DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/14

Glacier Ice as resource for freshwater export

Investigation of four glaciers from the Greenland Inland Ice. Field work and analysis

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Contents

0. Resume

During 2005 and 2006, GEUS investigated several glaciers in west and south Greenland regarding possible freshwater extraction for bottled water export. The investigations were carried out for Greenland Home Rule, Department of Industry, Agriculture and Labour.

During the summer of 2006, field investigations were carried out and ice samples were collected from four glaciers (Russell Glacier, Narsap Sermia, Nigerlikasik Bræ and Sermilik Bræ) that all fitted the criteria for selection of glaciers (ice-age, purity of the ice concerning sediment content and the accessibility to the glaciers, etc.).

Beside collection of ice samples for analyses, the field work included collection of information on topography, morphology and geology of the landscape in front of the glaciers, the glacier morphology etc. to verify and supplement interpretations made from air photos and satellite images. The physical conditions were described on location and documented by lots of photos and videos.

Russell Glacier
The ice is likely between 5,000 and 12,000 years old. At present, the ice margin is retreating at a modest rate.

Owing to lots of sediments in the inner part of Søndre Strømfjord, it is not possible to navigate any longer than Camp Lloyd. From this harbour a road leads to Kangerlussuaq and from Kangerlussuaq Russell Glacier is easy to access. A road leads directly from Kangerlussuaq and very close to the glacier front. The final c. 100 meters is marked by irregularities caused by melting dead-ice. The zone between the road and the glacier is easy to cross and it is unproblematic to move around on the glacier surface.

The content of chemical compounds and bacteria is low in the ice water. One value of ammonia extends the EU standard for drinking water. However, all values are within what are used for mineral water.

Narsap Sermia
The ice is between 5,000 and 12,000 years old. The glacier front is rather stable.

Navigation on most of the Nuup Kangerlua (Godthåbsfjord) is unproblematic for people with local knowledge. Due to significant danger from ice calving and densely packed calving ice in the fiord, it is neither possible nor advisable to approach the glacier front by boat. It is necessary to land a boat several kilometres from Narsap Sermia and cross the point of Narsaq. To access the glacier itself, it is necessary to cross a large lateral moraine because the cliffs are rather steep further alongside the glacier. The glacier is strongly crevassed and it is possible but not unproblematic to move around on the glacier surface.

The content of chemical compounds and bacteria is low in the ice water. It is below the EU drinking water standard and below values used for mineral water.

Nigerlikasik Bræ

The ice is between 5,000 and 12,000 years old. The glacier front is rather stable.

There is a good access to Nigerlikasik Bræ. It is possible to navigate and land very close to the glacier front that can be reached from both sides of the fiord. And it is easy to cross the flat foreland in front of the glacier and to move around on the glacier surface as well. The calving rate is very modest.

The content of chemical compounds and bacteria is low in the ice water. One value of ammonia extends the EU standard for drinking water. However, all values are within what are used for mineral water.

Sermilik Bræ

The ice is between 6,000 and 12,000 years old. The ice margin might thin more until stable configuration is found.

Sermilik Bræ is not easily accessible. Even though the calving rate is very modest, a strong current in the fiord and very steep cliffs make landing close to the glacier problematic. The landscape between the fiord/landing site and the glacier is marked by rather steep cliffs and loose blocks. It is difficult to cross the very soaked, muddy zone between the cliffs and the glacier itself, but it is easy to move around on the glacier surface.

The content of chemical compounds and bacteria is low in the ice water. It is below the EU drinking water standard and below values in water used for mineral water.

1. Introduction

During 2005 and 2006, the Geological Survey of Denmark and Greenland (GEUS) assessed several glaciers in western and southern Greenland for their freshwater extraction potential for bottled water export. This investigation was conducted for the Greenland Home Rule and the Department of Industry, Agriculture and Labour.

1.1 Background

GEUS databanks and archives coupled with glaciological knowledge of the Greenland Inland Ice provided the basis for detailed description of 42 glaciers from the Inland Ice, for the selection of four localities for field work and for collection of ice samples during the summer 2006. Since the quality of ice water is an important parameter regarding extraction potential, all of the ice samples were analysed for chemical and bacteriological components. The study reveals how the combined physical, chemical and biological characteristics can be used in recognizing suitable glaciers for ice water extraction.

1.2 Criteria for selection of glaciers

Important criteria (Bøggild et al. 2000, Bender et al. 2003a, Ahlstrøm et al., 2006) in the selection of glaciers from the Inland Ice were:

- The ice should be pure without major sediment content, refrozen blue-ice and major joints.
- Chemical and bacteriological components in the ice water must be within an acceptable level relative to EU levels for natural mineral/drinking water.
- Distance from the sea shore or the fiord should be less than 10 km.
- Accessibility to the glacier should be good with low calving activity and subdued terrain.
- Transport distance to towns (manpower, transport, infrastructure etc.) should be as short as possible.

Further, animal life, archaeological sites,and fishing and hunting activities must be considered.

In west and south Greenland, a total of 5692 glaciers flow toward the coast from the Inland Ice. The glaciers are registered in the GEUS inventory, database and glacier atlas (Weidick et. al. 1992). Based on the selection criteria, 42 glaciers south of 67^{o} N were chosen and described in more detail (Ahlstrøm et al. 2006, Mayer et al. 2003).

The descriptions document the name and location, identification-code, aerial photographs, satellite images, co-ordinates, orientation, longitudinal profile, highest and lowest points, area, glacier form, front characteristics, major source of nourishment, glacier advances or recessions, geology, terrain conditions and accessibility for each glacier. The age of the glaciers was evaluated in general terms. Chemical analysis exists for only a few glaciers. For each glacier, the description is followed by a nominal evaluation of the ice water potential, described as suitable, partly suitable or less suitable. Subsequently, four glaciers were selected for sampling and analysis (Fig. 1.1).

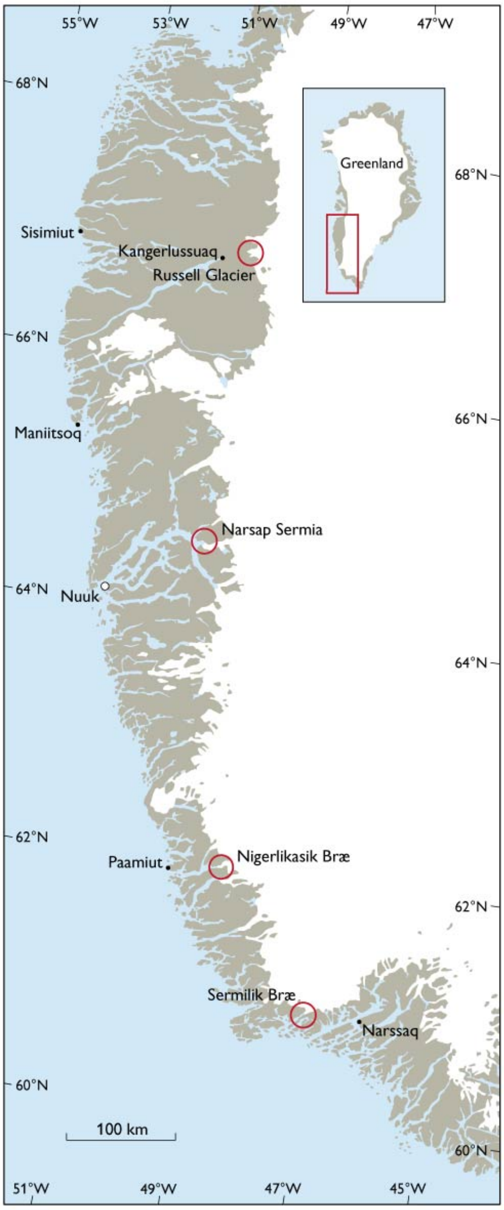

Fig. 1.1. Location of the investigated glaciers.

Russell Glacier, Kangerlussuaq, West Greenland.

The site under consideration is actually the ice sheet margin north of Russell Glacier.

Russell Glacier was chosen because the nearest town, Kangerlussuaq, is located only 35 km from the glacier.

Narsap Sermia, Nuup Kangerlua (Godthåbsfjord), West Greenland

Narsap Sermia was chosen for its glaciological conditions and close proximity to Nuuk.

Nigerlikasik Bræ, Nigerlikasik fiord, Kuanersôq (Kvanefjord), West Greenland

Nigerlikasik Bræ was chosen because of the access from the fiord Nigerlikasik, a side fiord to Kuanersôq, and because of the modest calf ice production. The nearest town, Paamiut, is located at an acceptable distance from the glacier.

Sermilik Bræ, Sermilik fiord, South Greenland

Sermilik Bræ was chosen because of the access from the fiord Sermilik, a modest calf ice production and a medium velocity and flux. Moreover, the distance between the glacier and Narsaq as well as other town in south-western Greenland is fairly modest.

1.3 Purpose of field work

The purpose of the field work was to collect central information about the physical conditions near the four target glaciers and to collect ice samples for analyses.

Field information was collected in order to verify and supplement interpretations made from air photos and satellite images concerning the landscape topography, morphology and geology and glacier morphology. The transportation between the towns and the glaciers (apart from Russell Glacier) was made by boat in order to document the navigational conditions within the fiords and the landing conditions close to the glacier fronts.

2. Investigations methods and instruments

2.1 Transport

The transport between the towns and the glaciers were made by boats (or car) in order to make observations of the navigation conditions in the fiords and of the landing conditions near the glaciers. Moreover, this navigation with local people and boats fostered valuable information to the project on ice and tide conditions etc.
The trip between Kangerlussuaq and Russell Glacier was made in a 4WD car hired from Per Mikkelsen, Air Greenland.
The trip between Nuuk and Narsap Sermia was made in a 25 ft. cabin cruiser, chartered from Michael Lüberth, Nuuk.
The trip between Paamiut and Narsap Sermia was made in a Flipper cabin cruiser, chartered from Betonkompagniet, Paamiut.
The trip between Narsarsuaq and Sermilik Bræ was made by a small traditional cutter, M/S J.F. Johnstrup from Kristian Egede, Narsaq. The speed was only about 8 knots and it was necessary to lie at anchor most of the night *c.* mid between Narsarsuaq and Sermilik Bræ, a total distance of about 150 km and about 100 km from Narsaq respectively.

2.2 Data collection and instruments

Data collection included field observations and photo and video documentation of the fiords, the landing sites, the areas between the landing sites and the glaciers, the glacier front and the glacier surface. Glacier ice samples were collected for further analyses.

Because all fieldwork equipment (tools, cameras, notebooks, ice samples, storage boxes, reserves of food and clothes, plus a minimum of “survival gear” etc.) had to be manually transported in rucksacks, there was a maximum limit regarding the number, type and weight of the gear.

2.2.1 Field observations and notes

Field observations were written in notebooks/field books. The notes included in situ observations as well as information on navigation conditions etc. given by the skipper. The field observations were collected in order to verify correct and supplement the aerial photograph interpretations and other kind of existing data. The notes included e.g. the steepness of the landing sites, the topography, morphology and geology of the landscape at the landing site and between the landing site and the glacier margin, the glacier morphology etc. The notes are included in the descriptions of the individual glaciers (section 7) and in the time/activity scheme (Appendix 3).

2.2.2 Camera, video and GPS-models

Numerous photographs and panoramic series were taken at the four areas visited using Canon digital cameras with minimum 5 mega pixels. Specific camera models were: Canon IXUS 50, Canon IXUS 500, Canon PowerShot S3 IS and Canon PowerShot Pro1. At least one video sequence was also taken at each location using a JVC G2-MG26E video recorder.

GPS models were established using Garmin, eTrex, and eTrex Legend devices..

2.2.3 Ice sampling, storage and transport

Ice samples were collected from the glacial surface and approximately 15 to 50 cm below the surface, where the ice quality was applicable for analyses. Specific sampling locations were selected to fit the demands of commercial reclamation of the ice, e.g. the shortest transport way between a possible landing location and ice of a usable quality.

All sampling positions were measured by GPS, with two GPS-positions typically recorded at each location. The sampling positions are listed together with the landing (and parking) positions in Appendix 4.

The easiest and quickest way to remove a sample of glacier ice is by means of an electric or fuel driven power chain saw. However, the electric saw was forfeited because it was impossible to carry a generator to the glaciers and whereas the fuel driven saw was not practical due to the pollution risk.

Consequently, a handsaw was first selected to assist in the removal of ice samples. Unfortunately, the handsaw was useful only in the outermost crumbling part of the ice, which was full of cracks and fissures and therefore of little value. Below the crumbling ice layer, about 15 cm below the surface, the ice was solid and suitable for sampling. Given the itegrity of the ice, it was impossible to manually sample with a handsaw. The point of the saw was then used to “file” out the ice samples, see Fig. 2.1. This approach yielded ice samples from two sites at Russell Glacier, but only after 5½ hours of intense sawing by four people.

Fig. 2.1 Very slow ice sampling at Russell Glacier, site 1. The ice was “filed” out by means of the point of the saws.

At the next glacier, Nigerlikasik, the equipment was supplemented by a battery-powered compass saw and two bricklayer's hammers and chisels. The compass saw was no better than the hand saw. The saw teeth were filled with ice and the battery was depleted rather quickly.
The bricklayer's hammers and chisels, however, yielded success. A broad furrow was simply hammered at the sides, back and below a rectangular “lump” of ice, see Fig. 2.2. By this method, two ice samples were collected at Narssap Sermia following 3½ hours of work by three people. This method was used afterwards and the time comsumption on Nigerlikasik Bræ and Sermelik Bræ was much the same size as for Nigerlikasik.

The rectangular blocks of ice measured about 50x30x20 cm to fit into the transport boxes. Before the ice was packed in the boxes, the ice lumps were sub-divided into smaller lumps (30x15x10 cm)(Fig.2.3) that fitted into the plastic bags, see Fig. 2.4. The ice samples were packed in ex-pected sterile RILSAN plastic bags and stored in polystyrene boxes to keep frozen during trans-port and storage. The boxes were carried from the landing position to the glacier and back again on carrying frames from large rucksacks (Fig. 2.5).

The polystyrene boxes were sent back to GEUS as (frozen) cargo from Kangerlussuaq, Nuuk, Paamiut and Narsaq. The ice samples were stored at GEUS laboratory at – 18° C until they were examined.

Fig 2.2 Ice sampling by means of a bricklayer's hammer. A broad furrow was hammered at the sides, at the back and below a rectangular “lump” of ice. Sampling situation from Narsap Sermia, site 1.

Fig. 2.3 The ice sample was split into minor lumps. Sampling situation from Narsap Sermia, site 1. The battery-powered compass saw in the foreground was unusable for ice sampling.

Fig. 2.4 .The ice samples were packed in expected sterile RILSAN plastic bags and stored in polystyrene boxes to keep frozen. The picture shows the very first sample from Russell Glacier, sampling site 1.

Fig. 2.5 The boxes were carried from the landing position to the glacier and back again on carrying frames from large rucksacks

2.2.4 Procedures for analysis of ice

Ice-samples were melted under sterile conditions and transferred to purified bottles and kept cooled before further analyses.

Inorganic nutrients:
Water samples were analysed for anions and cations on an ion chromatograph (Dionex DX-500 with either a AS14 or a CS12A column). Methods used were calibrated to low concentration standards (< 5 mg/l).

For ammonia and phosphate additional analyses were made using spectrophotometric methods. Ammonia was determined by indophenol-analyses and phosphate by phosphomolybdate method.

PAH and PCB - Eurofins method MK 2260:
The water sample is acidified to pH 2 and extracted three times with dichloromethane. The extracts are combined and concentrated by gentle evaporation. The analysis is done by gas chromatography with mass selective detection (GC-MS). The calculation is calibrated using 5 deuterated PAH and PCB-77 as the internal standards.

The limit of detection is 0.005 µg/litre for a single compound. The uncertainty measured as % RSD is 12% for PAH and 15% for PCB.

Pentachlorophenol - Eurofins method MK 2233:
The water sample is made alkaline, and the phenols are derivatized by extractive acetylation. The extract is concentrated by gentle evaporation. The analysis is done by gas chromatography with mass selective detection (GC-MS). The calculation is done by internal standard calibration using deuterated pentachlorophenol as internal standard.
The limit of detection is 0.02 µg/litre. The uncertainty measured as % RSD is 10%.

Pesticides by multicomponent analysis - Eurofins method MK 8212:
The water sample is extracted by solid-phase extraction (SPE), the extract is concentrated by gentle evaporation and analysed by LC-MS/MS, LC-MS and GC-MS. The calculation is done by internal standard calibration using deuterated internal standards.
The limit of detection is 0.01-0.02 µg/litre for the single compounds. The uncertainty measured as % RSD varies from 15% to 20%.

Desethyl desisopropyl atrazine - Eurofins method MK 8211:

The water sample is extracted by solid-phase extraction (SPE), the extract is concentrated by gentle evaporation and analysed by LC-MS. The calculation is done by internal standard calibration using a deuterated internal standard.

The limit of detection is 0.01 µg/litre. The uncertainty measured as % RSD is 20%.

2,6-dichlorobenzoic acid – Eurofins method MK 8213 :

The water sample is analysed by on-line solid-phase extraction (SPE) followed by LC-MS. The calculation is done by internal standard calibration using a deuterated internal standard.

The limit of detection is 0.01 µg/litre. The uncertainty measured as % RSD is 10%.

Trichloroacetic acid (TCA) - Eurofins method MK 2277:

The water sample is extracted by solid-phase extraction (SPE). After methylation the methyl ester is analysed by gas chromatography with mass selective detection (GC-MS). The calculation is completed using internal standard calibration.

The limit of detection is 0.01 µg/liter. The uncertainty measured as % RSD is 7%.

Glyphosate and AMPA - Eurofins method MK 2275:

The water sample is extracted by solid-phase extraction (SPE) followed by clean-up on a second column. After two derivatizations the derivates are analysed by gas chromatography with mass selective detection (GC-MS). The calculation is accomplished using internal standard calibration.

The limit of detection is 0.01 µg/litre. The uncertainty measured as % RSD is 15%.

Glyphosate and AMPA - Eurofins method MK 8270:

The water sample is analysed by derivatization by FMOCCl. The derivates are concentrated by on-line solid-phase extraction (SPE) and analysed by LC-MS. The calculation is done by internal standard calibration using a deuterated internal standard.

The limit of detection is 0.01 µg/litre. The uncertainty measured as % RSD is 7%.

Total bacterial counts:

Ice was melted and cells were concentrated on 0.2µm nucleopore filters. The filter were placed on an aqueous solution of the DNA stain DAPI that intercalates with RNA and DNA in the cell and makes the cell blue fluorescent. 30 vision areas of the filter were counted and the average numbers of bacterial cells were calculated.

The staining and counting of small bacteria is difficult, which probably leads to an underestimate of the cell numbers.

Viable bacteria:

Ice were melted and 100 µl were immediately plated in triplicate on 1/10 TSA agar with Natamycin to avoid fungal growth. 1/10 TSA consist of pr litre: 3 g of TSB (difco 0370-17-3) and 15 g agar (difco 213830) and water to 1 litre. pH is adjusted to 7,3+/-0.2 and autoclaved for 15 min at 121°C. When the agar has cooled to 50°C 0.5 ml of 25 mg/l Natamycin is added and the plates poured. Agar plates is incubated at -2°C, 4°C 10°C and 20°C and read every week (week 2 and 5 is presented).

3. Background data

A wide range of available information was scrutinized prior to the field operations and used in the field to locate the most accessible glacier ice at each site. Subsequently, this background data helpful in inertpreting the new data collected from each site. The following paragraphs describe the different types of background data that were used

3.1 Satellite images

Satellite imagery is useful in conducting visual surveys of remote locations, like the four sites visited as part of this investigation. Generally, the limitations are given by the temporal coverage and the resolution of the images. Satellite imagery is available from the 1960s until present-day, with substantial new data in recent years. With the notable exception of declassified military imagery (e.g. Corona), the imagery has generally gained resolution through time. For estimating glacier front positions of large outlet glaciers in Greenland, relatively coarse resolution images are sufficient. A pixel resolution of 250 metres in the MODIS (Moderate Resolution Imaging Spectroradiometer) defines the lower limit for the purpose of estimating glacier front positions. Images from finer resolution instruments such as Landsat TM/ETM+ (30 m/15 m), SPOT (20 m), ASTER (15 m) and IKONOS (2 m) represent further possibilities in terms of landscape interpretation and precision at the expense of a smaller image size and higher cost. In support of the fieldwork, imagery from Landsat and ASTER were used, as these images possessed sufficient while maintaining the overview qualities of a traditional map. For the subsequent landscape interpretation, high-resolution images have been specifically ordered from IKONOS and an airborne survey (depending on location).

Fig. 3.1. Part of a Landsat 7 ETM+ browse image, including the Nigerlikasik Glacier close to Paamiut.

3.2 Aerial photos

Aerial photography provides the means for accurate landscape characterization and interpretation, but is not always available or is too costly to acquire specifically. In the present case, it was possible to use paper copies of aerial photographs taken during mapping surveys in the 1980s. These photos where acquired as stereo-photogrammetric images, implying that they can also be used for production of digital elevation models (DEM's). Naturally, the DEM will be tied to the time of acquisition of the photo. Thus the DEM's provide a strong tool for estimating the ice-marginal elevation changes over time if compared with a DEM produced with present-day data. It has been possible to locate useful B/W paper copies of high-resolution aerial photos to assist the planning and conduction of the fieldwork. The resolution of such imagery is on the order of decimetres. Additional photographical material has been collected from helicopter surveys over the glaciers investigated. Such recent and close-up photos are very informative and are useful in revealing feasibility issues.

Fig. 3.2. Example of a photo taken from helicopter. The glacier front of Narsap Sermia in Godthåbsfjorden, West Greenland. View direction towards south. Note the extensive, light-coloured side moraine and the highly crevassed, floating glacier tongue.

3.3 Topographical and geological maps

The mapping effort of GEUS includes generating maps of Quaternary deposits and maps showing the underlying bedrock geology. The maps illustrate the geological conditions in the vicinity of the glaciers. The maps are available in the scales 1:500,000 (Quaternary geology) and 1:500,000/1:100,000 (bedrock geology) (GEUS, 2002).

The National Survey and Cadastre (KMS) have published a series of maps showing geography, terrain, cities and more. Saga maps cover almost all of the area investigated here in the scale 1:250,000 and these maps are available in digital form. In addition, tourist maps exist in selected areas in scales 1:100,000 and 1:75,000 and for a few areas in scale 1:20,000.

Also available is an atlas of environmental sensitivity to oil spill hazards along the coast and fiords of West Greenland from 60°N to 72°N, mapping a number of factors regarding the physical environment and nature that could prove sensitive to oil spill from ships or oil drilling. The region was mapped to the scale 1:250,000 and includes a text and a classification of the sensitivity (Mosbech et al., 2000, 2004).

3.4 Historical photos and descriptions

The glaciological archive at GEUS contains aerial photographs, satellite images, publications as well as notes and data material dating back to 1948. Results from research conducted in GEUS investigations appear in published form as well as unpublished notes and field diaries.

From the end of the 1950s to the beginning of the 1970s, GEUS (then GGU) conducted an identification and registration of all the glaciers in South and West Greenland from Nunap Isua (Kap Farvel) and up to 71°N. This work was conducted using the systematic approach of the WGMS (World Glacier Monitoring Service) for glacier registration worldwide. The glacier database of GEUS follows the international standards for glacier registration (Weidick et al., 1992).

3.5 Previous investigations

A considerable amount of knowledge has been gathered regarding the glaciology of Greenland through nearly 40 years of glaciological research and advisory activities at GEUS. The activities have included ice sheet dynamics, climate-related response and hydropower investigations. This knowledge can be transferred to the relatively recent subject of glacier-ice mined for export purposes, an issue which demands a unification of technical, logistical, economical and environmental factors in order to estimate the feasibility of commercial exploitation of glacier ice.
The task is to combine existing knowledge with new investigations for a highly specific purpose.

Four reports have been published by the Geological Survey of Denmark and Greenland on the subject of mining inland ice for export purposes:

1. Bøggild et al. (2000): 'Indledende lokalisering af grønlandske gletschere med is/vand egnet til eksport', GEUS Report **2000/13** (in Danish, with a map), 30 pp.

2. Mayer et al. (2003): ‘Ice studies in relation to ice/water export, a data collection, modelling and evaluation approach’, GEUS Report **2003/6**, 33 pp.
3. Ahlstrøm et al. (2006): ‘Analyse af gletschere fra Grønlands Indlandsis: Mulighed for anvendelse af gletschere til produktion af is til eksport af flaskevand’, GEUS Report **2006/50** (in Danish), 154pp.
4. Bender et al. (2003a): Drikkevandskvalitet af Grønlandsk indlandis. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2003/26**, 34 pp.

Together the material in these reports constitutes the basis for the fieldwork activities conducted in 2006 and presented here. In Bøggild et al. (2000), 45 glaciers were selected among a total of 5692 glaciers registered in the GEUS glacier database of West Greenland. The underlying criteria were ice of good quality for consumption, nearness of infrastructure, feasibility for shipping and proximity to available work force. In Mayer et al. (2003) these 45 glaciers were narrowed down to four areas of particular interest and supplemented with a modelling study and with data from fieldwork at a representative site. The four areas selected were Sermilik Bræ and surroundings in South Greenland, Avannarleq Bræ east of Paamiut/Frederikshåb, Nakkaasorsuaq in Bjørnesund north of Frederikshåb Isblink and Narsap Sermia in Godthåbsfjord. In the report of Ahlstrøm et al. (2006), a new analysis of glaciers was conducted with basis in the 45 glaciers selected in Bøggild et al. (2000) supplemented with two more. Three specific glaciers were recommended for further investigations, namely Sermilik Bræ in South Greenland, Nigerlikasik Bræ in Kuaersôq/Kvanefjord near Paamiut/Frederikshåb and Narsap Sermia in Godthåbsfjord near Nuuk. The recommendations of Ahlstrøm et al. (2006) were followed in the final selection of fieldwork sites. These three sites were supplemented by one more site: Russell Glacier near Kangerlussuaq.

4. Site-related and, ongoing investigations

Generally, three types of investigations relevant to the current issue of export of glacier ice take place: Commercial investigations, research activities and monitoring efforts. However, these different types are often mixed in Greenland. Commercial investigations are typically related to geological mapping or hydropower feasibility studies. The latter is more relevant here as hydropower in Greenland is often connected to glaciers and the Inland ice. Hydropower pre-feasibility studies have not been carried out exactly at any of the four sites investigated in this report. However investigations in the vicinity are also relevant as many glaciological parameters collected during the hydropower investigations in glaciated landscapes could become relevant to the current activity. In terms of research, current activities of immediate interest will be in focus. With regard to monitoring, DMI (the Danish Meteorological Institute) has the longest time series of weather data from the towns, which are almost exclusively coastal, sometimes extending back more than one hundred years. It is important to note that coastal conditions may be quite different from ice margin conditions due to the effect of continentality (i.e. distance from the sea). In many cases, ASIAQ/The Greenland Survey have been operating automatic climate/gauging stations in catchments near the Inland ice, but the data series extend to 1975 at most, with some stations recording for much shorter periods. GEUS has carried out glaciological monitoring at a few sites in western and southern Greenland, notably in the 1980s. This glaciological monitoring has now been re-initiated and extended to seven sites around the Greenland ice sheet margin. Two of those sites are located near the sites investigated in this report (i.e. Narsap Sermia and Sermilik Bræ).

<u>North of Russell Glacier:</u>

The Kangerlussuaq region has not been investigated for hydropower feasibility, but 70 km southwards lies the Tasersiaq basin with the largest hydropower potential in Greenland. This basin has been monitored by ASIAQ for discharge and climatology since 1975 and several glaciological campaigns have been carried out by GEUS, notably during the periods 1982-1990 (on Amitsuloq ice cap) and 1999-2003 (on the ice sheet margin). The ice margin near Russell Glacier has been investigated glaciologically for research purposes by Utrecht University since 1990, mostly to measure the surface melting and related processes. Many other smaller research projects have also been conducted since access from the airport is straightforward. DMI has monitored weather in Kangerlussuaq Airport since 1975 and even further back in Sisimiut at the coast.

<u>Narsap Sermia:</u>

The melting and surface climate of the glacier was monitored by GEUS during 2002-2005. The neighbouring glacier Qamarnarsup Sermia was monitored by GEUS during 1979-1987, an effort that will start again from 2007 and onwards. A new monitoring station, Nuuk Basic, has been established and will monitor climate, marine environment and ecology at a site in the Godthåbsfjord inland region from 2007 and onwards. DMI has monitored weather in Nuuk since 1890.

Nigerlikasik Bræ:

The ice margin north of Nigerlikasik Bræ has previously been considered for hydropower production for the town of Paamiut, and this effort has recently been re-activated. GEUS produced a report on the glaciological aspects of hydropower production in the area in 1982, but conclusions were mostly based on parallel investigations in southern Greenland and further north, near Nuuk. Currently, the fiord deposits are utilized for gravel extraction from ship, gravel which is in turn used for concrete production. DMI monitors weather in Paamiut and ASIAQ currently has an automatic climate station operating in a nearby catchment.

Sermilik Bræ:

The Sermilik Bræ has lately been the subject of some research activity, due to its strong recession of 5 km. The glacier and the ice margin behind it have been monitored by GEUS since 2001 and will continue to be monitored. It has been the subject of a PhD-thesis (Podlech, 2004) and is currently being investigated by British and US research teams. An automated camera has been installed in 2006 to obtain daily images of the glacier front. Calved icebergs are being ”fished” from the fiord of Qalleraliit Sermia, the neighbouring glacier to the east of Sermilik Bræ, to deliver ice-sheet water to vodka production.

5. Climate and permafrost

The overall climate of the southwest and south Greenland is known from a number of climate stations. The climate of all four localities (like Greenland itself) is classified as arctic, which means that the mean temperature for the warmest month is < 10^{o} C. Despite the general resemblance, the climate does vary between the localities. The variation is linked to the distance between the localities (Kangerlussuaq is located *c*. 690 km North of Sermilik Bræ) and to local physiography (coast versus up-fiords toward the ice cap The following descriptions are based on data collected by the Danish Meteorological Institute (DMI) published in DMI (2001), unless otherwise specified.

The climate of the Russell Glacier area is represented by climate data from Kangerlussuaq. The closest climate stations to Narsap Sermia and Nigerlikasik Bræ are Nuuk and Paamiut, respectively. These 3 stations are all located in the south-west region of Greenland. Kangerlussuaq is the northern part of the south-west region, Paamiut in the southern part and Nuuk in the middle. Sermilik Bræ is represented by data from Qaqortoq climate station in the south region. A number of climate parameters from these 4 stations are shown in Appendix 5, although the data are not representative of the up-fiords areas close to the ice cap.

In the south-west region, the sea ice causes almost no problems annual navigation. The winters are relatively warm in the coastal areas owing to the open sea conditions, while the summers are characterized by relatively cool and often unsettled weather, se Appendix 5, Nuuk and Paamiut. In the up-fiords areas, the winters are cold, while the summers are warmer, compare Appendix 5, Kangerlussuaq. There are large differences in the amount of precipitation between the climate stations. The largest amount of precipitation is found in the southern part of the region, in Paamiut and Nuuk. The precipitation is distributed throughout the year with the peak values in the summer months. In Kangerlussuaq, far inland from the coast, the yearly precipitation amount is much lower and close to zero in the winter months, resulting in very thin snow covers.

The mean wind speed in Nuuk is almost twice the value of Kangerlussuaq and Paamiut, and the most frequent direction is varying throughout the year, with predominantly northerly directions during the winter, which is typical for the southwest Greenland. In Kangerlussuaq, the most frequent wind direction is northeast throughout the year. In Paamiut, the most frequent wind direction is northwest from May to September, while the remaining, largest part of the year is characterized by calm weather.

The winter weather of the south Greenland climate region is generally changeable and varies a great deal from year to year. Inside the country, the summers are warm, while the cold sea causes lower temperatures near the coast. Fog is frequent in the coastal regions and the fog is brought into the sun-heated fiord areas by the sea breeze, where it is dissolved. In Qaqortoq, the mean temperatures are a little higher than in Paamiut, the amount of precipitation is almost the same, and the weather (“most frequent wind direction”) is characterized as “calm” throughout the year (DMI 2001).

Permafrost

The definition of permafrost is solely based on temperature. The term permafrost is used for a material (rock, sediment, etc.) that stay frozen for more than a year. This means that the temperature is not allowed to rise above the compressive melting point for ice (0^{o} C at atmospheric pressure) (Christiansen & Humlum 2000).

Russell Glacier and Narsap Sermia are both located in areas with continuous permafrost. Nigerlikasik is located at the border zone between continuous and discontinuous permafrost. Sermilik Bræ is located in an area, where sporadic permafrost may occur, but only as sporadic occurrences. Local conditions such as permanent shadow behind a cliff, in the bottom of a valley etc. are controlling factors for the presence of any local permafrost.

6. Sea level variations

Knowledge of the local sea level variations is desirable when navigating in the fiords and a must when constructing piers, jetties etc. at the coast. Most probably, sea level data from the inner parts of the fiords Kangerlussuaq/Søndre Strømfjord, Nuup Kangerlua, Nigerlikasik and Sermilik do not exist. At least, it has not been possible to find any sea level data from the fiords.

Still, some information of the sea level variations in the regions does exist. The Royal Danish Administration of Navigation and Hydrography (RDANH) publishes "Tide tables for Greenland waters" every year. These tide tables are based on tide gauge data measured every 15th minute during a period of time (in the 1990ies and the beginning of the 21st century) in a number of Greenlandic harbours (RDANH_1).

Søndre Strømfjord is located almost mid between Maniitsoq and Sisimiut, which are the nearest harbours, included in the tide tables. Based on data from the 2006 tide tables (RDANH_2), the tide of the outer end of Søndre Strømfjord is characterised as semidiurnal. The mean tidal range is about 2.4 metres, the spring tidal range is a little more than 4 metres and the neap tidal range is between 0.5 and 1 metre, see Fig. 6.1 and table 6.1.

Data for Nuuk as well as Paamiut are shown in the tide tables, mentioned above. From these data it is possible to estimate the approximate tidal ranges. So, the mean, spring and neap tidal ranges relating to Nuuk are *c*. 2.7, 5 and 1 metre, respectively. Relating to Paamiut, the corresponding values are *c.* 2, 3.3 and a little less than 1 metre. The nature of the tidal form is semidiurnal in both places (Fig 6.1 and table 6.1).

Concerning Sermilik fiord, the nearest location representing tidal data, Narsaq, is located at considerable distance from Sermilik fiord. Anyway, the nature of the tide and the tidal range of Paamiut and Narsaq, respectively, are almost similar in as much as the mean, spring and neap tidal ranges relating to Narsaq are *c*. 1.9, 3.3 and 0.5 metre, respectively (RDANH_2). The nature of the tide in the outer part of Sermilik fiord most probably resembles a combination of data from Narsaq and Paamiut. The nature of the tidal form in Narsaq is semidiurnal (Fig 6.1 and table 6.1).

All sea level variations mentioned so far solely reflect changes in water level caused by gravitational forces due to the sun and the moon. When the tidal wave traverses the fiords, the wave is modified. So, the tidal ranges in the inner parts of the fiords likely differ from the "outer fiord data". Furthermore, the changes in the water level are caused by meteorological (wind and barometric pressure) and oceanographically conditions (currents, ice-cover etc.). Episodic sea level changes also occur from ice calving, local as well as more distant. In Greenland, tsunamis may be caused by large landslides, but – owing to the local geology – this kind of catastrophic sea level changes is not expected to occur in the areas in question.

To achieve a much more detailed knowledge of the sea level variations in the inner part of the fiords it is necessary to mount an automatically logging tide gauge station for a longer period of time.

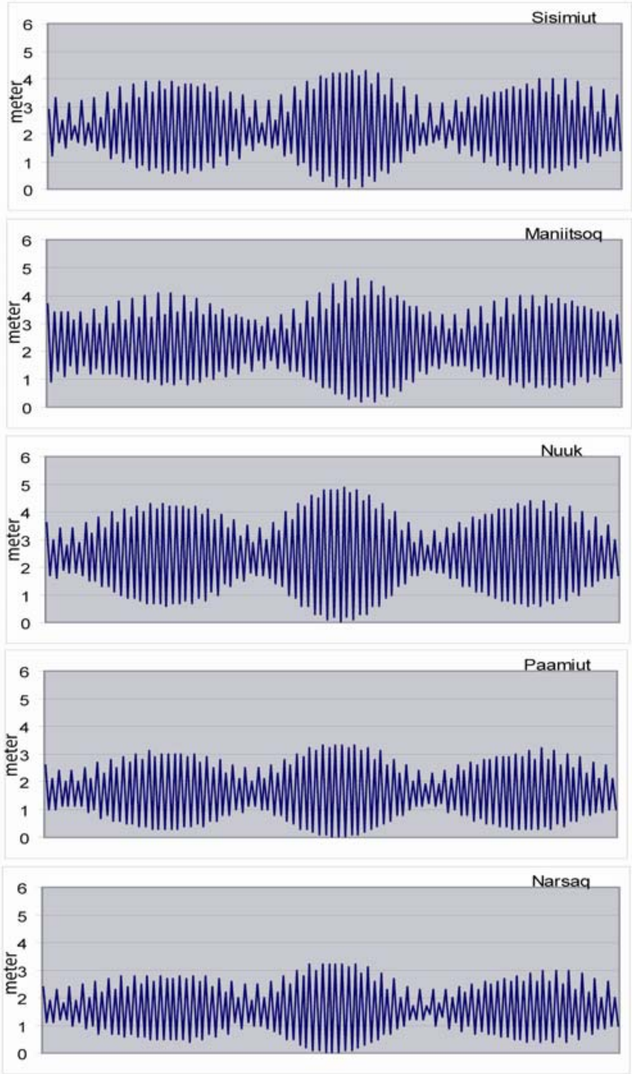

Fig. 6.1 Tide, Southwest Greenland.
The daily variation in the height of successive tides is seen in all the curves, but it is especially clear in Sisimiut and Narsaq. The curves (and Table 6.1) are based on data from the period between 6th March and 22nd April 2006, in the Tide Tables for Greenland Waters 2005, published by The Royal Danish Administration of Navigation and Hydrography (RDANH_2).

Table 6.1.

	Maniitsoq	Sisimiut	Nuuk	Paamiut	Narsaq
Mean tidal range (m)	2,48	2,36	2,75	2,06	1,85
Spring tide (m)	4,2	4,2	4,9	3,3	3,2
Neap tide (m)	1,1	0,5	0,9	0,8	0,5

7. The individual glaciers

7.1 Russell Glacier

Id code: 1DG02002 (+01). Area: 701.72 km^2.

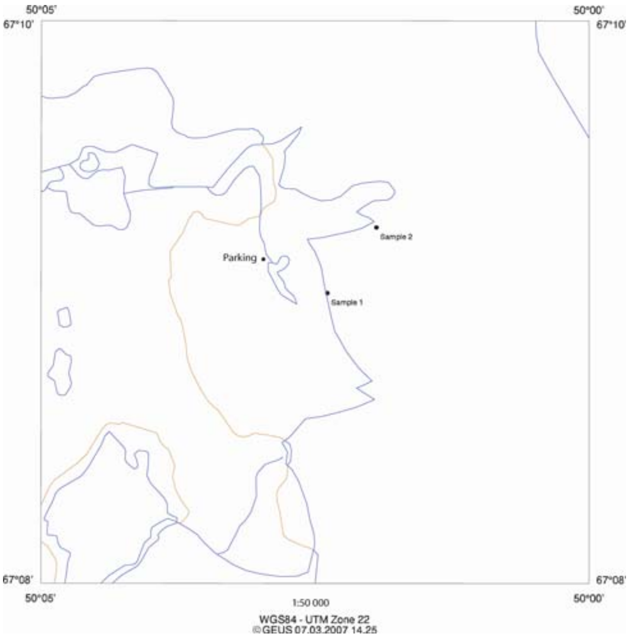

Fig. 7.1 Area map of part of the Russell Glacier where the position of the landing site and the sample sites are indicated. The distance between the sampling sites is 543 m.

<u>Age of the ice</u>

The ice margin north of Russell Glacier, Kangerlussuaq, flows slowly compared to regular glaciers. The “quiet” ice margin has a wide catchment area extending to the central parts of the Greenland Ice Sheet, but melting at the base suggested by ice sheet models makes the occurrence of ice age ice less likely. The ice is most likely of Holocene origin (i.e. younger than 11.700 years) but is probably more than 5000 years old, and possibly considerably more (Mayer et al., 2003). A black swan found on the ice sheet surface (emerging out of the ice) at a considerable distance from the margin was dated to be over 2000 years old. The ice found between the finding site of the swan and the ice edge, thus has to be older than 2000 years as the ice must be older closer to the edge due to the nature of the ice sheet flow.

<u>Glacier morphology</u>

The site under consideration is not Russell Glacier in itself, but rather the ice sheet margin north of the glacier. The ice margin is easily accessible from land and free from crevasses, see Fig. 7.2 and 7.3. This part of the ice margin is almost entirely flat and moves very slowly. There is considerable surface melting of several metres going on every summer and the surface is darkened by windblown dust from the nearby land. The surface melting is largely balanced by ice flow.

Fig. 7.2 Russell Glacier at sampling site 1 and the lateral moraine seen from the P-place at the end of the road.

Fig. 7.3 Russell Glacier, the surroundings at sampling site 2. The width of the glacial stream is not larger than it is possible to jump over.

Glacier development

The ice sheet is experiencing a modest thinning in his region, but has not retreated significantly. No significant change is discernable between 1985 (aerial photo) and 2001 (satellite image). Although the ice sheet is expected to be sensitive to climatic changes in this region over a long time period, it is only likely to respond slowly as the margin is not as sensitive as outlet glaciers in general (and floating tidewater glaciers terminating in fiords in particular). The field visit in 2006 provided evidence that the margin at the chosen site was retreating at a modest rate. This conclusion is based on a combination of the low angle of the ice margin, the darkened ice surface and local knowledge of recent ice margin behaviour.

Geology

The bedrock consists of granodioritic gneisses belonging to the Nagssugtoqider. In front of the glacier there is an about 100 m wide zone of combined active dead-ice moraine landscape and end-moraine. This zone contains a lot of buried ice that continuously creates dead-ice holes as it melts away. Widespread till deposits are found in front of the glacier, se Fig. 7.4, 7.5 and 7.6

Fig. 7.4 Deposits in front of Russell Glacier.

Fig. 7.5 Dead-ice holes created by the melting of buried ice within the 100 m zone of combined end moraine and dead-ice landscape, at the rim of the glacier.

Fig. 7.6 End moraine at the rim of the glacier. Note the grainsize variation between clay and boulders.

Morphology of the coast and land

The front of the glacier lobe is located rather over 30 km ENE of Kangerlussuaq, almost 200 metres above sea-level. From here, the ground rises along the front in the direction towards ENE to well 500 m.a.s. at the ice divider to the naboring glacier,1DG02001.

The ground in front of the upper part of the glacier is undulating and holds a number of smaller and bigger lakes. The lower part of the glacier front is fronted by an outwash plain with wide glacial streams and lakes.

A very long and narrow rocky crest divides the outwash plain into a northern and a southern part. North of the rocky crest, there is only about 1 km of outwash plain before the lake Aajuitsup Tasia is met. More or less continuous, the southern outwash plain of sand and gravel stretches out for about 30-35 km via Akuliarusiarsuup Kuua (Sandflugtsdalen/Sand drift Valley) to Kangerlussuaq.

The coasts along the inner part of Kangerlussuaq are rocky coasts with shorter segments of talus and/or moraine coasts. The innermost *c*. 8-9 km of the fiord is shallow and filled with outwash sediments and navigation is not possible, see Fig. 7.7. Given such constraint, harbour Camp Lloyd (Strømfjordshavn) was located in some distance from Kangerlussuaq.

Fig. 7.7 Photo of Søndre Strømfjord taken from the plane. Camp Lloyd (Strømfjordshavn) is visible just above the centre of the photo. The shallow, sand filled inner part of Søndre Strømfjord is seen in the lower right side of the photo.

Accessibility

Access to the glacier is very easy because of the road that leads directly and very close to the glacier front. (Fig. 7.8). The last 100 m of the road is generally more impassable due to melting of buried ice, see Fig. 7.9. The glacier is located *c.* 35 km NE of Kangerlussuaq.
Between Kangerlussuaq and the harbour, Camp Lloyd (Strømfjordshavn), is about 9 km. Camp Lloyd is navigable from early July to the end of October. At Camp Lloyd (Strømfjordshavn), the mean high spring tidal range is 3 m and the nip tidal range is *c*. 1.6. Anchorage is made *c*. 800 m E of Brennan Pynt. There is a tanker berth, 300 m length, a wharf 46 m long and a depth of 3.0 m alongside (Mosbech et al. 2000).

There is further *c*. 150 km from Camp Lloyd to open sea. Several anchoring places are located in the entrance area: one at Angujaartorfik (*c*. 108 km inside the entrance), one at Tatsip Ata (water depths of 18 – 55 m, good shelter) *c*. 20 km SW of Camp Lloyd and one for small vessels (depths 20 – 31 m) at Umiiviit (some 15 km from Camp Lloyd). Moreover, it should be possible to anchor close to the shore, in glacial mud and gravel, in the first 80 km of the fiord inside the entrance. It is possible to land c. 1.5 km E of the anchoring place at Umiiviit and possible also at the entrance of several rivers (Mosbech et al. 2000).

Fig. 7.8 The landscape and road between Kangerlussuaq and the Russell Glacier.

Fig. 7.9 Photo of the road very close to Russell Glacier, where melting of buried ice causes irregularities of the ground. Our car is parked in the distance.

Local knowledge is essential for navigation on the fiord. In general, the waters within this fiord are deep, however, the fiord has not been mapped and sunken rocks etc. may constitute danger to navigation.
The entrance may be influenced by fiord and sea ice but the ice is often broken up by the tides and storms. The tidal range in the entrance area is described in section 6.
The most important airport in Greenland is Kangerlussuaq Airport, an international all-season, asphalt surface airport (2815 x 60 m), with regular flights to Copenhagen. From Kangerlussuaq Airport there are flight connections to most towns in west Greenland.

Energy resources and –scenarios

Nearby town: Kangerlussuaq/Søndre Strømfjord
In spite of the presence of the international airport, Kangerlussuaq is still a relatively small settlement of a few hundred people. It is situated 35 km down the road from the ice margin site north of Russell Glacier. Currently, Kangerlussuaq relies exclusively on diesel power. It is possible that this might change if a hydropower plant is constructed at either Tasersuaq (50 km from Sisimiut

and 75 km from Kangerlussuaq) - currently a high priority plan - or at the larger, more distant Tasersiaq basin to the south.

Locally at the glacier front (micro-hydropower feasibility)
No significant possibilities exist for micro-hydropower facilities as there is very little elevation difference to exploit, although there are numerous lakes in the area.

Other conditions
The fiord holds a modest fishery and a few seal colonies. Moreover, the number of archaeological sites is low (Mosbech et al. 2000).

7.1.1 Water quality of Russell Glacier

Inorganic compounds
Analysis of inorganic salt and nutrients were performed as a full scan of anions and cations separately. Generally, the results show that the content of inorganic compounds was very low in the samples from the Russell Glacier. However, ammonia extends the EU standard for drinking water in sample 1.

Re-analyses of phosphate and ammonia showed high variability within different sub samples of ice blocks. The result of the re-analised sample 1 showed considerably lower values which all where below the EU standard for drinking water. The relative high concentration of phosphate and ammonia may be a result of atmospheric deposition, and variations during the deposition/compaction. The values are still within the range that is used for mineral waters.

In sample 2 from the Russell Glacier the fluoride content (1.44 mg/l) was close to the drinking water requirement value of 1.5 mg /l.

PAH and PCB compounds
Previously, PAH compounds (polycyclic aromatic hydrocarbons) in addition to some PCB's (polychlorinated biphenyls) at low concentrations were detected in near surface samples from the Russell Glacier (Bender et al. 2003a,b).

In this study all 16 PAH compounds (the US EPA standard PAH's) were below detection level (0.005 µg/l) in both samples from the Russel Glacier. The samples were also analysed for PCB content: PCB's were not detected in any of the samples.

Pesticides

The samples were also analysed for 34 pesticides and degradation products of pesticides. These compounds are mostly herbicides and herbicide degradation products normally found in ground-water in Denmark. The selection contains some of the more persistent organic pesticides (POP's) including the triazines. Only two of the compounds were detected in the samples: 4-nitrophenole and TCA. The 4-nitrophenole was believed to be a result of contamination from the RILSAN bags.

TCA was found in both samples from Russell Glacier (0.084 µg/l and 0.019 µg/l). This compound can have both natural and anthropogenic sources; finding TCA was thus expected. TCA is found to be present almost all over the world (lowest analysis-result found in rainwater in Europe is 0.03 µg/l and highest measured is 20 µg/l. In the Arctic and Antarctica, TCA has been found only patchily and in low concentrations (max. 0.035 µg/l). The TCA compound was found in quantities below EU drinking water requirements for pesticides (below 0.1 µg/l).

Bacterial content

Bacterial counts were carried out after staining the cells with DAPI blue and inspecting them directly using a microscope. In the samples from the Russell Glacier 1100 and 500 cells per ml of melted ice was observed, and the amount of bacteria able to form colonies on 1/10 TSA (tryptic soy agar) was below 10 colony forming units (CFU) pr ml.

The bacterial content of the samples was found in values below drinking water standard.

Sediment content

The ice water samples contain fine-grained, suspended sediment material in amounts of 23.55 mg/l and 119.90 mg/l. However, the ice is still regarded as pure.

7.2 Narsap Sermia

Id code: 1CH17002. Area: 1187.96 km^2.

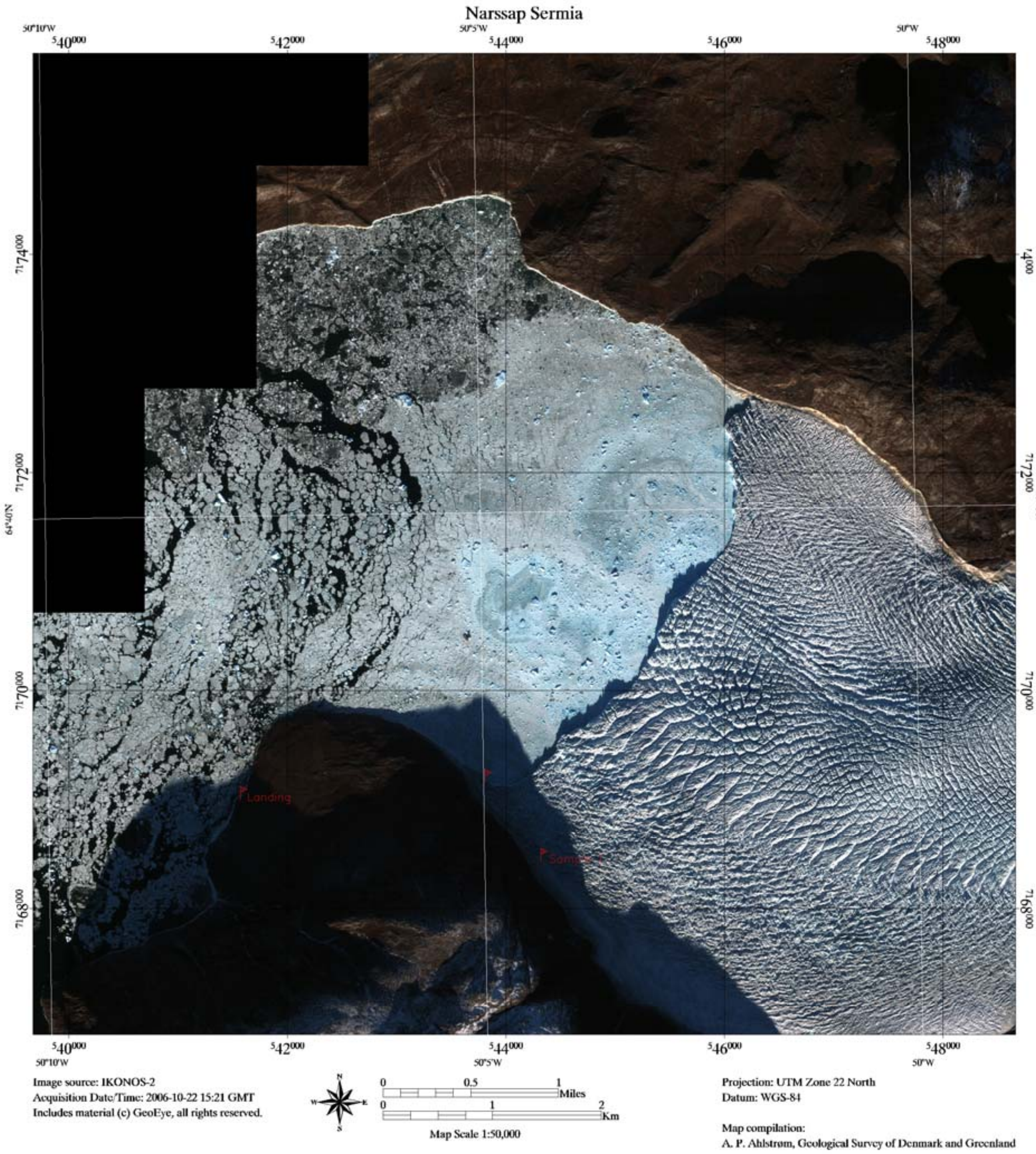

Fig. 7.10 Satellite image of Narsap Sermia. Sample locations and landing site are marked on the image. Distance between the sample sites is 890 m.

Age of the ice

The balance velocity modelling study of Mayer et al. (2003) shows that this glacier has an intermediate flux value with a catchment extending to the central parts of the Inland ice sheet. The balance velocity study also shows that the age of the ice is over 5000 years, but is probably of Holocene origin (i.e. younger than 11.700 years).

Glacier morphology

The glacier Narsap Sermia descends gradually from the Inland ice sheet over nearly 30 km and into Nuup Kangerlua (Godthåbsfjord). The glacier is strongly crevassed over the entire length, without any debris-covered regions or medial moraines. At the front it is roughly 5 km wide, but has a relatively modest calving rate. The glacier front floats in the fiord and is therefore influenced by tidewater, both with respect to regular iceberg calving and to overall stability of the floating ice tongue.

Glacier development

The glacier front seems to have been stationary over the last 100 years or more, although both sides of the glacier exhibit a slim trim line zone suggesting a minor recent lowering of the glacier surface. The development has been deduced from a rich archive of photos and satellite images from the years 1903, 1930, 1936, 1943, 1946, 1948, 1968, 1985, 1999, 2001, 2005 and 2006. The glacier frontal position was confirmed at the visit in 2006. It is important to note, however, that floating tidewater glaciers are prone to sudden retreat after a period of glacier thinning. As the floating glacier thins, it also lifts itself (as it is floating) causing sea water from the fiord to intrude further underneath the original ground line of the glacier. As the front may rest on an underwater end-moraine, thinning may cause the glacier to loose this “foothold”, forcing it to retreat back to the next “foothold” which may be several kilometres up the fiord.

Geology

The bedrock consists of Archean gneiss with elements of amphibolites. Quaternary deposits are found widespread in the area west of the glacier, with bedrock sticking up through till deposits (Figures 7.14 and 7.15). Along the glacier a lateral moraine is build up on both sides of the glacier (Fig. 7.16). Marine deposits are found op to level *c.* + 90 m.

Morphology of the coast and land

The front of the glacier is characterized as a glacier coast. The adjacent coasts on both sides of the fiord are moderately steep rocky coasts. Along the southern side of the glacier, the cliffs are quite steep. A few kilometres from the glacier front, the rocky coasts are replaced by steep talus coasts (applies to both sides of the fiord). The talus coasts in their turn are replaced by rocky coasts.

Accessibility

It is not advisable to approach the glacier front by boat due to the significant danger from calving events. The glacier lobe has dammed three lakes along its descent towards the fiord implying that water release events underneath the glacier into the fiord are likely, with potential danger to nearby boats. Further, it is difficult to approach the glacier front by boat because of densely packed calved ice, see Fig. 7.11. It is worst in the northern part of the fiord in front of the glacier, but calved ice is found widespread in the area owing to a high calved ice production from the nearby glaciers Akullersuup Sermia and Kangiata Nuaanta Sermia. If the ice situation permits, it is possible to land a boat only few kilometres from the southern side of the glacier front, on the west side of the Narsaq point. Locally, the ice has smoothed the cliffs and formed roche moutonnée which can easily be reached from smaller boats, see Fig. 7.12 and 7.13. From here, it is possible to cross Narsaq point at a certain level above and in a distance to the fiord, where the cliffs are less steep. In this area, the surface between outcropping bedrock and large boulders is often covered by tundra vegetation, locally rather thick, wet and pond-like (Fig. 7.14 and 7.15).

Fig. 7.11 Photo of the southern part of Narsap Sermia and the ice filled Godthåbsfjord in front of the glacier. Narsaq point is seen in the right part of the photo. See Fig. 3.2 for a photo of the highly crevassed, floating glacier tongue taken from helicopter.

Fig. 7.12 The landing site on the west side of the Narsaq point. Landing is possible locally at the roche moutonnées.

Fig. 7.13 The landing site on the Narsaq point and the hinterland as seen from the fiord.

The access to the glacier itself is across a lateral, apparently not ice-cored, moraine at the outermost part of the glacier (Fig. 7.16), as the cliffs are too steep further alongside the glacier to access it (Fig. 7.17).

Fig. 7.14 An example of the landscape on the Narsaq point a few kilometres from the front of Narsap Sermia. The easiest way to cross Narsaq point is by following the small track trodden by reindeer.

Fig. 7.15 Another view, facing northwest, of the landscape on the Narsaq point with bedrock sticking up through till deposits which is covered by tundra vegetation

Fig. 7.16 Photo of the extensive, light-coloured side moraine and the highly crevassed glacier tongue.

Fig. 7.17 Ice sampling on Narsap Sermia, site 1. The surface of the ice is darkened by dust from the side moraine. At this place, the side moraine is much smaller, compared to the distal part next to the front of the glacier. Remark the very steep cliffs behind the side moraine.

The innermost part of Nuup Kangerlua (Godthåbsfjorden) has not been mapped. From the stretch between Ilulialik to immediately south of Kikiallit digitized survey maps exist. From here and toward southwest, to the Nuuk waters, the fiord is covered by multibeam data. Maps and data are obtainable from The Royal Danish Administration of Navigation and Hydrography. Navigation in the inner part of Nuup Kangerlua is difficult because of the calved ice. Local knowledge is essential for navigation on the fiord where sunken rocks etc. may constitute danger to navigation (Mosbech et al., 2000).

Apparently, no harbours exist in the vicinity of Narsap Sermia. It is unknown, if landing is possible at some of the river mouths.

Fig. 7.18 Ice sampling on Narsap Sermia, site 2.

Nearby town: Nuuk/Godthåb

As the capital of Greenland, the town is centre of all trade, shipping, industry and administration. The port at Nuuk is a modern Atlantic harbour and the base harbour of western Greenland. It is navigable all year, and it is called regularly from Aalborg. Nuuk airport is located 4 km NE of Nuuk. It has one asphalt runway of 950 m and is equipped by Distance Measuring Equipment.

Energy resources and –scenarios

Nuuk is the closest major town and has been supplied with hydroelectric power since 1993, with two diesel powered plants in the town for backup. The hydropower plant situated in Kangerluarsunnguaq (Buksefjorden) and delivers 192 GWh/yr from two turbines. The hydropower plant has a potential for increasing the electricity production by adding a third turbine and enlarging the catchment.

Locally at the glacier front (micro-hydropower feasibility)
There are no streams of significance terminating on the southern shore near the glacier front. However, a minor lake at an elevation of 250-300 m.a.s. is drained by a stream terminating into the southern moraine approx. 5 km up-glacier from the glacier front. On the northern shore of the fiord, approx. 1 km from the glacier front, there is also a stream draining into the fiord, from a group of smaller lakes at elevations 200-400 m.a.s.

Other conditions
The inner part Nuup Kangerlua holds a very modest fishery. An important fishery is located at Qussuk, a northern branch of Nuup Kangerlua. In the outer parts of the fiorda sparse fishery plus a number of bird colonies are located at Sermitsiaq (Saddelø) and Qoornup Qeqertarsua (Bjørneø). The entrance area of Nuup Kangerlua is characterised by numerous islands with rich bird life and plenty of hunting and fishing (Mosbech et al. 2000).

7.2.1 Water quality of Narsap Sermia glacier

Inorganic compounds
Analysis of inorganic salt and nutrients were performed as a full scan of anions and cations separately. Generally, the results show that the content of inorganic compounds was very low in the samples from Narsap Sermia, and they are found in values below EU drinking water standard.

PAH and PCB compounds
The analysis revealed a very low level of organic compounds in the samples from Narsap Sermia. All 16 PAH compounds (the US EPA standard PAH's) were below detection level (0.005 µg/l) in both samples. The samples were also analysed for PCB content: PCB's were not detected in any of the samples.

Pesticides
The samples were also analysed for 34 pesticides and degradation products of pesticides. These compounds are mostly herbicides and herbicide degradation products normally found in groundwater in Denmark. The selection contains some of the more persistent organic pesticides (POP's) including the triazines. Only 4-nitrophenole was detected in the samples, and the 4-nitrophenole was believed to be a result of contamination from the RILSAN bags.

Bacterial content

Bacterial counts were carried out after staining the cells with DAPI blue and inspecting them directly using a microscope. From Narsap Sermia 750 cells per ml in both samples were found, the amount of bacteria able to form colonies on 1/10 TSA (tryptic soy agar) was a maximum of 390 CFU (colony forming units) pr ml for sample 1 and 30 CFU pr ml for sample 2.

The bacterial content of the samples is found in values below drinking water standard.

Sediment content

The ice water samples contain fine-grained, suspended sediment material in amounts of 56.56 mg/l and 35.13 mg/l. However, the ice is still regarded as pure.

7.3 Nigerlikasik Bræ

Id code: 1BG06002. Area: 438,89 km^2.

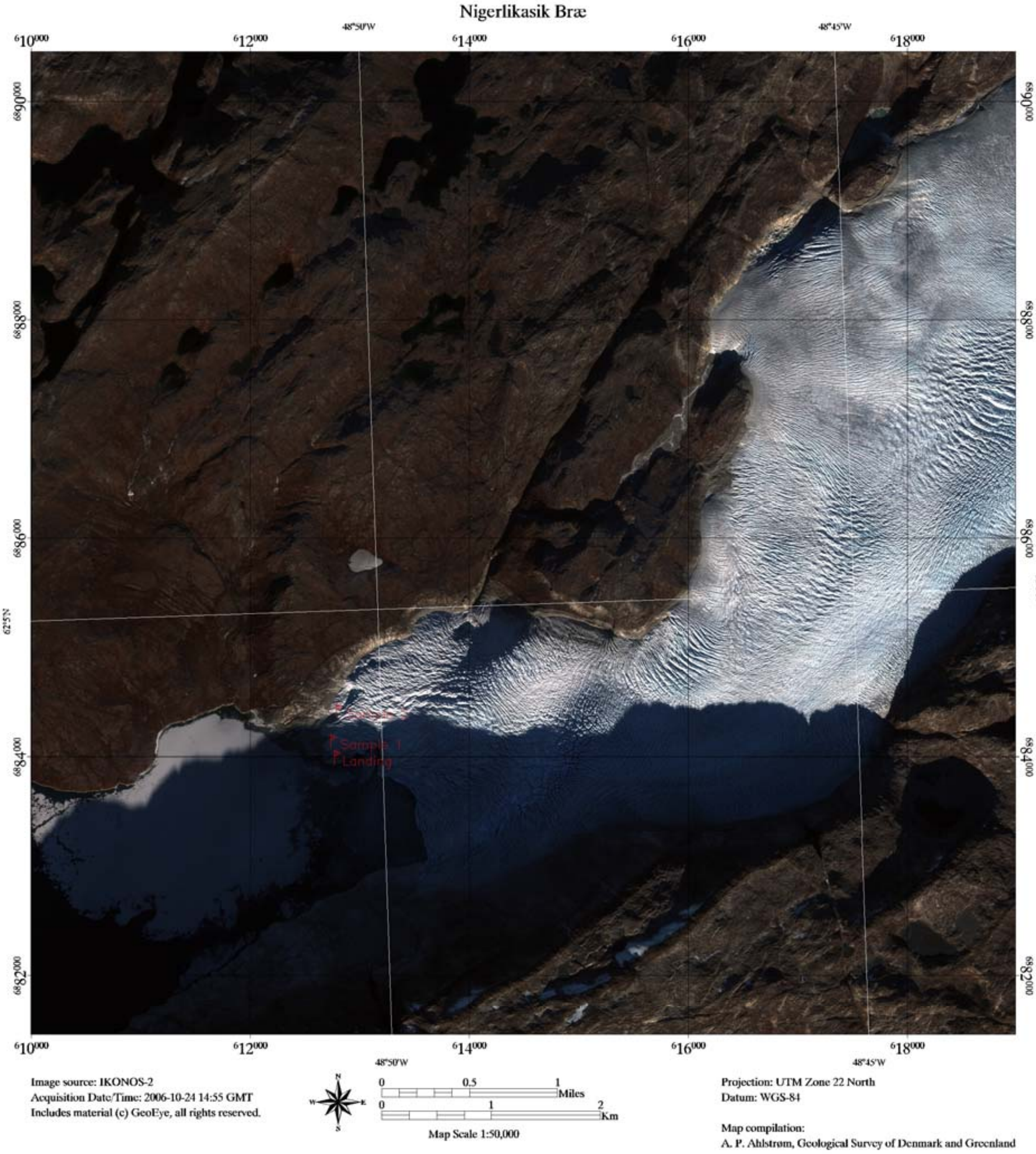

Fig. 7.19 Satellite image of Nigerlikasik Bræ. Sample locations and landing site are marked on the image. The distance between the sample sites is 285 m.

Age of the ice

Although the balance velocity modelling study of Mayer et al. (2003) disregards this glacier compared to the northern neighbour (Avannarleq Bræ) a closer study of the ice sheet flow lines from aerial photographs necessitates a re-evaluation. Nigerlikasik Bræ is situated immediately south of the large and highly productive Sermilik Glacier (not the one investigated in South Greenland). The balance velocity study could not distinguish this from the much slower Nigerlikasik Bræ, which has its own separate ice sheet catchment and is thus likely to contain ice from the central parts of the southern dome of the Greenland Ice Sheet. Nigerlikasik Bræ is slower than Avannarleq Bræ and thus considered to contain older ice. The balance velocity study shows that the age of the ice is over 5000 years, but is likely to be of Holocene origin (i.e. younger than 11.700 years).

Glacier morphology

The glacier originates from the Inland ice and descends over a sub glacial threshold into the fiord, see Fig. 7.20. It is moderately crevassed over its entire length of 10 km and has a relatively narrow glacier front 1-2 km wide, calving icebergs into the fiord. The northern part of the glacier front rests on a rocky outcrop turning into a flat foreland (Fig. 7.21 and 7.22), while the central and southern parts calve into the fiord with a very modest calving rate (Fig. 7.23). The glacier has no medial moraines and is not covered by debris.

Fig. 7.20 Nigerlikasik Bræ seen from a distance. Note the steep descent of the glacier from the Inland ice. At the right side of the photo an end-moraine is stretching out into the fjord as a peninsula, marking a former stage of the glacier.

Fig. 7.21 Photo of the northern part of the glacier front resting on a rocky outcrop.

Fig. 7.22 A closer view of the northern part of the glacier front and the flat foreland.

Fig. 7.23 View of the central and southern part of the glacier front calving into the fiord with a very modest calving rate. The photo was taken from the flat foreland in front of the northern part of the glacier front.

Glacier development

The steep descent of the glacier from the Inland ice implies that the frontal position is not very sensitive to climatic and ice-dynamic changes. The glacier has undergone a minor recession since *c.* 1900 of less than 2 km. Photos and satellite images from 1918, 1919, 1921, 1948, 1955, 1964, 1985, 2001, 2003 and 2005 show a rather stable position of the front, that has retreated up and almost out of the fiord and is now resting on the underlying rock. The field visit in 2006 supported the analysis from satellite and aerial photos stating that the ice front had a rather stable configuration, as only a very small part of the tongue was floating in the fjord. There has been no discernable change in the ice marginal position since the 2005 satellite image. There are steep parts along the ice front that can potentially be dangerous due to ice breaking off.

Geology

The bedrock of the area consists of Archean gneiss with elements of amphibolites.
Due to the recent retreat of the ice, the bedrock in front of the ice is fresh and shows no sign of alteration, and it is covered with scattered and thin layers of till. Locally, where the bedrock is exposed, it is clearly seen that the ice has smoothed the cliffs and formed roche moutonnée (Fig. 7.24 and 7.25).

Fig. 7.24 The recently exposed bedrock in front of the Nigerlikasik Bræ

Fig. 7.25 Photo of the roche moutonnée, where landing was possible.

The former position of the ice is marked by an end-moraine. Generally, widespread Quaternary deposits are found in the area at the northern flank of the glacier. Several end-moraines mark older stages of glacier movements.

Marine deposits are found op to level + 52 m.

A meltwater river is located in the northern flank of the glacier front, see Fig. 7.26.

Fig. 7.26 The melt water river from the northern flank of the glacier front. For scale: a person lying on the ground next to the river.

At the southern flank there is a lateral moraine along the glacier, which can be followed in front of the glacier, marking the most recent former position. Next to the lateral moraine, and also in front of the glacier, there is an alluvial fan, build up in front of a ravine, see Fig. 7.28.

Fig. 7.27 Ice sampling at Nigerlikasik Bræ. The person indicates the location of sampling site 1.

Accessibility

Access to the glacier is possible from Kuanersôq (Kvanefjord). There is a good access to the glacier front from both sides of the fiord, but especially from the gently sloping roche moutonnée right in front of the northern glacier flank.

The distance between the glacier and the open sea is *c*. 50 km. The prevailing current is 0.5 knots setting to the northwest along the coast. Local sea ice, pack ice and icebergs can cause problems entering Paamiut. But the calf ice production from Nigerlikasik Bræ is very modest. The innermost parts of Kuanersôq (Kvanefjord) have not been mapped, but outside the point, where the fiord split up to the three branches Avannarleq, Akulleq and Nigerlikasik, digitized survey maps do exist. Digitized multiplex data exist for the area further toward the west. Maps and data are obtainable from The Royal Danish Administration of Navigation and Hydrography. Kuanersôq (Kvanefjord) is wide, it seems to be deep and it is almost without islands and islets inside the entrance area. Still, local knowledge is essential for navigation on the fiord where sunken rocks etc. may constitute danger to navigation (Mosbech et al., 2000).

Fig. 7.28 Ice sampling at Nigerlikasik Bræ. The persons indicate the location of sampling site 2. The alluvial fan and the ravine at the southern flank of the glacier front are seen in the background.

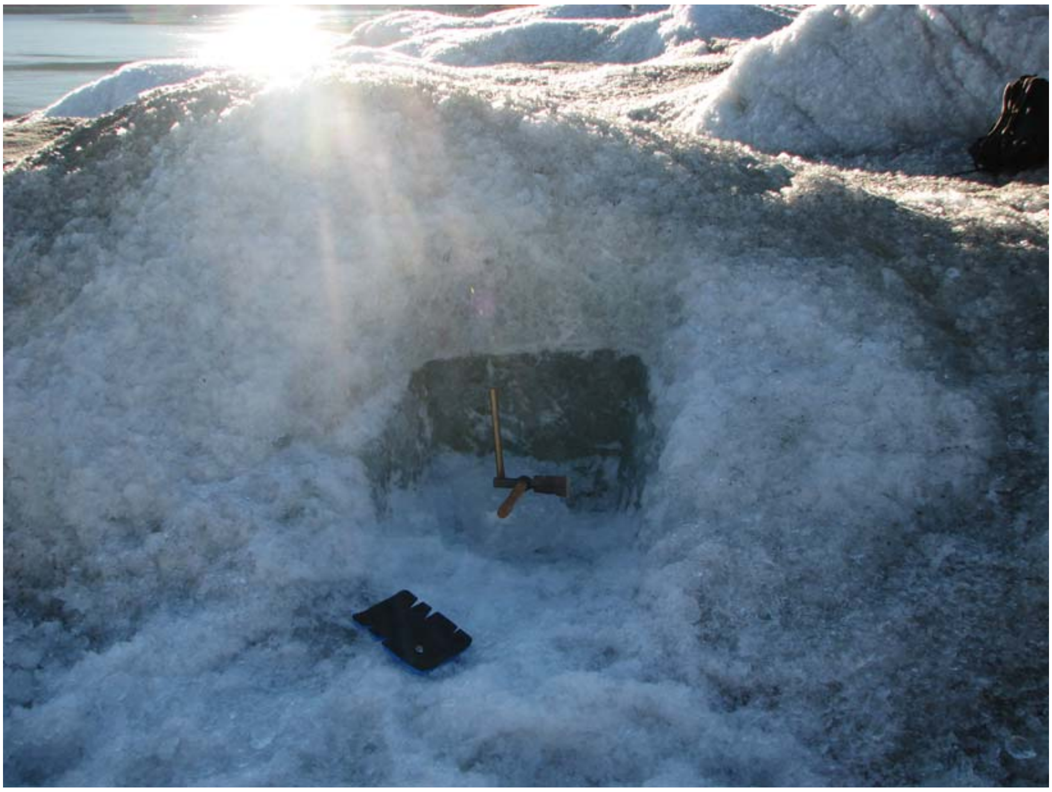

Fig. 7.29 Close-up photo of sampling site 2. The boundary between the crumbling ice layer and the useful solid ice is very clear.

Nearby town

The town Paamiut (Frederikshåb) is located at the entrance of Kuanersôq/Kvanefjord. In Paamiut there are about 2100 inhabitants, and the main trade is in the fishing industry. The port at Paamiut is navigable all year, and it is called regularly from Aalborg and Nuuk. At present there is a heliport at Paamiut, with flight connections to/from Nuuk, Kangilinnguit and Narsarsuaq. An airport is under construction and planned to be finished in 2007. At present (2006) there are numerous vacant flats in Paamiut.

Energy resources and –scenarios

Currently, energy in Paamiut is derived from diesel powered plants. However, a hydropower plant is under consideration, capable of delivering approx. 50 GWh/yr from the catchment Iterlaa in Qassitfjord 37 km NE of Paamiut. Unfortunately, this is 30 km NW from Nigerlikasik Bræ.

Locally at the glacier front (micro-hydropower feasibility)

A small stream terminates in the Nigerlikasik fiord just 1.5 km from the northern side of the glacier front. It originates from a tiny lake at an elevation of approximately 400 m.a.s. The stream flow is likely to be strongly dependent on precipitation and snowmelt events.

Other conditions

There is number of archaeological sites west of Paamiut in the archipelago. A number of sensitive fishing and hunting areas (e.g. shrimping) are likewise located in Kuanersôq/Kvanefjord. There are a few colonies of breeding birds on both sides of the fiord (Mosbech et al. 2000).

7.3.1 Water quality of Nigerlikasik Bræ

Inorganic compounds

Analysis of inorganic salt and nutrients were performed as a full scan of anions and cations separately. Generally, the results show that the content of inorganic compounds was very low in the samples from the glacier. However, ammonia extends the EU standard for drinking water in sample 1.

Re-analyses of phosphate and ammonia showed high variability within different sub samples of ice blocks, and 2 of the re-analised samples had considerably lower values of ammonia. The relative high concentration of phosphate and ammonia may be a result of atmospheric deposition, and variations during the deposition/compaction. The values are still within the range that is used for mineral waters.

PAH and PCB compounds

The analysis revealed a very low level of organic compounds in the samples from Nigerlikasik. All 16 PAH compounds (the US EPA standard PAH's) were below detection level (0.005 µg/l) in both samples. The samples were also analysed for PCB content: PCB's were not detected in any of the samples.

Pesticides

The samples were also analysed for 34 pesticides and degradation products of pesticides. These compounds are mostly herbicides and herbicide degradation products normally found in groundwater in Denmark. The selection contains some of the more persistent organic pesticides (POP's) including the triazines. Only two of the compounds were detected in the samples: 4-nitrophenole and TCA. The 4-nitrophenole was believed to be a result of contamination from the RILSAN bags.

TCA was detected in sample 2 from the Nigerlikasik Bræ (0.2 µg/l). This compound can have both natural and anthropogenic sources; finding TCA was thus expected. TCA is found to be present almost all over the world (lowest analysis-result found in rainwater in Europe is 0.03 µg/l and highest measured is 20 µg/l. In the Arctic and Antarctica, TCA has been found only sporatically and in low concentrations (max. 0.035 µg/l).

Bacterial content

Bacterial counts were carried out after staining the cells with DAPI blue and inspecting them directly using a microscope. In the samples from Nigerlikasik Bræ there were 350 and 300 cells per ml melted ice, the amount of bacteria able to form colonies on 1/10 TSA (tryptic soy agar) were up to 900 CFU pr ml in sample 2, and below 10 CFU pr ml in sample 1.

The bacterial content of the two samples from Nigerlikasik Bræ is found in values below drinking water standard.

Sediment content

The ice water samples contain fine-grained, suspended sediment material in amounts of 16.79 mg/l and 17.78 mg/l. However, the ice is still regarded as pure.

7.4 Sermilik

Id code: 1AI05001. Area: 227.27 km^2.

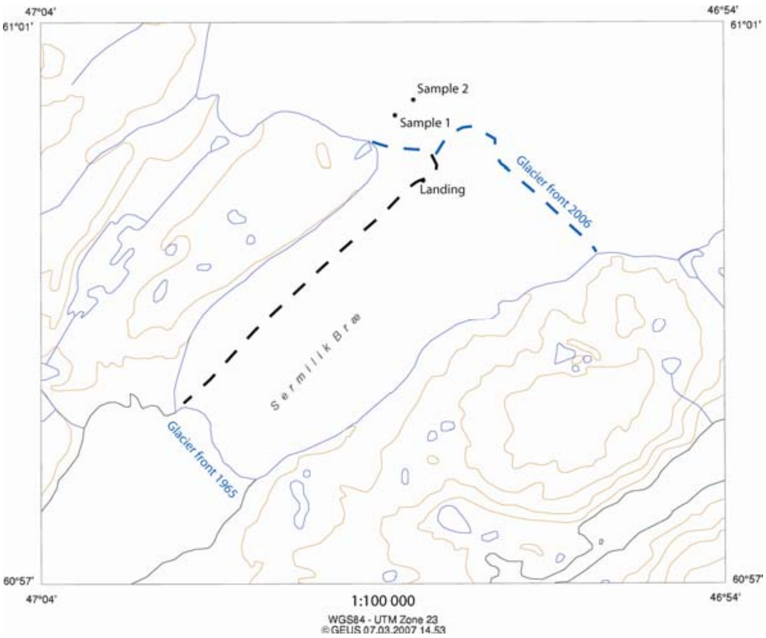

Fig. 7.30 Area map of the termination of the Sermilik Bræ. The recent glacier front is indicated with the stipled line. Also the position of the landing site and the sample sites are indicated. The distance between the sampling sites is 315 m.

Age of the ice

Stable isotope measurements on ice from this site show that the ice is of Holocene origin (i.e. younger than 11.700 years) and that balance velocity modelling gives estimates of approx. 6000 years of age (Mayer et al., 2003).

Glacier morphology

The glacier slopes gently from the Inland ice into the northeastern end of Sermilik fiord. The glacier front recently retreated 5 km and the glacier front is now approximately 3 km wide with a moderate iceberg calving rate. The glacier calving and stability is influenced by tidewater in the fiord. The glacier itself is moderately crevassed in its central and floating parts, but it is accessible from land on the western side where crevassing is not as strong. Sermilik Bræ has thinned and accelerated somewhat during the last decade and the nearby ice margin has also retreated, but much less (< 1 km) than the floating ice tongue of Sermilik Bræ. The western side of the glacier is darkened by windblown dust from the nearby lateral moraine.

Glacier development

The glacier has experienced a strong thinning over the last *c.* 100 years. From 1869 over 1953 to 1985 the front retreated slowly *c.* 1 km. Since then, the front has undergone a significant retreat of *c.* 5 km from 1985 to 2001. The development has been documented in detail by Mayer et al. (2003) and Podlech (2004). The glacier has now retreated to its minimum position as the ice margin now terminates almost directly into the fiord, without a floating ice tongue. Further thinning of the ice sheet behind the glacier is possible, and would cause the neighbouring ice sheet margin to retreat more than the current minor recession of < 1 km. The field visit in 2006 showed that the glacier was actively calving large icebergs, causing temporary disintegration of still floating parts of the ice front. However, the current configuration of the ice front (which has lost its floating tongue) implies that any missing part of the ice front is rapidly filled in by ice-dynamic flow from the ice sheet proper. It is likely that the loss of the ice tongue has caused Sermilik Bræ to accelerate, which means that the nearby ice margin might thin additionally before a new and more stable configuration is found.

<u>Geology</u>

The bedrock of the area consists mainly of granite rocks belonging to the Julianehåb Batholith. Quartsofeldspatic gneiss (Ketilidic metasediments) are located northwest of the glacier. A few amphibolites and alkaline intrusions are seen in the gneiss. Moreover, the gneisses and granites are cut by a few Gardar dolerite dikes.

Widespread occurrences of Quarternary till deposits are located along the glacier. Due to the recent retreat of the ice, the bedrock in front of the ice is fresh and shows no sign of alteration, and it is covered by scattered and thin layers of till. Hardly any vegetation is seen in the recently exposed areas in front of the glacier, see Fig. 7.31 and 7.32. Marine deposits are found up to level + 49 m.

Fig. 7.31 Sermilik Bræ and the bedrock in front of the western part of the ice tongue.

Fig. 7.32 A view across the Sermilic Fjord. Note the line between the upper part of the mountain-side with vegetation and the lower part without vegetation. This line marks the maximum extention of the glacier

Accessibility

It is not advisable to approach the glacier front by boat due to the significant danger from calving events although the calf ice production is sparse. The glacier can be reached from land in close vicinity of the glacier after sailing from e.g. Qagssimiut or Narsaq. Melt water from the glacier produces a very strong current in the fiord in front of the glacier and it is difficult to navigate close to the rather steep rocky coast. But locally, on the western side of the fiord, where the ice has smoothed the cliffs and formed roche moutonnée, it is possible to land peoble from a rubberboat, see Fig. 7.33 and 7.34.

Fig. 7.33 The landing site on the western side of the fiord, where the ice has smoothed the cliffs and formed roche moutonnée. Remark the rather steep rocky coast in the background.

Fig. 7.34 The landing site as seen from the distance.

Fig. 7.34 An example of the landscape between the landing site and Sermilik Bræ. The cliffs are rather steep and over strewn with movable gravel, cobbles and boulders.

It is possible, although difficult in places, to ascend the steep cliffs (between the shore and the glacier) that are overstrewn with movable gravel, cobbles and boulders (Fig. 7.34 and 7.35). Likewise, it may by problematic to cross the water-soaked muddy till, which is located between the cliff and the glacier ice, see Fig. 7.36. During the fieldwork, a few moulins were observed on this glacier (Fig. 7.37); otherwise it was unproblematic to make one's way on the ice. The distance between the landing site and the glacier was about 2 km.

Fig. 7.36 An example of the area between the bedrock and the glacier ice. This zone is marked by a water-soaked muddy till that may be difficult to pass.

The depths of the innermost part of Sermilik fiord have been mapped by GEUS (Mayer et al. 2003). Digitized survey maps exist from about 10 km of the inner part of the fiord. The fiord outside this area has not been mapped. The digitized survey maps are obtainable from The Royal Danish Administration of Navigation and Hydrography. The nearest anchorages are some 6 km east of Saqqarmiut and 7 km southwest of Qassimiut, respectively. Generally, the coasts of this area are rocky coasts and it has not been possible to find information on any landing sites. The entrance area of Sermilik fiord is an archipelago with numerous islands and skerries and local knowledge is essential for navigation (Mosbech et al., 2000). The distance from the glacier to the sea/coast is about 35 km.

Fig. 7.37 One of a few moulins observed on this glacier during field work.

Fig. 7.38 Sampling site 1 at Sermilik Bræ and the surrounding ice landscape.

Fig. 7.39 Sampling site 2 at Sermilik Bræ. Remark the character of the crumbling ice in the fore-ground.

Energy resources and –scenarios

Nearby town: Narsaq or Qaqortoq/Julianehåb

There are no towns close to Sermilik Bræ. There is a settlement, Qagssimiut, at a distance of at least 40 km, but the closest major towns, Narsaq and Qaqortoq/Julianehåb are 100-120 km away from the glacier. The two towns are to be supplied with hydropower energy from a common plant at Qorlortorsuaq sometime during 2007. The plant will deliver a total of 27.5 GWh/yr for the 5,000 inhabitants of the two towns.

Locally at the glacier front (micro-hydropower feasibility)
There is a minor lake on the western shore of the Sermilik fiord, with an outlet approx. 5 km downstream from the glacier front. The lake is situated at an elevation of approx. 150 m.a.s. Note that inspection of aerial photos show that this lake might cause landslides of water-saturated clay down to the fiord and that it is consequently not advised to land a boat in the vicinity of the outlet stream.

Other conditions
The fiord holds a deal of hunting and fishery, e.g. of crabs. The entrance area also holds some fishery and hunting plus a deal of bird colonies (Mosbech et al. 2000).

7.4.1 Water quality of Sermilik Bræ

Inorganic compounds
Analysis of inorganic salt and nutrients were performed as a full scan of anions and cations separately. Generally, the results show that the content of inorganic compounds was very low in in the samples from the glacier.

PAH and PCB compounds
The analysis of the two samples revealed a very low level of organic compounds in the samples from the glacier. All 16 PAH compounds (the US EPA standard PAH's) were below detection level (0.005 µg/l) in the samples from Sermilik Bræ. The samples were also analysed for PCB content: PCB's were not detected in any of the samples.

Pesticides
The samples were also analysed for 34 pesticides and degradation products of pesticides. These compounds are mostly herbicides and herbicide degradation products normally found in groundwater in Denmark. The selection contains some of the more persistent organic pesticides (POP's) including the triazines. Only two of the compounds were detected in the samples: 4-nitrophenole and TCA. The 4-nitrophenole was believed to be a result of contamination from the RILSAN bags.

TCA was detected only in sample 2 from the Sermilik Bræ (<0.02µg/l). This compound can have both natural and anthropogenic sources; finding TCA was thus expected. TCA is found to be present almost all over the world (lowest analysis-result found in rainwater in Europe is 0.03 µg/l and highest measured is 20 µg/l. In the Arctic and Antarctica, TCA has been found only sporatically and in low concentrations (max. 0.035 µg/l).

Bacterial content

Bacterial counts were carried out after staining the cells with DAPI blue and inspecting them directly using a microscope. In the samples from Sermilik Bræ 1200 and 1000 cells per ml of melted ice were found, the amount of bacteria able to form colonies was up to 720 CFU pr ml in sample 1 and up to 170 CFU pr ml in sample 2.

The bacterial content of samples from the glacier is found in values below drinking water standard.

Sediment content

The ice water samples contain fine-grained, suspended sediment material in amounts of 7.39 mg/l and 14.17 mg/l. However, the ice is still regarded as pure.

8. Conclusion

Russell Glacier

The ice is likely between 5,000 and 11,700 years old. At precent the ice margin is retreating at a modest rate

Owing to lots of sediments in the inner part of Søndre Strømfjord, it is not possible to navigate any longer than Camp Lloyd. A road leads from the harbour to Kangerlussuaq, afterwhich Russell Glacier is easy to access. The final c. 100 meters of road is marked by irregularities caused by melting ice. The zone between the road and the glacier is easy to cross and it is unproblematic to move around on the glacier surface.

The content of chemical compounds and bacteria is low in the ice water. One value of ammonia extends the EU standard for drinking water. However, all values are within what are used for mineral water.

Narsap Sermia

The ice is between 5,000 and 11,700 years old. The glacier front is rather stable.

Navigation on most of the Nuup Kangerlua (Godthåbsfjord) is unproblematic for people with local knowledge. Due to significant danger from calving ice and densely packed calving ice in the fiord, it is neither possible nor advisable to approach the glacier front by boat. It is necessary to land a boat several kilometres from Narsap Sermia and cross the point of Narsaq. To access the glacier itself, it is necessary to cross a large lateral moraine because the cliffs are rather steep further alongside the glacier. The glacier is strongly crevassed and it is possible but not unproblematic to move around on the glacier surface.

The content of chemical compounds and bacteria is low in the ice water. It is below the EU drinking water standard and below values in water used for mineral water.

Nigerlikasik Bræ

The ice is between 5,000 and 11,700 years old. The glacier front is rather stable.

There is a good access to Nigerlikasik Bræ. It is possible to navigate and land very close to the glacier front that can be reached from both sides of the fiord. Further, it is easy to cross the flat foreland in front of the glacier and move around on the glacier surface as well. The calving rate is very modest.

The content of chemical compounds and bacteria is low in the ice water. Two values of ammonia extend the EU standard for drinking water. However, all values are within what are used for mineral water.

<u>Sermilik Bræ</u>
The ice is between 6,000 and 11,700 years old. The ice margin might thin more until stable configuration is found.

Sermilik Bræ is not easily accessible. Even though the calving rate is very modest, a strong current in the fiord and very steep cliffs make landing close to the glacier problematic. The landscape between the fiord/landing site and the glacier is marked by rather steep cliffs and loose blocks. It is difficult to cross the very wet, muddy zone between the cliffs and the glacier itself, but it is easy to move around on the glacier surface.

The content of chemical compounds and bacteria is low in the ice water. It is below the EU drinking water standard and below values in water used for mineral water.

9. Literature

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10. Appendix 1. Map data

Topographic and geologic maps

Topographic maps: 1:250.000. Tage Schøtt and the National Survey and Cadastre (A66/90).

Saga maps 1: Qaqortoq (Julianehåb) og Uummannarsuaq (Kap Farvel). 1992.
Saga maps 2: Ivittuut (Ivigtut), Narsarsuaq (Narssarssuaq) and Qaqortoq (Julianahåb). 1992.
Saga maps 3: Narsarsuaq (Nassarssuaq) and Taateraat Kangersuasiat (Kap Herluf Trolle). 1992.
Saga maps 4: Paamiut (Fredrikshåb) and Ivittuut (Ivigtut). 1992.
Saga maps : Nuuk (Godthåb). 1991.
Saga maps 7: Maniitsoq (Sukkertoppen). 1992.
Saga maps : Sisimiut (Holsteinsborg) and Kangerlussuaq (Søndre Strømfjord). 1991.

Hiking maps south Greenland (Vandrekort Sydgrønland) 1:100.000/1:75.000. Greenland Tourism a/s.

1. Tasermiut fjorden – Nanortalik.
   6. Narsarsuaq/Narsaq/Qaqortoq
   7. Nasarsuaq/Narsaq/ Qaqortoq
   8. Narsarsuaq/Narsaq/Qaqortoq
   9. Ivituut (1:75.000)
   10. Nuuk (1:75.000)
   11. Asussuit (1:75.000)
   12. Maniitsoq (1:75.000).
   13. Evighedsfjorden (1:75.000)
   14. Kangerlussiaq
   15. Pingu
   16. Sisimiut

Geological maps: The Geological Survey of Denmark and Greenland (GEUS/GGU, 2002).

Geology 1:500.000

Sheet 1 Sydgrønland 1975
Sheet 2 Fredrikshåbs Isblink – Søndre Strømfjord 1982.

Sheet 3 Søndre Strømfjord – Nugssuaq 1971.

Geology 1:100.000

20 maps between Nanortalik and Isukasia 1967 – 1989.

Quaternary geology 1: 500.000

Sheet 1 Sydgrønland 1987.

Sheet 2 Frederikshåbs Isblink – Søndre Strømfjord 1978.

Sheet 3 Søndre Strømfjord – Nugssuaq 1974.

11. Appendix 2. Aerial photographs and satellite images

11.1.1 Russell Glacier

Air photos: KMS-1985 route: 7/9 1985, route 886L no. 845

Satellite picture data:

ASTER ID nos.:

2015899472, 5007013008717610

Landsat 5 TM ID nos.:

5007013008722410

Landsat 7 ETM+ ID nos.:

7007013000023650, 7007013000109450, 7007013000119050, 7007013000222550, 7007013000306850, 7007013000311650, 7007013000314850, 7007013000319651, 7007013000413552, 7007013000415151, 7007013000419952, 7007013000421552, 7007013000507350, 7007013000513750, 7007013000520150, 7007013000521750, 7007013009928150

11.1.2 Narsap Sermia

Air photos: KMS-1985 route: 20/7 1985, route 886L no. 1806.

Satellite picture data:

ASTER ID nos.:

2006214232, 2015416751

Landsat 5 TM ID nos.:

5006015008720110, 5007014008717610, 5007014008722410

Landsat 7 ETM+ ID nos.:

7006015000005350, 7006015000008550, 7006015000014950, 7006015000026150, 7006015000029350, 7006015000108750, 7006015000110350, 7006015000118350, 7006015000121550, 7006015000204250, 7006015000209050, 7006015000213850, 7006015000217050, 7006015000221850, 7006015000226650, 7006015000309350, 7006015000320551, 7006015000322151, 7006015000417652, 7006015000424052, 7006015000425652, 7006015000508250, 7006015000606950, 7006015009922650, 7006015009925850, 7007014000017250, 7007014000023650, 7007014000109450, 7007014000119050, 7007014000125450, 7007014000208150, 7007014000211350, 7007014000214551, 7007014000228950, 7007014000306850, 7007014000311650, 7007014000314850, 7007014000326052, 7007014000415151, 7007014000419952, 7007014000421552, 7007014000507350, 7007014000510550, 7007014000513750, 7007014000520150, 7007014000521750, 7007014000528150, 7007014009928150

11.1.3 Nigerlikasik Bræ

Air photos: KMS-1985-route: 19/7 1985, KMS route 886N, no. 1684

Satellite picture data:

ASTER ID nos.:

2003237009, 2013700892, 2017132821

Landsat 7 ETM+ ID nos.:

7004017000107350, 7004017000108950, 7004017000112150, 7004017000123350, 7004017000126550, 7004017000207650, 7004017000218850, 7004017000222051, 7004017000225250, 7004017000230050, 7004017000307950, 7004017000311150, 7004017000314350, 7004017000411453, 7004017000416251, 7004017000417851, 7004017000422651, 7004017000429051, 7004017000508450, 7004017000511650, 7004017009921251, 7004017009926050

11.1.4 Sermilik Bræ

Air photos: KMS-1985 rute: 7/8 1985 KMS rute 887E no. 4057.

Satellite picture data:

ASTER ID nos.:

2003167163, 2015891122

Landsat 7 ETM+ ID nos.:

7001017000008250, 7001017000014650, 7001017000030650, 7002017000008950, 7002017000013750, 7002017000021750, 7002017000026550, 7002017000118750, 7002017000123550, 7002017000228650, 7002017000320952, 7002017000328954, 7002017000419651, 7002017000424451, 7002017000426053, 7002017000427652, 7002017000526250, 7002017000529450, 7003017000012850, 7003017000022450, 7003017000109850, 7003017000111450, 7003017000119450, 7003017000205350, 7003017000206950, 7003017000211750, 7003017000216550, 7003017000221350, 7003017000224550, 7003017000308850, 7003017000313650, 7003017000321652, 7003017000407551, 7003017000417152, 7003017000425152, 7003017000507750, 7003017000525350, 7003017000528550, 7003017009918950

12. Appendix 3. Time / activity table

TIME / ACTIVITY TABLE (APA and SN working on Icemon project as well, visiting Automatic Weather Stations on glaciers from Nuuk and Narsarsuaq)

<u>July 20 – Thursday</u>

21:00	SN: Arrival at Kangerlussuaq Airport from Upernavik (field work on Automatic Weather Station on the Steenstrup Glacier), check in Kangerlussuaq Hotel (at Bachelor Officers Quarters, BOQ).

<u>July 21 to July 22</u> SN: Collecting thermo-boxes (for the ice samples) from the post office, acquiring permission and key for padlock to use private road to the ice sheet (Sisimiut Municipality Service Centre, opposite, KISS). Contacting KISS (Kangerlussuaq Science Service Centre, phone +229 84 14 72) for rental of 4WD car.

<u>July 23 – Sunday</u>

09:00	SN: Breakfast.
09:15–15:30	SN: Collecting 4WD car from Per Mikkelsen, Air Greenland (phone +229 52 42 60). Reconnaissance trip to the Russell Glacier at Point 660, about 35 km from Airport.

<u>July 24 – Monday</u>

06:30–07:00	MB, PRJ, and APA: Check in, Copenhagen Airport.
09:15	MB, PRJ, and APA: Departure, Copenhagen Airport. SN: Breakfast, shopping for lunch.
09:55	Arrival, Kangerlussuaq Airport, meeting with SN. Check in, Kangerlussuaq Hotel. Packing for fieldwork, visiting KISS for flash card to use at Sermilik Glacier Camera (See August 1).
11:15–13:00	Driving into Russell glacier (Northern Section, 1 DG 02002).
13:00–14:00	Preliminary survey of the glacier front, plus reconnaissance and photo documentation. Lunch.
15:00	Start on ice sampling.
16:40	The first ice sample is taken.
20:30	Completion of ice sampling, reconnaissance and photo documentation Driving back to Kangerlussuaq.
22:00	Back in Kangerlussuaq. Dinner.

July 25 – Tuesday

08:00	Check out, Kangerlussuaq Hotel. Returning of key to Municipal Service Centre. Delivery of 2 ice samples for cold storage at Air Greenland Cargo until air freight to GEUS 26-07-06. Returning of rented car. Breakfast.
09:30	SN: Check in, Kangerlussuaq Airport.
10:00	MB, PRJ and APA: Check in, Kangerlussuaq Airport.
10:35	SN: Departure, Kangerlussuaq Airport.
10:50	MB, PRJ and APA: Departure, Kangerlussuaq Airport.
11:35	SN: Arrival, Nuuk Airport.
11:45	MB, PRJ and APA: Arrival, Nuuk Airport. Accommodation and lunch at Pinngortitaleriffik (Greenland Institute of Natural Resources). Shopping for better ice sampling tools (bricklayers' hammers, chisels), food etc. Searching for our thermo-boxes (for the ice samples) and sleeping bags in the post office and the Nuuk Airport. Various meetings at Asiaq and Pinngortitaleriffik (Greenland's Nature Institute) Greenland Institute of Natural Resources. Meeting with Michael Lüberth, inspection of chartered boat (25 ft. cabin cruiser), renting car for transport of equipment (Auto & Marine Service Nuuk).
18:00–18:30	Visiting a local road/tunnel construction project. Dinner, packing and making preparations for next day's field trip.

July 26 – Wednesday

10:35	Sailing from Nuuk. Lunch en route.
14:30	Arrival at Nunalugtuarssuk, the South-Western point of Ivisartoq. From this point it was possible to observe the navigation conditions of the fiord right in front of Narsap Sermia. Sailing to the point of Narsaq.
16:00	Landing at the point of Narsaq. Walking to Narsap Sermia. Reconnaissance and photo documentation of landscape and glacier front
18:25	Start on ice sampling.
22:00	End of ice sampling. Walking back to the boat.
23:15	Back on the boat. Sailing to the side fiord Aninganeq, spending the night on the boat.

July 27 – Thursday

01:00-01:30	Dinner.
09:00	Arrival of AS350-B2 from Air Greenland (GEUS charter, Storø Camp).
09:20	APA & SN: Lift off for Narsap Sermia glacier.

09:40-10:45	APA & SN: Visiting and dismantling Automatic Weather Station (AWS) Nuuk 2 (heavily damaged), helicopter search for AWS Nuuk 3 (unsuccessful) and AWS Nuuk 1 (probably lost at calving glacier front).
11:25	Helicopter, APA and SN return to Aninganeq. The instruments from the AWS Nuuk 2 are brought on board and the boat sails toward Nuuk.
15:00	Back in Nuuk. Un- and repack at Pinngortitaleriffik (Greenland Institute of Natural Resources). Posting of ice samples and equipment to GEUS (Air Greenland Cargo) etc.
19:30	Dinner.

July 28 – Friday

06:00	Check in, Nuuk Airport. Helicopter cancelled because of fog in Paamiut.
12:30	Check out. Accommodation at the Hans Egede Hotel in Nuuk.
15:30–18:00	Sightseeing in Nuuk.

July 29 – Saturday

Morning:	Late breakfast, shopping, relaxing, lunch.
14:30–16:00	Sightseeing and museum visiting.

July 30 – Sunday

06:00	Breakfast and check-out, expected departure from Nuuk Airport 07:20.
07:00–10:30	Departure delayed, waiting in Hotel for new departure time.
10:00	Leaving Hotel Hans Egede for Nuuk Airport, further waiting for departure to Paamiut.
11:10	Entering the helicopter. Anyway, owing to a technical defect (airlocks in fuel tubing), the departure was delayed.
13:30	Entering the helicopter for the 2nd time and flying to Paamiut.
15:00	Arrival at Paamiut. Accommodation and re-packing at the “Hotel Paamiut”.
16:05	Sailing from Paamiut to the glacier Nigerlikasik Bræ. Boat charter, a Flipper 25 (?) cabin cruiser, Betonkompagniet.
17:30	Landing at the rocky coast very close to Nigerlikasik Bræ. Walking to the locations for ice sampling. Reconnaissance and photo documentation of landscape and glacier front. Ice sampling.
20:30	Sailing back to Paamiut.
C. 22:00	Back in Paamiut.

July 31 – Monday

07:30	Departure from Hotel Paamiut, ice samples collected by Blue Water Shipping, for transport to GEUS.
08:00	Check in, Paamiut Airport.
10:15–12:00	Flying from Paamiut to Narsarsuaq.
13:00–14:00	Claiming of various gear in the airport and Base Supply building S-528, “Ikea”, DMI Ice Patrol.
14:30	Sailing from Narsarsuaq in the direction of the glacier Sermilik Bræ. Charter “JF Johnstrup, Narsaq (Former GGU travel boat, Christian Egede).
22:00	Anchoring at Qagssimiut for the night.

<u>August 1 – Tuesday</u>

06:00	Weighing anchor and resume sailing toward Sermilik Bræ. Breakfast
09:30	Landing at the rocky coast at some distance from Sermilik Bræ. Walking to the locations for ice sampling. Reconnaissance and photo documentation of landscape and glacier front.
11:15	Start on ice sampling.
13:00	End of ice sampling. Walking back to the boat.
14:25	Back on the boat. Lunch.
16:00	SN, APA and PRJ are sailed back to the coast to make an inspection of a monitoring camera belonging to Jason Box, University of Ohio. MB stays on the boat to record fiord depths.
20:00	Sailing from Sermilik Bræ toward Narsarsuaq. Staying the night on the boat in the port of Narsaq, arrival *c.* 03:30.

<u>August 2 – Wednesday</u>

09:00–10:00	Delivery of boxes with ice samples to Royal Arctic Line (RAL) for cold storage until transport to GEUS.
10:00–11:00	Breakfast at skipper Christian Egedes home.
11:00–13:00	Shopping for various gears for repairing of the monitoring camera and installation of solar panel.
13:00–16:00	Sailing from Narsaq back to Narsarsuaq. Check in at Narsarsuaq Hotel.

<u>August 3 – Thursday</u>

09:00–14:00	Tourist trip to Qassiarsuk (Brattahlid).
Afternoon:	We all took a walk to the airport to make a charter arrangement with Air Greenland. APA & SN: Claiming of various gear in the Base Supply building S-528, “Ikea”, DMI Ice Patrol.

August 4 – Friday

09:00–12:00 PRJ & MB packing and checking out of hotel.
APA & SN: preparing equipment for helicopter trip to glacier Saturday
Lunch at Narsarsuaq harbour.

Afternoon: PRJ & MB: check in, Narsarsuaq Airport and returning to Denmark.
APA & SN: still preparing equipment for helicopter trip.

August 5 – Saturday

08:00 Breakfast.

09:00 Driving to Narsarsuaq Airport, Air Greenland Charter. Helicopter lift off delayed until 10:30 due to low clouds.

10:30 Lift off for Sermilik Glacier, Air Greenland.

11:00–14:15 Arrival at AWS 71.2v2 for servicing and downloading of data.

14:20–16:15 Transfer to monitoring camera, installing power supply and solar panel, starting camera.

16:20–17:00 Search for ASW 72 (failed due to whiteout, low clouds), photo reconnaissance of Narsaq Bræ en route to Narsarsuaq Airport.

August 6 – Sunday Backup of data, packing equipment, delivery of goods (tools, sleeping bags, instruments etc.) to RAL at Narsarsuaq for shipping to GEUS.

August 7 – Monday

09:00 Breakfast.

10:00–12:00 Packing, check-out of hotel.

12:00 Check-in Narsarsuaq Airport, returning to Denmark.

13. Appendix 4. Landing and sampling positions

Location	Point	Zone	UTMx	UTMy
Russell Glacier	Parking	22W	541144	7448703
Russell Glacier	Sample 1	22W	541607	7448481
Russell Glacier	Sample 2	22W	541923	7448920
Narsap Sermia	Landing	22W	541575	7168996
Narsap Sermia	Sample 1	22W	544321	7168420
Narsap Sermia	Sample 2	22W	543807	7169147
Nigerlikasik Bræ	Landing	22V	612765	6883926
Nigerlikasik Bræ	Sample 1	22V	612734	6884072
Nigerlikasik Bræ	Sample 2	22V	612782	6884353
Sermilik Bræ	Sample 1	23V	393178	6765227
Sermilik Bræ	Sample 2	23V	392929	6765029
Sermilik Bræ	Landing	23V	393274	6764160

14. Appendix 5. Climate data

Station 04231 Kangerlussuaq													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temperature (ºC).* 1973-99													
	-19,8	-21,4	-18,1	-7,8	2,5	8,6	10,7	8,2	3,0	-5,5	-12,1	-16,4	-5,7
Average daily maximum temperature (ºC). 1976-99													
	-14,5	-16,4	-12,4	-2,2	7,6	13,9	16,3	13,4	7,5	-1,8	-7,6	-11,0	-0,6
Absolute maximum temperature (ºC)* 1976-1999													
	11,0	11,9	14,4	16,0	22,4	23,1	25,5	21,8	18,7	16,9	15,7	11,9	25,5
Average daily minimum temperature (ºC). 1976-99													
	-24,4	-26,7	-24,0	-13,3	-2,5	3,3	4,8	3,0	-1,4	-9,8	-16,4	-20,8	-10,7
Absolute minimum temperature (ºC)* 1976-1999													
	-47,2	-46,4	-45,4	-34,4	-21,8	-4,7	0,3	-4,6	-12,9	-29,7	-36,3	-45,5	-47,2
Number of ice days (t_{max} < 0 ºC)* 1976-99													
	26,5	25,4	27,4	17,8	3,6	0,0	0,0	0,0	1,3	17,9	32,2	25,8	169,1
Number of cold days (t_{min} < -10 ºC)* 1976-99													
	28,1	27,0	28,2	18,3	2,5	0,0	0,0	0,0	0,5	14,2	22,5	27,2	168,5
Mean wind speed (m/sec). 1985-99													
	3,7	3,4	3,3	3,2	3,7	4,1	3,7	3,7	3,3	3,5	4,0	3,8	3,6
Most frequent wind direction (%). 1985-1999													
	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
	66	61	54	36	21	22	34	37	39	59	68	67	47
Mean accumulated precipitation (mm).* 1976-99													
	5	4	5	6	8	15	24	33	18	14	11	7	149

* indicates missing monthly values within the mentioned years.

Station 04250 Nuuk.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temperature (ºC).	-7,4	-7,8	-8	-3,8	0,6	3,9	6,5	6,1	3,5	-0,7	-3,7	-6,2	-1,4
Average daily maximum temperature (ºC).	-4,6	-4,7	-5,1	-1,2	3,1	7,0	9,9	9,3	6,0	1,4	-1,3	-3,5	1,4
Absolute maximum temperature (ºC)* 1958-1999	13,5	13,0	11,5	13,0	16,0	19,0	20,0	22,0	20,0	14,5	13,9	12,1	22,0
Average daily minimum temperature (ºC).	-10,0	-10,7	-10,7	-6,3	-1,7	1,1	3,5	3,5	1,4	-2,7	-5,9	-8,6	-3,9
Absolute minimum temperature (ºC)* 1958-1999	-29,5	-28,5	-27,3	-19,6	-13,4	-4,0	-2,6	-1,5	-5,2	-12	-17	-23,6	-29,5
Number of ice days (t_{max} < 0 ºC)	24,1	20,8	24,0	17,6	4,3	0,0	0,0	0,0	0,2	9,9	18,8	22,3	141,9
Number of cold days (t_{min} < -10 ºC)	14,7	15,4	17,3	6,5	0,1	0,0	0,0	0,0	0,0	0,3	3,9	12,0	70,0
Mean wind speed (m/sec). Provisional normal average.* 1963-1999	7,1	7,2	7,3	6,6	5,4	5,2	5,2	5,4	5,6	5,9	6,7	7,2	6,2
Most frequent wind direction (%). 1963-1999	N	N	N	N	S	S	S	S	S	NE	NE	NE	N
	24	26	29	28	24	29	33	33	26	29	29	24	21
Mean accumulated precipitation (mm).	40	47	49	47	55	61	86	85	89	66	73	54	752

Climatological standard normals, 1961-90

* indicates missing monthly values within the mentioned years.

Station 04260 Paamiut	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temperature (ºC).	-6,6	-6,4	-6,0	-2,3	1,4	3,7	5,6	5,3	3,5	0,1	-2,8	-5,4	-0,8
Average daily maximum temperature (ºC).	-3,4	-3,0	-2,7	0,6	4,2	6,5	8,8	8,2	6,2	2,9	0,3	-2,3	2,2
Absolute maximum temperature (ºC)* 1958-1999	11,5	12,2	11,2	16,6	20,5	20,6	21,2	20,5	18,6	16,5	15,5	14,4	21,2
Average daily minimum temperature (ºC).	-10,1	-10,2	-9,9	-5,7	-1,1	1,1	2,8	2,7	0,8	-2,8	-6,1	-8,9	-4,0
Absolute minimum temperature (ºC)* 1958-1999	-28,9	-29,6	-30,9	-18,5	-14,6	-4,0	-4,0	-2,2	-6,5	-14,1	-20,5	-25,3	-30,9
Number of ice days (t_{max} < 0 ºC)*	21,9	19,2	20,1	13,0	2,0	0,0	0,0	0,0	0,0	5,6	14,5	20,6	116,5
Number of cold days (t_{min} < -10 ºC)*	14,8	14,4	15,2	5,4	0,1	0,0	0,0	0,0	0,0	0,7	6,7	13,0	68,3
Mean wind speed (m/sec).	4,2	4,4	4,1	3,8	3,6	3,5	3,0	3,1	3,5	3,3	3,5	4,1	3,7
Most frequent wind direction (%). 1960-1999	Calm	Calm	Calm	Calm	NW	NW	NW	NW	NW	Calm	Calm	Calm	Calm
	32	32	29	28	31	30	28	28	28	34	36	34	28
Mean accumulated precipitation (mm).*	66	64	64	58	58	67	91	92	80	71	84	83	874

Climatological standard normals, 1961-90.

* indicates missing monthly values within the mentioned years.

Station 04272 Qaqartoq												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temperature (ºC).Climatological standard normals, 1961-90.												
-5,5	-5,0	-4,4	-0,6	3,3	5,2	7,2	7,2	5,0	1,2	-1,9	-4,4	0,6
Average daily maximum temperature (ºC).												
-2,2	-1,7	-1,0	2,8	6,9	9,2	11,1	11,0	8,0	3,9	0,8	-1,4	4,0
Absolute maximum temperature (ºC)* 1961-1999												
12,3	11,5	10,8	14,0	20,4	20,0	20,4	22,0	18,5	16,6	13,7	12,0	22,0
Average daily minimum temperature (ºC).												
-9,2	-8,8	-8,4	-4,4	-0,4	1,3	3,3	3,7	1,9	-1,7	-5,0	-7,8	-2,9
Absolute minimum temperature (ºC)* 1961-1999												
-30,0	-25,2	-26,0	-16,4	-12,8	-6,0	-2,4	-3,4	-8,5	-11,0	-18,0	-21,6	-30,0
Number of ice days (t_{max} < 0 ºC)												
18,5	15,7	16,7	6,7	0,3	0,0	0,0	0,0	0,0	3,9	13,2	17,7	92,7
Number of cold days (t_{min} < -10 ºC)												
13,2	12,3	12,7	4,0	0,0	0,0	0,0	0,0	0,0	0,1	4,1	11,8	58,2
Mean wind speed (m/sec).												
5,4	5,5	4,6	3,7	3,4	2,9	2,3	2,6	3,1	3,4	4,3	5,0	3,8
Most frequent wind direction (%). 1961-1999												
Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm	Calm
29	28	34	38	38	41	46	43	41	42	35	31	37
Mean accumulated precipitation (mm).												
57	51	57	56	56	75	97	93	92	72	78	73	858

Climatological standard normals, 1961-90.

* indicates missing monthly values within the mentioned years.

15. Appendix 6. Results of ice analysis

Locality	Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses Inorganic ions, mg/l	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Fluoride	0.15	1.44	0.08	0.07	0.73	0.13	0.05	0.08
Chloride	0.44	2.09	0.51	0.59	4.96	0.42	0.90	0.99
Nitrate	b.d.	0.24	0.06	b.d.	0.15	0.06	0.04	b.d.
Phosphate	0.02	0.04	**1.24**	0.01	**2.05**	b.d	b.d.	b.d.
Sulfate	0.39	0.94	0.70	0.43	2.99	b.d.	0.29	0.28
Sodium	2.36	0.53	0.36	0.88	1.84	0.18	1.24	0.51
Ammonia	**0.98**	0.07	**0.10**	**0.12**	**0.55**	**0.14**	b.d.	**0.11**
Potasium	1.23	0.41	0.22	0.63	0.85	0.23	0.39	0.25
Magnesium	0.23	0.15	0.13	0.16	0.15	0.14	0.13	0.18
Calcium	1.05	0.70	0.51	0.73	0.53	0.57	0.63	0.66
Suspended material								
>0.45um fraction, mg/l	23.55	119.90	56.56	35.13	16.79	17.88	7,39	14.17

b.d.: below detectionlimit

Re-analyses of phosphate and ammonia

Locality		Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
		Russel 1	**Russel 2**	**Nuuk 1**	**Nuuk 2**	**Paamiut 1**	**Paamiut 2**	**Sermilik 1**	**Sermilik 2**
Analyses									
Ammonia	Method	mg / l							
1. sample	spectrometric	0.383	0.063	0.085	0.124	0.507	0.036	0.059	0.051
2. sample	spectrometric	0.026		0.060		0.008			
2. sample refrozen	spectrometric	0.062		0.039		0.023			
1. sample	IC	0.980	0.070	0.100	0.120	0.550	0.140	b.d.	0.110
Phosphate	Method	mg / l							
1. sample	spectrometric	0.149	0.084	0.080	0.020	0.035	0.124	0.005	0.035
2. sample	spectrometric	0.015		0.045		0.010			
2. sample refrozen	spectrometric	0.030		0.104		0.020			
1. sample	IC	0.020	0.040	1.240	0.010	2.050	b.d	b.d.	b.d.

Locality	Russell’s Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
PAH compounds								
Naphthalene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Acenapthylene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Acenaphthene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Fluorene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Phenanthrene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Antrachene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Fluoranthene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Pyrene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Benzo (a) anthracene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Chrysene / Triphenylene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Benz (b+j+k) fluoranthene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Benzo (a) pyrene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l

Locality	Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Indeno (1,2,3 – cd) pyrene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Dibenzo (a,h) antrhacen	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Benzo (g, h, i) perylene	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
Sum PAH (16 EPA)	# not found	# not found	# not found	# not found	# not found	# not found	# not found	# not found
Polychlorinated biphenyls								
PCB # 28	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
PCB # 52	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
PCB # 101	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
PCB # 118	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
PCB # 138	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
PCB # 153	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l
PCB # 180	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l	<0.005 µg/l

Locality	Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Pesticides and degradation products from pesticides								
AMPA	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Atrazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Bentazone	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
4-CPP	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
2.4-D	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
2.6-DCPP	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Desethylatrazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Desethyldesisopropylatarzine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Desethylterbutylazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Desisopropylatrazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Dichlobenile	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
2.6-dichlorbenamide	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l

Locality	Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
2.6-dichlorobenzoicacid	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Dichloroprop (2.4-DP)	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Dinoseb	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Diuron	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
DNOC	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Glyphosate	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Hexazinon	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Hydroxyatrazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Hydroxysimazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Hydroxy-terbuthylazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Isoproturon	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
MCPA	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Mechlorprop ((MCPP)	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l

Locality	Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Metamitrone	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Metribuzine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Metribuzine-diketo	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l
Metribuzine-desamino-diketo	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l
4-nitrophenole*	**<0.02 µg/l**	**0.032 µg/l**	**<0.02 µg/l**	**0.019 µg/l**	**<0.02 µg/l**	**0.021 µg/l**	**0.022 µg/l**	**0.024 µg/l**
Pendimethalin	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Simazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
TCA	**0.084 µg/l**	**0.019 µg/l**	<0.010 µg/l	<0.010 µg/l	**0.20 µg/l**	<0.010 µg/l	<0.010 µg/l	**<0.02 µg/l**
Terbuthylazine	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l	<0.010 µg/l
Wood fungicide								
PCP	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l	<0.020 µg/l

Locality	Russell's Glacier		Narsap Sermia		Nigerdlikasik Bræ		Sermilik Bræ	
Analyses	Russel 1	Russel 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Viable bacteria								
CFU on TSA; 2 weeks -2 °C	0	0	0	0	0	0	0	0
CFU on TSA; 2 weeks 4 °C	0	0	0	0	0	0	0	0
CFU on TSA; 2 weeks 10°C	0	0	6 ml^{-1}	0	0	0	3 ml^{-1}	0
CFU on TSA; 2 weeks 20°C	0	0	20 ml^{-1}	20 ml^{-1}	3 ml^{-1}	3 ml^{-1}	0	3 ml^{-1}
CFU on TSA; 5 weeks -2 °C	0	0	0	0	0	0	0	0
CFU on TSA; 5 weeks 4 °C	0	3 ml^{-1}	300 ml^{-1}	15 ml^{-1}	0	120 ml^{-1}	720 ml^{-1}	30 ml^{-1}
CFU on TSA; 5 weeks 10°C	6 ml^{-1}	6 ml^{-1}	390 ml^{-1}	?	6 ml^{-1}	900 ml^{-1}	160 ml^{-1}	170 ml^{-1}
CFU on TSA; 5 weeks 20°C	3 ml^{-1}	0	30 ml^{-1}	30 ml^{-1}	3 ml^{-1}	6 ml^{-1}	0	3 ml^{-1}
Total bacteria								
(DAPI stained bacterial cells visible in microscope)	1100 ml^{-1}	500 ml^{-1}	750 ml^{-1}	750 ml^{-1}	350 ml^{-1}	300 ml^{-1}	1200 ml^{-1}	1000 ml^{-1}