Beach processes and recent sea-level changes at Tönsneset, Kongsfjorden, northwestern Spitsbergen

Jonas Svensson
Institutionen för naturgeografi och kvartärgeologi
Stockholms universitet

Förord


Författaren är ensam ansvarig för uppsatsens innehåll.

Stockholm, den 17 november 2009

Clas Hättestrand
Studierektor
Beach processes and recent sea-level changes at Tönsneset, Kongsfjorden, northwestern Spitsbergen.

Abstract
Beaches occur throughout the coastal regions of the world. Ridges found on beaches can be used as indicators of past climatic and oceanographic conditions. Sea-level changes can also be extrapolated from these landforms, if the correct conditions occur, when the facies between eolian and intertidal sediments can be found. Ground penetrating radar and fieldwork has been used to investigate the origins, processes, and the connection with sea-level fluctuations on a beach and the associated berm-ridge, located at Tönsneset in Kongsfjorden, northwestern Spitsbergen.

The beach has a moderately simple internal structure, with the stratigraphy of the beach revealing layers with a low gradient towards the sea on the foreshore, and overwash layers with an inclination landwards on the backshore. Layers alternate mostly with sand and gravel, and a majority of them having low angle cross lamination characteristics. Previous datings, together with preliminary datings from this study, signify an origin from late Holocene for the berm-ridge. The berm-ridge at Tönsneset does not indicate any clear-cut evidence of a former sea-level and it cannot be used as evidence for a suggested recent transgression.
Jonas Svensson
1. Introduction

Beaches are common landforms found along the coastal regions of the world. Beach systems constitute the link between terrestrial and marine environments. The primary agents of deposition in these environments are waves and wind. They are known to drive sediments across beaches to deposit beach-ridges. Diversity concerning definitions for beach-ridges exists in the literature. However, Otvos (2000) proposes a homogeneity in the definition. Otvos (2000) redefines beach-ridges “as intertidal-supratidal, narrow, relict landforms” (p. 105). This applies to relict coastal ridges, eolian and wave-built, consisting of a variety in clast sizes from fine sand to cobbles and boulders. In the initial stages of beach-ridge formation, when the ridge is in contact with an active shore environment, they are referred to as berm-ridges (Otvos, 2000). Berm-ridges are strictly wave-built and reside in the area between the landward backshore margin (often the lagoon margin) and foreshore margin (fig. 1) (Otvos, 2000).

Beach-ridges’ frequency of occurrence depends on the fine sediment availability in the near shore zone (Carter, 1986). Beach-ridges have been argued to form during high energy wave conditions (storms) (Carter, 1986; Fletcher et al., 1993; Mason & Jordan, 1993; Møller, 1995, Otvos, 2000; Orford et al., 2003). Additionally has periods of low energy waves, constructing waves, or a combination of these, been argued to produce beach-ridges (Taylor & Stone, 1996; Otvos, 2000; Orford et al., 2003). As a consequence, beaches and the accompanying beach-ridges and berm-ridges can give an indication of oceanographic conditions and also the climatic conditions (Carter, 1986; Fletcher et al., 1993, Mason & Jordan, 1993; Møller, 1995, Taylor & Stone, 1996; Otvos, 2000; Orford et al., 2003; Brooke et al., 2008). Additionally, they can provide a record for former sea-levels (Stapor et al., 1991; Taylor & Stone, 1996), however, Otvos (2000) and Orford et al. (2003) postulate that the sea-level can only be determined if a certain facies between eolian and intertidal sediments is found within the beach-ridge.

Sea-level changes occurring throughout the Quaternary is foremost a result of the cyclic trend of ice sheets, with expansion and reduction stages, resulting in low sea levels and high sea levels, respectively (Lambeck & Chappell, 2001). The mechanisms behind these sea-level fluctuations during the Quaternary are glacio-isostasy: rebound of the earth’s crust as ice sheets melt (Lambeck & Chappell, 2001), and eustasy: a change in sea-level due to adding or reducing the water volume (Miller et al., 2005). Sea-level change can result in transgression, which reflects the process of shoreline retreat towards land as water progresses over land. Regression, on the contrary, is a movement.
of the shoreline seaward (Curray, 1964). Present day sea-level changes are not signified by a simple trend in sea-level rise, instead the ocean masses are suggested to be redistributed. This also applies for the last 5,000 years (Mörner, 2005).

In this paper a beach and its associated berm-ridge (sensu Otvos, 2000) has been investigated in the high arctic, Tönsneset, located in Kongsfjorden, northwestern Spitsbergen (fig. 2). This investigation has put an emphasis on the morphology and the stratigraphy of the beach. The examination consisted of interpretation of Ground Penetrating Radar (GPR) profiles and fieldwork.

Fig. 2. Location of Tönsneset. Adopted from Alexanderson (written communication).

The prominent beach system at Tönsneset that is currently interacting with the ocean has been interpreted as a modern storm beach (Forman et al., 1987; Forman, 1990; Forman et al., 2004). It has been suggested that northwestern Spitsbergen experiences an ongoing transgression, or have had a recent one (Feyling-Hanssen, 1955; Blake, 1961; Rudberg, 1986; Forman et al., 1987 and references therein; Forman, 1990; Andersson, 2000; Brückner & Schellmann, 2003; Forman et al., 2004; Salvigsen & Høgvard, 2005; Peterson, 2008) and consequently, this beach is a result of it. This study aims to investigate the origins of the beach and determine whether it can be used as evidence for an ongoing transgression in the region. If so, is Tönsneset a representative transgression beach? The following questions will additionally be raised and discussed: what processes are acting upon and have been acting upon the beach and the berm-ridge; how is the beach constructed?

2. Investigation Area

The beach at Tönsneset is located on the northern coast of Kongsfjorden (fig. 2). The oceanographic environment in Kongsfjorden is characterized by the relatively warm and saline northward flowing West Spitsbergen Current (WSC), which originates from the Norwegian Atlantic Current (Svendsen et al., 2002). Additionally, a coastal current with cold fresh Arctic water flows northward on the ocean shelf. Kongsfjorden remains frozen throughout the winter season with break up and melting taking place between April and July (Svendsen et al., 2002). The tide inside the fjord has an amplitude of about 0.5 m (Svendsen et al., 2002), and the prevailing fetch is from the west (Forman, 1990).
The northwestern region of Svalbard is argued to have been deglaciated by roughly 13 \(^{14}\)C ka ago, in contrast to eastern Svalbard where the deglaciation did not take place until roughly 10.5-10 \(^{14}\)C ka ago (Forman, 1990; Lehman & Forman, 1992; Forman et al., 2004; Landvik et al., 2005; Salvigsen & Høgvard, 2005). The glaciation in northwestern Svalbard was characterized by fast flowing ice streams flowing through the fjords, draining ice from the inner portions of Spitsbergen. The ice between these ice streams was less dynamic and, therefore, preserved part of the landscape (Landvik et al., 2005). The northwestern region has been under the influence of a fluctuating sea-level since the time of deglaciation, with transgressive and regressive circumstances, creating series of raised beaches that occur up to an elevation of 45 m aht (m above high tide mark) (Forman et al., 2004). The highest raised beaches on eastern Svalbard have been recorded at an altitude of 130 m aht (Forman et al., 2004). This unevenness has been argued to reflect former ice sheet thickness in the different areas in Svalbard during late the Weichselian (Forman, 1990; Landvik et al., 1998; Forman et al., 2004). The sea-level change for northwestern Spitsbergen during the Holocene can be seen in figure 3, where Forman et al. (1987) bases his emergence curve on \(^{14}\)C dated whalebones and shells.

![Fig. 3. Late Weichselian and Holocene relative sea level curve for Brøggerhalvøya, Spitsbergen (located on the southern coast of Kongsfjorden). From Forman et al. (1987).](image)

A transgression has been proposed by several authors to be taking place presently or have been taking place in the last thousand years in western and northern Spitsbergen (Feyling-Hanssen, 1955; Blake, 1961; Rudberg, 1986; Forman et al., 1987 and references therein; Forman, 1990; Andersson, 2000; Brückner & Schellmann, 2003; Forman et al., 2004; Salvigsen & Høgvard, 2005; Peterson, 2008). These suggestions of a modern transgression have been based on observations such as: anthropogenic whaling features being eroded into the present ocean, terrestrial peat covered by marine deposits, and whalebone datings.

### 3. Methods

Fieldwork for this study took place during August 2009, when a two and half week visit to Tønsneset and Kongsfjordhallet was completed, with the majority of the fieldwork conducted on the latter location, for the purpose of a separate project (SciencePub).
Field methods for this study consisted of geomorphological and stratigraphical techniques: a thorough measuring of the beach and digging holes to determine the stratigraphy. The instruments utilized consisted of Garmin GPS60, Suunto PM-5 clinometer, spade, and measuring tape. Localities for dug pits can be seen in figure 4, where they are all presented. The depth of each pit varied significantly between each hole, as external factors played a role as to how deep I could dig. Stratigraphy logs J05, J06, J07 and J08 were documented along one of the erosional sides created by the currently dry river, which had its entire south-facing side excavated in order to examine the large scale layering of the berm-ridge. Sand samples were collected at two of the digging sites, considered to be the most fit for Optically Stimulated Luminescence (OSL) dating, and shell fragments were collected for $^{14}$C dating. These datings will not be completed before the completion of my work and are therefore not included in this report. Samples which have been collected on the Tönsneset beach by the SciencePub project in 2007 will, however, be briefly discussed in this report.

The digging sites on the beach were chosen after interpretation of the GPR-profiles revealed the most interesting investigation localities, although certain places were picked based on their practical availability as well. The most interesting sites were the ones where an old vegetated surface could be found. An attempt to dig into the foreshore (ca. 10 m from the high tide mark) of the beach was made, to locate an interpreted old vegetation surface, however, due to the sediments high water-saturation, it was hard to dig into the foreshore, and therefore most of the holes were dug on the backshore. A standard lithostratigraphical logging procedure was utilized for documenting the sediments and stratigraphy and section logs were drawn in the field and later digitized in Adobe Illustrator. Measurements completed in the field with GPS were incorporated into a GIS program, ESRI ArcGIS, where digitalizing took place to create a geomorphological map of the area. All of the pits that were dug are not presented in the geomorphological map.

GPR-profiles (transects, diagonally, and perpendicular over the beach) had been collected for the area by the SciencePub project in 2007. The GPR is a Sensors & Software pulseEKKO 100 radar and the profiles were recorded with an antenna frequency of 200 MHz. As explained by Neal (2004, p. 262), where a thorough discussion concerning GPR exists, “GPR detects electrical discontinuities in the shallow subsurface of the earth’s surface by generation, transmission, propagation, reflection and reception of electromagnetic waves in the MHz frequency range”. As a result, different properties and materials such as the water table, sediment structures, and lithological changes produce reflections that can be observed with GPR. These primary reflections can be interpreted as different GPR-facies, which can be organized into GPR-units (fig. 7 a & b). These units are separated by different GPR-surfaces (Neal, 2004). The GPR-profiles, therefore, made an introductory interpretation of the stratigraphy possible. Digging in the field and observing the bedding of sediments made a correlation between the GPR-profiles and the visual bedding possible.

4. Results
Data collected in the field resulted in a geomorphological map (fig. 4) and stratigraphical logs of pits dug (fig. 5 a-f).
Beach processes and recent sea-level changes at Tönsneset, Kongsfjorden, northwestern Spitsbergen.

Fig. 4. Geomorphological map of Tönsneset.
4.1. Geomorphology

The beach is situated in a roughly N-S direction (see fig. 4). The berm-ridge has a distinctive crest, with a foreshore and backshore side on the western and eastern side of the crest, respectively. The height of the ridge, with the zero level regarded as the high tide mark, was determined with an inclinometer to approximately 3.5 m high, which can be assumed for the crest running on top of the ridge, except in two areas, where two small rivers have eroded through the berm-ridge (fig. 4). Both of the rivers vary greatly in discharge due to seasonal variations, to the extent that one is dry during the summer months. The landward end of the backshore borders a vegetated area that has several lagoons, which also have a seasonal variation. Another feature that exists on the berm-ridge are springs that comes up through the ridge on two different places (spring A and B in fig. 4) on the northern end of the beach. Beach cusps were also observed on the beach.

4.2. Stratigraphy

Within the beach and the berm-ridge, layers with a low gradient towards the sea were observed in the two pits excavated on the foreshore side of the crest, whereas on the backshore side of the crest, layers had a landward inclination (fig. 6). The angle of the bedding was grossly estimated to 2°-6° on both sides of the crest.

The specific stratigraphy for each digging site is presented in fig. 5 a-c and fig. 6. A distinguishing feature of the stratigraphy was the alternating sand and gravel layers. The stratigraphy of the three section logs (J09, J10 and J11) that were not digitized had an overall agreement of the layering with the other section logs from the beach. Permafrost was found at one of the sites, J10, at a depth of 2.7 m. The groundwater table was reached in holes J02 and J03, at 1.75 m and 1.20 m, respectively. Fresh water was found on the foreshore at a depth of 1 m, ten m from the high tide mark.

Two interpreted GPR-profiles are presented in fig. 7 a-b. Each color corresponds to sediments with a different depositional history. Yellow matches up with sediments deposited in the foreshore, orange shows layers on the backshore, purple represents a former foreshore and a surface today characterized by vegetation, blue indicates a water source, and red shows surfaces that separate the layers.

Table 1. Lithostratigraphic codes used in Fig. 5.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sm</td>
<td>massive sand</td>
</tr>
<tr>
<td>GSm</td>
<td>massive gravelly sand</td>
</tr>
<tr>
<td>SG/GSm</td>
<td>sandy gravel/massive gravelly sand</td>
</tr>
<tr>
<td>Gmm</td>
<td>matrix-supported massive gravel</td>
</tr>
<tr>
<td>SGmm</td>
<td>matrix-supported massive sandy gravel</td>
</tr>
<tr>
<td>Slc</td>
<td>low angle cross lamination sand</td>
</tr>
<tr>
<td>GSlc</td>
<td>low angle cross lamination gravelly sand</td>
</tr>
<tr>
<td>Glc</td>
<td>low angle cross lamination gravel</td>
</tr>
<tr>
<td>SGig</td>
<td>inversely graded sandy gravel</td>
</tr>
<tr>
<td>SGng</td>
<td>normally graded sandy gravel</td>
</tr>
<tr>
<td>GSng</td>
<td>normally graded gravelly sand</td>
</tr>
<tr>
<td>$\chi$</td>
<td>shellfragment</td>
</tr>
</tbody>
</table>
Beach processes and recent sea-level changes at Tönneset, Kongsfjorden, northwestern Spitsbergen.

Fig. 5. Stratigraphy logs of (a) J02, (b) J03, (c) J07.
Fig. 6. Overview of layering from the side of the dry river bed. Logs presented are J05, J06, J08 (top to bottom).
Fig. 7 a & b. GPR-profiles displaying the different GPR-units of the beach. The ocean is located in the direction of the top of the page in (a) and on the opposite, the bottom of the page in (b). Color guide: Yellow corresponds to sediments in the foreshore; Orange indicates layers on the backshore; Purple represents a former foreshore (a) and a surface today characterized by vegetation (b); Blue indicates a water source; Red show surfaces that separate the layers.

4.3. Sediments
The clast size of the sediments on the beach were medium to coarse sand, rarely fine sand was found but not in significant amounts, and the coarsest particles were cobbles
to small boulders (~25 cm). The particles tended to be sub-rounded to well-rounded, however, some sediments that had an sub-angular character were also encountered, especially in the dug pits. Another feature encountered were particles that had undergone frost shattering, as a lot of cracks in the cobbles and boulders were observed. Coarser particles were found with silt on top of them, while a carbonate precipitation was found at the bottom of them. Shell fragments were found throughout the dug pits at varying depths. Sediments with an eolian deposition history could not be found at Tönsneset.

4.4. Chronology

Samples taken during previous field work (2007) revealed a relatively wide range of ages depending on the stratigraphic position of the item dated. One whalebone, located in one of the lagoons, indicated an age of 225±35 14C years BP and one bone on the foreshore 75±35 14C years BP, while a mollusc shell had an age of 1380±35 14C years BP. The shell was found at less than 1 m depth in the backshore layers. Similar dates were provided by two OSL-datings, 0.7±0.2 ka and 1.8±0.3 ka, which also had been taken in layers from the backshore. This year’s preliminary OSL-datings from the bottom of J02 and J03 (Fig. 3) have suggested ages between 10 ka and 5 ka old.

5. Discussion

5.1. Interpretation of data

The beach system at Tönsneset can be interpreted as a berm-ridge after reviewing all of the available data. Based on the interpretation of GPR-profiles, it has been confirmed that the beach and accompanying berm-ridge at Tönsneset demonstrate a rather straightforward internal structure. The low seaward inclination of the bedding on the foreshore and the landward inclination of the bedding on the backshore, seen in the field and in GPR-profiles, argues for this wave-built supratidal landform (Otvos, 2000). This berm-ridge is currently interacting with the ocean and is migrating landwards, and through time will become a wave-constructed beach-ridge according to Otvos (2000). Although it has been proposed that berm-ridges have a smaller size (Otvos, 2000), the relatively large berm-ridge at Tönsneset must therefore be explained by the wave conditions that exist in Kongsfjorden today.

The occurrence of cobbles and small boulders on the beach surface and throughout the beach stratigraphy can be explained by high energy events as well as by the rivers, which bring coarser materials from a higher altitude down to the beach. Wind, which can act as an erosional factor, would have, in the situation where it was present and dominant, transported away sand from the beach surface to form dunes (Trenhaile, 2005). The mixture of sand and coarser particles at Tönsneset is evidence of a lack of eolian process acting upon the beach. The beach composition at Tönsneset can instead be explained by high energy wave events. Møller (1995) postulated that single storm events in northern Norway can deposit layers in the range of tenths of centimeters on the backshore. The prominent overwash layers on the backshore at Tönsneset confirm this conclusion.

Fluvial erosion is a significant process that can be found on the beach. It has a distinctive seasonal pattern, and the two existing rivers most probably erode through the ridge each spring or early summer after the ridge has gone through reconstruction and
Beach processes and recent sea-level changes at Tönsneset, Kongsfjorden, northwestern Spitsbergen.

Redeposition of sediment throughout the rest of the year. The rivers also, on the contrary, transport sediments into the area to some degree.

The roundness of the materials can be explained by the littoral environment in which they exist. Shore processes (wave action) can be attributed for this. Evidence of soil formation were also found on the coarser particles, which meant silt material accumulating on the side facing up for the coarse particle and carbonate precipitation on the side facing down (Forman & Miller, 1984).

5.2. Chronology

The age of the beach system can be constrained to late Holocene, with dates supporting this argument. The exact age at which the berm-ridge started to form is difficult to determine with the current available datings, although, a minimum age of 1.8 ka can be suggested.

5.3. Sea-level change and climatic conditions

The recent literature proposes beaches and beach systems as good markers of sea-level change, if the facies where wave deposited beach sediments and the wind deposited dune cap can be found (Otvos, 2000; Orford et al., 2003). Since no wind deposited sediments were observed at Tönsneset, it cannot be used as an indicator of sea-level change. This proposition is a little bit problematic however, since a former foreshore that is topped by a vegetated surface, indicated by the red line between the purple and the orange (fig. 6 a & b), is interpreted as being overridden by the overwash layers on the current berm-ridge at Tönsneset. This observation indicates a change in the sea-level in some form at Tönsneset.

Currents have vividly been discussed in scientific papers as a factor for berm-ridge and beach-ridge formation. Warm water conditions produced ice-free conditions in northern Svalbard and beach-ridges could form (Brückner et al., 2003). Storm activity and periods pronounced with storms have been argued to form berm-ridges and beach-ridges (Fletcher et al., 1993; Mason & Jordan, 1993; Møller, 1995; Møller et al., 2002). Tönsneset’s complete connection to storms is rather difficult to hypothesize, at least, from the results of this paper. Storms are most likely part of the formation of the Tönsneset berm-ridge, however.

To fully understand the changing beach system one needs to understand the processes active throughout the coastal zone (Dingler, 2005). Therefore, to be able to make further interpretations concerning the beach, additional measurements and understanding of the coastal zone would have been needed to make further inclinations.

5.4. Suggested future research

Future research should focus on other beaches in the area and witness what kind of similarities and non-similarities could be found. An importance would be to try to observe a larger number of beaches in the area in order to examine and compare the general characteristics spotted at Tönsneset.

Another important factor would be to monitor the beach at Tönsneset more closely, especially throughout the course of the year and follow storm events and direct consequences from them. Furthermore, it would be interesting to survey the spring and
early summer melting and the erosion on the ridge from the rivers, and the backwards migration (if there is one) of the current berm-ridge.

6. Conclusions

- The beach at Tönsneset, roughly encompassing a width of 100 m, length of 700 m, and height of 3.5 m, consists of a relatively simple structure with a backshore, foreshore, and some lagoons. It overlies a buried surface and has two rivers that cut through it.
- There is evidence suggesting that a transgression is occurring at Tönsneset. However, the evidence is not conclusive that Tönsneset can be used to support an ongoing transgression in the northwestern area of Spitsbergen. Other authors have, nonetheless, offered evidence of a transgression occurring.
- Tönsneset cannot be considered a representative transgression beach due to the fact that it cannot be postulated whether Tönsneset can be used as an indicator of a sea-level change.
- There is some evidence of the oceanographic conditions that prevail in the area. It is characterized by occasional storms which deposits sediments on the beach.
- The major processes acting upon the beach today involves the agents of waves and the erosion of two different rivers.

7. Acknowledgements

This study was a part of the SciencePub project (http://www.ngu.no/sciencepub). Field work was financed by grants from Svalbard Science Forum to Helena Alexanderson and Heidi Ryen. I would like to thank Heidi Ryen for assistance in the field and also for the help in trying to interpret the beach. I am indebted to my advisor Helena for all the different ways she helped me. I would also like to thank classmates and family for various assistance throughout the course of this bachelor’s thesis project.
8. References


Landvik, J.Y., Bondevik, S., Elverhøi, A., Fjeldskaar, W., Mangerud, J., Siegert, M.J., 
Salvigsen, O., Svendsen, J., Vorren, T.O., 1998: The Last Glacial Maximum of 
Svalbard and the Barents Sea area: ice sheet extent and configuration. 
*Quaternary Science Reviews*, 17, 43-75.

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, 

Lehman, S., & Forman, S.L., 1992: Late Weichselian Glacier Retreat in Kongsfjorden, 
West Spitsbergen, Svalbard. *Quaternary Research*, 37, 139-154.

Mason, O.K., Jordan, J.W., 1993: Heightened North Pacific Storminess during 
Synchronous Late Holocene Erosion of Northwest Alaska Beach Ridges. 
*Quaternary Research*, 40, 55-69.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, 
M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N., Pekar, S.F., 2005: The 

Møller, J.J., 1995: Sandy Beaches as records of changes in relative sea-level and storm 
frequency. In Finkl, C.W. Jnr, editor. Holocene cycles: climate, sea levels, and 
sedimentation, *Journal of Coastal Research* Special Issue, 17, 169-172.

Møller, J.J., Yevzerov, V.Y., Kolka, V.V., Corner, G.D., 2002: Holocene raised-
beaches ridges and sea-ice-pushed boulders on the Kola Peninsula, northwest 


Neal, A., 2004: Ground-penetrating radar and its use in sedimentology: principles, 

Peterson, G., 2008: The development and relative chronology of landforms at 
kvartärgeologi. Stockholms Universitet.

Otvos, E.G., 2000: Beach ridges—definitions and significance. *Geomorphology*, 32, 
83-108.

superimposed dunes in north-east Ireland: mechanisms and timescales of fine 
and coarse beach sediment decoupling and deposition. *Marine Geology*, 194, 
47-64.
Beach processes and recent sea-level changes at Tönsneset, Kongsfjorden, northwestern Spitsbergen.


