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Quaternary geological and geomorphological maps of Fredheim and Skansbukta

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Introduction

Two Quaternary geological maps have been completed for cultural heritage sites from Inner Isfjorden. Fredheim has been conducted in 1:3000 for a 0.8 km2 area, and a 0.5 km2 area at Skansbukta has been mapped in 1:2000. The work was carried out by Evangeline Sessford in the frame of a Master thesis under the supervision of Anne Hormes at UNIS – The University Centre in Svalbard.

The Quaternary maps serve as important stepping stones to evaluate landscape development of the area. In the frame of a project initiated by the Governor of Svalbard, we aim to establish a better understanding of interactions between Holocene climate changes and its impact on natural hazards including coastal erosion. A Holocene landscape analysis has been done within the frame of the Master thesis by Evangeline Sessford, based on the Quaternary map and additional data. The aim of this project is to conduct spatial and temporal terrestrial analysis for the field sites that will be used in the production of geological hazard risk assessment. The resulting observations of this study will provide the Governor of Svalbard with an assessment that can be used to define tolerance limits for Fredheim and Skansbukta and thereby acted upon to preserve the cultural heritage in the most optimal manner. A correlation of past natural hazard events and past climate variability might help to understand the occurrence of future hazardous events.

However, Quaternary mapping is of use to many research and industry fields. For example, often biologists require knowledge pertaining to sediment types and landforms to understand chemical compositions and impact on biological processes. Infrastructure development and protection are dependent upon sediment type and landforms for ground stability assessments.

The project objectives were to create detailed Quaternary geological maps of the cultural heritage sites. In Fredheim documented erosion rates along the coast have been reported with a high variability between 11 and 57 cm/year. The buildings in Fredheim are of vital interest for local tourism and history, and the Governor has to evaluate measures in order to prevent the buildings from toppling down the coastal cliff in the next couple of decades. A Svalbard Miljøvernfond funded project aims to visualize different erosion protection measures along the coastline of Fredheim. The mapping exercise in Skansbukta revealed gelifluction, debris flow and avalanche processes, but coastal erosion in this protected bay is negligible.

Contents

Methods and sources of error

Both Quaternary maps were created using a combination of differential global positioning system (DGPS) measurements, aerial image analysis, digital terrain models (DTM) and field observations (Map insert 1, pages 8-9 and map insert 2, pages 18-19). Fieldwork at both sites was conducted in August 2011 and June 2012. Fredheim was also visited on a number of occasions intermittently between the two dates so as to gain an understanding of seasonal changes affecting landforms. During fieldwork it was possible to collect DGPS points, however real time processing was not functioning and thereby post-processing of data collection using Leica GeoOffice software was essential. At Fredheim, the ground control point (GCP) is located within one km of all points and measurements were satisfactory in their post processing. However, at Skansbukta the GCP is between 6 and 7 km away from all collected points and at times were unable to be measured during post-processing and remain as navigated points thereby producing larger errors. The majority of points that were unable to be processed are those at the top of the slope near to the cliffs, however sometimes the rover malfunctioned elsewhere causing larger errors. Processed DGPS points, aerial images and DTM (Norwegian Polar Institute, 1990) were combined in ArcGIS 10 software for mapping purposes. Errors associated with the specific data sets are shown in Table 1. Personal photographs from fieldwork were examined during map creation to recall specific landforms for true representation. Maps are projected through UTM zone 33N using the WGS 1984 datum.

Contours are extracted from the DTM which has a resolution of 20 m. This unfortunately produces contours which can only be used for approximate elevations due to the large scale maps.

For all marine radiocarbon ages we report conventional dates and 68% (1 sigma standard deviation). All marine radiocarbon dates including mollusks and foraminifera from marine sediments in isostatically uplifted marine terraces, were recalibrated to calendar ages using a reservoir age of 440 ± 52 years corresponding to ΔR 107±52 years (Mangerud et al., 2006). The recalibration is based on two different recommendations using a marine reservoir effect of 450 ± 52 (Mangerud in Mangerud et al. 2006) and 438 ± 52 years (Bondevik and Gulliksen in Mangerud et al. 2006) for mollusks and foraminifera in Spitsbergen. The calibration is based on the Fairbanks ’0107’ calibration curve with the online calibration software as this curve uses only coral U/Th dates (http://radiocarbon.ldeo.columbia.edu/research/radcarbcal.htm) (Fairbanks et al., 2005).

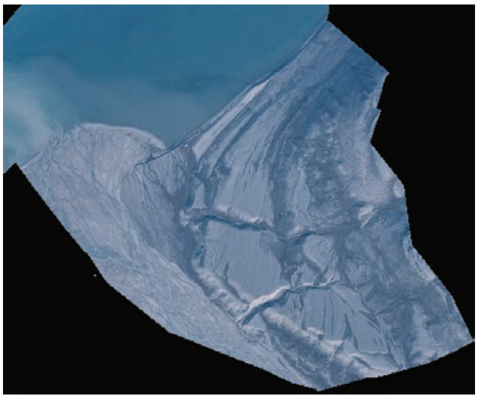


Figure 1 (left)
Aerial image 13824_00048 of Fredheim (Norwegian Polar Institute, 2009)

Figure 2 (right)
Aerial image 13822_00081 of Skansbukta (Norwegian Polar Institute, 2009)

Fredheim: Quaternary superficial deposits

Glacial deposits and glacial history

The study area (Map 1,2, Figure 1,2) is known to have been glacially covered during the Last Glacial Maximum (LGM), based on studies of isostatically uplifted marine terraces (Salvigsen, 1984) and marine studies in Tempelfjorden

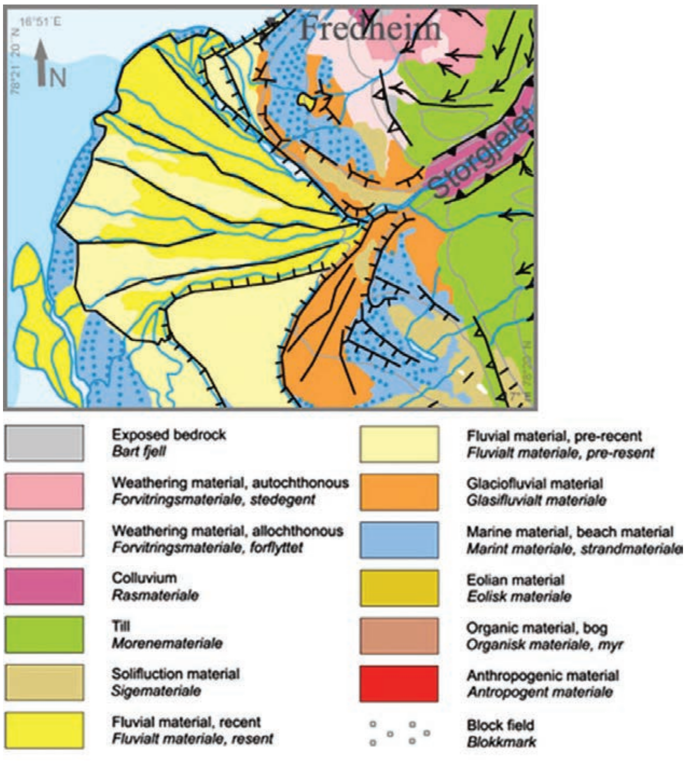
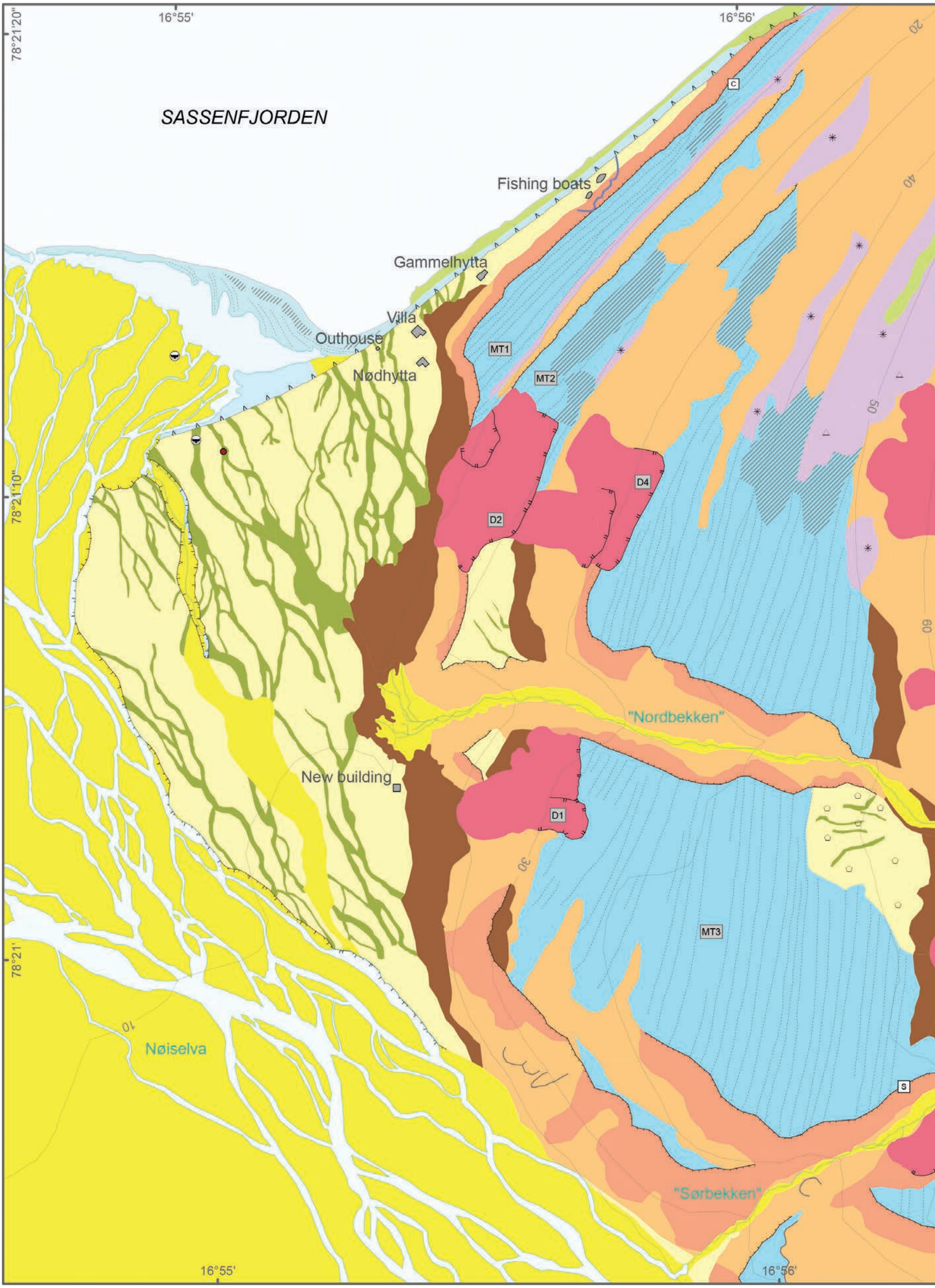
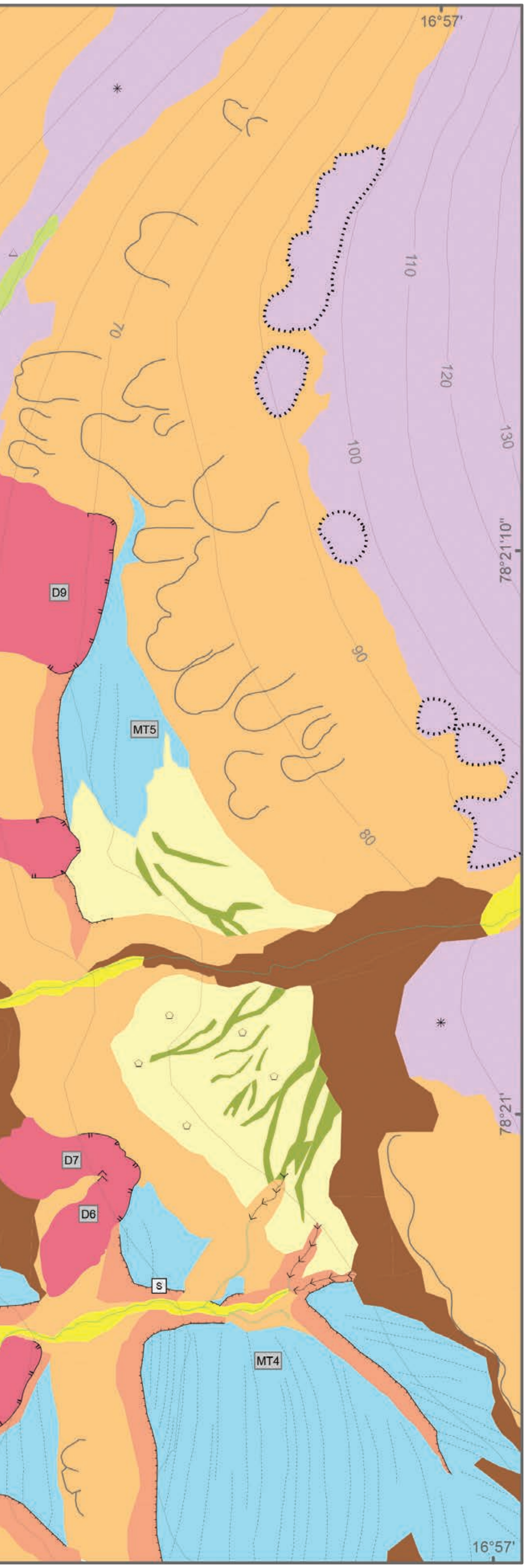


Figure 3
Modified exerpt and original legend from map C9Q Adventdalen Geomorphological and Quaternary Geological Map; coordinates are approximate. The orange areas indicate the glaciofluvial material identified at Fredheim in Tolgensbakk et al. 2000



78°21'20"
16°55'
16°56'
SASSENFJORDEN
Fishing boats
Gammelhytta
Villa
Outhouse
Nødhytta
MT1
MT2
D2
D4
"Nordbekken"
New building
D1
MT3
30
78°21'10"
78°21'
10
Nøiselva
"Sørbekken"
S
C
20
40
50
60
16°55'
16°56'

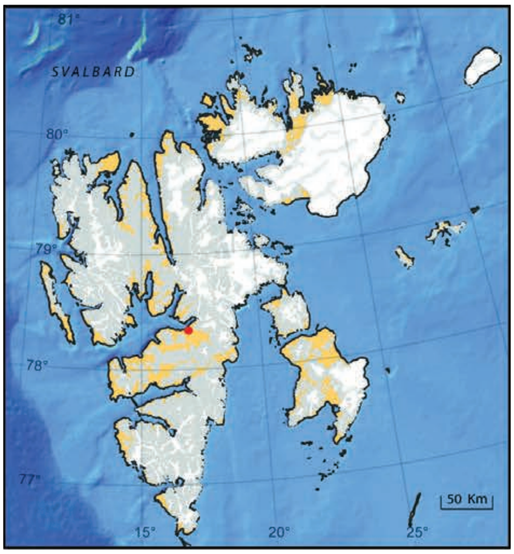


FREDHEIM, Isfjorden, Svalbard
Quaternary Geology and Geomorphology

- Bedrock, Gipshuken Fm.
- Autochtonous bedrock weathering
- Marine beach material, recent
- Marine beach material, pre-recent
- Fluvial material, recent
- Fluvial material, pre-recent
- Organic material
- Colluvium
- Active layer detachment slide
- Gelifluction material
- Gelifluction terrace front lip
- Relict river/groundwater channel
- River
- Spring melt river
- Groundwater outflow
- Lagoon
- Beach ridges
- Beach deformation by ice
- Pitted beach
- Slide scarp
- Coastal erosion scarp
- Fluvial erosion scarp
- Terrace edge
- Gulley
- High frequency of surface boulders
- Surface strongly influenced by frost activity
- Distinct bedrock mound
- Small bedrock exposure
- Patterned ground
- Whale bones
- Buildings and other artifacts (cultural heritage objects)

Localities for investigation

- S Radiocarbon sample
- Thermistor string
- C Automatic camera



Projection: UTM Zone 33X
Datum: WGS 1984
Contour Interval: 10 m (Norwegian Polar Institute 1990)

1:3 000

0 25 50 100 150 200 Meters

N

Evangeline Sessford (2013)
University of Oslo and University Centre in Svalbard
Master Thesis in Geoscience

(Forwick & Vorren, 2009). On the plateau east of Fredheim glacial erratic boulders and lateral meltwater channels have been found that would need further investigation, but that are assumed to date to LGM, therefore, the existence of till cover southeast of Fredheim has been confirmed.

It has been suggested on the C9Q Adventdalen Geomorphological and Quaternary Geological Map (Tolgensbakk et al. 2000) that there is glaciofluvial material along the edge of the pre-recent fluvial sediments and the gelifluction areas coming down from marine terraces, more or less where organic material is labeled on this map (Figure 3). This has not been described in this map as it was not found in any sections along the boundary between the Nøiselva and marine terraces. However, this does not rule out the possibility of glaciofluvial sediment being present under colluvium, gelifluction or organic material.

Marine deposits and Holocene emergence

The present day shore at Fredheim is made up of a beach and deltaic system with sediment deposition dominated by fluvial and wave (longshore drift) energy (Figure 4). It is considered a soft, weakly consolidated and easily erodible coast as described by Fairbridge (2004). The system acts as an analogue for past Holocene landform development. Beach sediments are clast dominated by mostly well rounded plates. The delta is made up of well-rounded clasts and sand that have been fluvially transported, less sorted than the beach deposits. The delta is prograding northward into Sassenfjorden and eastward along the shore due to longshore drift and is easily distinguishable due to the beach ridges formed during movement. It has grown 189,47m along the coastline at an average rate of 5,92m/yr between 1977 and 2009 (Guegan et al., in prep). Pits are formed on the delta and beach from sea ice and icebergs that have been thrust onshore and/or by the ice foot (henceforth referred to as shore ice if all three ice types are discussed) (Caline, 2010; Rodzik, 2009; Nichols, 1961). The ice foot as described by Caline (2010) is a fringe of ice attached to and along the shore and may be of varied widths. It is especially of interest in regards to its role in shore erosion and sediment transport as discussed further in (Guegan et al., in prep; Allard et al., 1998). The ablation of shore ice is unevenly distributed and causes the creation of ice tumuli overlain by gravel deposits that produce pitted beaches as ice thaws out (Rodzik, 2009; Nichols, 1961). Both pits and beach ridges appear on the present day shore. Within the delta there is a lagoon which is changing in shape, size and outflow location on a yearly basis (field observations and DGPS measurements, this study) and can be observed through aerial image analysis from photos taken in 1977, 1990, 1995 and 2009 (Norwegian Polar Institute, aerial image depository) (Guegan et al., in prep).

There are five uplifted marine terraces at Fredheim (MT1 – MT5) (Map excerpt 1). On the map these are numbered as five being the oldest and at the highest elevation while one is the lowest and youngest. Their relative age can be reconstructed based on their geomorphological relationship as the younger terraces cut older terraces. They are coloured blue and described in the legend as pre-recent marine beach material. The terraces are covered with fairly well rounded, flat stones or round pebbles which have undergone periglacial frost cracking.

The uppermost terrace, MT5, lies between 70 and 80 m a.sl. It is not very extensive and is visible only on the north side of the spring meltwater creek (henceforth referred to and unofficially named as Nordbekken) that flows from Fjordnibba, the mountain to the east of Fredheim, though not shown in the map. There are two faint beach ridges on its surface, running from north to south. It has not been possible to date MT5, but it is assumed to be older than the Last Glacial Maximum (LGM).

This interpretation is based on three arguments:

1 Radiocarbon dates established from beach sediments on MT4 and MT3 indicate Early Holocene ages.

2 Marine terraces of comparable age along the west coast of Spitsbergen were dated to represent preserved pre-LGM marine landforms that were only covered with non-erosive glacier ice during LGM (Forman et al., 1987; Landvik et al., 2012, 2005)

3 The marine sediments of MT3 lie on top of a glacimarine diamicton that is interpreted as LGM till. Therefore MT3 represents some of the oldest Holocene marine deposits and this supports our interpretation under point 2.

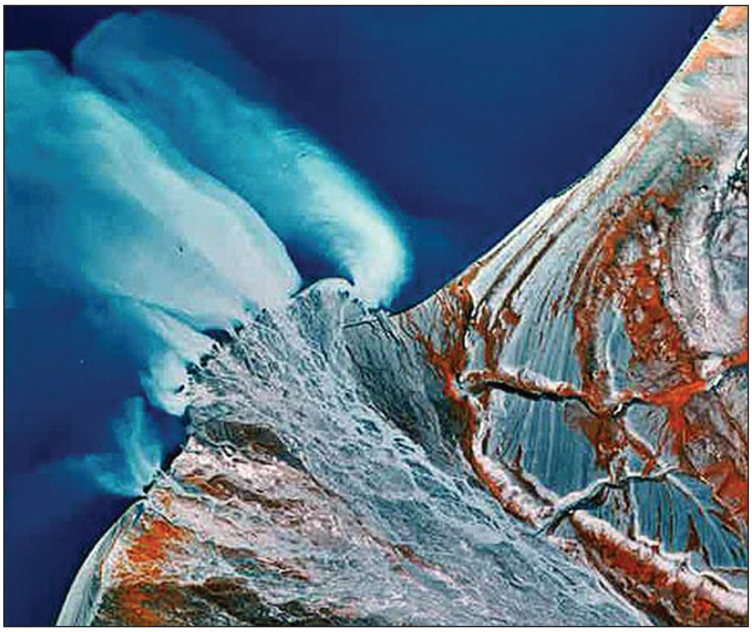


Figure 4
Fluvially dominated sedimentation affected by longshore drift and fjord circulation at Fredheim (Aerial image S90, Norwegian Polar Institute, 1990)

MT4 only extends to the south of Nordbekken and mostly to the south of Sørbekken (unofficially named) between 60-65 m a.s.l. This is likely because the steepness of the slope to the north did not allow for beach sedimentation and build-up to occur. Interestingly, while beach ridges on MT5 are trending north south, beach ridges on upper MT4 show east west trending beach ridges. It seems more plausible that the upper part of MT4 is actually part of MT5, due to this difference in beach ridge deposition; however, there is no large gradient change or steep slope dividing the two sections only a modern meltwater channel that may formerly have been a lagoon. MT4 has been radiocarbon dated to 10767 ± 193 and 11061 ± 174 cal BP (9 927 ± 60 and 10 106 ± 57 14C years BP; Ua-44107, Ua-44108) with Mya Truncata shell fragments at point S, approximately 60 m a.s.l. at 78° 20' 57.2'' N and 16° 56' 31.1'' E. The shells were found along the gulley cut out by Sørbekken in loose sand/gravel at a depth of 86-83 cm below the surface (See: Sessford, Master thesis 2013 for a complete overview of dated material).

The largest and most extensive of the marine terraces is MT3 which lies between 30 and 55 m a.s.l. The terrace has been dated from Mya Truncata shell halves and fragments at 51 m a.s.l. along Sørbekken at 78° 20' 56.6'' N and 16° 56' 13.6'' E. Two samples, taken from depths between 240 and 267 cm below the surface return 14C dates of 10636 ± 170 and 10690 ± 186 cal BP (9842 ± 60 and 9 878 ± 64 years BP; Ua-44104, Ua-44105). Samples were found in bimodal beach deposits directly above a sharp erosional boundary dividing it from glaciomarine diamicton containing red clay chunks and striated clasts. We interpret the glaciomarine diamicton as LGM till. The upper 55 cm of the terrace are bimodal beach sediments largely made up of pebbles, a third sample of shell fragments returned a date of 10674 ± 181 cal BP (9867 ± 63 14C years BP; Ua-44106). Beach ridges on the surface are clear, numerous and relatively evenly spaced (Figure 5). MT3 is the first terrace with pitted beaches.

Figure 5
Beach ridges on MT3, note linearity and spacing. Image taken from the northeast of the map facing south west, Nordbekken can be seen in the bottom right corner of the photo (Sessford, 2012)

MT2 is a relatively narrow terrace with no distinct beach ridges. It is being overrun by gelifluction in the northeast and active layer detachments toward the south. The geomorphological expression of this terrace is the least clear of all marine terraces due to overprint by gelifluction processes, light vegetation and several ice pits on its surface.

The lowest of the terraces is MT1. Along with MT3, it is the most distinct terrace containing very clear beach ridges and some pitted areas in the northeast. In Figure 6 the ride up of the sea ice/iceberg can be seen in the middle of this lowermost terrace (Governor of Svalbard 2000). It is not exactly clear what type of ice has deformed the sediments, but it appears to be either sea ice ride up or pile up. The ice floe was thrust onshore and destroyed two boats belonging to the cultural heritage site (Figure 6) (Bjerck, 1999).

Figure 6
Ice ride up / pile up from 1999 (Image from Governor of Svalbard, 2000 (Eide, 1999))

Fluvial deposits

Some of the most dominant features in the map are the fluvial sediments. There are two main types, recent and pre-recent (dark yellow and light yellow, respectively). The distinguishing factor between the two is whether or not water flows on an annual basis through the landform thereby entraining, transporting and depositing clasts and sediment. Therefore, in Nordbekken, Sørbekken and the alluvial fan at the mouth of Nordbekken recent fluvial sediments which are affected mostly by spring meltwater are mapped. The creeks usually run dry by September. Nøiselva and the delta are also considered recent sediments as they are reworked annually. The sediment in the channels as opposed to channel bars consists of fewer fines as those are washed out by repeated spring meltwater events. There is one region marked as recent fluvial sediments that lies between pre-recent alluvial sediments and does not have the river symbol within it and from

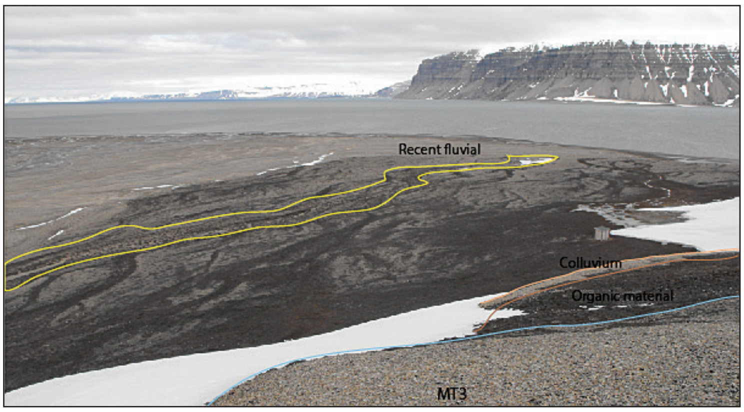


Figure 7
Pre-recent fluvial plain with recent fluvial sediments indicated in yellow. The limit between the pre-recent Nøis alluvial plain and the recent Sassen estuary is a sharp boundary seen clearly with vegetated river channels on the pre-recent delta (Sessford, June 2012)

Figure 8
Backcutting of relict channel due to spring meltwater flow (Sessford, June 2012)

first appearance looks to be a relict channel. Contrary to the relict channels, there are less fines and vegetation (Figure 7).

The surface of this section appears to have recently been used for surface meltwater flow but has since been abandoned at its southern end. However, it has undergone significant (approximately 150 m) backcutting from spring meltwater flow at its northern end from the coastal escarpment (Figure 8).

Pre-recent sediments are those that are no longer undergoing sediment displacement due to surface flow of water. There are four distinct locations where pre-recent alluvial sediment is present, MT5, MT3, MT2 and between MT1 and the recent fluvial sediments of the Nøiselva. Those sediments which are on the terraces override the beach sediments, making beach ridges indiscernible and distributing fines which are susceptible to ice segregation and frost cracking (French and Shur, 2010). It may well be that these pre-recent sediments are relict alluvial fans that were deposited shortly after the uplift of each terrace (Figure 9). Relict fluvial channels (coloured moss green) are easily discernible on the surface of pre-recent sediments due to the high vegetation content and their elongated, braided depressions. In regions close to organic material where standing water is present, and near the alluvial fan at the mouth of Nordbekken, some surface water flows along these channels (Figure 10). However, it always

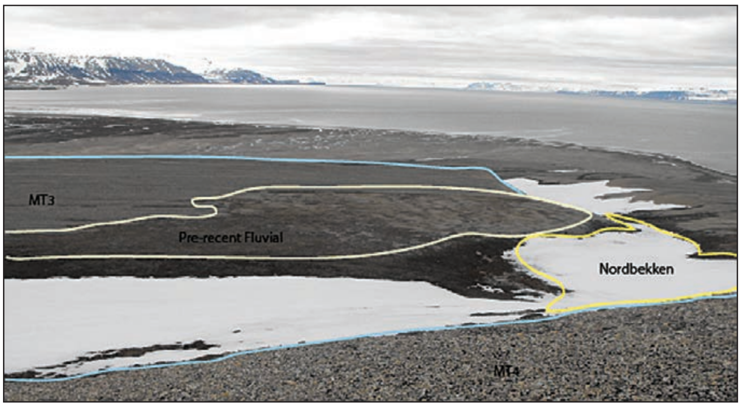


Figure 9
MT3 with beach ridges overlain by alluvial fan containing some vegtated relict channels (Sessford, June 2012)

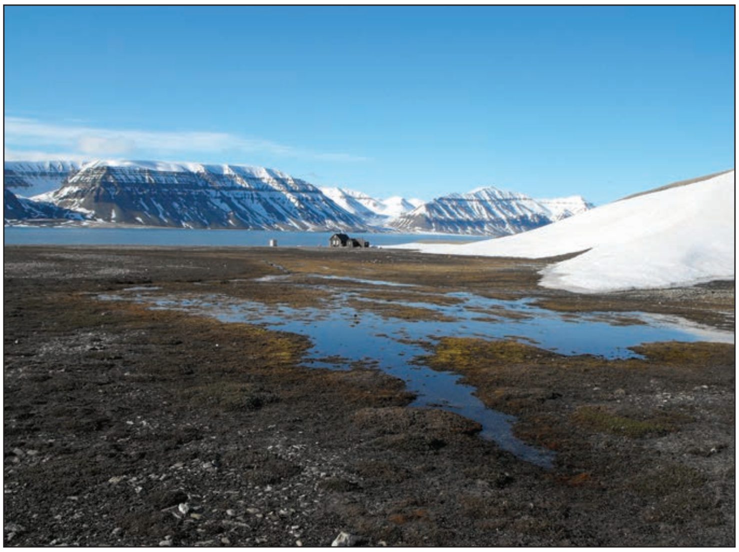


Figure 10
Organic material below Nordbekken alluvial fan and relict channels leading away from the fan toward the buildings and the fjord (Sessford, June 2012)

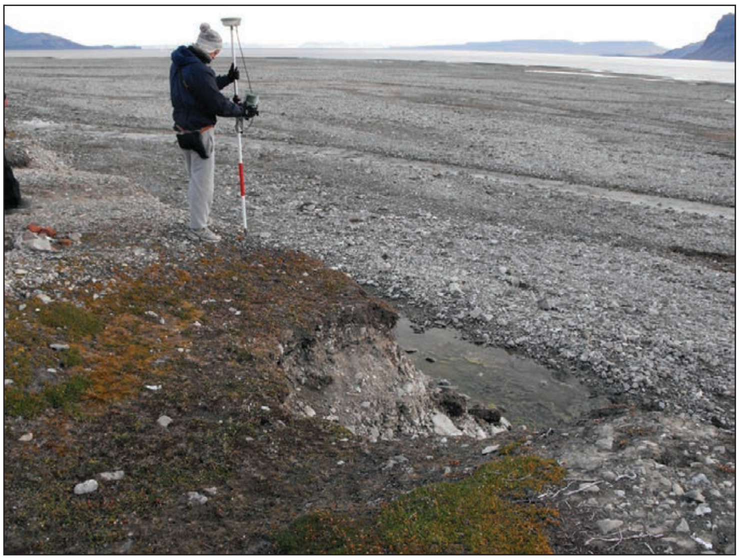


Figure 11
Strong backcutting and erosion where relict channels meet the coastal escarpment due to concentrated active layer interflow (note water at base of escarpment) (Sessford, August 2011)

changes to water which flows within the active layer, above the permafrost table as what will henceforth be termed active layer interflow, groundwater, and flows out as surface water when reaching both the coastally and fluvially eroded scarps (Figure 11).

Slope deposits

Solifluction is a product of two mechanisms; gelifluction, thaw induced saturated flow of sediments, and creep, frost heave followed by thaw settlement (Matsumoto, 2002). It is a common feature found on Svalbard's slopes. The majority of movement at Fredheim is undergone in well saturated sediments containing excessive vegetation. Therefore, solifluction on the map has been labeled as gelifluction (light orange). The beach ridges on the marine terraces do not contain enough fines and are well drained and therefore less subject to gelifluction, even though the terraces have a slight gradient. The general trend at Fredheim is that gelifluction creeps downslope through two-sided freezing inducing plug-like flow and thereby dislocating the surface layer and creating lobes (Matsuoka, 2001). At Fredheim, lobes are found on steeper slope gradients, tend to be between 0,1 and 0,5 m in height, have a steep front lip and a slight depression toward the slope. The front lip may be either turf-banked (vegetated) or stone-banked (Matsuoka, 2001). However, in some places gelifluction accumulations can produce large solifluction sheets or terraces such as above MT4 and MT5 where a large section of active layer made up of many smaller gelifluction lobes moves as 'one' piece forming a long, distinctive front lip (Matsuoka, 2001) (Figure 12).

Figure 12
Examples of a gelifluction lobe where the line indicates the front lip (Sessford, June 2012)

Figure 13
Non-vegetated area on the slope of MT3 consisting of colluvium. The shovel shows the boundary between the present day surface and colluvium. At this particular location (nearby to the radiocarbon sample), one can see cracking where the initialization of a possible slope failure may occur in the future (Sessford, October 2011)

On this map, colluvium refers to loose clasts and sediments that are originally a part of the beach terrace surfaces but are now on the sides of the slopes due to erosion (Figure 13).

The dark pink parts of the map indicate active layer detachment slides (ALDS), some of which are labeled D#. Those that are labeled are more distinct in their appearance and their scarps have been measured to analyse past active layer thicknesses. ALDS have three distinct parts to them, the detachment or slide scarp, the detached zone and the depositional zone. In most cases at Fredheim, the detached and depositional zones are difficult to discern due to post-detachment processes such as gelifluction and/or secondary detachments from within the first. As detachment depths are only to the base of the active layer/top of the permafrost it is suggested in (Sessford, master thesis 2013) that scarp depths may be used as an indicator for past active layer thicknesses and thereby correlated with air temperatures to determine relative timing/frequency of ALDS detachment and probability of future events. ALDS D7 and D6 are interesting in that they appear to have been divided because of a small bedrock exposure.

Periglacial features

All of the landforms and sediments at Fredheim have undergone periglacial processes in some form or manner. To the northeast of the map, slopes and some areas on the marine terraces containing exposed bedrock have undergone autochthonous weathering. It is hard to say how deep the weathering penetrates into the rock as no further investigations have been made in this study. More detail is given in the Bedrock section below.

Patterned ground is not very common in the area; however it is present on some of the pre-recent alluvial fans on the terraces. It has not been investigated as to whether or not ice wedges are associated with the patterned ground, but there is distinct cracking within the surface sediments.

Bedrock

The presentation of bedrock geology in this map is limited due to the extensive Quaternary deposits draped over the surface. However, there are outcrops of the Gipshuken Fm. that have recently been exposed by the beach and within the tidal zone as a result of coastal erosion. This formation has been identified as part of the Gipsdalen Group and is of Sakmarian – Artinskian age (ca. 290 Ma) (Major, 1972; Cutbill and Challinor, 1965; Dallmann et al., 2001). The Gipshuken Fm. at Storgjelet and Sveltihel (locations in the near vicinity of Fredheim) is described as platform deposits of limestone/dolomite containing marly, shaley or sandy interbeds and thin gypsum layers (Major, 1972). This is representative of the upper section of the Fm. which has informally been named the Skansdalen Mb. by Dallmann, ed.(1999) who further describes the deposits as consisting of regularly bedded dolomites containing intercalcated marly beds where bioturbation, algal mats and erosional surfaces are commonly found. The sediments represent cyclic deposits and are interpreted to have developed in a sabkha flat environment trending toward lagoonal deposition (Dallmann, 2001; Blomeier, 2009; Hüneke et al., 2001).

Higher up on Marine terrace MT3, the Gipshuken Fm. clearly crops out again in a similar manner to that at the present day coast and is likely analogous to it. The outcrop is escarpment-like, with many large well rounded boulders at the base of the cliff and appears to have been heavily eroded by water both chemically and mechanically (Figure 14). However, it is clear that the rock has been exposed to the elements for much longer than the present day cliff as wind erosion has also made its mark by creating facets on exposed surfaces, and frost shatter has downsized boulders (Figure 15).

Bedrock exposure also occurs in those places marked as Autochthonous bedrock weathering on the map. These locations are mostly at higher elevations, but also in the steeper, northern region of the marine terraces. Blockfield-like exposures that are heavily frost-shattered, weathered and broken appear at the base of every slope between two marine terraces. On the northern part of MT3, only a thin veneer of beach sediments have been lain down and bedrock boulders heavily influenced by frost activity are present.

Between 90 and 100 m a.s.l. relatively large and distinct bedrock mounds are observed (Figure 16). These do not appear as outcrops but rather stand out as small hills and could easily be misinterpreted as marine terraces. However, there are no beach sediments on their surface but only weathered bedrock. They are divided laterally by small depressions containing vegetation and undergoing gelifluction.

Figure 14
Bedrock exposure on MT3, note well roundedness (Sessford, June 2012)

Figure 15
Mechanical (wind) and chemically eroded boulders that have undergone frost shatter (Sessford, June 2012)

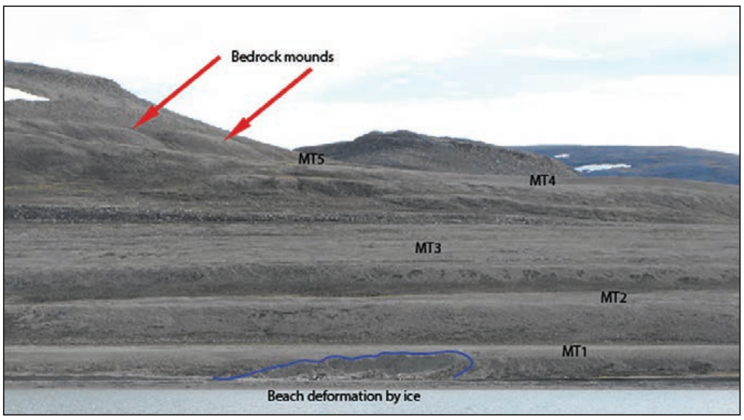


Figure 16
Terraces and bedrock mounds as indicated, purple line delimits the beach deformation by sea ice (Sessford, August 2012)

Anthropogenic structures and recent events

There are five buildings in Fredheim, four of which are cultural heritage buildings and protected by law. The structures were built by Hilmar Nøis and his kin and served as their main hunting station (Figure 17). The fifth building, south of the alluvial fan, is a recent structure built for tourists to relieve themselves. There are also remnants of two small fishing boats which stood in exactly the location at which the ice floe was thrust onto shore and unfortunately crushed them entirely. Two of the cultural heritage buildings, the Outhouse and Gammelhytta (Old Hut) have been moved south, away from the coastal escarpment due to the threat of coastal erosion and disappearing shoreline.

Figure 17
Buildings at Fredheim from left to right: Nødhytta (emergency hut), Outhouse, Villa, Gammelhytta (Old hut) (Sessford, May 2012)

Organic material

Locations marked as organic material are areas in which standing water is present in the spring and early summer thereby allowing for high vegetation growth. There was an attempt to drill to the base of these bogs in the hopes of dating macrofossils as these regions are present on each terrace and could have been a good proxy for regional isostatic uplift. However, all dates turned up modern and therefore cannot indicate the onset of terrestrial plant growth due to uplift but rather due to other factors. Perhaps sediment or water availability was not extensive enough until modern times.

This study has placed one thermistor string as marked by a red dot within the active layer to observe freeze and thaw of the active layer in the pre-recent fluvial sediments. It was installed on October 1, 2011 and will run until April, 2013 (Figure 18). There has also been an automatic camera installed at the point marked with a C to observe sea ice changes and coastal erosion. It was installed on July 5, 2012 and will take one photo daily at 12:00 until uninstalled sometime in April 2013 (Figure 19). Data from both instruments will be discussed in Sessford's master thesis, 2013. Radiocarbon samples mentioned in the Marine deposits and Holocene emergence section were taken from the north side of Sørbekken gulley in sections having become naturally exposed through slumping and colluvium deposition (Figure 20). The sediments were in permafrost that had been exposed and were quite saturated.

On the present day delta there are parts of a whale skeleton from a whale that has been beached within the last 20 years, as it lies on the section of delta which did not exist before 1990. A few bones from this skeleton have been displaced and moved up to the pre-recent fluvial material.

Figure 19
Location of automatic camera and direction of photos taken by camera (Sessford, July 2012)

Figure 20
Colluvium undergoing erosion through slumping. Location of radiocarbon samples for MT3 (Sessford, June 2012)

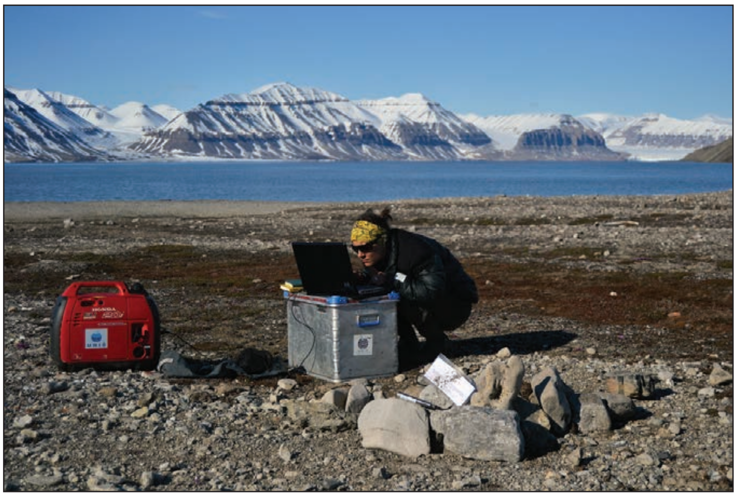


Figure 18
Setting up the thermistor string (Hassberg, June 2012)

Skansbukta: Quaternary superficial deposits

Marine material

All beach material at Skansbukta is considered to be recent i.e. there are no uplifted marine terraces located within the map that can be identified and dated. The well rounded, flat, flaggy beach clasts reach from sea level to approximately four meters a.s.l. The beach has a relatively steep coastline which has prograded since 1918 when the gypsum pier was constructed at the shore and can be seen in Figures 21 and 22. This is also shown by the way the cultural heritage items which have been left on the beach since 1918 have become partially covered by beach stones, and that the gypsum pier which used to reach the coastline is now approximately ten meters from the present day coastline (Figure 22). However, a recent study suggests that between 1990 and 2009 the overall trend, though minimal, is erosion of the Skansbukta coast (Guegan and Sessford, in prep). The location of the coastline on the map has been measured using DGPS points of the high tide line on August 14, 2011. As indicated by tidal gauges in Ny-Ålesund, the morning high tide was 143 cm (Vannstand.no).

Figure 21
Steep shoreface at Skansbukta (Sessford, August 2011)

Figure 22
The beach at Skansbukta where stones overlying wooden structures and half burying mining buckets indicate progradation (Kelley, September 2011)

The darker blue coloured marine deposits with open circle markers indicate covered with lichen covered beach, and thereby distinguished from those without (Figures 23 and 24). Other than the presence of Xanthoria elegans, an orange lichen, there is no other distinguishing factor between this beach material and that of the recent beach. One interesting note is that there are no lichens close to the anhydrite pier. There is lichen-covered beach material dividing the vegetated colluvial and beach material from the recent beach material everywhere except at the southern parts of the beach. The distribution of the lichen vegetation would suggest that where recent progradation has happened no lichen growth is possible.

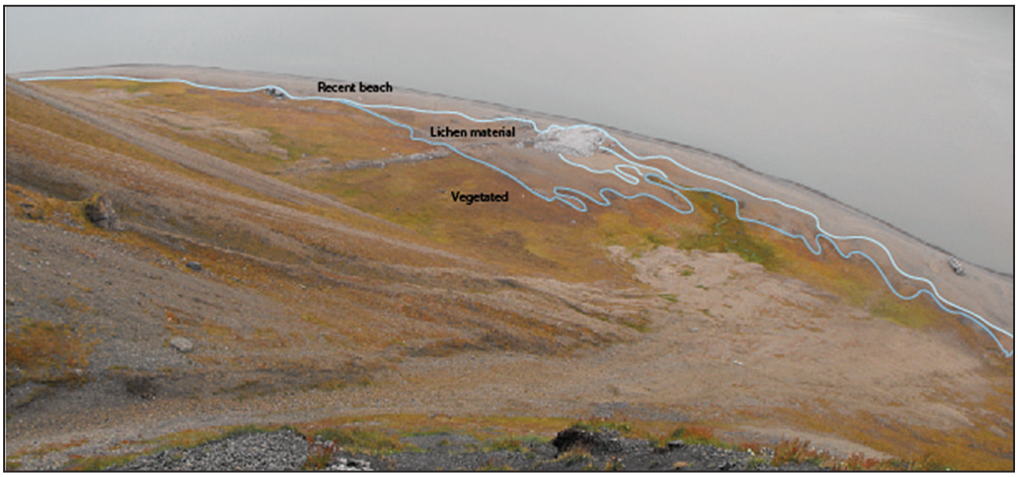


Figure 23
Approximate division of beach material at Skansbukta. Recent beach material is above the light blue line, vegetated material is below the dark blue line and lichen covered material is between the two (Sessford, August 2011)

The darker blue beach material containing vegetation symbols represents a combination of beach and colluvial material which is vegetated mainly by various types of moss (Figure 25). It also contains a significant amount of fines as can be observed by the presence of patterned ground as described within the periglacial features section. A smaller feature which only appears in the northwest corner of the map is small seasonal ponds. These are small (between 10 and 30 cm deep) depressions in the lichen/vegetated beach deposits that do not contain any vegetation within them. They have a higher gradient slope on their southeast, towards the coast. They are marked as seasonal ponds because it is presumed that there is longer standing water/snow in them in the spring time and therefore vegetation is not growing in them. The last marine associated landform is beach hummocks shown as diagonal grey lines on the map. These are non-uniform mounds and depressions close to the present shoreline and within the recent marine material. It is presumed that the hummocks are formed from sea ice as it is thrust up onto the shore during winter (Figures 26 and 27).

Figure 24
Seasonal pond, note steep gradient toward coast and lack of vegetation (Sessford, August 2011)

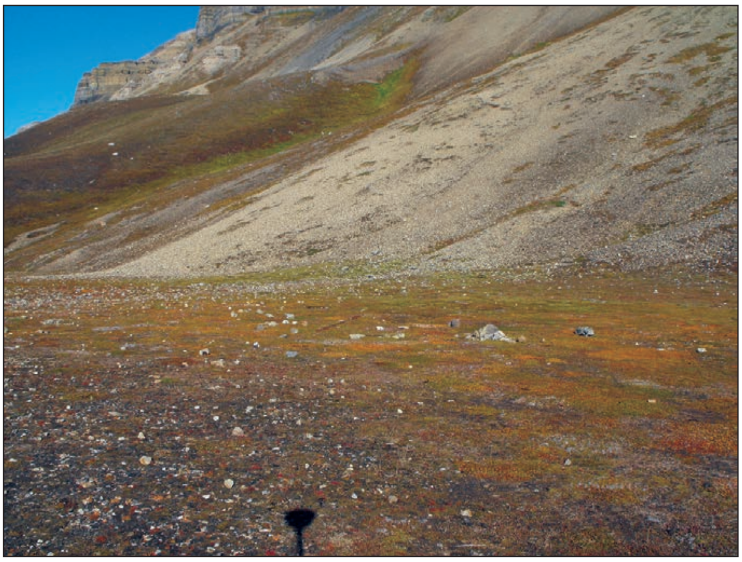


Figure 25
Vegetated beach and colluvial sediments, note rock fall material lying on surface (Sessford, August 2011)

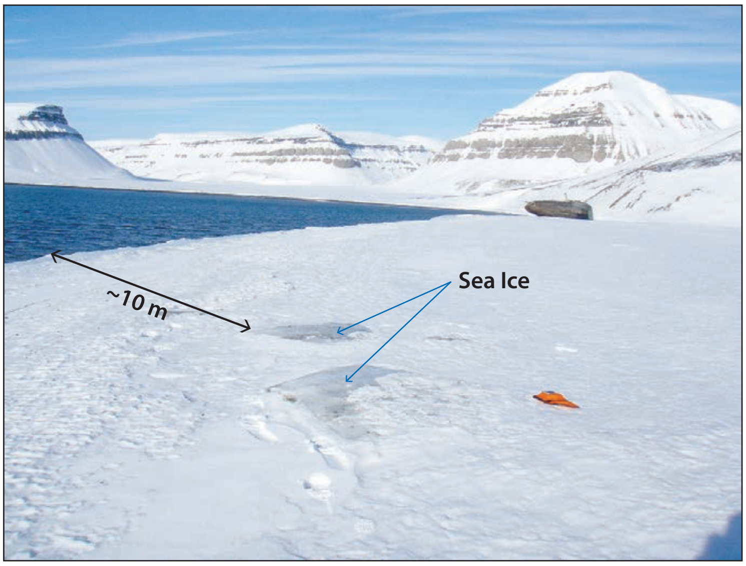


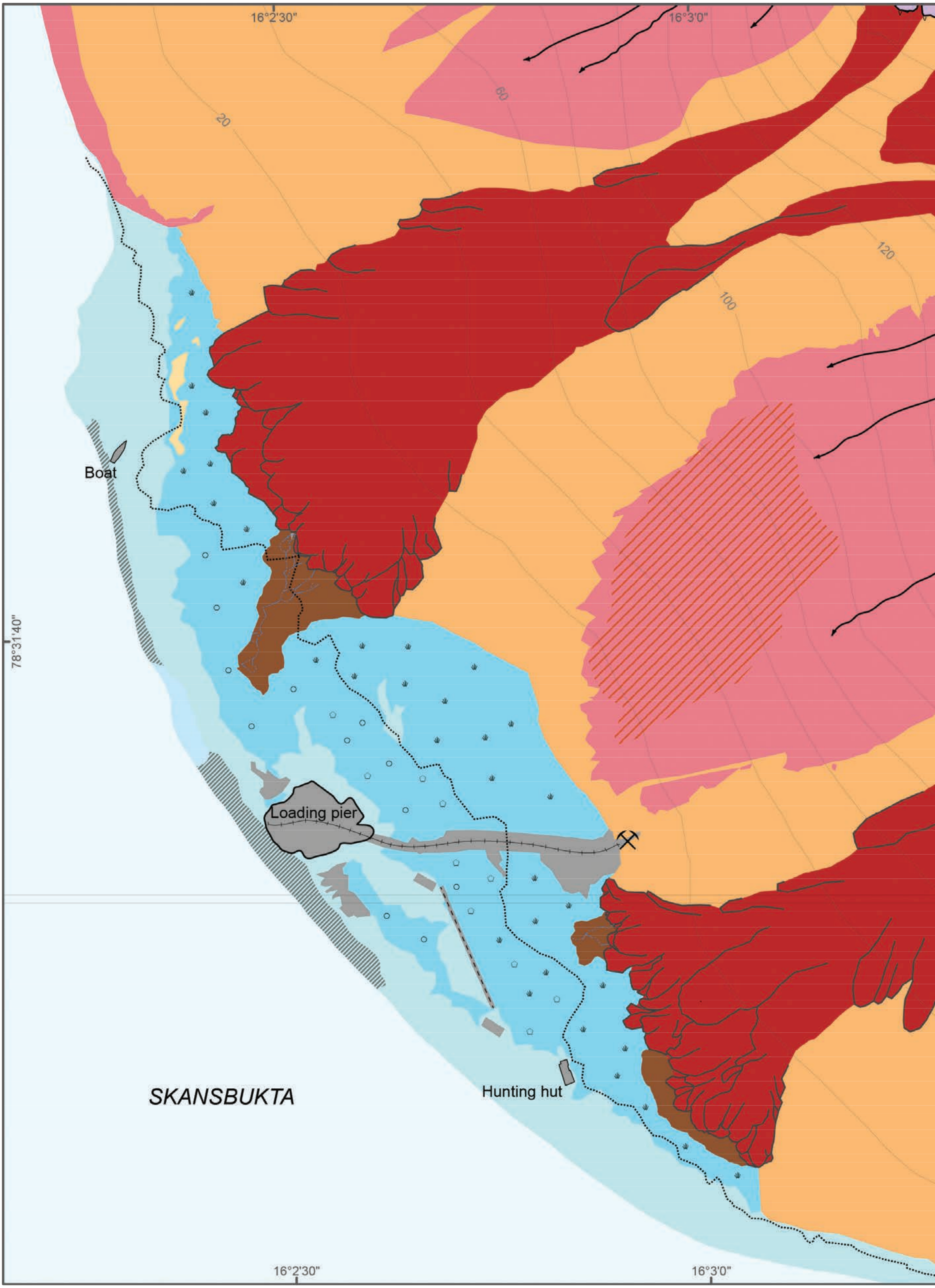
Figure 26
Sea ice thrust on shore during winter (Sessford, April 2012)

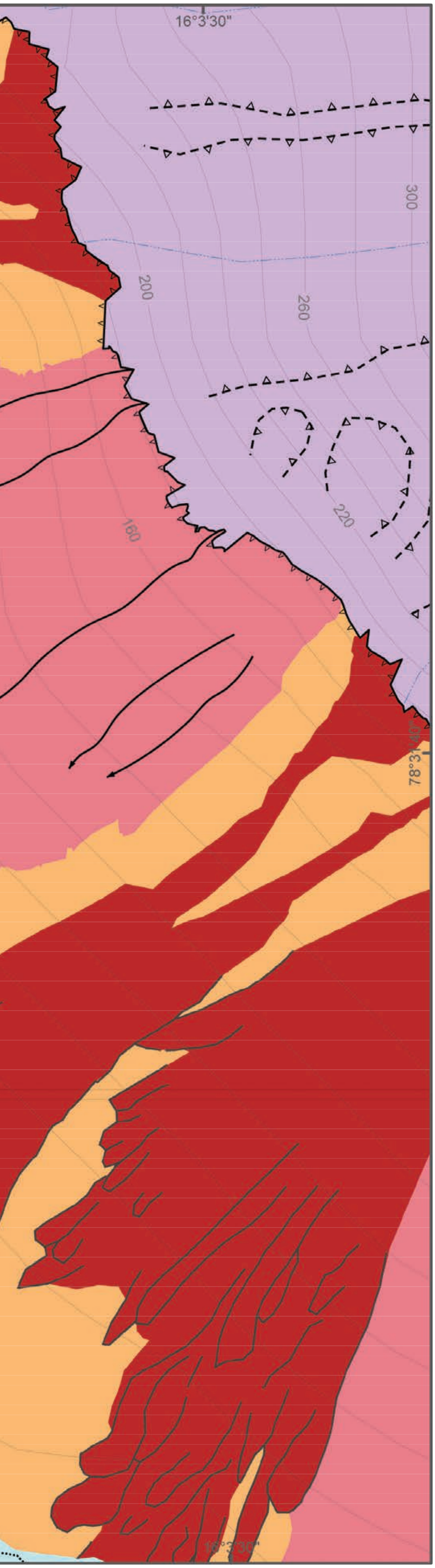
Figure 27
Beach hummocks from the south side of Skansbukta (Sessford, June 2012)

Slope deposits

The slopes at Skansbukta are made up of a number of different landforms the main components of which are rapid mass movement, rock fall, debris flow and snow avalanche deposits (Figure 28). Frost shattering within gully systems induces rock fall which collects at the base of the cliff in accumulation zones (Figure 29). At some point these accumulation zones are flushed out by an extreme event such as oversaturation and create debris flows. Debris flows are marked in red on the map and are characterized by very coarse, well compacted and stable angular clasts. They are deposited as elongated mounds or lobes and originate from chute like erosional gullies on the cliffs which are marked by gully edges on the map. These can be identified by their convex shape, lobe divisions, levees and steeper gradients in the upper regions, and spread out low gradient lower regions. It is likely that avalanche deposits co-exist with debris flow deposits but distinctions between the two is difficult on these particular deposits without direct observations (Eckerstorfer et al., 2012). Lobes represent different debris flow events and are marked out as lobe divisions (Figure 30). None of the lobes have been examined to gain understanding of event timing. However, it can be assumed that those on the surface are younger than those that are overridden because of their geomorphological relationship. Snow avalanche deposits and debris flows tend to originate from a confined area and spread out horizontally as they move downslope. Smaller, finer grained debris flows are present on the rapid mass movement deposits and are marked as black arrows. These seem to be more frequent and do not have long life preservation due to their small size and activity of rock fall and gelifluction which override them easily.

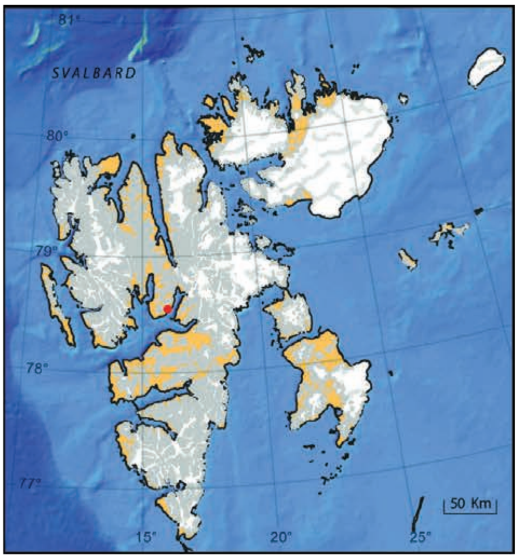
The rapid mass movement deposits are shown in pink on the map and are located below vertical cliff faces, as opposed to gullies. The main rapid mass movement deposit in the middle of the map is made up of angular, blocky clasts of varying size but mainly in the pebble to small boulder range. Little to no gelifluction movement is indicative of active rock fall and


16°2'30"
16°3'0"
60
20
120
100
Boat
78°31'40"
Loading pier
SKANSBUKTA
Hunting hut
16°2'30"
16°3'0"



SKANSBUKTA, Billefjorden, Svalbard
Quaternary Geology and Geomorphology

- Autochtonous bedrock weathering
- Marine beach material, recent
- Marine beach material, lichen cover
- Vegetated beach and colluvial sediments
- Rapid mass movement deposit
- Snow avalanche deposit/debris flow deposit in lower part
- Gelifluction steps, vegetated
- Gelifluction, coarse material
- Seasonal pond
- Organic material
- Groundwater outflow
- Cultural heritage zone
- Beach hummocks
- Debris lobe division
- Debris flow, small, medium coarse material
- Rockfall extent, DGPS measurement 2011
- Gulley edge
- Intermittent river
- Cliff base
- Mine entrance
- Patterned ground
- Tram tracks
- Walking path



Projection: UTM Zone 33X
Datum: WGS 1984
Contour Interval: 20 m (Norwegian Polar Institute, 1990)

1:2 000

0 20 40 80 120 160 Meters

N

Evangeline Sessford (2013)
University of Oslo and University Centre in Svalbard
Master Thesis in Geoscience

Figure 28
Skansbukta slopes from the bay, note the rapid mass movement deposit in the middle of two debris flow accumulations (Hassberg, June 2012)

Figure 29
Rock fall accumulation at the base of gully below cliff and above debris flow run-out (Sessford, August 2011).

Figure 30
Elongated debris flow accumulations overriding each other with well-defined levees covering the snow avalanche deposits (Sessford, August 2011)

Figure 31
Rapid mass movement deposit showing less active rock fall on the left where gelifluction is the more predominant slope movement, and the right side where rock fall is predominantly active (Sessford, September 2011)

Figure 32
Gelifluction steps to the side and above mine entrance. Note how rock fall is caught on the surface of each step (Sessford, June 2012)

Figure 33
Large rock fall boulder stopped in bog area (Sessford, August 2011)

Figure 34
Rock fall debris come to stop on gelifluction steps, vegetation and cultural heritage material at mine entrance (Sessford, June 2012)

Figure 35
Small rock fall and aeolian debris caught on snow patch surface (Sessford, June 2012)

rapid mass movement in the southeastern part of the accumulation. Whereas gelifluction in coarse material, shown as thin diagonal orange stripes is more active in the northwestern section of the map unit. You can also see in Figure 31, that there are some relict fan sections that are becoming covered by thin vegetation.

There are two types of gelifluction in Skansbukta. The first has already been mentioned and is only present on the rapid mass movement (Figure 31). The second is turf banked gelifluction lobes which are located in vegetated slopes and shown as a light orange colour on the map. Steps are between 0,1 and 0,5 m in height and have a front lip and a small depression on the slope side as described in the Fredheim map description. At Skansbukta, gelifluction lobes act as debris catchers during rock fall (Figure 32).

Rock fall debris extends out from the base of the slope to the dotted blue line overlying beach material. Most rock fall does not have a run out zone extending until the recent beach material likely because of two reasons. One, because rock size is generally not very large (with the exceptions of some boulders such as seen in Figure 33) and therefore does not contain enough kinetic energy to move a great distance, but mainly due to the presence of vegetation, either on the slopes where there are gelifluction steps, or at the base of the slope which absorbs rock fall energy thereby slowing the rocks so that they come to a stop sooner (Figure 34) (Jones et al., 2000; Ritchie, 1963). It is quite probable that most rocks extending to the recent beach material have been moved there due to anthropogenic activity. Most of the rock fall is in fact quite small as seen in Figure 35, and there is much occurring in the spring or melting seasons which is caught on snow patch surfaces (Figure 35). It is also possible that much of the smaller debris is aeolian material.

The cliff base as distinguished by the solid black line with triangles and at the top of the slope has been measured using DGPS, therefore the position of this line represents the base of the cliff, and not the top. The base is at approximately 180 m a.s.l. and extends upwards approximately to 250 m a.s.l. although not necessarily entirely vertical.

Periglacial features and hydrology

Patterned ground in Skansbukta is not easily seen when standing directly on its surface but can be seen from above when standing on the slopes as shown in Figure 36. It is only present in the vegetated pre-recent beach deposits which likely have a large amount of fine grained aeolian sediments in them to allow for frost cracking. This is due to this area being less well drained and having finer sediments than the other beach areas. Patterned ground is not present in the organic material areas coloured in brown, as these are more bog like and have too much excess water for ice wedges to form (Figure 37). It is presumed that during the active mining times, most of the vegetated pre-recent beach area had an extensive amount of standing water in it during spring. The reason for this assumption comes from small drainage like channels within the path shown in Figure 38 and the presence of the bridge (now collapsed) for the trolley track (Figure 36).

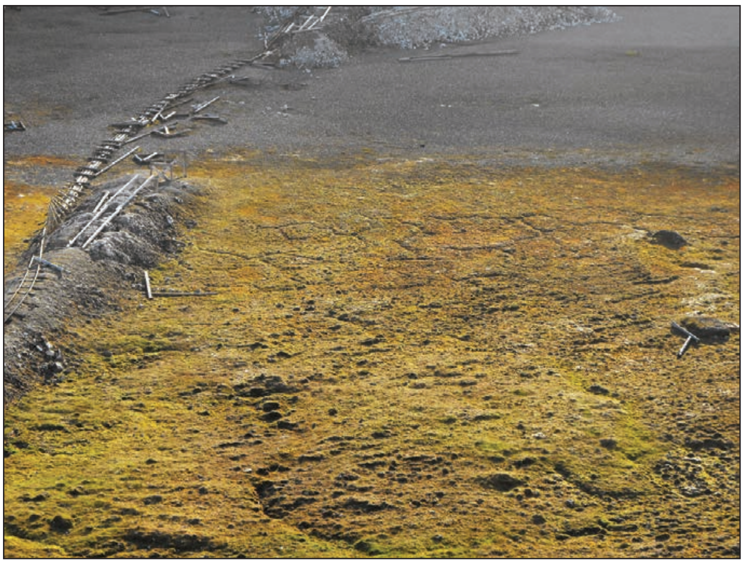


Figure 36
Patterned ground as seen from the slopes above the mine entrance (Sessford, August 2011)

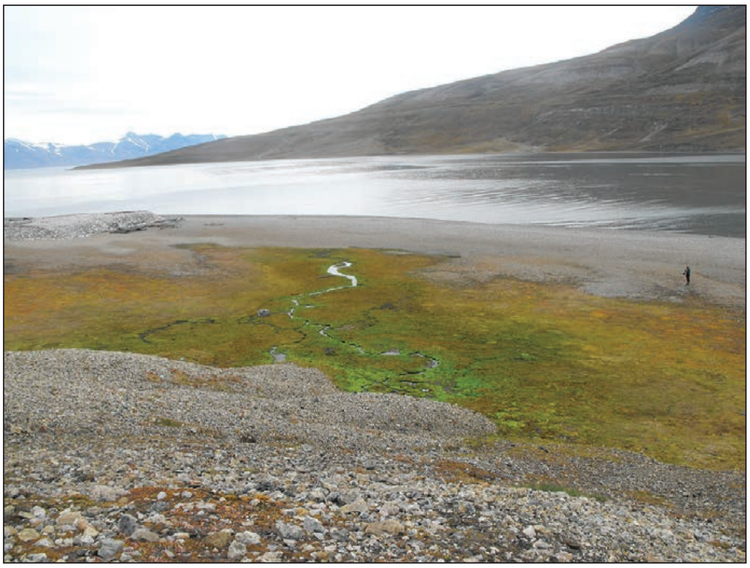


Figure 37
Bog north of cultural heritage zones and below debris flow accumulation (Sessford, August 2011)

Figure 38
Man made path with small drainage opening (Sessford, July 2011)

Small fluvial channels labeled as intermittent rivers on the map originate from snow melt in the spring and throughout the summer if snow accumulation over the winter was excessive enough. Much snow accumulates above the cliff, within the gullies as well as on top of the plateau. Water flows through the gullies and as small waterfalls over the cliffs above debris flow and snow avalanche accumulations (Figure 39). There is no water flow above the rapid mass movement deposits. Water continues to flow down to the sea as groundwater through the debris flow accumulations and resurfaces in the bogs to again flow as groundwater to the sea. Only in one place is groundwater outflow visible at the recent beach coastline.

Bedrock

The lowermost geologic unit of the towering cliff of Skansen is the Gipshuken Formation of Early Permian age. Anhydrite dominates the lowermost section but is overlain with intermittent layers of dolomite. Skansen has a very well exposed, 115 m thick, continuous section of finely-laminated algal

Figure 39
Waterfall over cliff from gulley (Sessford, August 2011)

Figure 40
Lowermost bedrock of the Gipshuken Fm. upper cliff exposures of the Kapp Starostin Fm. Both showing autochthonous weathering (Sessford, August 2011)

dolomites above the anhydrite. These uppermost deposits are suggested by Lauritzen et al. (1989) to be sabkha deposits and terminate with caliche horizons, a sedimentary deposit of mainly hardened calcium carbonates evaporated from uprising ground water. The Kapp Starostin Formation rests conformably above the Gipshuken Formation, dates to the Late Permian and is lithologically composed of cherts, siltstones, siliceous sandstones and spiculitic shales

Figure 41
The loading boat (Sessford, August 2011)

Figure 42
The hunting and fishing cabin (Sessford, August 2011)

Figure 43
All cultural heritage zones as seen from the slopes above (Sessford, August 2011)

(Lauritzen et al., 1989) (Figure 40). Its resistance to weathering produces a distinct marker boundary between it and the underlying Gipshuken Formation. The base of Kapp Starostin Formation is made up of the Vøringen Member, a bioclastic, coarse grained limestone containing brachiopod and bryozoan fauna, marking the large scale transgression of Late Artinskian-Early Kungurian age (Lauritzen et al., 1989). Bedding is almost horizontal; the dip is ca. 2° SW. The cliff base begins at an altitude of 232 m a.s.l. and rises straight up approximately 250 m a.s.l. It is split periodically by gullies often containing a buildup of allochthonous weathering material and seasonal flow of water. Autochthonous bedrock weathering is present on all exposed bedrock surfaces. The photo (Figure 40) is taken from outside the map area in the south-east and looking back toward the cliffs above Skansbukta.

Anthropogenic structures

Skansbukta is protected as a cultural heritage site by the Governor of Svalbard (Sysselmannen.no). The cultural zones that are marked out in grey are structures from a number of different activities. Though originally constructed as a gypsum mining site, excavations were stopped when it was determined that the area is dominated by anhydrite and not gypsum (Prestvold, 2003). However, much of the mining infrastructure still remains along with more recent cultural items such as the hunting and fishing cabin which is also protected. Items included in the cultural heritage zones are the mine entrance, the trolley track leading from the mine to the loading bay, the loading bay, log piles and steel baskets, walking path from the cabin to toward the tracks, the cabin, the loading boat and log posts which used to serve as support for buildings (see figures throughout description and Figures 41-43).

References

Allard, M., Michaud, Y., Ruz, M.H. & Hequette, A. 1998: Ice foot, freeze-thaw of sediments, and platform erosion in a subarctic microtidal environment, Manitounuk Strait, northern Quebec, Canada. Canadian *Journal of Earth Sciences 35(9)*, 965-979.

Bjerck, H. 1999: Overvåkning av kulturmiljø på Svalbard: Målsetting, metode, lokaliteter og overvåkning. *Rapportserie. S. Miljøvernavdeling. Longyearbyen, Sysselmannen på Svalbard, nr. 3 / 1999*, 63 pp.

Blomeier, D., Scheibner, C. & Forke, H. 2009: Facies arrangement and cyclostratigraphic architecture of a shallow-marine, warm-water carbonate platform: the Late Carboniferous Ny-Friesland Platform in eastern Spitsbergen (Pyrefjellet Beds, Wordiekammen Formation, Gipsdalen Group). *Facies* 55, 291-324.

Caline, F. 2010: *Coastal-sea-ice action on a breakwater in a microtidal inlet in Svalbard*. Doctoral Thesis, Department of Civil and Transport Engineering. Trondheim, Norwegian University of Science and Technology, 263 pp.

Cutbill, J.L. & Challinor, A. 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geological Magazine 102(5)*, 418-439.

Dallmann, W.K., ed. 1999: *Lithostratigraphic Lexicon of Svalbard. Upper Palaeozoic to Quaternary bedrock. Review and recommendations for nomenclature use*. Committee on the Stratigraphy of Svalbard / Norsk Polarinstitutt. 320 pp.

Dallmann, W.K., Kjærnet, T. & Nøttvedt, A. 2001: Geological map of Svalbard 1:100,000 Sheet C9G Adventdalen. *Norsk Polarinstitutt Temakart* 31/32.

Eckerstorfer, M., Christiansen, H.H., Vogel, S. & Rubensdotter, L. 2012. Snow cornice dynamics as a control on plateau edge erosion in central Svabard. *Earth Surface Processes and Landforms, doi: 10.1002 / esp. 3292*.

Fairbridge, R.W. 2004: Classification of coasts. *Journal of Coastal Research 20 (1)*, 155-165.

Forman, S.L., Mann, D. & Miller, G.H., 1987. Late Weichselian and Holocene relative sea-level history of Brøggerhalvøya, Spitsbergen, Svalbard Archipelago. *Quaternary Research 27*, 41–50.

Forwick, M. & Vorren, T.O. 2009: Late Weichselian and Holocene sedimentary environments and ice rafting in Isfjorden, Spitsbergen. *Palaeogeography, Palaeoclimatology and Palaeoecology, 280(1-2)*, 258-274.

French, H. & Shur, Y. 2010: The principles of cryostratigraphy. *Earth-Science Reviews 101(3-4)*, 190-206.

Guegan, E.B.M., Sessford, E.G. & Schomacker, A. (in prep): Timelapse aerial photography reveals significant coastal erosion on Svalbard, Norwegian high Arctic.

Hüneke, H., M. Joachimski, Buggisch, W. & Lützner, H. 2001: Marine carbonate facies in response to climate and nutrient level: The upper carboniferous and Permian of central Spitsbergen (Svalbard). *Facies 45(1)*, 93-135.

Jakobsson, M., Macnab, R., Mayer, L., Anderson, R., Edwards, M., Hatzky, J., Schenke, H.-W., Johnson, P. 2008: An improved bathymetric portrayal of the Arctic Ocean: Implications for ocean modeling and geological, geophysical and oceanographic analyses. *Geophysical Research Letters 35*, L07602

Jones, C. L., Higgins, J. D. & Andrew, R. D. 2000: *Colorado rockfall simulation program version 4.0 (for Windows)*. Colorado Department of Transportation, 127 pp.

Landvik, J., Brook, E.J., Gualtieri, L., Linge, H., Raisbeck, G., Salvigsen, O. & Yiou, F. 2013: 10Be exposure age constraints on the Late Weichselian ice sheet geometry and dynamics in inter ice-stream areas western Svalbard. *Boreas in print*.

Landvik, J.Y., Ingólfsson, Ó., Mienert, J., Lehman, S.J., Solheim, A., Elverhøi, A. & Ottesen, D. 2005: Rethinking Late Weichselian ice-sheet dynamics in coastal NW Svalbard. *Boreas 34*, 7-24.

Lauritzen, Ø., Salvigsen, O., Winsnes, T.S. & Andresen, A., 1989: Geological Map Svalbard 1:100 000, C8G Billefjorden, *Norsk Polarinstitutt Temakart 5*.

Major, H. & Nagy, J. 1972: Geology of the Adventdalen map area. *Norsk Polarinstitutt Skrifter* 138 pp.

Matsumoto, H. & Ishikawa, M. 2002: Gelifluction within a Solifluction Lobe in the Kärkevagge Valley, Swedish Lapland. Geografiska *Annaler, Series A, Physical Geography 84 (3/4)*, 261-266.

Matsuoka, N. 2001: Solifluction rates, processes and land forms: a global review. *Earth-Science Reviews 55*, 107-134.

Nichols, R.L. 1961: Characteristics of beaches formed in polar climates. *American Journal of Science 259*, 694-708.

Prestvold, K. 2003: *Isfjorden*: *a journey through the nature and cultural history of Svalbard.* Governor of Svalbard.

Ritchie, A.M. 1963: *The evaluation of rock fall and its control.* Highway Research Record, National Academy of Sciences – National Research Council, Washington, DC 17, 13-28.

Rodzik, J. & Zagórski, P. 2009: Shore ice and its influence on development of the shores of southwestern Spitsbergen. *International Journal of Oceanography and Hydrobiology 38(1)*, 183-180.

Salvigsen, O. 1984: Occurence of pumice on raised beaches and Holocene shoreline displacement in the inner Isfjorden area, Svalbard. *Polar Research 2(1)*, 107-113.

Sessford, E.G. 2013: Spatial and temporal analysis of Holocene coastal development: *applications to erosion assessment and cultural heritage mitigation in Svalbard.* Master thesis, Department of Geosciences, Oslo, University of Oslo, 149 pp.

Statens Kartverk 2011: Vannstandsdata, Ny-Ålesund August 14, 2011. *http://vannstand.no/index.php/en/english-section/sea-level-data*. 26.10.2012

Sysselmannen på Svalbard 2000: *Fredheim, flytting.* Document number 00133.

Tolgensbakk, J., Sørbel, L. & Høgvard, K. 2000: Adventdalen geomorphological and Quaternary geological map, Svalbard 1:100,000, Spitsbergen sheet C9Q, *Norsk Polarinstitutt Temakart* 32.

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