Ice drilling and mass balance at Pâkitsoq, Jakobshavn, central West Greenland

Henrik Højmark Thomsen, Ole B. Olesen, Roger J. Braithwaite and Carl Egede Bøggild

Hot water drilling and mass-balance measurements were made on the Inland Ice at Pâkitsoq north-east of Jakobshavn. Two arrays of moderate and shallow-depth thermistor strings have been installed in the ice to map the englacial temperature from the ice margin to the equilibrium line. Water fluctuations were observed in a drill hole connecting to the ice bed. The measurements indicate a high subglacial water pressure close to the ice overburden pressure.

H. H. T., O. B. O., R. J. B. & C. E. B., Geological Survey of Greenland, Øster Voldgade 10, DK-1350 Copenhagen, Denmark.

Glaciological field work was carried out in 1990 on the Greenland ice sheet margin at Pâkitsoq north-east of Jakobshavn, West Greenland (Fig. 1). From 7th to 13th May the study area was visited daily by helicopter while field work was supported from a base camp on the ice in the period 29th July to 19th August. The glaciological research in the Pâkitsoq area was started by the Geological Survey of Greenland (GGU) in August 1982, to aid planning of hydro-electric power for Jakobshavn, and the continuous studies since then have involved a number of different fields within glaciology (Thomsen *et al.*, 1989). GGU's activities at Pâkitsoq, combined with inland investigations along the EGIG-line (Expédition Glaciologique Internationale au Groenland) just north of the basin, make the area one of the best studied sectors of the Greenland ice sheet. This has attracted international attention, and researchers from several countries have initiated research or made reconnaissance studies there (Thomsen *et al.*, 1989; Thomsen & Olesen, 1990). The combined efforts in the area have extended the existing basis for hydropower planning and contribute to international work on ice-climate relationships. In 1990 GGU collaborated with teams from the Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany, and the Swiss Federal Institute of Technology (ETH), Zürich, Switzerland.

Initiation of Swiss ice sheet project

A Swiss research project on glacier-climate interaction was started in the Pâkitsoq area in May 1990 by a group from ETH. Energy-balance measurements at the equilibrium line were made from a permanent field station on the ice. GGU provided basic data and advised in the logistic planning of the project as well as assisting in the reconnaissance and site selection for the station. A programme for ice-temperature measurements was also set up by GGU in collaboration with the Swiss project.

Ice drilling and englacial temperatures

In May 1990 a thermistor string TS1 was drilled into the ice to a depth of 10 m close to the ice margin near lake 326 (Fig. 1). Thermistor temperatures were read by a data logger connected to the string. The work was carried out in collaboration with N. Reeh and H. Oerter from AWI who are making stable isotope studies on the ice margin at this location for palaeoclimatic investigations (Reeh *et al.*, 1989). The latter includes sampling of surface ice and shallow ice coring (Oerter *et al.*, 1990). The purpose of the temperature registration is to detect the penetration of the zero degree isotherm into the ice to evaluate the depth to which ice composition could be influenced by surface meltwater. Ice temperatures were recorded every six hours in the period 12th May to 15th August. Taking into account ablation during the recording period and the accuracy of the temperature sensors (± 0.2°C), the zero degree isotherm penetrated to a depth between 0.7 and 1.2 m below the surface by 15th August.

In August several drillings were made on the ice to measure englacial temperatures and to investigate the subglacial drainage system. The work was carried out

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from a base camp located on the Inland Ice at an elevation of 560 m a.s.l. about 8 km from the margin (Fig. 1).

Englacial temperatures to moderate depths were measured by GGU at three different locations in the area (Fig. 1). Two thermistor strings, TD1 and TD3, situated at an elevation of 455 and 615 m a.s.l. respectively, reached the bottom of the ice. The ice thickness at the two locations was 300 and 350 m. Thermistor TD2 is located at an elevation of 490 m a.s.l. and reached a depth of 202 m. The ice thickness at this location is 470 m according to the latest improved ice thickness map based on radio-echo soundings in 1985–1987 (Thorning & Hansen, 1987). This is significantly different from the ice thickness of 300 m quoted in Thomsen (1988) based on an earlier version of the ice thickness map. The temperature readings at all locations revealed slightly negative temperatures throughout the ice body with a minimum temperature of −2.1°C (Thomsen, 1988; Thomsen & Olesen, 1990).

As a continuation of the 1989 field season new attempts were made to install further thermistor strings at higher elevations, an enterprise favoured by good conditions on the ice in 1990. Drillings were made using the GGU hot-water drill described by Olesen (1989). Two thermistor strings TD4 and TD5 were installed to depths of 500 and 600 m respectively. TD4 is located at an elevation of 965 m a.s.l and TD5 at the Swiss field station at approximately 1140 m a.s.l. (Fig. 1). The ice thickness at location TD4 was expected to be around 500 m, but drilling was made to 600 m without reaching bedrock; this was the deepest that could be reached with the available supply of drill hose. The discrepancy in ice thickness is not surprising because of the limited coverage of radio-echo data at this elevation of the ice sector (Thorning & Hansen, 1987).

The Swiss station was located just outside the area covered by the GGU radio-echo soundings. However, from an extrapolation of the GGU data and sparse radio-echo data from Overgaard (1984), an ice thickness of 1000 m would be a reasonable guess for this location. A 50 m thermistor string was drilled here for the Swiss team to extend their mapping of shallow depth ice temperatures.

To extend the mapping of shallow depth ice temperatures over the whole ablation zone at Påkitsoq two additional thermistor strings, TS2 and TS3, were drilled to a depth of 14 m. TS2 and TS3 are located at elevations of 615 and 890 m a.s.l. (Fig. 1). Temperature readings will be made in the spring of 1991.

Ice drilling and water pressure measurements

Hot-water drillings for investigating the subglacial drainage system were made in the vicinity of the GGU

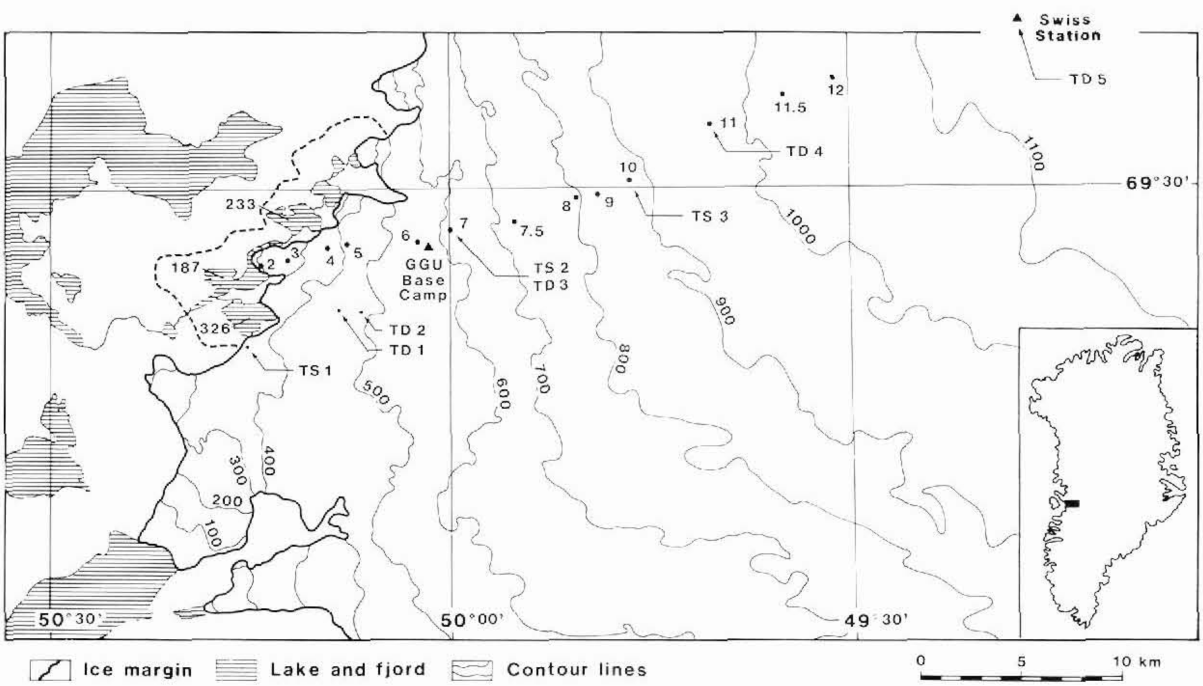

Fig. 1. Drainage basin at Påkitsoq showing stakes for measuring mass balance. Contours are in metres. Locations are marked of shallow depth (TS) and deep (TD) thermistor strings used for measuring englacial temperatures.

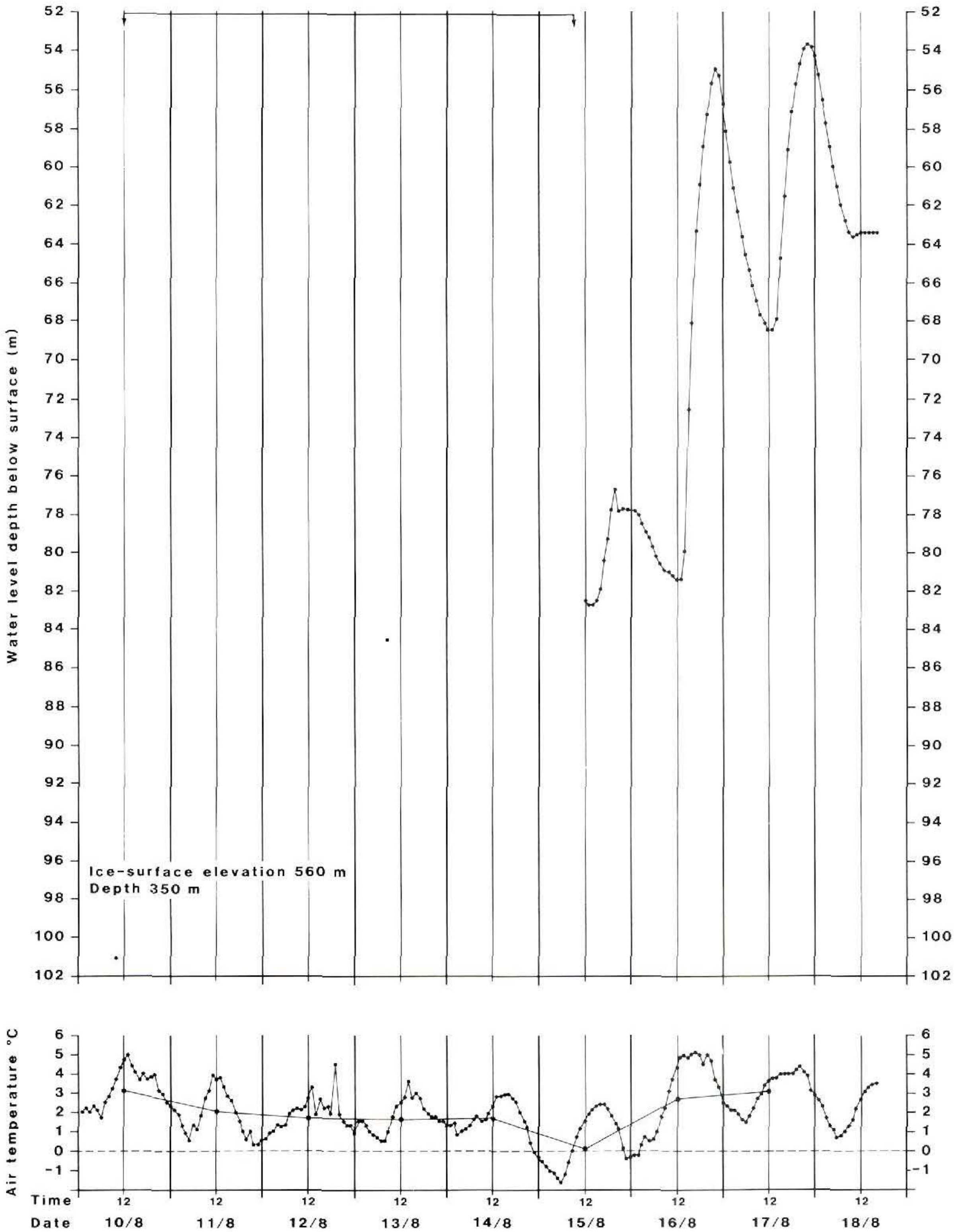

Fig. 2. Upper diagram shows water level recordings in borehole, August 1990. Vertical arrows connected with a bar indicate period when surface water was led to the borehole. Lower diagram shows measured air temperature at two metres of elevation. Straight lines are daily mean air temperatures.

base camp (Fig. 1). According to radio-echo soundings the ice thickness in the area varies from 360 to 400 m. Three holes with depths of 354, 254 and 217 m were located on a local ridge on the ice surface. From registration of the drill advance and readings of a load cell measuring the tension of the drill hose it is believed that the deepest drilling (354 m) reached the bottom of the ice sheet. The two remaining holes probably stopped at a debris horizon in the ice. No draining of the water took place in the boreholes. Explosives were detonated in the 354 m hole in an attempt to force a connection to the subglacial drainage system but without success.

Three further holes were drilled nearby in a local depression of the ice surface. All holes reached the bottom at depths of respectively 341, 347 and 350 m. In all cases water level dropped several metres when the drill stopped advancing at the bottom of the ice. To prevent the holes from freezing small surface streams were directed to drain into the holes, but despite these counter measures only the 350 m hole remained open. An explanation for this could be that an insufficient supply of surface water was directed to the other holes; the 350 m hole was fed by a stream with an estimated discharge of 0.05 m^3/s and the remaining two holes received only 0.01 m^3/s. Water level was recorded in the 350 m hole after stopping the water supply to the hole. The recordings were made manually by detecting the water level from the surface and by a data logger connected to a pressure sensor installed in the hole. At the same location air temperatures were recorded at two metres above the ice surface.

The continuous recordings showed a marked diurnal oscillation in water levels with higher levels at 20.00–22.00 hours and minima at 12.00–13.00 hours (Fig. 2). From the nature of the recordings there is good reason to believe that the drill hole connected to the subglacial drainage system. The maximum and minimum registrations in the continuous record correspond to a basal water pressure of 94 and 85 percent of the ice overburden pressure. This is comparable with measurements made further downstream on the ice in 1988 and 1989 (Thomsen & Olesen, 1991). The water level variation seems to follow the variation in air temperature but with a delay of 2 to 5 hours between maximum air temperature and maximum water level. Two single measurements in the borehole, made while a stream was flowing into the hole, showed the lowest water levels recorded; there is no obvious explanation for this. The daily mean air temperatures in this period were close to the mean for the measuring period, and gradual freezing around the pressure sensor can be excluded as control measurements of the water level from the surface were in agreement with the sensor data.

A more detailed analysis of the data is needed to make any conclusion about the type of drainage system responding in the way described.

Mass-balance measurements

The stakes (Fig. 1) established for mass-balance measurements in earlier years were visited by helicopter on 10th May and 15th August. Winter snow cover on the ice at the beginning of the season showed a similar pattern to earlier years. Snow cover was very patchy and confined mainly to drifts in gullies and crevasses up to an elevation of about 500 m a.s.l. At higher elevations snow cover was continuous. As no signs of melting were observed the distribution of the snow cover is probably entirely due to wind drifting. The transient balance for the winter period was measured in snow pits and by depth sounding at the stakes. The measurements of transient balance for the summer period refer to changes in elevation of the glacier surface in relation to the stakes. These surface changes are converted into water equivalent on the basis of density measurements in nearby snowpits and by assuming an ice density of 900 kg/m^3.

Previous years' measurements of the mass balance showed the annual equilibrium line to be about 1100 m a.s.l. The uppermost stake (stake 12), at an elevation of 1070 m a.s.l., showed an annual balance of −621 mm for the period 14th August 1989 to 15th August 1990. This is the highest ablation recorded at this elevation since 1985 when measurements were started at this stake location. Extrapolation of the mass balance data to elevations higher than stake 12 indicates an annual equilibrium line to be about 1160 m a.s.l.

A reconnaissance was made for a future study of mass balance conditions in the lower accumulation zone at Pâkitsoq. A stake net was established from 1100 to 1600 m a.s.l., extending the existing stake line which has been measured since 1982. The work is aimed at a study of melting, refreezing and runoff to estimate expected sea level changes due to global warming arising from the greenhouse effect.

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