DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/76

Glacier Ice as resource for freshwater export

Investigation of four glaciers from the Greenland Inland Ice, carried out for the Greenland Home Rule

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MINISTRY OF CLIMATE AND ENERGY

G E U S

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GEUS

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exceptions are ammonia and iron which are found values over the standard in both water samples. The content can be explained as a natural component.

The analysis of bacteria and spores show values below the EU drinking water quality standard.

The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section15.2) and TCA (natural component).

<u>Narsap Sermia</u>

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exceptions are ammonia and iron which are found in values over the standard in both water samples. The content can be explained as a natural component.

The analysis of bacteria and spores show values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section15.2).

<u>Nigerlikasik Bræ</u>

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 fore-land in front of the glacier and to move around on the glacier surface as well. The calving rate is very modest.

The general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water. The pH values are neutral.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exception are ammonia which are found in one sample in value over the standard. The content can be explained as a natural component.

The analysis of bacteria and spores show values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section 15.2) and TCA (natural component).

<u>Sermilik Bræ</u>

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exception is ammonia which is found in one sample in value over the standard. The content can be explained as a natural component.

The analysis of bacteria and spores show values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section 15.2) and TCA (natural component).

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. A wide range of different kinds of background data are available: satellite images, aerial photos, topographical and geological maps, historical photos and descriptions, previous investigations, etc.

Satellite images

Satellite images (available from the 1960s until present-day) are useful in conducting visual surveys of remote locations, for estimations of glacier front positions, glacier morphology, landscape interpretation, ice conditions in the fiords etc.

Aerial photography

Aerial photography provides the means for accurate landscape characterization and interpretation, and as the photos are acquired as stereo-photogrammetric images, they can also be used for production of digital elevation models (DEM's). Additional photographical material exists locally from helicopter surveys. Such recent and close-up photos are very informative.

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, 2006).

Topographical maps:

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 (Mosbech et al., 2000, 2004), mapping a number of factors regarding the physical environment and nature that could prove sensitive to oil spill from ships or oil drilling (GEUS 2007).

Historical photos and descriptions:
The glaciological archive at GEUS contains aerial photographs, satellite images, publications, notes etc. 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 late 1950s to the early 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 using the systematic approach of the World Glacier Monitoring Service for glacier registration worldwide, see Fig. 1.1 GEUS's glacier database follows the international standards for glacier registration (Weidick et al., 1992).

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. Four reports (Bøggild et al., 2000; Mayer et al., 2003; Ahlstrøm et al., 2006; Bender et al., 2003a) have been published by GEUS on the subject of mining inland ice for export purposes. Together the material in these reports constitutes the basis for the fieldwork activities planned for 2006.

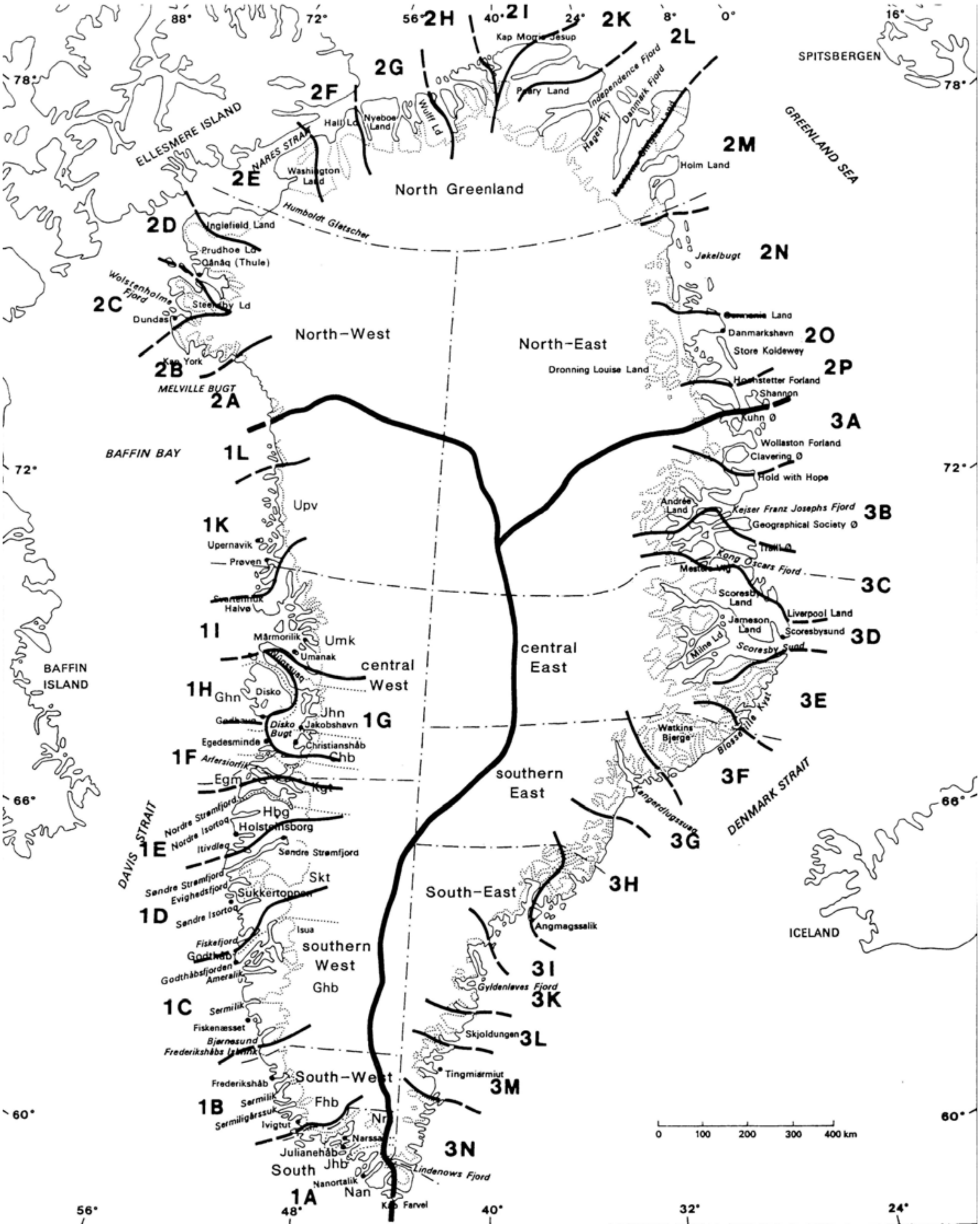


Fig. 1.1. Glacier hydrological main division of Greenland into districts. (After Weidick et al. 1992).

1.2 The quality of the ice

The quality conditions of the Inland Ice are the total of the chemical matters and the content of sediment in the ice. The age of the ice is an important parameter as the fact that ice, which can be dated back to time prior to the initiation of human induced pollution, is expected to be free from any matters injurious to the environment and only hold natural components.

1.2.1 Sediment and particles

Generally, the glacier ice from the Inland Ice is a clean natural product. However, this fact does not prevent that the ice may hold very small concentrations of fine terrestrial dust and meteoric particles deposited or fallen down from the atmosphere. Moreover, it is possible to detect ashes, soot and charcoal that have been carried to the ice by the wind. Still, some of the particles may be regarded as predominantly sterile material. However, the melting at the ice front causes the impurities to concentrate on the surface, which causes certain areas of the ice sheet surface to appear dirty. But the fact that the ice is impermeable means that the pollution of the surface only influences the quality of the ice on a limited scale.

Special geological conditions exist, where inclusions can be incorporated into the ice and reduce the quality locally. These conditions occur in connection to 1) crevasses (blue bands), 2) dead-ice and 3) shear planes in the ice. When extracting the ice, it is important to avoid the blue bands because the quality and age of blue band ice is uncertain owing to seeping water from the surface. So, the quality of consumption ice produced from blue band ice can not be guaranteed.

Fig. 1.2. Sample site 1 at Nigerlikasik Bræ illustrating the heterogenic conditions which may occur on the glaciers.

The occurrence of mid moraines on the ice surface indicates that basal material, picked up from the geological substratum, has reached the glacier surface. Generally, it is recommended not to extract the deepest and most marginal parts of the ice, because this ice has been close to the subjacent bedrock during floating and may hold even high concentrations of matters injurious to the environment. These matters include silt, sand and gravel and locally clay and minerals with disadvantageous properties such as high radioactivity. Based on the geological conditions it is recommended that an estimation of the surface is carried out prior to extraction. This estimation can minimize the risk for extraction of dead-ice that has been in contact with the substratum, or ice with many blue bands.

The distribution of impurities on and in the Inland ice is very heterogeneous and it is not possible to give certain rules for the relation between clean and impure ice. Therefore sampling sites have to be chosen on location. It will probably not be possible to take samples which will give a representative picture because of the heterogenic conditions (fig. 1.2).

Local glaciers are expected to hold a higher concentration of alien substances that have blown in from the surrounding land. Together with the considerable younger age of the ice in local glaciers, these glaciers are characterized as a less suitable product for extraction.

1.2.2 Chemical conditions

The origin and – especially – the age of the ice might be the most essential sales parameters for bottled water that originates from the Greenlandic Inland Ice. However, a positive expectation for a special product is spoiled if any matters of pollution can be found in the ice or water. Although the age of the ice is determined, there is a theoretical possibility that the ice surface is exposed to pollution from modern industrial chemicals through precipitation. So, to secure a high quality of the ice, it is crucial that the ice does not contain any matters of pollution that derive from the industrialized time. Moreover, for most purposes the ice must not hold any natural but health threatens matters. Besides, it would be reasonable to accomplish identical types of analyses of the ice water that apply to natural mineral water and spring water.

It is essential to call attention to the fact that the present legislation does not allow the ice to be called natural mineral water. The ice has to be called something ells. It is recommended that legislation is established by now, which rank the ice alongside with natural mineral water concerning minimum claims for quality.

In practice this implies that the quality claims valid at present for natural mineral water, spring water and bottled / wrapped water can be used as a template for the choice of quality parameters to be used for a valuation of melted inland ice for drinking water production. The most extensive rules apply to the designation natural mineral water, while the demands for spring water and wrapped water are less. It is possible that demands identical to the Danish proclamation no. 1015 of 10/12 2003 could be used for water from the Greenlandic Inland Ice (ice water).

By Greenland ice water is understood bacteriological healthy water and the water is characterized by its natural purity. It should only be marketed as water bottled from the Greenland Inland Ice if it fulfils a series of specific conditions and comply with the maximum limits for natural found constituents and if the exploitation of the ice and the bottling of the ice water are carried out in agreement with the regulations. Treatment and admixture need to be stipulated by rules about filtrations or decantation.

It is necessary to accomplish analyses for the following:

- Inorganic chemistry: There has to be analysed for the common components: Major ions and selected heavy metals.
- Micro biology: The melted ice water must have a low content of perfectible micro organisms and give evidence of effective protection of the ice towards any pollution. It is especially important that the ice and the bottled water must be free from parasites and pathogenic micro organisms. At the sale, the total content of perfectible micro organisms in Greenlandic ice water is solely allowed to arise from the normal development of the bacteriological content in the water, originating from the ice.
- Micro pollutions: Quantifiable amounts of pesticides or pesticide remnants must not be found in the ice. Neither is it allowed to find PCB or other organic micro pollutions in the ice.

1.2.3 Existing chemical data

The suitability of the ice as drinking water (referring to the EU and Danish drinking water rules) has so far only been estimated in 2003 on 4 ice samples from South and West Greenland:

Three samples were collected west of Narsarsuaq in South Greenland and one sample was collected from Russell's Glacier north-east of Sdr. Strømfjord. All samples have been analysed for pesticides and metabolites, PAH's, PCB's and micro biology. The analyses demonstrated pollution of the young Inland Ice in South Greenland with high concentration of organic matters injurious to the environment. Amongst other things pentachlorophenol (6.1 µg/l) and 15 different PAH's were found in concentrations of 0.014 – 0.65 µg/l. On this background, it is important to investigate if the pollution found in this young inland ice is widespread or if it only an isolated occurrence (Bender et al. 2003a).

Moreover, the influence from global pollution on the Inland Ice was considered. Amongst other things it was concluded, that no matters injurious to the environment was found in the samples of old ice, but the younger ice contained a high level of matters injurious to the environment and a low content of micro biological embryo (Bender et al. 2003b).

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.

1.3 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 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.

The ice originating from the Inland Ice has a quality that by far exceeds the quality of local glaciers in the coastal region. This is why the outlet glaciers from the Inland Ice are in focus and the Sukkertoppen and nearby glaciers are disregarded.

Moreover, to evaluate the accessibility criteria, it has been necessary to make a determination of the distance from the glacier front to nearest fiord/sea-coast. In this way, the distance from the glacier front to the fiord/sea-coast (in nearest whole kilometre) has been measured. If the distance exceeds 10 kilometres, the glacier is considered less interesting and is disregarded. The distance between the debouchment of the glacier in the fiord and the sea-coast or a bigger town may be much longer. These distance conditions are also included in the estimations. A map of the localization of the investigated glaciers in South and West Greenland is shown in Fig. 1.3, next page.

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 & 2007, Mayer et al. 2003).

1.4 Descriptions of the glaciers

Every single glacier has been described in relation to a series of different kinds of parameters (Ahlstrøm et al. 2006). These are shortly listed below:

ID: Name and glacier identification according to the worldwide system (Weidick et al. 1992).

Aerial photographs: Year, photo-route, photo-number(s).

Satellite images: ASTER and Landsat image-number, date.

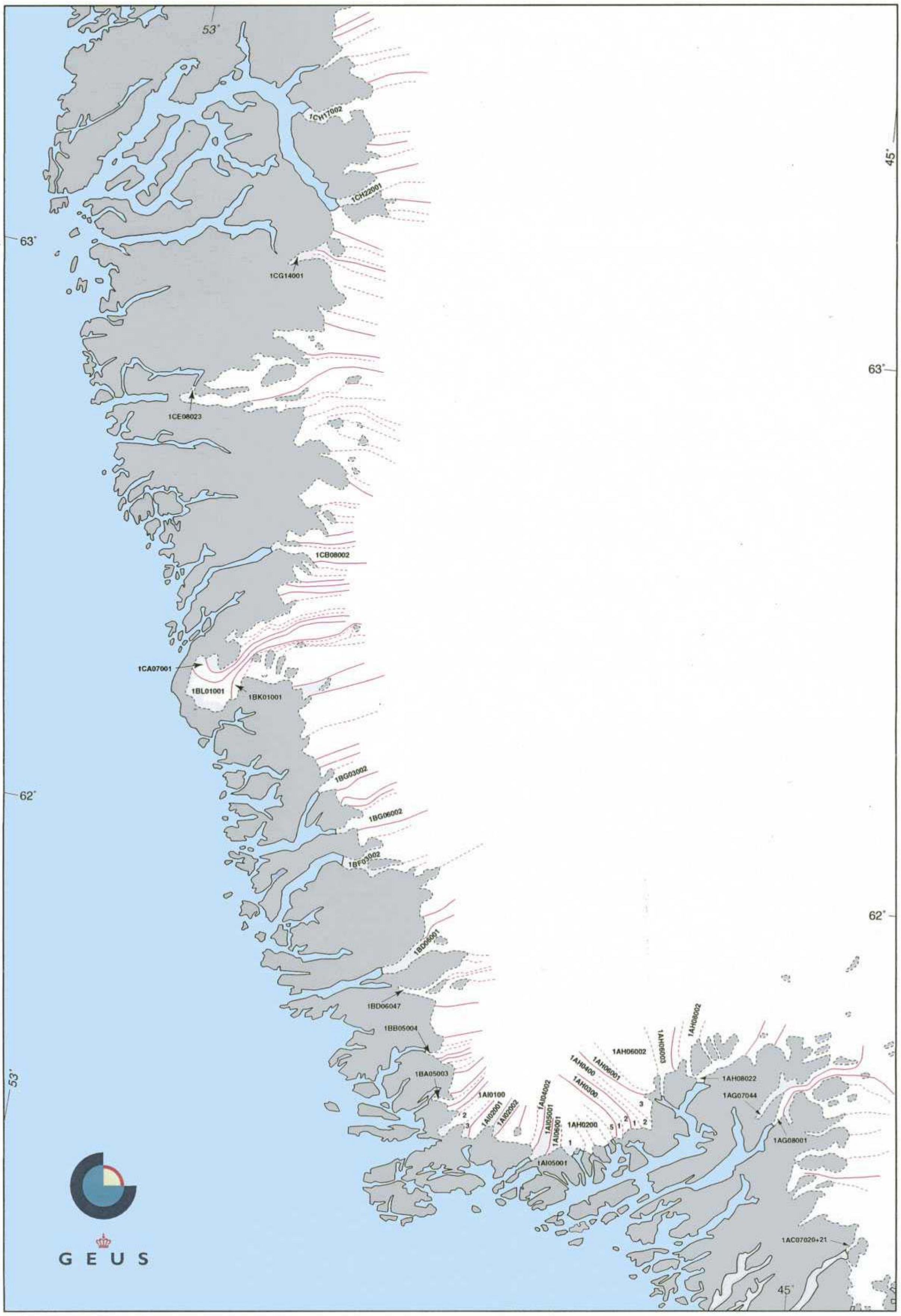
Localization: Name of nearest fiord, distance between the fiord/sea coast and glacier front, etc.

Glacier co-ordinates: Geographical co-ordinates for longitude and latitude of a point on the centre line of the glacier movement in the ablation area.

Topographic maps: Number of the KMS Saga map and any tourist/hiking maps on which the glacier is located and the maps that show the accessibility conditions (fiords etc.).

Glacier delimitation: Orientation of the downward motion of the ablation area. Maximum level / highest point of the glacier (in metres above sea level, m.a.s.). Minimum / lowest point of the glacier (in metres above sea level, which is zero if the glacier debouches into a fiord). Area of the glacier surface (in square km). The area is digitized and the upper delimitation is given by the contour line 1800 m.a.s.

Fig. 1.3 (next page): Map of the localization of the investigated glaciers in Sout and West Greenland, incl. Id-codes. Scale: c. 1:2.000.000. (After Bøggild et al. 2000).


53°
45°
63°
63°
1CH17002
1CH22001
1CG14001
1CE08023
1CB08002
1CA07001
1BL01001
1BK01001
1BG03002
1BG06002
1BF03002
62°
62°
1BD06001
1BD06047
1BB05004
1BA05003
1AI0100
1AI02001
1AI02002
1AI04002
1AI05001
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1AH06001
1AH06002
1AH06003
1AH08002
1AH08022
1AG07044
1AG08001
1AI05001
1AC07020+21
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Glacier morphology: The condition of the glacier at the reference time is described (crevassing, icefalls, mid moraines, shear planes, dust covers, etc.). Moreover, the morphological code is given (6 number illustrating: primary glacier classification, glacier form, front characteristics, longitudinal profile, main source, glacier activity).

Glacier development: Descriptions of changes observed during the last century. The changes reflect late and recent climate changes and are important to know in case of establishment plans close to the ice border, the accessibility of the ice front and evaluations of the age conditions of the ice. Moreover, the characteristics that can be deduced from the modelling (flux conditions etc.) are mentioned.

Terrain conditions, coast and land: The conditions of the terrain around and in front of the glacier are described (landscape characterization, morphology, steepness, till covers, end moraines, materials, etc.).

The fiord: If the glacier debouches into a fiord, the conditions of the fiord are described (availability and nature of bathymetric data, tidal data, etc.).

Geology: The geological conditions of the bedrock and the overburden Quaternary deposits are described in general terms.
Accessibility: The accessibility conditions of the landscape adjacent to the glacier front are described (distance between glacier front and fiord / coast / open sea / nearest town, character of the landscape, calved ice conditions, etc.)

Other conditions: Description of any industrial and/or environmental conditions that are sensitive to or can be affected by navigations activities (oil spill), establishment of buildings/harbours (other pollution) close to the glacier (fishery, hunting, colonies of birds and mammals, archaeological sites, etc.).

Total evaluation: The descriptions are ended by a preliminary assessment of the suitability of the glacier for production of ice for bottled water, based on the existing information. Three categories have been used: Potentially suitable, partly suitable, and less suitable.

The age of the glaciers was evaluated in general terms. Directly dating methods of the ice are uncertain, difficult and expensive. So, numerical model calculation of the ice´ age has been a commonly used method though the models might be even very complicated. Generally, the age determination will become more precise as the degree of details used in the model is increased. But the age conditions of a specific outlet glacier from the Inland Ice are greatly determined by the local topographical, ice dynamical and meteorological conditions. On a larger scale and at the middle part of the Inland Ice, the local conditions are of less importance. That is why the age distribution of the Inland Ice is best described by means of large-scale models in which the ice dynamic conditions at the central parts of the Inland Ice are essential. Based on modelling results, it can be concluded that a high accumulation rate combined with melting and basal sliding along the sole of the ice, beside the often small ice thickness is the cause that the age of the ice is generally youngest in the southernmost Greenland. So, if the age of the ice is very important it is recommended to locate the extraction as northerly as possible. Moreover, the model calculations demonstrate that many glaciers in South and West Greenland contain ice, which is more than 5,000 years old.

Chemical analysis already exists for only a few glaciers, se section 1.2.

The most interesting areas were the following:
The area north of Bredefjord and Nordre Sermilik in south Greenland is most attractive because the margin of the Inland Ice borders on to the coast with large areas of ”pure” ice and without the strong calved ice production that otherwise characterize the head of many fiords. The following glaciers have been designated from this region: Western Kangerluarsuk Bræ (1 AH 03001), Ilorlliit Sermiut (1 AH 02005), Qalerallit Sermia (1 AH 02001), No name (1 AI 06001) and Sermilik Bræ (1 AI 05001).

Other localities with fewer suitable glaciers are found along the coast toward north: Arsuk Bræ (1 BB 05004) in Arsuk fiord, Nigerlikasik Bræ (1 BG 06002) in Kvanefjord/Nigerlikasik fiord, Avannarleq Bræ (1 1 BG 03002) in Kvanefjord/Avennarleq Fjord, Nakaissorsuaq (1 CB 08002) in Bjørnesund, Narssap Sermia (1 CH 17002) in the inner part of Godthåbsfjord and Russell’s Glacier (1 DG 02002 +01) at Sdr. Strømfjord

Based on these possibilities, the four glaciers below are recommended for further investigations under Option 1. The relevant glaciers represent outlet glaciers from three areas: South Greenland north of Narsaq, the middle region around Frederikshåb Iceblink and the western region around Nuuk and Sdr. Strømfjord. So, the glaciers are geographically spread over the entire analysed coastal area (Fig. 1.3, next page).

<u>Russell Glacier, Kangerlussuaq, West Greenland.</u>
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

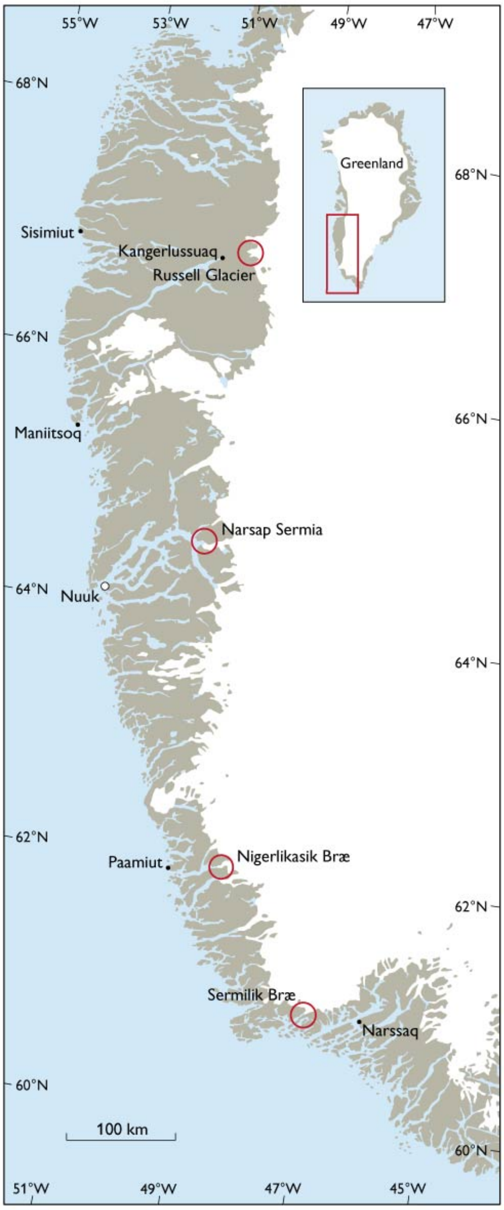
Narsap Sermia was chosen for its glaciological conditions and close proximity to Nuuk.

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.



1.5 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.

Fig. 1.3. Location of the four investigated glaciers.

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

The selection of sampling localities was based on criteria set up in the primary selection of the glaciers (Ahlstrøm et al., 2006) and the inspection of the site during the field work. Specific sampling locations were selected to fit the demands of commercial extraction of the ice, e.g. the shortest transport way between a possible landing location and ice of a usable quality.

In the primary selection glaciers that potentially might have impurities have been excluded, such as local glaciers and glaciers with mid moraines, in order to select glaciers with high degree of purity, and homogeneity (Ahlstrøm et al. 2006).

During the field work the most suitable location for extraction of ice was estimated based on morphology of the surroundings as well as morphology of the glacier, and sampling was conducted in that particular part of the glacier. The distance between the sampling sites was adjusted to the local glacier morphology, but a minimum of 250 m was chosen in order to be able to detect eventual inhomogenities within the glacier composition. 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.

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 expected sterile Rilsan plastic bags and stored in polystyrene boxes to keep frozen during transport 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 around 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

2.3 Procedures for analysis of ice

Ice-samples were melted under sterile conditions and transferred to purified bottles and kept cooled before further analyses. The samples from each locality were not mixed before the analysis. It is important to find original chemical differences between the various parts of the ice and mixing of the samples would not show these especially if the elements occurs in very small concentrations. In a production process it will always be possible to mix water from the different parts of the glacier.

The samples were analysed at the commercial laboratory Eurofins A/S and at GEUS Microbiological and Chemical laboratories. There are four collections of analysis: A. Analyses of general characters, major ions, heavy metals and bacteria. (September 2007, Eurofins Danmark A/S), B. Analysis of ammonia and phosphate (February 2007, GEUS), C. Analysis of major ions (January 2007 GEUS) and D. Analysis of PAH, PBC, pesticides and bacteria (December 2006, Eurofins Danmark A/S and GEUS).

Al the results from the analysis are found in chapter 15 as Appendix 6. In this chapter a short general description of the chemical conditions with remarks on some problems will be presented. The quality conditions for each glacier occur in the relevant chapters.

Inorganic ions, heavy metals and general characters – Eurofins methods:

At Eurofins Laboratory the analysis of the inorganic ions, heavy metals and general characters are performed according to “Dansk Akkreditering” .

Inorganic ions – GEUS methods:

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 – GEUS method:

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.

<u>Viable bacteria – GEUS method:</u>

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).

<u>Bacteria and spores – Eurofins methods:</u>

At Eurofins Laboratory the analysis of bacteria and spores are preformed according to “Dansk Akkreditering”.

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) (Se Appendix 2).

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 (Appendix 2).

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, 2006).

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.
   English version: Bøggild et al. (2000): Preliminary localization of greenlandic glaciers with ice/water suitable for export. GEUS Report **2000/73**, 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).

North of Russell Glacier:

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.

Narsap Sermia:

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 15^{th} 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.

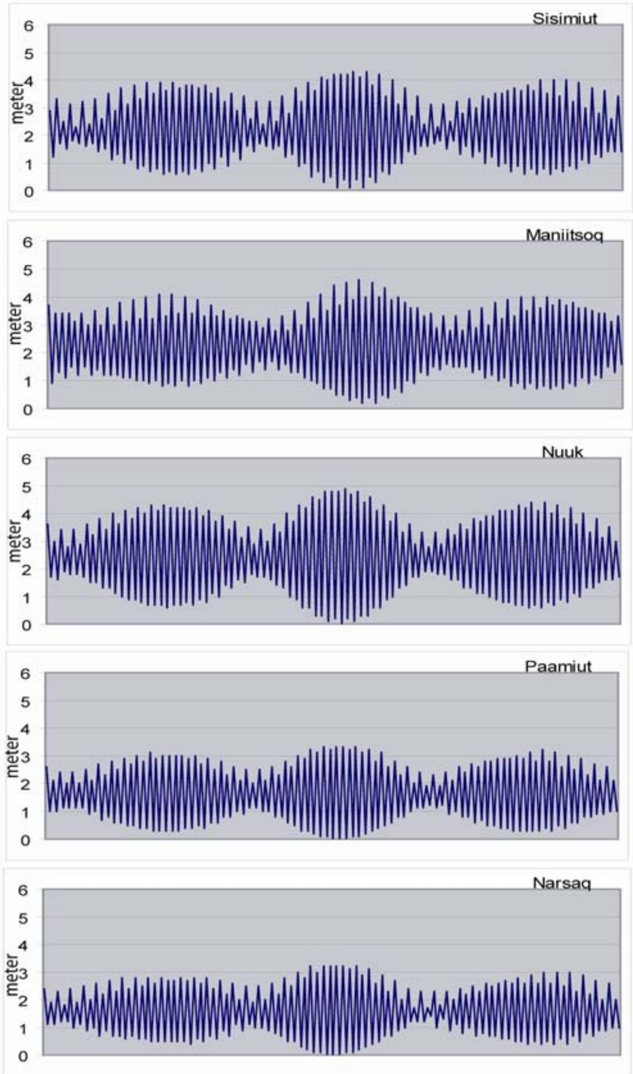


Fig. 6.1 Tide, Southwest Greenland. The daily variation in the height of successive tides is seen in all the curves, but it is especially clear in Sisimiut and Narsaq. The curves (and Table 6.1) are based on data from the period between 6th March and 22nd April 2006, in the Tide Tables for Greenland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

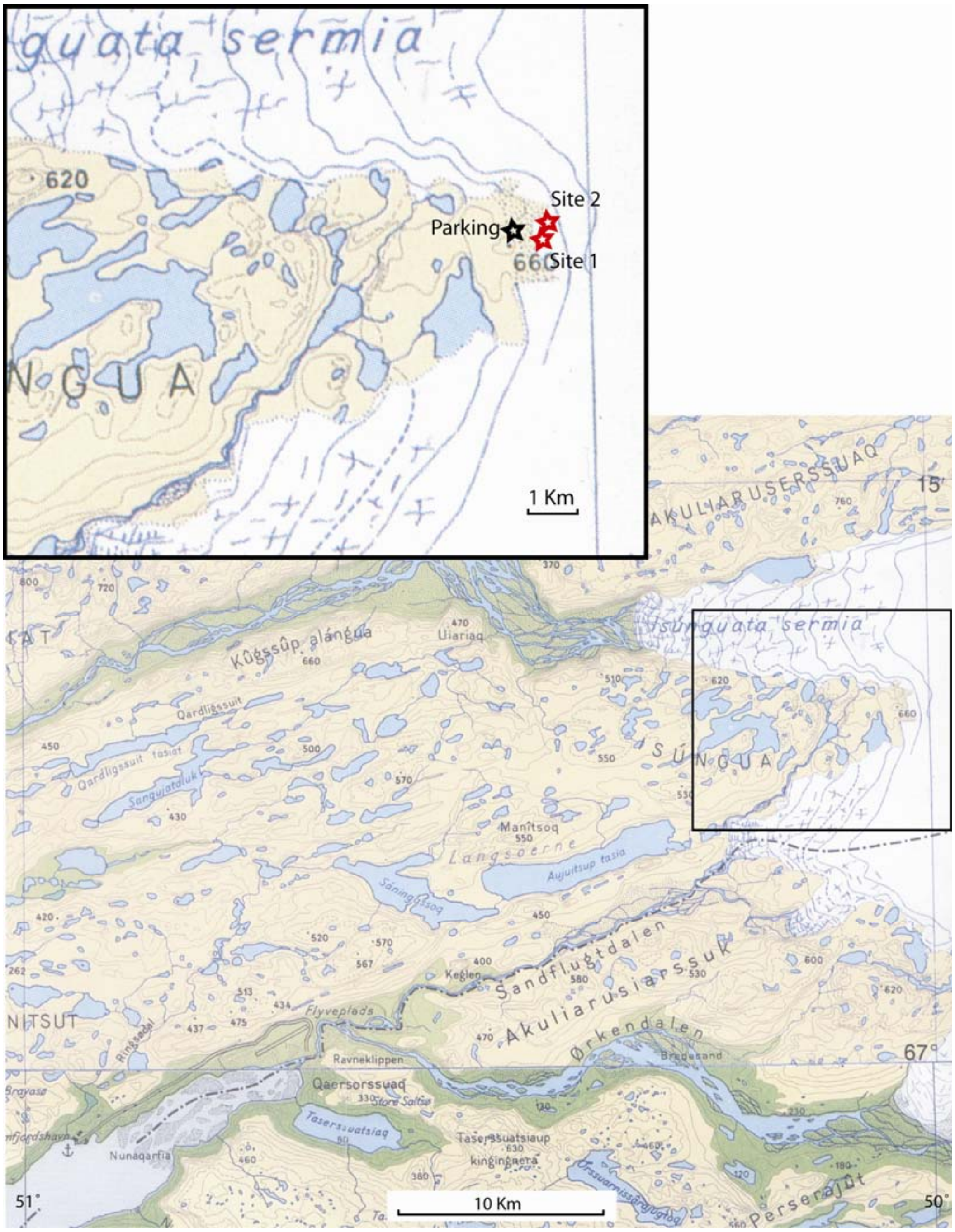


Fig. 7.1 Area map of part of the Russell Glacier where the position of the landing site and the sample sites are indicated. The distance between the sampling sites is 543 m.

Age of the ice

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.

Glacier morphology

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. The margin of the Russell Glacier at sampling site 1. The glacier surface is smooth and gently dipping. The lateral moraine consists of a mixture of all grain-sizes from clay to large boulders. Generally, the surface of the lateral moraine is firm and solid but in a zone along the ice border, the sediments may be soaked with water and rather soft.


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. Locally, the ice surface is covered by a thin layer of wind-blown dust.

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 (Fig. 7.4). For this reason, the character (stability, water content etc.) of the surface in the dead-ice moraine landscape varies from time to time. Widespread till deposits are found in front of the glacier, se, 7.5 and 7.6

Fig. 7.4 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. 7.5 Deposits in front of Russell Glacier. The grain-sizes of the deposits range from clay to boulders.

Fig. 7.6 End moraine at the rim of the glacier. Note the grainsize variation between clay and boulders. Also note the sediment covered ice-cone to the right of the large boulder.

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. and the section: Geology. The glacier is located *c.* 35 km NE of Kangerlussuaq.

Fig. 7.8 The landscape and road between Kangerlussuaq and the Russell Glacier. At most of the distance between the glacier and Kangerlussuaq, the quality of the unpaved road is very good.

Fig. 7.9 Photo of the road very close to Russell Glacier, where melting of buried ice causes irregularities of the ground. Dead-ice holes are continuously created when the dead-ice melts away. For this reason, the character (stability, water content etc.) of the surface in this area varies from time to time. Our car is parked in the distance.

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).

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).
Tourism: There is some tourism in the area. Kangerlussuaq offers different kinds of adventures. Just a couple of kilometres from Kangerlussuaq's airport it is possible to see some of the area's approximately 5,000 musk oxen. Frequently in the summer season, trips with a cross-country vehicle go right up to the edge of the ice sheet north of Russell Glacier. From the parking ground, it is possible to cross a small bridge and take a walk on the ice sheet. Furthermore, the very stable climate of the winter season is perfect for dogsled trips. (www.Greenland.com).

7.1.1 Water quality of Russell Glacier

General chemical characters

The analysis show that the water is soft, slightly acid (pH 6.0), with low values of conductivity and hydrogenecarbonate and high values of aggressive CO2, turbidity and NVOC. These values do not fulfil the EU drinking water quality standard, but the characters are as expected for this type of water.

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.

The analysis of the heavy metals shows very low values. The iron content is in both samples above the recommendated EU standards. The content is probably caused by fine-grained dust.

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 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 could be a result of contamination from the Rilsan bags (see section 15.2).

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

Analysis for colony counts 22 ^{o}C and 37 ^{o}C, coliform baciteria 37 ^{o}C, E. coli, Clostridium perfringens, and Clostridium perfringens spores gives values below the EU drinking water quality standard.

Bacterial counts were also 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 (inorganic rest) in amounts of 23.55 mg/l and 119.90 mg/l. However, the ice is still regarded as pure as the values are below the EU drinking water quality standard.

7.2 Narsap Sermia

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

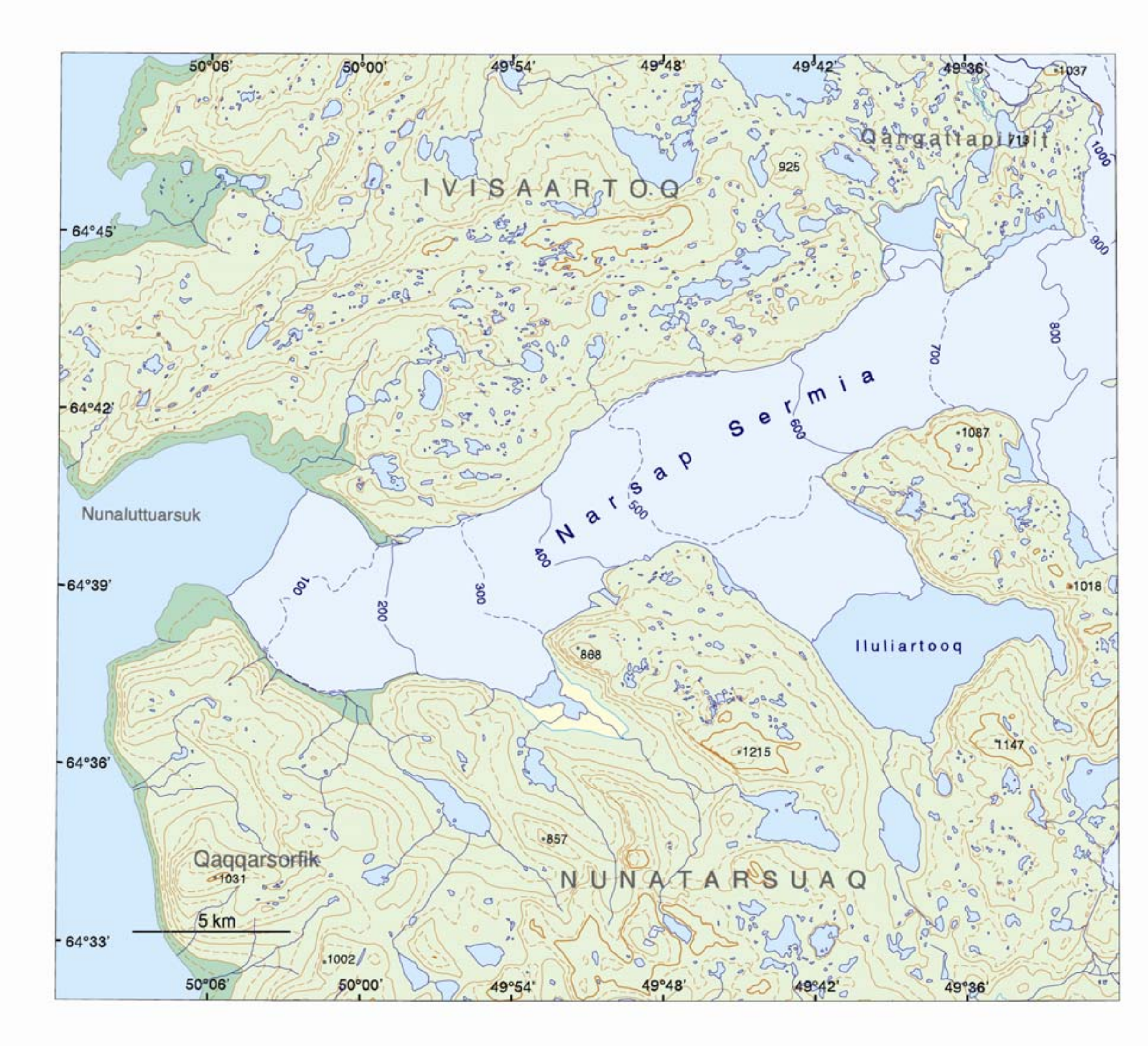


Fig 7.10. Area map of Narsap Sermia.

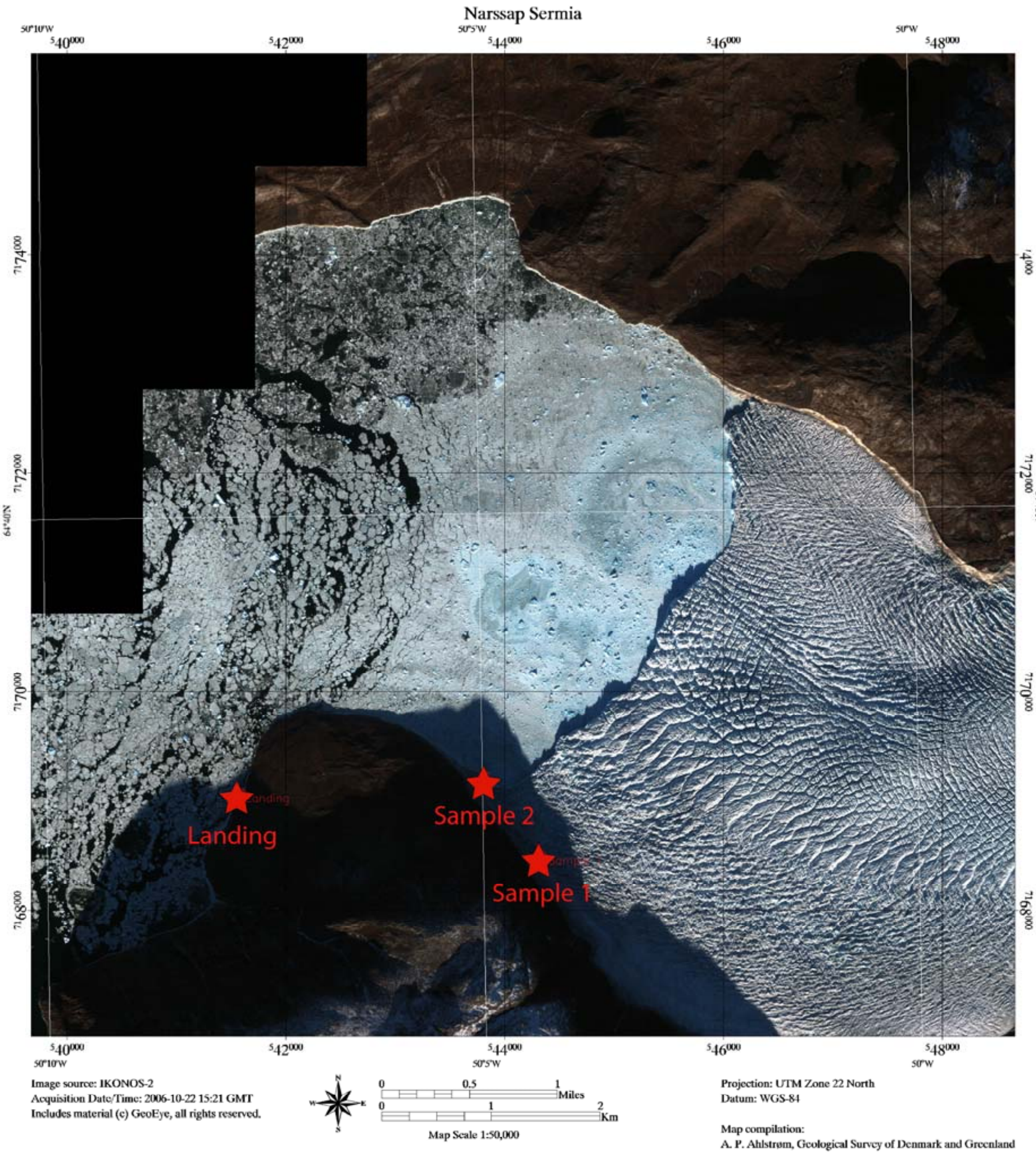


Fig. 7.11. Satellite image of Narsap Sermia. Sample locations and landing site are marked on the image. Distance between the sample sites is 890 m. Note that the front of the glacier has re-treated after the sampling.

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, see Fig. 7.12, 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.

Fig. 7.12. Detail of the outer part Narssap Sermia showing the strongly crevassed morphology of the ice. The photo is taken from helicopter. View direction to the South-West.

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 7.13 and 7.14). Along the glacier a side moraine is build up on both sides of the glacier (Fig. 7.15 and 7.16). Marine deposits are found op to level *c.* + 90 m in the area.

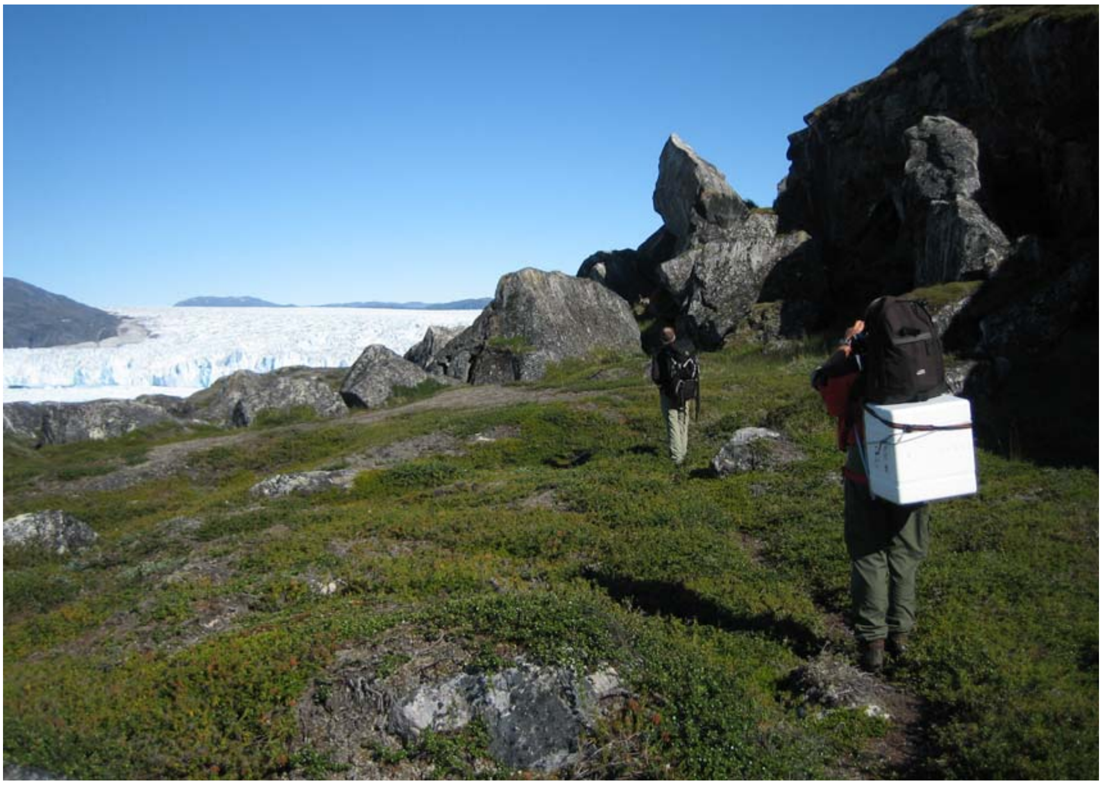


Fig. 7.13 An example of the landscape on the Narsaq point a few kilometres from the front of Narsap Sermia. Narsaq Point is till covered, with bedrock sticking up. Tundra vegetation is growing on the till deposits.

Fig. 7.14 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. 7.15 Photo of the extensive, light-coloured side moraine.

Fig. 7.16. The side moraine along the steep cliffs next to the glacier

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 (Fig.7.16). 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. 7.17 and 7.18. In the northern part of the fiord and in front of the glacier, the calved ice is most dense. 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 (Fig. 7.19 and 7.20). From here, it is possible to cross Narsaq point. 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. 7.17 Panorama of the glacier front 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, 7.12 and 7.18 to see the highly crevassed nature of the floating glacier tongue.

Fig. 7.18. The front of Narsap Sermia. The strongly crevassed glacier has a high calving rate.

Fig. 7.19 The landing site on the west side of the Narsaq point. Landing is possible locally at the roche moutonnées.

Fig. 7.20. The landing site on the Narsaq point and the hinterland as seen from the fiord.

The access to the glacier itself is across a side moraine at the outermost part of the glacier (Fig. 7.15, 7.16 and 7.22), as the cliffs are too steep further alongside the glacier to access it (Fig. 7.16 and 7.21).

Fig. 7.21. Ice sampling on Narsap Sermia, site 1. The surface of the ice is darkened by dust from the side moraine. Remark the very steep cliffs behind the side moraine.

Fig. 7.22. Ice sampling on Narsap Sermia, site 2. Access to the glacier is along and across the side moraine seen in the background

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.

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 fiord a 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).

Some (4) archaeological sites are located on the southern shore in a distance of *c*. 3-5 km west of the southern ice front. (Another 3 archaeological sites are located on the northern shore in a distance of *c*. 2-5 km west of the northern ice front, from where ice extraction is not to be recommended).
Site specific species (Iceland gulls and kittiwakes, Black guillemots and Great cormorants) have been mapped no closer than 30 kilometres from the glacier front.
The closest resource use (fishery and occasional hunting) is mapped some 20 kilometres north of the glacier front, in Ujarassuit Paavat side fiord.
The summary of the shoreline sensitivity according to oil spill next to Narsap Sermia is a low ranking (Mosbech et al. 2004).
A few reindeers were observed south of the fjord close to the glacier front during the field work (July 2006) and according to the local people, reindeer hunting does take place in the area, although not often.
Tourism: There is no known tourism in the area next to Narsap Sermia. Most probably, the distance between Nuuk and Narsap Sermia is to long. Furthermore, the area is not very accessible to most tourists.

7.2.1 Water quality of Narsap Sermia glacier

General chemical characters

The analysis show that the water is soft, slightly acid (pH 6,1-6.2) with low values of conductivity and hydrogencarbonate and high values of aggressive CO_2, turbidity and NVOC. These values do not fulfil the EU drinking water quality standard, but the characters are expected for this type of water.

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 quality standard.

The analysis of ammonia and iron gives values above the EU drinking water quality standard.
The analysis of the heavy metals gives very low values.

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.

<u>Pesticides</u>

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 could be a result of contamination from the Rilsan bags (see section 15.2).

<u>Bacterial content</u>

The analysis for colony counts 22^{o}C and 37 ^{o}C, coliform bacteria 37 ^{o}C, E. coli, Clostridium perfringens and Clostridium perfringens spores gives values below the EU drinking water quality standard.

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.

<u>Sediment content</u>

The ice water samples contain fine-grained, suspended sediment material (inorganic rest) in amounts of 11 mg/l and 45 mg/l. However, the ice is regarded as pure as the values are below the EU drinking water quality standard.

7.3 Nigerlikasik Bræ

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

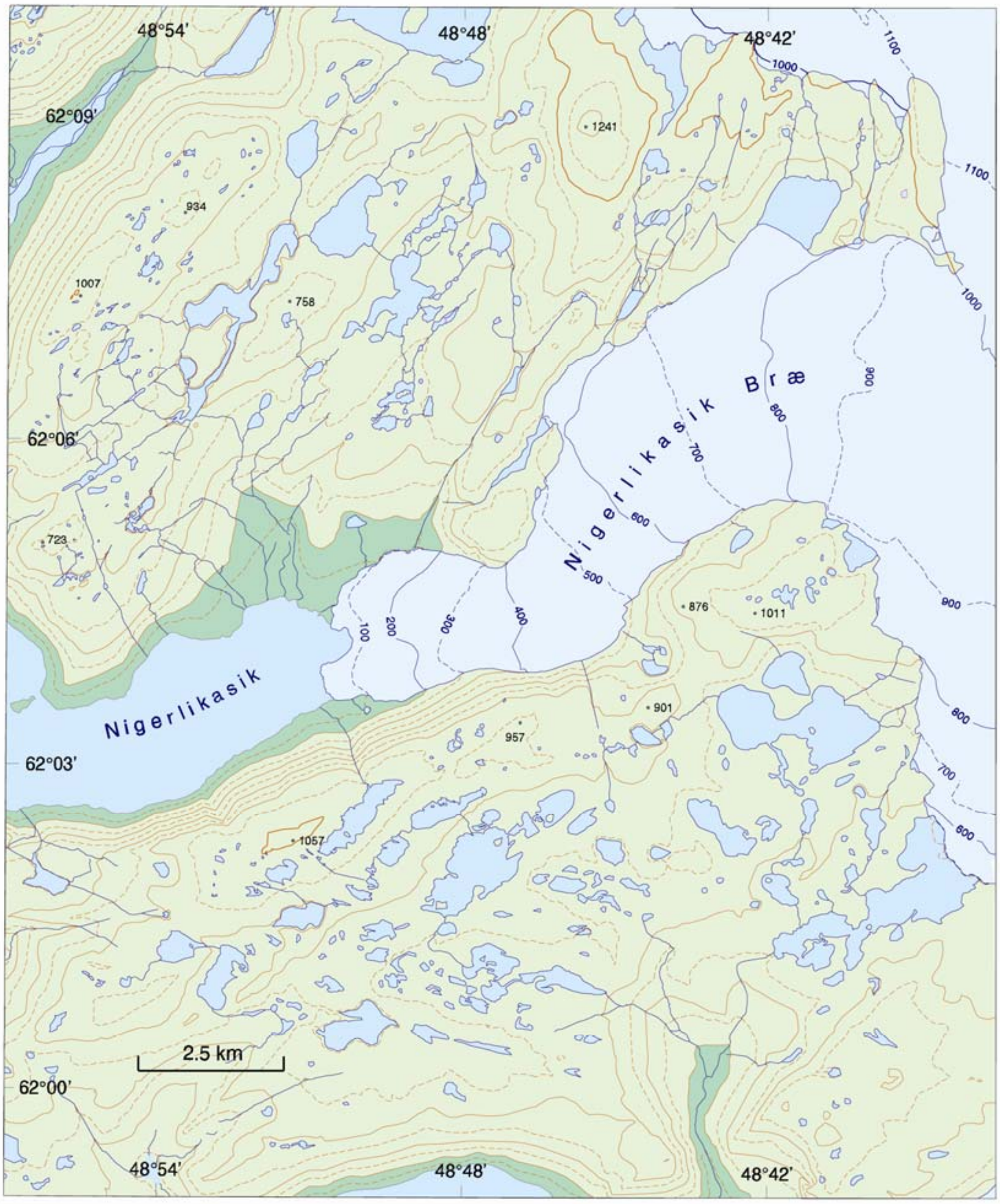


Fig. 7.23, Area map of Nigerlikasik Bræ

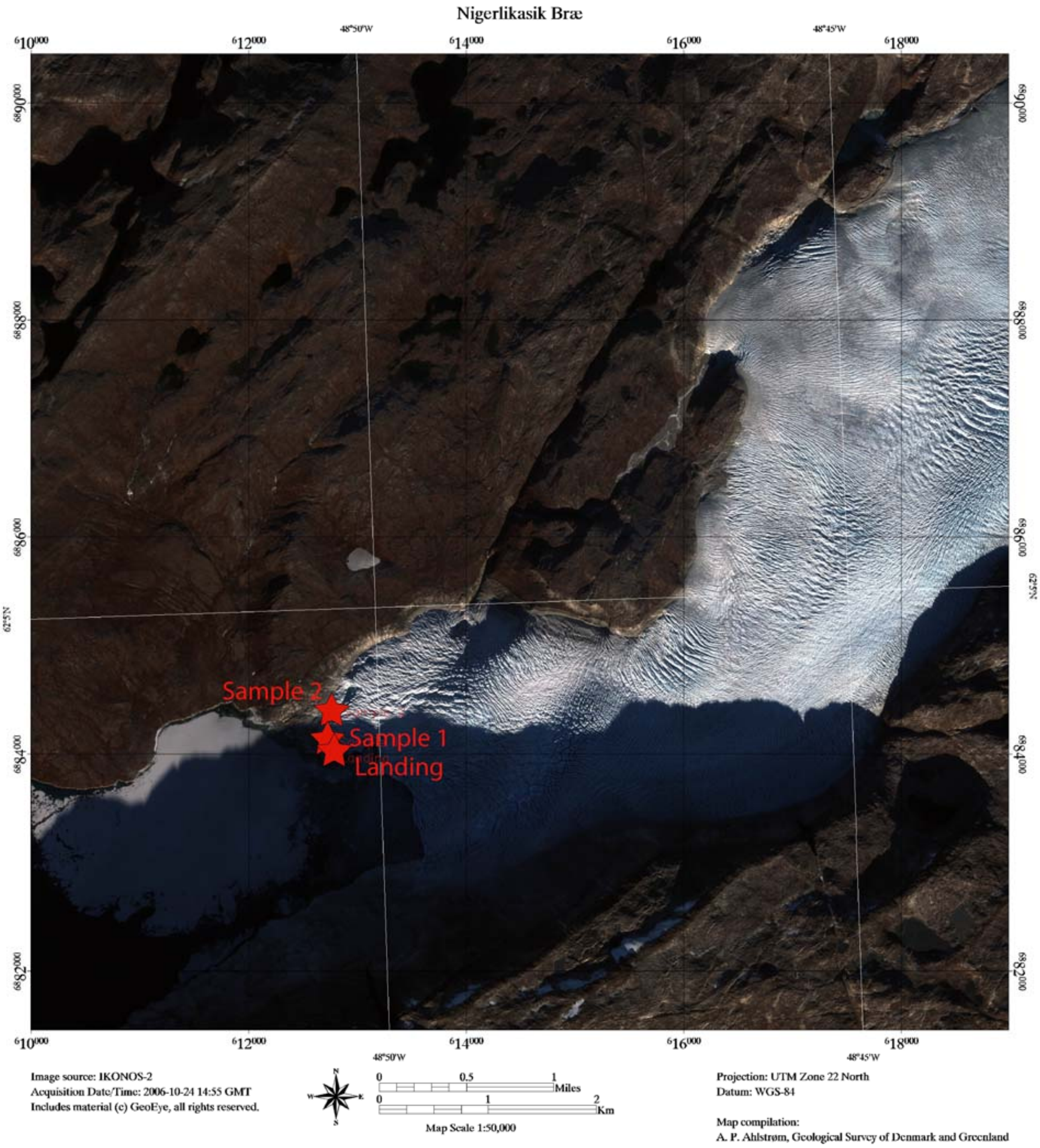


Fig. 7.24 Satellite image of Nigerlikasik Bræ. Sample locations and landing site are marked on the image. The distance between the sample sites is 285 m.

<u>Age of the ice</u>

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).

<u>Glacier morphology</u>

The glacier originates from the Inland ice and descends over a sub glacial threshold into the fiord, see Fig. 7.23, 7.24 and 7.25. 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. 7.25 Nigerlikasik Bræ seen from a distance. Note the steep descent of the glacier from the Inland ice. The glacier is calving in the right side of the photo (the bluish part). The rest of the glacier rests on rocks that recently have been exposed.

Fig. 7.26 Photo of the northern part of the glacier front resting on a rocky outcrop. The rocks have been exposed due to the retreat of the melting ice-front during the last 5-10 years.

Fig. 7.27 View of the central and southern part of the glacier front. Calving occurs with a very modest rate in the southern (distant) part of the front. 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 (Fig.7.26, 7.27 and 7.28. Locally, where the bedrock is exposed, it is clearly seen that the ice has smoothed the cliffs and formed roche moutonnée (Fig. 7.29).

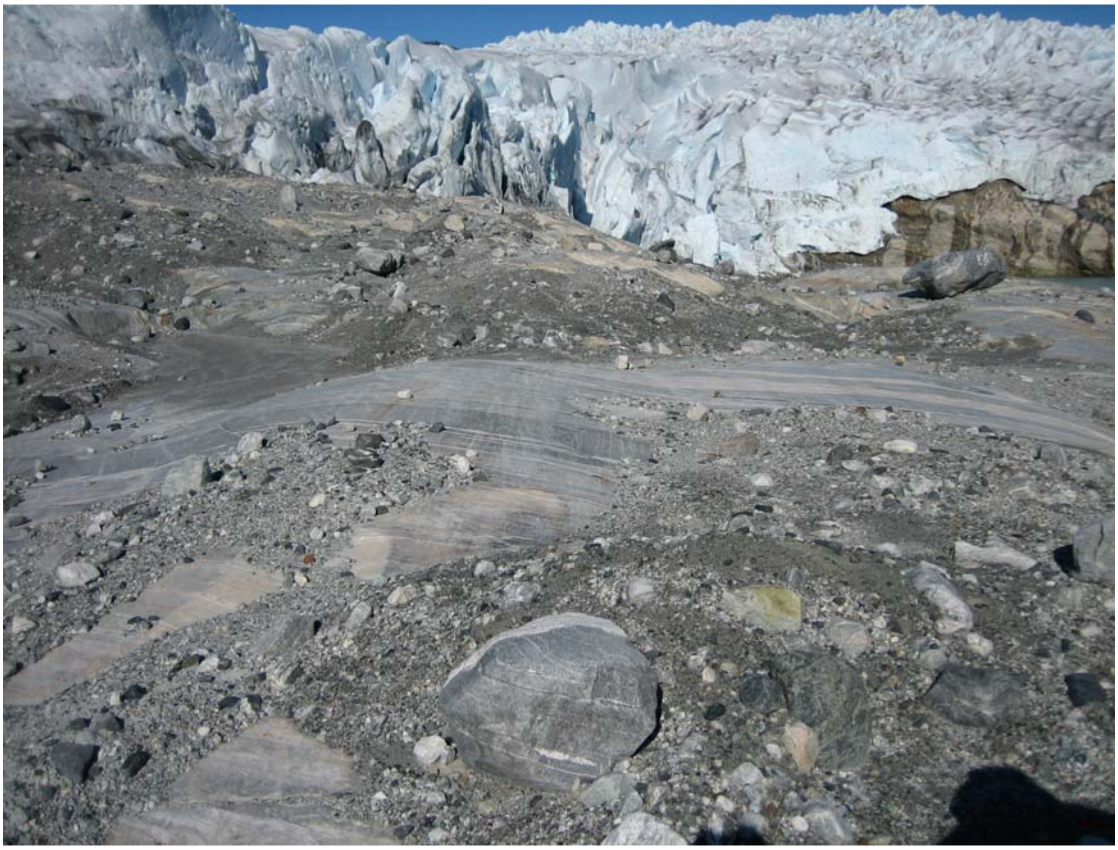


Fig. 7.28 The recently exposed bedrock in front of the Nigerlikasik Bræ. The rocks are only covered by a thin and scattered layer of till material.

Fig. 7.29. 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 in the area. A meltwater river is located in the northern flank of the glacier front, see Fig. 7.23, 7.30 and 7.31.

Fig. 7.30. 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. 7.31. Ice sampling at Nigerlikasik Bræ. The person indicates the location of sampling site 1. This is also where the meltwater river emerges from the ice.

<u>Accessibility</u>

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 rocks right in front of the northern glacier flank (Fig 7.26 and 7.29).

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. 7.32. 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.

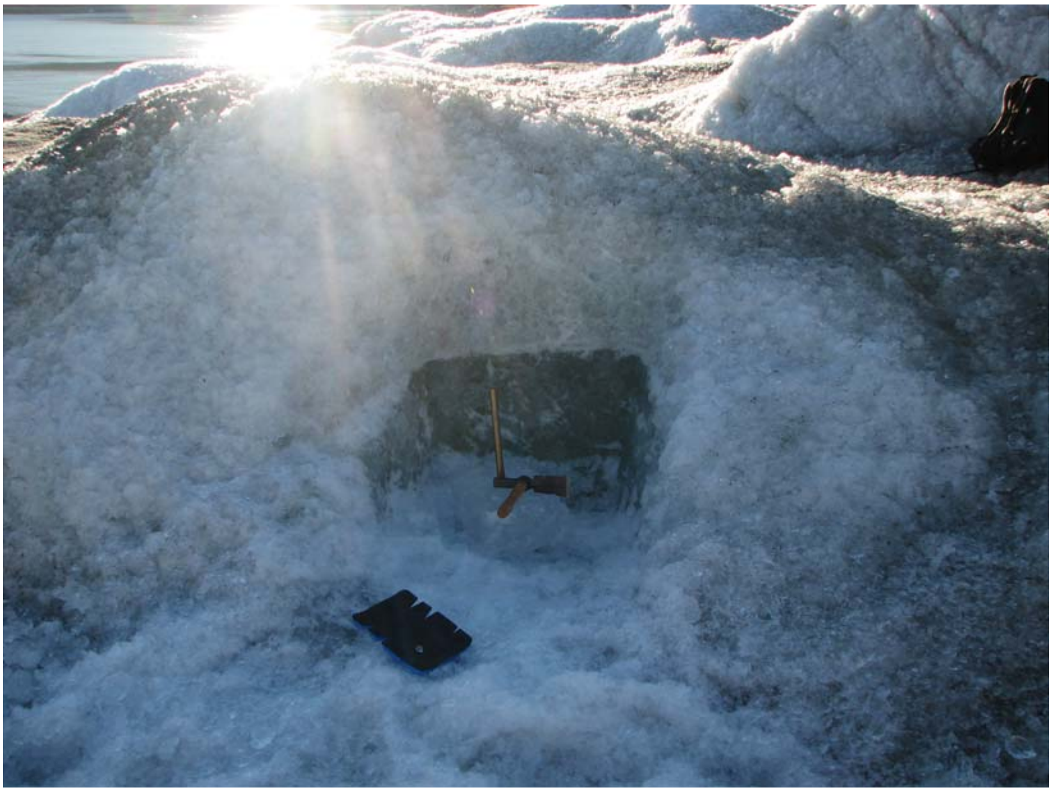


Fig. 7.33. Close-up photo of sampling site 2. The boundary between the crumbling ice layer and the useful solid ice is very clear.

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).

Two archaeological sites are located in a distance of *c*. 6-7 km west of the ice front, one of each side of the fjord.

Site specific species (Kittiwakes and Iceland gulls) have been mapped about 10 kilometres from the glacier front.

Shoreline species (Gull breeding colony with kittiwakes and Capelin fishery) have been mapped *c*. 12 kilometres from the glacier front.

The closest resource use (Small capelin fishery in the spring, and fishery for redfish throughout the year) is mapped some 12 kilometres southwest of the glacier front, in Kuannersooq (Kvanefjord).

The summary of the shoreline sensitivity according to oil spill next to Nigerlikasik is a high ranking (Mosbech et al. 2004).

Tourism: Excursions to the Inland Ice via Kvanefjord do occur. Cruises are seldom scheduled in Paamiut but can be arranged on demand (www.visitgreenland.dk).

7.3.1 Water quality of Nigerlikasik Bræ

General chemical characters

The analysis show that the water is soft, neutral (pH 7.2-7.3) with low values of conductivity and hydrogencarbonate and high values of aggressive CO_2, turbidity and NVOC. These values do not fulfil the EU drinking water quality standard but the characters are expected for this type of water.

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.

The values of the heavy metals are very low. In sample 2 the iron content is slightly above the EU drinking water quality standard.

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 could be a result of contamination from the Rilsan bags (see section 15.2).

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

The analysis concerning colony counts 22 ^{o}C and 37 ^{o}C, coliform bacteria 37 ^{o}C, E. coli, Clostridium perfringens and Clostridium perfringens spores gives values below the EU drinking water quality standard.

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 (inorganic rest) in amounts of 16.79 mg/l and 43 mg/l. However, the ice is regarded as pure as the values are below the EU drinking water quality standard.

7.4 Sermilik

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

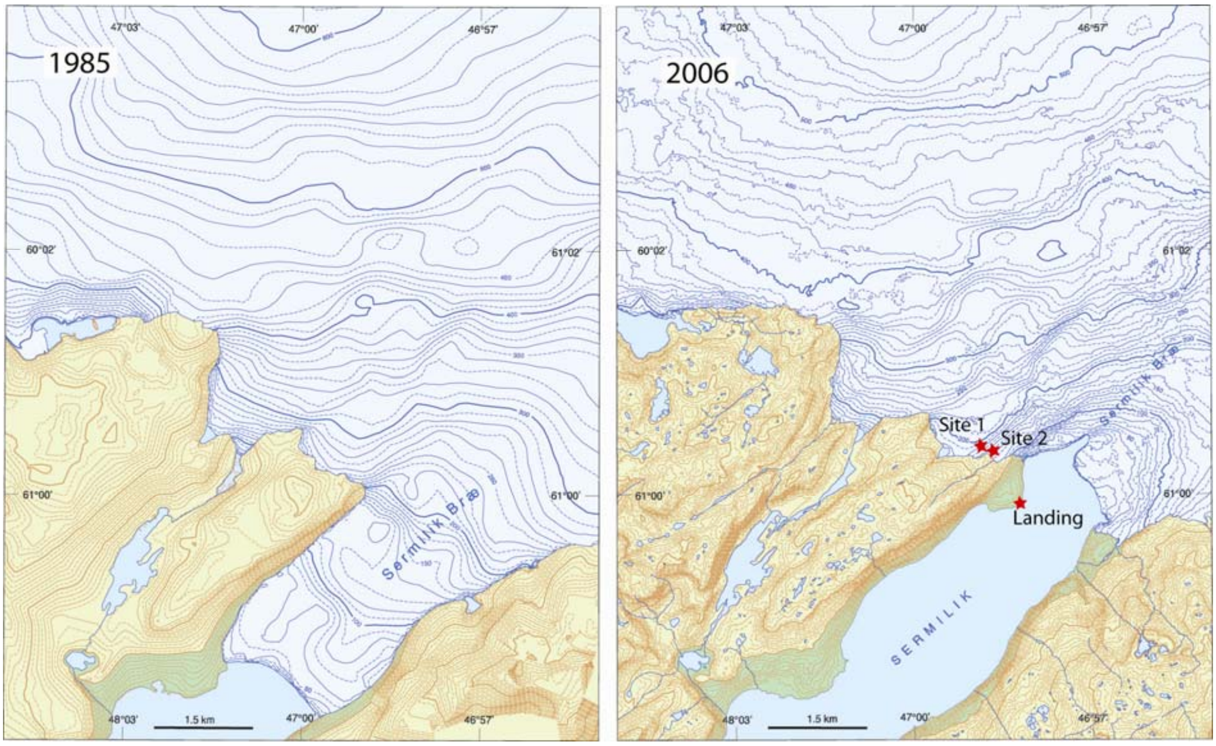


Fig. 7.34. Area map of the termination of the Sermilik Bræ. To the left, an area map from 1985 showing the position of the glacier front at that time. To the right, an area map from 2006 showing the present position of the glacier front. Also the position of the landing site and the sample sites are indicated. The distance between the sampling sites is 315 m.

<u>Age of the ice</u>

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).

Fig. 7.35. Panorama of the front of the Sermilik Bræ

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 (Fig. 7.34 and 7.35). 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.

Fig. 7.36. A view across the Sermilic Fjord. Note the line between the upper part of the mountainside with vegetation and the lower part without vegetation. This line marks the maximum extention of the glacier.

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 (Fig.734 and 7.36). 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 (Fig.7.35). 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.

Geology

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 (Fig. 7.37). Moreover, the gneisses and granites are cut by a few Gardar dolerite dikes.

Fig. 7.37. Gneiss and amphibolite (black) at the landing place.

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, deposited by the melted ice. Hardly any vegetation is seen in the recently exposed areas in front of the glacier, see Fig. 7.36 7.37 and 7.38. Marine deposits are found up to level + 49 m.

Fig. 7.38. Sermilik Bræ and the bedrock in front of the western part of the ice tongue. The bed-rock is covered by scattered and thin layers of till, deposited by the melted ice.

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. 7.37 and 7.39.

Fig. 7.39 The landing site on the western side of the fiord, where the ice has smoothed the cliffs and formed roche moutonnée. Notice the rather steep rocky coast in the background.

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. 7.38 and 7.40). Likewise, it may by difficult to cross the water-soaked muddy till, which is located between the rocks and the glacier ice, see Fig. 7.41. During the fieldwork, a few moulins were observed on this glacier (Fig. 7.42); otherwise it was unproblematic to make one's way on the ice (7.43). The distance between the landing site and the glacier was about 2 km.

Fig. 7.40. An example of the landscape between the landing site and Sermilik Bræ. The cliffs are rather steep and partly covered with gravel, cobbles and boulders.

Fig. 7.41 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.

Fig. 7.42. One of the moulins observed on this glacier during field work.

Fig. 7.43 Sampling site 1 at Sermilik Bræ and the surrounding ice landscape.

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.

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).

One archaeological site is located in a distance of *c*. 5 km southwest of the ice front, on the northern shore.

Locations of shoreline resource use (Human use) are located at both sides of the fjord, some 10 kilometres southwest of the glacier front. On the northern shore, the resource include: fishery for snow crab (important), Atlantic cod, Greenland halibut and arctic char at coast and in 5 rivers (all important), plus hunting for seals. On the southern shore, the resource include: fishery for snow crab, scallop, capelin, lumpsucker (important), Atlantic cod and Greenland halibut, plus hunting for seals and guillemots.

Additional "shoreline resource use" areas are located in a further distance from the glacier front. Site specific species have only been mapped in the outer part of the fjord, close to open ocean water, in a distance of more than 30 kilometres from the glacier front.

The summary of the shoreline sensitivity (according to oil spill!) in the innermost c. 7 kilometres of the fjord (closest to Sermilik Bræ) is a moderate ranking. Outside this area, where the "shoreline resource use" areas are located, the shoreline sensitivity ranking is extreme (Mosbech et al. 2004).

Tourism: There is no known tourism in the area next to Sermilik. First of all, the area is not accessible to most tourists. Furthermore, the distance between Sermilik and Narsaq, Qaqortoq, Narsarsuaq, respectively, is to long.

7.4.1 Water quality of Sermilik Bræ

<u>General chemical characters</u>

The analysis show that the water is soft, slightly acid (pH 6.1-6.4) with low values of conductivity and hydrogencarbonate and high values of aggressive CO_2, turbidity and NVOC. These values do not fulfil the EU drinking water quality standard but the characters are expected for this type of water.

<u>Inorganic compounds</u>

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 low in in the samples from the glacier. Especially the heavy metal content is very low.

<u>PAH and PCB compounds</u>

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.

<u>Pesticides</u>

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 (see section 15.2).

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

The analysis concerning colony counts 22 ^{o}C and 37 ^{o}C, coliform bacteria 37 ^{o}C, E. coli, Clostridium perfringens and Clostridium perfringens spores gives values below the EU drinking water quality standard.

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 (inorganic rest) in amounts of 7.39 mg/l and 57 mg/l. However, the ice is still regarded as pure as the values are below the EU drinking water quality standard.

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive $CO_{2,}$ conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exceptions are ammonia and iron which are found values over the standard in both water samples. The content can be explained as a natural component.

The analysis of bacteria and spores shows values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section 15.2) and TCA (natural component).

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exceptions are ammonia and iron which are found in values over the standard in both water samples. The content can be explained as a natural component.

The analysis of bacteria and spores shows values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section 15.2).

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water. The pH values are neutral.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exception is ammonia which is found in one sample in value over the standard. The content can be explained as a natural component.

The analysis of bacteria and spores shows values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section 15.2) and TCA (natural component).

Sermilik Bræ

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 general ice water quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard. This is to be expected in this type of water.

The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exception is ammonia which is found in one sample in value over the standard. The content can be explained as a natural component.

The analysis of bacteria and spores shows values below the EU drinking water quality standard. The PAH, PCB and pesticides have values below EU drinking water quality standard except for 4-nitrophenole (see section 15.2) and TCA (natural component).

9. Literature

Ahlstrøm, A.P., Binderup, M., Jacobsen, C.S., Jakobsen, P.R., Gravesen, P. & Weidick, A. 2006: Analyse af gletschere fra Grønlands Indlandsis: Mulighed for anvendelse af gletschere til produktion af is til eksport af flaskevand. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2006/50**, 154 pp.

Ahlstrøm, A.P., Binderup, M., Jacobsen, C.S., Jakobsen, P.R., Gravesen, P. & Weidick, A. 2007: Résumé of the possibilities for the use of Greenland Inland Ice for export. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2007/22**, 29 pp.

Bender, M., Felding, G. & Jacobsen, C.S: 2003a: Drikkevandskvalitet af Grønlandsk indlandsis. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2003/26**, 34 pp.

Bender, M., Felding, G. & Jacobsen, C.S: 2003b: Global forurening af den Grønlandske indlandis med miljøfremmede stoffer og tilstedeværelsen af levedygtige mikrobielle kim. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2003/64**, 35 pp.

Bøggild, C.E., Weidick, A. & Olesen, O.B., 2000: Indledende lokalisering af grønlandske gletschere med is/vand egnet til eksport. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/13**, 28 pp.
English version: Bøggild et al. (2000): Preliminary localization of greenlandic glaciers with ice/water suitable for export. GEUS Report **2000/73**, 30 pp.

Christiansen, H.H. and Humlum, O.: Permafrost. In: Topografisk Atlas Grønland. (Red.: B.H.Jakobsen et al.) Det Kongelige Danske Geografiske Selskab & Kort- og Matrikelstyrelsen. København 2000. 278 pp.

Clausen, H.B., Stampe, M., Hammer, C.U., Hvidberg, C.S., Dahl-Jensen, D. & Steffensen, J.P., 2001: Glaciological and Chemical Studies on the Cores from Hans Tausen Iskappe, Greenland.- Medd. om Grønland, 39 pp. 123-149.

DMI 2001: Cappelen, J., Jørgensen, B.V., Laursen, E.V., Stannius, L.S., Thomsen, R.S., 2001: The observed climate of Greenland, 1958-99 – with Climatological Standard Normals, 1961-90. Klimaobservationer I Grønland, 1958-99 – med klimanormaler 1961-90. DMI. Technical Report 00-18. Copenhagen 2001. 151 pp.

GEUS, 2006: Catalogue of Greenland. Publications and Data, GEUS, Nov. 2006, 79 pp.

Mayer, C.J., Bøggild, C.E., Olesen, O.B. & Podlech, S., 2003: Ice studies in relation to ice/water export, data collection, modelling and evaluation approach. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2003/6**, 33 pp.

Mosbech, A. et al., 2000: Environmental Oil Spill Sensitivity Atlas for the West Greenland Coastal zone between 62^o N and 68^o N. Produced by NERI and GEUS, The Danish Energy Agency, Ministry of Environment and Energy, 199 pp.

Mosbech, A. et al., 2004: Environmental Oil Spill Sensitivity Atlas for the South Greenland Coastal Zone between 56^o N and 62^o N. Produced by NERI and GEUS. NERI, Ministry of Environment, 124 pp. + App. A-F.

Podlich, S., 2004: The Qagssimiut Lobe, South Greeenland. An assessment of significant ice margin thinning. Ph.D. thesis. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2004/67**, 137pp + appendices.

RDANH_1: The Royal Danish Administration of Navigation and Hydrography. http://www.frv.dk/data_produkter/vandstand_gr.htm

RDANH_2: The Royal Danish Administration of Navigation and Hydrography. Farvandsvæsnet 2005: Tide tables 2006 for Greenland waters (in Danish only "Tidevandstabeller for grønlandske farvande”).

Weidick, A., Bøggild, C.E. & Knudsen, N.T. 1992: Glacier inventory and atlas of West Greenland. Grønlands Geologiske Undersøgelse Rapport **158**, 194 pp.

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.

<u>July 28 – Friday</u>

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.

<u>July 29 – Saturday</u>

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

<u>July 30 – Sunday</u>

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.

<u>July 31 – Monday</u>

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. The chemical analysis of the ice samples

15.1 General remarks

Drinking water analysis made on sterile melted glacier ice samples are described in chapter 2.3. All the analysis can be found below. Most of the analysis has been preformed by the commercial laboratory Eurofins Danmark A/S while some are done at the Microbiological and Chemical laboratories at GEUS.

The samples from the four glaciers are described under the relevant chapters but here is given a few general remarks. The measured values are compared with the EU drinking water quality standard levels and the Danish standard.

The chemical composition of the ice is very like the composition of snow precipitation deposited on the glacier surface where it will freeze into ice but in the wet snow and percolation zones of outer part of the inland ice the water can percolate down into fractures in the ice and later run off as meltwater (Ahlstrøm et al., 2006). The snow contains natural chemical compounds from the atmosphere and sometimes wind blown pollution materials. The snow will not as on the land surface where it percolate down through sediments and rocks react with the materials or dissolved substances (natural or pollution). Therefore the ice water is mainly in the same chemical situation as water in rivers, springs and some lakes.

General characteristics
Some of the general parameters do not fulfil the drinking water criteria, as shown in the tables below. The water from the melted ice is soft and slightly acid (pH). It has a very low content of ions and therefore the electric conductivity must be low and will not make up the 30 mS/m as required. Neither will hydrogen carbonate nor aggressive CO_2 match the criteria.
The content of sediment rest (non-dissolved material) is in all samples well below the EU drinking water value.

Main inorganic ions
Most of the metal ions and cations occur in very low concentrations and the values fulfil the criteria for drinking water. The low values causes that it is impossible to calculate an ion balance of the analysis. Ammonia occurs in values above the EU drinking water quality standard. Ammonia precipitates from the atmosphere which will give rise to a certain concentration level because very low consumption or conversion to nitrite or nitrate will be present at the actual temperature level.

Ammonia is of terrestrial biological origin and is known from several levels in the inland ice as a wind blown component together with dust and volcanic materials (Clausen et al, 2001). The iron content is close to limit in some samples and the soil dust itself are regarded as the main contributor to the high iron content. Phosphate and fluoride have high values at one glacier.

Heavy metals
All the heavy metals are found in very low concentrations and fulfil the criteria for drinking water.

PAH and PCB compounds
The compounds were below the detection limit.

Pesticides
Most of the pesticides were not detected in the analysis. TCA was found at three glaciers but in low values or below the EU drinking water limit. TCA can have both natural and anthropogenic sources. 4-nitrophenole was also detected and a special investigation of this pesticide follows in chapter 15.2.

Bacteria and spores
The analysis concerning colony counts at 22 ^oC and 37 ^oC, coliform bacteria 37 ^oC, E. coli, Clostridium perfringens and Clostridium perfringens spores show no or very low values well below the EU drinking water quality standard. Also the bacteria counts show low value below the EU drinking water quality standard values.

Organic material (NVOC)
Organic fall out or deposition from the atmosphere however, will occur globally which will give rise to concentration levels from 3 to 9 mg/l all exceeding the requirement. The organic content and soil dust are responsible for the high colour-index and turbidity.

Final remarks
The chemistry of the ice water shows the following remarkable characters:

The general quality shows relation to the chemistry of precipitation and surface water. Most of the values of pH, hardness, aggressive CO_2, conductivity, turbidity, oxygen and NVOC do not fulfil the EU drinking water quality standard.
The main metals, cations and heavy metals show very low values below the EU drinking water quality standard. Exceptions are ammonia and iron.

The analysis of bacterias and spores show values below the EU drinking water quality standard.

The PAH, PCB and pesticides have values below EU drinking water quality standard except for the special conditions of 4-nitrophenole and TCA.

15.2 Notes on the use of Rilsan plastic bags for storage of frozen snow and ice

We found 4-nitrophenol in levels just around the quantification limit in 5 out of 8 samples see table 1.

Nitrophenols are formed in the atmosphere by photochemical reactions between NO_x and aromatic hydrocarbons (benzene, toluene, etc.). In the atmosphere, mono-nitrophenols are further transformed into di-nitrophenols and the relation between mono- and di-nitrophenols is an indicator of the distance from the source of formation. In the same way, methylated mono-nitrophenols are transformed to methylated di-nitrophenols such as DNOC (2-methyl-4,6-dinitro-phenol).The concentration of 4-nitrophenol was close to the detection limit in most of the samples, and if DNOC is formed in a less degree its concentration may be beneath the detection limit.

However, we found 4-nitrophenole in control samples prepared by placing a Rilsan bag or a small pieces of a polystyrene box in two separate flasks with milliQ water for 24 hours. A third flask with pure milliQ water was incubated in the same way. The commercial laboratory analysed the water samples, and 4-nitrophenol was detected in the samples incubated with the Rilsan bag and the pieces of polystyrene, respectively, whereas the flask with pure milliQ water did not contain 4-nitrophenol (see Table 1).

Hence, even if the concentration of 4-nitrophenol in one or both of the samples from all glaciers was a little higher than in the two control samples, we consider the results too doubtful since 4-nitrophenole clearly can originate from the plastic bag.

	4-nitrophenol (µg/l)	
Russells glacier.	<0.02	0.032
Narssap Sermia	<0.02	0.019
Nigerlikasik Bræ.	<0.02	0.021
Sermilik Bræ.	0.022	0.024
Rilsan bag	0.014	
Polystyrene box	0.031	
MilliQ water	< 0.010	

Table 1. Concentration of 4-nitrophenol in snow samples and control samples

The measured concentration of 4-nitrophenol in the control sample incubated with the Rilsan bag, gave rise to a critical evaluation of the use of Rilsan bags for storage of solid samples in the inevstigation. The bags are generally used for storage of environmental and forensic samples, due to the inertness of the Rilsan material with respect to migration of contaminants to the sample matter.

The material was tested in 2001 at Miljø-kemi (now Eurofins A/S) for the migration of typical phtalates, BTEX and PAH (16 EPA). The migration test was made using 100 ml of 3% acetic acid, 200 cm2 material, exposed for 2 hours at 70 °C. None of the selected contaminants was detected in the test. (Detection limits of the method: BTEX: 10 µg/l, phtalates: 10 µg/l, PAH: 1 – 10 µg/l). The Rilsan material (polyamide 11) is produced from castor oil, which consist of mixed triglycerides, principally of ricinoleic acid. Further preparation steps produce the monomer 11-amino-undecanoic acid. According to the provider of the bags, P-B Miljø A/S, nitrophenols are not used in the synthesis process (Sakarias Petersen-Bach, personal communication). The provider suggests that 4-nitrophenol from the material may be remaining from plant uptake. However, as 4-nitrophenol was also found in the polystyrene sample, there may be another unknown external source.

15.3 A. Analysis September 2007 (Eurofins Danmark A/S)

Locality	**EU quality standard**	**Russell's Glacier**		**Narssap Sermia**		**Nigerlikasik Bræ**		**Sermilik Bræ**	
General Characters		**Russell 1**	**Russell 2**	**Nuuk 1**	**Nuuk 2**	**Paamiut 1**	**Paamiut 2**	**Sermilik 1**	**Sermilik 2**
pH	*7-8,5*	**6,0**	**6,0**	**6,1**	**6,3**	7,2	7,3	**6,4**	**6,1**
Conductivity mS/m	*>30*	**0,3**	**0,2**	**0,2**	**0,2**	**0,6**	**0,2**	**0,3**	**0,4**
Aggressive CO_2 mg/l	*<2*	**5,2**	**4,9**	**4,5**	**4,2**	**3,5**	**5,8**	**4,3**	**5,1**
Hydrogencarbonate, mg/l	*>100*	**<3,0**	**<3,0**	**<3,0**	**<3,0**	**<3,0**	**<3,0**	**<3,0**	**<3,0**
Turbidity FTU	*<0,3*	**13**	**23**	**1,5**	**4,3**	**3,0**	**4,0**	**0,64**	**6,3**
Colour mg Pt /l	*<5*	2,3	1,7	1,3	1,7	1,1	**15**	**9,9**	2,0
NVOC mg/l	*<4*	**9,3**	**8,2**	**--**	**9,2**	**7,8**	**3,0**	**6,2**	**4,8**
Total Hardness dH	*5-30*	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
Colour Visual	-	None	None	None	None	None	None	None	None
Clearness Visuel	-	Slightly unclear	Clear	Slightly unclear	Clear	Clear	Unclear	Slightly unclear	Clear
Smell	-	None	None	None	None	None	None	None	None

	EU quality standard	**Russell 1**	**Russell 2**	**Nuuk 1**	**Nuuk 2**	**Paamiut 1**	**Paamiut 2**	**Sermilik 1**	**Sermilik 2**
Taste	-	Normal	Normal	Normal	Normal	Flat	Flat	Normal	Flat
Inorganic rest mg/l	*1500*	36	210	45	11	40	43	<10	57
Oxygen mg/l	*<5*	**7,5**	**6,6**	**8,2**	**10,1**	**7,6**	**6,9**	**8,2**	**8,0**
Major ions									
Ammonia mg/l	*<0,05*	**0,098**	**0,057**	**0,057**	0,039	**0,12**	0,034	0,032	0,049
Iron mg/l	*<0,2*	**0,24**	**0,51**	0,11	**0,52**	0,077	0,18	0,026	0,18
Calcium mg/l	*<200*	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
Magnesium mg/l	*50*	<0,10	<0,10	<0,10	<0,10	<0,10	<0,10	<0,10	<0,10
Potassium mg/l	*10*	<0,20	<0,20	<0,20	<0,20	<0,20	<0,20	<0,20	<0,20
Sodium mg/l	*175*	0,16	0,11	0,38	0,28	0,57	0,15	0,25	0,28
Manganese mg/l	*0,05*	<0,005	0,006	<0,005	0,006	<0,005	<0,005	<0,005	<0,005
Nitrite mg/l	*0,1*	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005
Nitrate mg/l	*50*	1,1	1,0	0,75	0,71	0,75	0,80	0,75	1,0

	EU quality standard	Russell 1	Russell 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Total- Phosphorous mg/l	*0,15*	0,010	0,033	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005
Chloride mg/l	*250*	0,72	0,58	0,57	0,52	1,3	<0,50	0,75	1,1
Flouride mg/l	*1,5*	<0,050	<0,050	<0,050	<0,050	<0,050	<0,050	<0,050	<0,050
Sulphate mg/l	*250*	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
Heavy metals									
Nickel µg/l	*20*	0,71	1,1	0,35	0,88	0,37	0,63	0,29	0,46
Antimony µg/l	*200*	<0,20	<0,20	<0,20	<0,20	<0,20	<0,20	<0,20	<0,20
Arsenic µg/l	*10*	<0,030	<0,030	<0,030	0,031	<0,030	<0,030	<0,030	<0,030
Barium µg/l	*700*	5,2	11	1,8	2,9	1,1	3,1	<1,0	2,0
Lead µg/l	*10*	0,49	0,50	0,26	1,1	0,15	0,57	0,22	0,47
Boron µg/l	*1000*	<1,0	1,3	2,9	<1,0	2,0	<1,0	1,3	3,4
Cadmium µg/l	*5*	0,053	0,028	0,028	0,051	0,013	0,025	0,026	0,068
Chromium µg/l	*50*	4,0	3,2	2,6	2,6	3,7	2,5	1,8	2,2

	EU quality standard	Russell 1	Russell 2	Nuuk 1	Nuuk 2	Paamiut 1	Paamiut 2	Sermilik 1	Sermilik 2
Mercury µg/l	*1*	<0,0050	<0,0050	<0,0050	<0,0050	<0,0050	<0,0050	<0,0050	<0,0050
Selenium µg/l	*10*	<0,050	<0,050	<0,050	<0,050	<0,050	<0,050	<0,050	<0,050
Zinc µg/l	*3000*	24	13	10	16	8,3	18	5,4	16
Copper µg/l	*2000*	1,8	3,1	1,0	2,1	0,62	2,0	0,68	1,8
Bacteria and spores									
Clostridium perfringens CFU/ml	*i.m.*	<1	<1	<1	<1	<1	<1	<1	<1
Clostridium perfringens spores CFU/ml	*i.m.*	<1	<1	<1	<1	<1	<1	<1	<1
Coliform bacteria 37 C ant./100ml	*i.m.*	<1	<1	<1	<1	<1	<1	<1	<1
Escherichia coli ant./100 ml	*i.m.*	<1	<1	<1	<1	<1	<1	<1	<1
Colony counts 22^{o}C ant./ml	*50-200*	5	6	5	5	1	<1	6	9
Colony counts 37^{o}C ant./ml	*5-20*	1	4	<1	<1	2	2	5	1

15.4 B. Analysis February 2007 (GEUS)

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.

15.5 C. Analysis January 2007 (GEUS)

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

15.6 D. Analysis December 2006 (Eurofins A/S)

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}