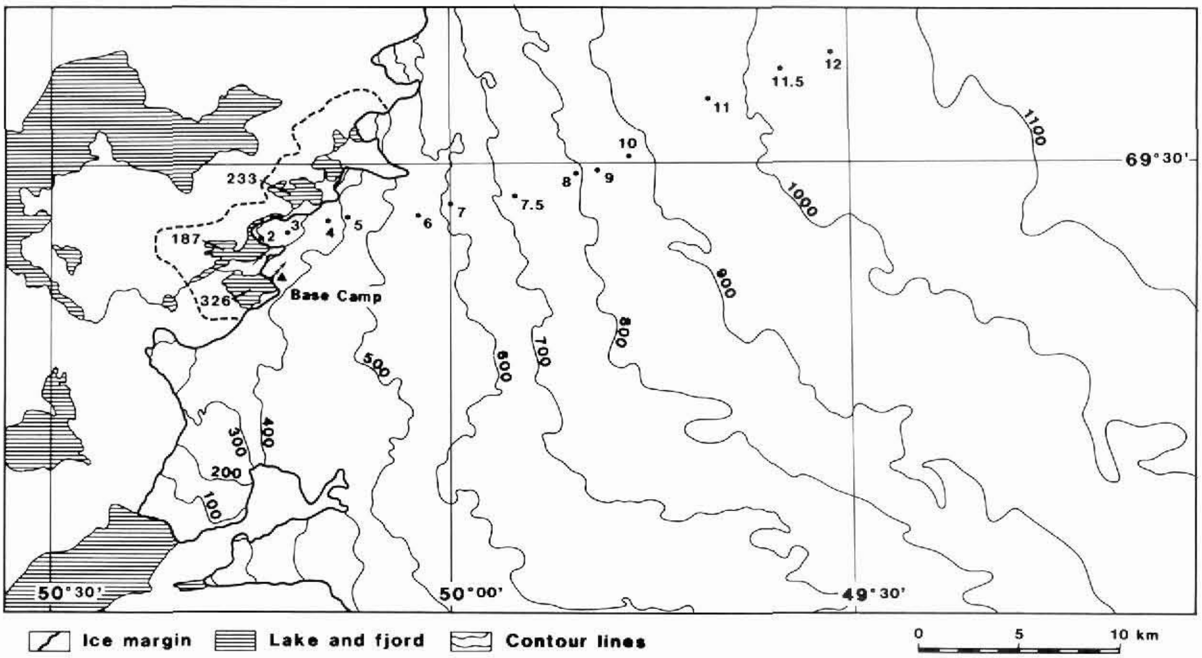

Fig. 1. Drainage basin at Påkitsoq. Stakes for measuring mass balance are shown. Contours in metres. Arrow shows location of new outlet from lake 326. Ice sample profile, near base camp, is given with line of arrows.

gullies and crevasses up to an elevation of about 500 m a.s.l. At higher elevations the snow cover was continuous, except at stake 8, where no snow was recorded. The transient balance for the winter period was measured in snow pits and by depth sounding at the stakes. As there were no signs of heavy melting during the winter the observed distribution of snow cover is probably due to wind drifting. At elevations of about 600 m a.s.l. the 1988/89 annual balance was close to the mean annual balance for the measurement period 1982–89. Stake readings on 14 August show an annual fixed year equilibrium line at approximately 1100 m a.s.l.

The seven year record of mass-balance measurements presently under computation is being related to temperature records collected on the ice (Thomsen, 1985). The data have already been used for calibration of run-off models for the Påkitsoq basin (Braithwaite & Thomsen, 1989) and will be used for future studies of the 'greenhouse effect' (Braithwaite, 1990).

Hot-water drilling and borehole logging

Hot-water drilling to investigate thermal and hydraulic conditions in and beneath the ice was continued. The drillings were made with a new, improved version of the hot water drill described by Olesen & Clausen (1988). The drill was a replacement for the drill lost during operations in 1988 (Thomsen *et al.*, 1989b). Despite minor technical problems with the new drill, nine holes were drilled with a total length of 1872 m, the deepest being 520 m. Eight holes were drilled near the base camp along two profiles on the glacier tongue leading to lake 326 (fig. 1). In all the holes water level dropped several metres below the ice surface either during drilling or when the drill stopped advancing at the bottom of the ice, indicating connection to an englacial or subglacial drainage system. Water level was recorded in all the holes either manually or by dataloggers connected to pressure sensors. In four of the holes continuous readings of water level fluctuations were obtained, whereas only scattered data were recorded in the remaining holes due to freezing problems. The continuous recordings showed a marked diurnal oscillation with higher water levels around 16.00–19.00 hours and minima at 7.00–9.00 hours local time. From the nature of the water level fluctuations there are good reasons to believe that the drill holes made connections to the subglacial drainage system. The measurements show a subglacial water pressure close to the ice-overburden pressure. The generally high water pressure and the observation that the water-ice pressure ratio is very similar from hole to hole confirms assumptions in the modelling of subglacial drainage (Thomsen *et al.*, 1989a).

Englacial temperature

Englacial temperature readings were made with a string of thermistors installed in the ice in 1988 at stake 7, 9.5 km upstream from the ice margin. The temperature readings reveal slightly negative temperatures from −0.1°C to −0.3°C through the ice body from the bottom, decreasing to −2.1°C in the upper fifty metres. In continuation of the 1988 work it was planned to install further thermistor strings at higher elevations on the ice, one at stake 11 and one at an elevation of 1150 m a.s.l., respectively 23 km and 41 km upstream from the ice margin. Reconnaissance showed that drilling at the 1150 m position was impossible because there was over half a metre of slush on the surface at this part of the ice sheet. At stake 11 a hole was drilled to a depth of 520 m, which is close to the bottom according to the radio-echo sounding measurements (Thorning & Hansen, 1987). The advance of the drill slowed considerably in the depth interval 175–250 m, but increased again below this depth. The reason for this is not obvious as no debris layers are expected at this depth and elevation on the ice sheet. Installation of the thermistor string in the hole failed because the cable stuck at the same depth and had to be cut after several unsuccessful attempts to free it by drilling along the cable to enlarge the hole.

Palaeoclimatic and dynamic investigations

Ice samples for stable isotope analysis were collected along a profile transverse to the ice margin at the glacier lobe ending in lake 326 (fig. 1). The profile extended from the ice edge and 1000 m up-glacier from this. Samples were taken at every 20 m. The sampling was a part of the mapping of Wisconsinan ice along the ice margin at the Pâkitsoq ice sheet sector. The samples collected will be analysed for $\delta^{18}O$ at AWI. Stake readings and redrilling of stakes for mass balance and velocity measurements were also carried out near the ice margin south of lake 326. This work is part of the close cooperation with AWI who undertook a similar ice margin programme in North-East Greenland also in 1989 as part of GGU's expedition to the area (Henriksen, 1990).

Observations in connection with tapping of lake 326

Lake 326 is impounded in a broad valley along the margin of the Inland Ice (fig. 1) and dammed by ice in its north-eastern part. At an elevation of 326 m a.s.l. the lake has a natural outlet over a bedrock threshold in its northern part where water drains to lake 187. This drainage has been stable for at least 41 years as determined from aerial photographic study. On arrival in the area on 30 July 1989 it was observed that lake 326 had been tapped (fig. 2), the water level had dropped 14.5 m which corresponds to a water loss of 30×10^6 m^3.

Greenland Technical Organisation (GTO) who operate a water level recorder at the outlet of lake 187, recorded an unusual increase during the period from January to May (Ole Smidt, GTO, personal communication). There are good reasons to believe that this marks the time of the lake tapping although further calculations and interpretation of the hydrograph are underway. The lake level was stable during our three week stay on the ice in August. Following the drop in lake level the earlier natural water outlet has dried out but a large river has started draining from the ice margin, about 650 m north of the lake 326 (fig.1). The water drains through a waterfall to lake 187. From present knowledge it seems likely that the water drained out of lake 326 beneath the ice until a critical water level was reached and drainage stopped. The later spring flow took this new drainage path and water now drains out

Fig. 2. View from the ice over the tapped lake 326. The earlier water level is seen as the light coloured zone along the lake shore.

from the lake beneath the ice. However, it is too early to discuss details in the draining mechanism before more data are collected. During the field work a water level board was painted on the rocks so that possible future water level changes in the lake can be easily recorded.

Lakes 187 and 233 have been proposed as reservoirs for the hydropower plant. The tapping from lake 326 has no serious consequences for the proposed project as the water from the lake still drains to lake 187. However, in case of a closing off of the new drainage path, the lake will need to fill up to its earlier natural level before water again flows to lake 187. Earlier discharge measurements from lake 326 (GTO, 1986) indicate that such a filling will take about 2 years for the difference in level of 14.5 m.

Reconnaissance studies

In connection with the mass-balance measurements, T. Konzelmann examined the conditions for a possible future Swiss project of energy-balance measurements at the equilibrium line which would include air-turbulence measurements on a 30 m tower and ultraviolet radiation studies.

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