

Late Weichselian Periglacial Landforms in the Bjergsted area, north-western Zealand, Denmark

Hanne Hvidtfeldt Christiansen

Christiansen, Hanne Hvidtfeldt: Late Weichselian Periglacial Landforms in the Bjergsted area, north-western Zealand, Denmark. *Geografisk Tidsskrift* 93:39-48. Copenhagen 1993.

Detailed geomorphological investigations in the central part of the Bjergsted landsystem have revealed the existence of different Late Weichselian periglacial landelements.

A large alluvial cone, named the Bjergsted cone, with ice-wedge casts and sediment-structures indicating dead-ice melting has been investigated. Different methods, such as thermoluminescence (TL) dating and geographical information system (GIS) analysis, have been used in order to date and trace the source area of the sediment in the Bjergsted cone. Several dry valleys and niches caused by nivation as well as windpolished boulders have also been found in the Bjergsted area.

Keywords: *The Bjergsted area, Late-Glacial periglacial processes, GIS-modelling, TL-dating, ice-wedge casts, nivation niches, dry valleys, windpolish.*

Hanne Hvidtfeldt Christiansen, M.Sc. Ph.D. student, Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.

This paper presents various Late Weichselian (from about 15,000 BP) periglacial landforms which have been identified in the Bjergsted area, north-western Zealand, Denmark (Fig. 1). The investigation of the periglacial landforms is an important step in the development of a comprehensive deglaciation model for this area and essential for elucidating the climatic conditions during the Late-Glacial period in this part of Denmark.

As a basis for the examination, a detailed geomorphological investigation has been carried out on the evolution of the present landscape and consequently the glacial history of the regional area has been reconstructed.

THE BJERGSTED GLACIAL LANDSYSTEM

Located in the north-western part of Zealand in Denmark (Fig. 1), the Bjergsted landsystem is situated within an area surrounded by several other Late Weichselian terminal moraine systems, revealing the high number of glacial advances and readvances. The area of the Bjergsted landsystem is about 20 x 15 km². The glacial landsystem concept is defined (Christiansen, 1991) as the assembly of land units, all created during the same glacial advance in a given area.

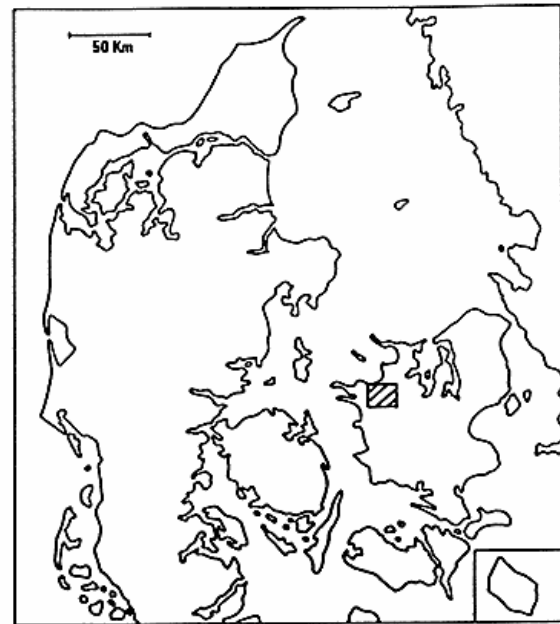


Fig. 1. Map showing the location of the Bjergsted area in the north-western part of Zealand, Denmark.

The completeness of the glacial Bjergsted landsystem is conspicuous. Nearly all the different land units that theoretically belong to a glacial landsystem exist. The preservation of the entire Bjergsted landsystem is primarily the result of no further ice advancing over the area since the Young Baltic Advance.

Three large-scale glacial land units occur; a central zone, a terminal zone and a proglacial sandur (Christiansen, 1991) as shown on Fig. 2. In the central zone subglacial erosion has been dominant. The subglacial origin of this zone is revealed by the presence of terrainstripes and some drumlin forms indicating regional iceflow from the east and northeast.

The terminal zone consists of; distinct push-moraine ridges, 30 to 40 metres high in the outer part, and kamehills, likewise rising 30 to 40 metres above the surrounding landscape in the inner part of this zone (Christiansen, 1991). The position of the terminal zone reflects the typical lobate outline (Fig. 2) of the lowland glacier that covered the area during the Young Baltic Advance. These moraine ridges were already in 1900 described as terminal moraine ridges by Rørdam & Milthers.

The morphology of the central and terminal zone reveals that the glacier was of a subpolar type. The glacier was frozen to the its bed in the terminal zone where the pushing of sediment occurred, and wet-based in the central zone as indicated by the presence of the subglacial landelements. The kamehills in the inner part of the ter-



Fig. 2. Regional presentation of the landsystem in the Bjergsted area. 1) The terminal zone consisting of small-scale composite, moraine ridges in the outer part, and kamehills in the inner part. 2) The central subglacially dominated zone with terrain stripes and some drumlins, whose directions are marked by lines indi-

cating the direction of iceflow. 3) The outer proglacial zone built of sandur sediment. The lines between the different zones are dashed in areas where the delimitation is not directly morphologically based but hypothetical. The position of fig. 3 is framed. Equidistance 5 m.

minal zone indicate that, in the terminal part, the glacier must have been covered by debris, leading to areal deglaciation, while deglaciation was frontal in the central area.

In front of the terminal zone, a proglacial sandur was built up.

THE PERIGLACIAL LANDFORMS IN THE BJERGSTED AREA

In the Bjergsted area, various landforms and sedimentary structures indicate a former periglacial environment. These comprise; a large alluvial cone, dry valleys, wind-polished boulders and nivation niches. They are found to have been developed primarily during the early deglaciation period in Late-Glacial time, when the climate was still characterized by short cold periods, such as the Late Dryas and especially the Younger Dryas. All the periglacial landforms of the landscape have been eroded into or been superimposed onto the glacial landforms.

THE BJERGSTED ALLUVIAL CONE

The largest single landform created during the deglaciation of the area is the Bjergsted alluvial cone. On Fig. 3, the cone, which is approximately 2.5 km², is shown. The cone is situated in the most proximal position on the sandur directly towards the terminal moraine system.

Sedimentology and stratigraphy

Investigations of the sedimentology and stratigraphy of the cone sediment in a large gravel pit, Bjergsted Sten- og Grusgrav (Figs. 3 & 4), where the thickness of the cone varied from 6 to 10 m, showed a cyclical deposition of alternating layers of sand with thicknesses from 10-20 cm, and fine-grained sediments of silt and clay only about 1-6 cm thick (Fig. 5). In the massive sandlayers, no sediment structures were found, while in the fine-grained silt and claylayers a pronounced horizontal stratification was present. The sandlayers were continuous within the gravel



Fig. 3. Map showing the Late Weichselian periglacial landforms and landelements developed in the centre of the Bjergsted area at the Bjergsted cone. South of the Bjergsted cone the rests of the outline of a less distinct cone, called the Stenrand cone, is delimited by a dashed line. The recent drainage areas connected to the

Bjergsted cone and to the Stenrand cone are also shown. Dry valleys are shown by arrows on the eastern side of the Bregninge å-dal. The last shallow stream channels developed on the cones are also shown by arrows. The position of fig. 7 is framed. Equidistance 2.5 m.



Fig. 4. The general stratigraphy of the gravel pit, Bjergsted Stenog Grusgrav. Distinctly stratified cone sediment overlies hetero-

geneous sandur sediment. The height of the section is about 25 m. September 1991.

pit, whereas the fine-grained layers were not horizontally continuous for more than a few metres at any stratigraphic level.

The deposition of the cone is assumed to have been going on in the beginning of the deglaciation period, partly controlled by meteorologically conditioned events. During periods of high sheet-like runoff all over the cone, the sand layers were deposited. The high energy situations, when sand layer deposition took place, are perceived as reflecting spring snowmelt or heavy rainstorm events during summer. In contrast to this, the fine-grained sediment layers show deposition in small basins on the cone during more quiet periods between the events, hereby indicating low energy depositional environments primarily occurring during summer periods, with only normal melting of ice in the sediment source area.

GIS analysis of sediment source area

An estimation of the volume of the Bjergsted cone was performed by the use of a GIS, OSU-MAP version 3.0 (1989).

It was possible, by use of the OSU-MAP, to reconstruct

the bottom layer of the cone based on a relatively large number of water drillings in the area and on the investigations carried out in the gravel pit. The recent terrain surface of the cone was digitized and a topographical 3-D model was made. By making a subtraction between the terrain surface and the bottom layer of the cone in OSU-MAP, the volume of the Bjergsted cone was computed to be about 22 mill m^3 .

The cone must have been built up from the summit close to the terminal moraine system, but not by normal glacio-fluvial deposition, as there is a clear limit to the underlying sandur sediment which is much more heterogenous than the cone sediment (Fig. 4).

By calculation it can be demonstrated that if the cone-sediment should have been coming exclusively from the recent drainage areas (Fig. 3), more than 4 metres of sediment should have been eroded from all that area; a number hardly probable. Therefore the Late-Glacial drainage area must have been larger than the present one, a situation supposedly made possible as dead-ice at that time made up most of the surface of the terrain behind the terminal moraine ridges. In this way sediment from a

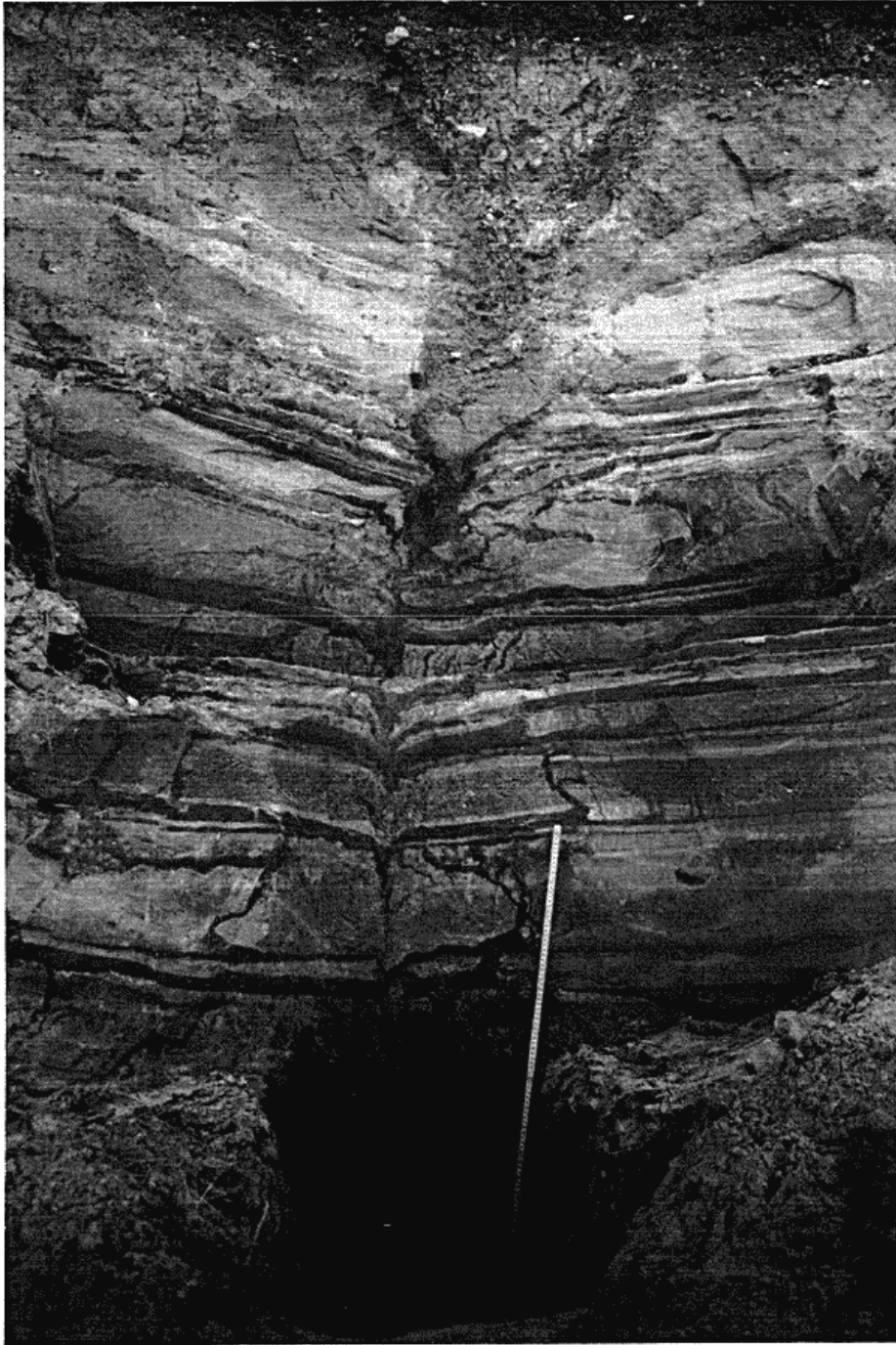


Fig. 5. Sedimentological log showing lithology and primary sedimentary structures from the western part of the gravel pit, Bjergsted Sten- og Grusgrav. On the log, the positions of samples taken for TL-dating and grainsize analysis are marked.

larger area could be transported out onto the sandur and deposited as a cone until the dead-ice in the terminal zone slowly disintegrated so much that the surface level of the dead-ice was lowered more than the apex of the cone.

In this way, the quantification of the cone sediment indirectly gave important information on the palaeoenvironment at the time when the cone was deposited.

Thermoluminescence dating of the Bjergsted cone

In order to attempt a dating of the Bjergsted cone, and to obtain information on the length of the deposition period, the thermoluminescence (TL) dating technique was used. As deposition presumably took place in shallow water, and as previous TL-dating of Late-Glacial glaciofluvial sediment deposited during the Younger Dryas period has been successful (Mejdahl, 1991), the TL method was assumed usable. Lack of organic material in the cone sediment excluded the C^{14} dating method.

With the TL dating method it is possible to date when sediment was exposed to light or last heated to more than 500 °C. The fine- to medium-grained sandlayers in the cone sediment were assumed to have been transported several kilometres; a distance long enough for the sediment to have received enough light to be zeroed satisfactorily. Three samples for TL-dating were taken from sandlayers; in the bottom, in the middle and in the top of the cone sediment, to see, simultaneously, whether it was possible to obtain information on the deposition rate using this technique.

TL-dating was undertaken by the author at the Nordic Laboratory for Luminescence Dating at the Risø Research-centre, Denmark. The work with the TL technique showed that it was impossible to date the cone sediment because of a lack in the admission of light to the sediment during deposition. The main reason why the sediment was not zeroed sufficiently during deposition of the sandlayers in the cone is most likely due to very high current velocities and high sediment concentrations combined with a relatively short subaerial transport distance.

Dead-ice sediment structures and ice-wedge casts

After the deposition of the Bjergsted cone ceased, periglacial conditions were still present in the area for some time. This is revealed by secondary sediment structures found in the cone sediment in the gravel pit.

Three well-marked, ice-wedge casts varying in depth from 3 to 5 m, with widths from 70 to 110 cm at the top and from 0,5 to 6 cm in the deeper parts, were found, see Fig. 6. The surrounding sediment was bent upwards along the wide upper parts of the wedges, and downwards around the narrow lower parts. This morphology of the wedges and the surrounding sediment is the basis for the

interpretation of the genesis of the wedges to be bi-lateral. The lower narrow parts are presumably syngenetic real ice-wedge casts, secondarily filled with the surrounding cone sediment, while the upper wider parts of the wedges are thought to be epigenetic soil-wedges, primarily filled with the superjacent cone sediment.

A 8-10 m long syncline was found in the cone sediment and it continued 1 m down into the underlying coarse-grained, sandur sediment in the gravel pit. Along the edges of the syncline in the cone sediment, normal and reverse faults existed and the syncline was filled up with a non-disturbed, top layer. These facts indicate that the structure must have resulted from dead-ice melting after the cone was deposited, just as it shows that a larger body of ice was transported out onto the proglacial sandur area, probably by a jökelhlaup event, before cone deposition started. As this body of ice did not melt until the cone was deposited, periglacial conditions have existed from the very early deglaciation of the area when sandur deposition ceased. Finally, on top of the syncline, a more heterogeneous sediment with stones was deposited which partly levelled the terrain surface, probably due to solifluction processes, but it is also possible that farming activity can have contributed to the levelling too.

On the sandur surface outside the Bjergsted cone another large circular depression about 200 m in diameter and 5-7 m deep can be seen. This form has been likewise interpreted as originating from dead-ice melting, showing that this process was normal in the area.

At the same time a dead-ice covered area existed in the terminal zone of the Bjergsted landsystem and kamehills were deposited. In this area, material from the Allerød period has been identified, proving the existence of dead-ice at least until the end of this period (Milthers, 1943).

The genesis of the Bjergsted cone

When combining the results of the investigations made on the Bjergsted cone, it is possible to reconstruct the genesis of this periglacial landform in a detailed way.

The deposition of the cone reflects the very early changes in the condition of the glacier at the absolute beginning of the deglaciation period. Deposition presumably started just after the sandur deposition finished and lasted for about 50 to 100 years, estimated from the existing number of layers, when assuming that the deposition of one sandlayer and one fine-grained layer lasted maximally one year. The absence of light during the deposition of the cone sediment proves that the sandlayers were deposited quickly, probably by water with high sediment concentration. Using the luminescence dating technique also proves that the cone-sediment had not been eroded from a light-exposed surface.

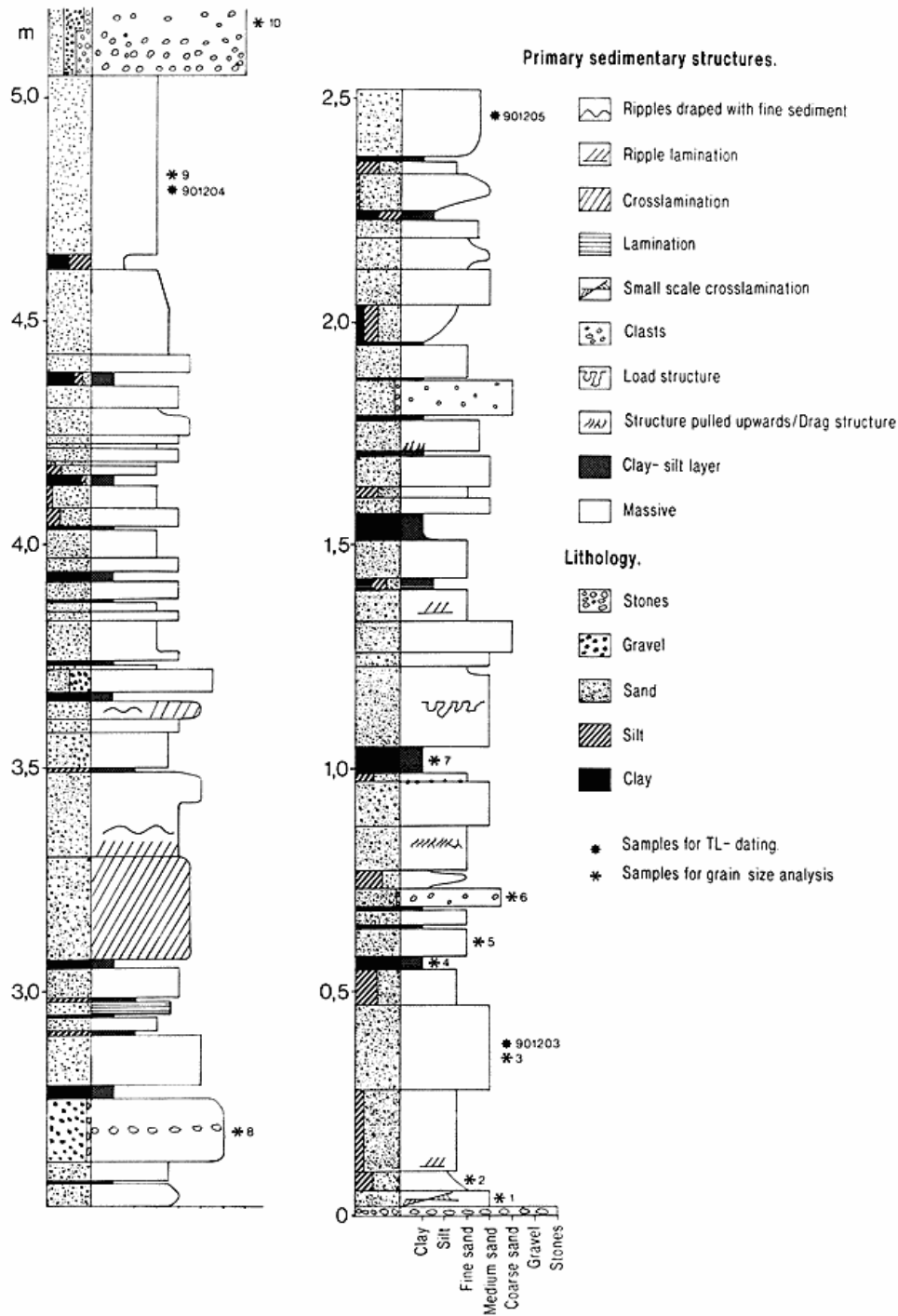


Fig. 6. Ice-wedge cast from the gravel pit, Bjergsted Sten- og Grusgrav. The excavated part of the wedge is 380 cm, and the ruler is about 150 cm long. September 1991.

These facts lead to the conclusion that the cone must be the result of englacial, and to some extent also subglacial, meltwater activity, originating from dead-ice melting in the marginal part of the glacier. As the meltwater did not leave any morphological sign on the present terrain surface, englacial meltwater dominated. This emanation of dead-ice meltwater was meteorologically influenced not only by events such as rainstorms, and enormous snowmelt in spring, but also by normal melting of dead-ice during the summertime, making the deposition of the very distinct layers in the cone possible. The conditions show that the very early melting of dead-ice took place from a rather coherent glacier, and that the entire drainage system in the glacier had broken down at that time, making only processes in the marginal part of the glacier crucial for the production of meltwater and transport of sediment to the cone. The deposition of cone sediment ceased as the dead-ice disintegrated too much for a large area to drain as far as to the cone area.

As there is a clear indication of continuing periglacial conditions until the cone was deposited, the build-up of the cone must have been going on in the very early local deglaciation period in the Late-Glacial period before the Bølling warm period started about 13,000 years BP. The local deglaciation in the Bjergsted area is thought to have started just before 14,000 years BP, according to a magneto-stratigraphical dating of a glacio-lacustrine deposit in the neighbouring Røsnæs terminal moraine system giving the age to be 14,100 years BP (Brehmer, 1990). This deposit is indirectly connected to the deglaciation from the Røsnæs line, that started slightly after the deglaciation of the Bjergsted landsystem (Christiansen, 1991).

DRY VALLEYS

A flat-bottomed extra-marginal meandering valley, Bregninge å-dal (Fig. 3) has been eroded from 2 to 20 m down into the proglacial sandur. In the outer part of the former river curvatures, where the slopes of the valley are particularly well developed, inclinations vary from 15° to 25°. Along the sides of the Bregninge å-dal, fluvially-shaped, small, dry valleys are found, see Fig. 3. They vary in length from 50 to 400 m and in width from 20 to 60 m, all cut into the east side of the valley, where the sandur surface above is inclined towards the extra-marginal valley.

There are no signs of deposition of sediment in front of the dry valleys in Bregninge å-dal, indicating that Bregninge å-dal must have been active later than or simultaneously with the development of the dry valleys.

The dry valleys probably formed by backward erosion in the sandur (Krüger, 1985), particularly during the snow-melting period in spring. On the sandur surface, the fossil glacio-fluvial braided stream courses were used for snow

meltwater to run off and erode the dry valleys, which therefore indicates that the otherwise well-drained, coarse-grained sandur sediment must have been frozen at that time. Whether the development of the dry valleys is an indication of the presence of permafrost, or a seasonal freezing layer of the ground, is not known.

WINDACTION

In the early descriptions in connection with the first geological mapping of the Bjergsted area, Rørdam & Milthers (1900) describe a dense sprinkling of large blocks all over the highest and most well-developed moraine ridges at Bjergsted. This sprinkling had impeded cultivation in most parts of the highest moraine ridges at that time (Rørdam & Milthers, 1900).

Today, most of the terminal moraine ridges are overgrown by very dense scrub vegetation, not allowing a closer investigation of these areas. However, in a smaller area (300 m x 500 m), the vegetation has been felled and burned down. Here the moraine ridges are sprinkled by outstandingly large stones and boulders on slopes exposed towards the east, while on the slopes exposed towards the west only a few stones, nearly covered by sediment can be seen.

This asymmetrical distribution of stones can result from the time when the ridges were pushed up by the glacier, and reflect that the side of the ridges with contact to the glacier did receive stones from the glacier surface during a longer period. But it is also possible that the stones exposed towards the west have been buried by sediment transported by wind from the east side to the west side of the ridges.

An investigation of the possible remnants of windpolish showed the existence of ventifacts on some of the stones and boulders on the top and upper parts of the eastern side of a ridge, which was investigated in detail. On 4-5 boulders clear windpolish was found in the form of facets, and microforms such as grooves and furrows see Fig. 7, indicating a palaeowind direction from about 90° to 110°. This means that the prevailing wind was from the east as opposed to the western winds of the Holocene in the same area. However, some variation does occur and a few forms indicate more north-easterly (45° and 75°) palaeowind directions, probably the result of topographic controls on local winds. An overall regional easterly palaeowind direction could originate from katabatic winds falling down from the glacier, which in the early deglaciation period was still present immediately east of the moraine ridges in the central zone of the Bjergsted landsystem. A dominance of easterly palaeowind directions during the deglaciation period has been likewise demonstrated in the southern parts of Sweden (Svensson, 1992). In northeast-



Fig. 7. Part of a windpolished boulder found on the eastern side of the investigated terminal moraine ridge near the top. Facets made by windabrasion by drifting snow or sandgrains can be seen. The match, 5 cm long, indicates the palaeowind direction.

ern Jutland, Jørgensen (1988) has registered palaeowind directions from the east as indicated by facets on stones on deflation surfaces covered by aeolian sediment, with an age of 17,000 +/- 2,000 BP and 18,000 +/- 2000 BP determined by TL-dating. Jørgensen (1988) concludes that the easterly palaeowind direction is from the period before the ice advanced to the Main Stationary Line in Jutland, supporting the hypothesis that easterly wind directions can be expected along the southern part of the Scandinavian ice cap.

In order to estimate the applicability of the scattered observations of windpolish, it must be emphasized that frost shattering must have clearly removed pre-existing windpolish in large parts of the examined boulders, as was shown by the missing, frost shattered parts of the examined boulders. Former, much more widespread windpolish was most likely once present on the boulders, but extensive frost shattering and, in all probability, chemical

On the vertical part of the boulder, and in two parts on the top, frost shattering and plucking, has evidently interrupted the otherwise rather complete windpolish on the boulder surface. October 1992.

weathering, eroded a large part of the windpolished areas. Chemical weathering probably had a pronounced effect, particularly during the long Holocene period when the moraine ridges were covered by vegetation.

SNOWPATCHES AND NIVATION NICHES

On the north-western outer side of the moraine ridges, some niches as large as 75 metres in diameter and several meters deep, have been eroded into the moraine ridges, as can be seen on Fig. 8.

These niches are interpreted as having been created in the Late-Glacial period by nivation caused by snowdrift from the east, because the prevailing wind came from that direction, as argued above. The drifting snow was deposited at the very top of the lee side of the moraine ridges as large snowpatches, making possible the existence of large perennial snowpatches. This position of the niches at the top of the moraine ridges strongly supports their origin

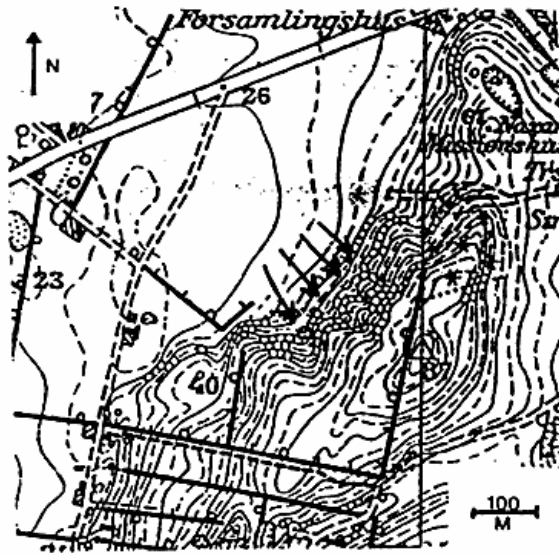


Fig. 8. Map showing the steepest front of one of the terminal moraine ridges and the most proximal part of the Bjergsted cone. The arrows indicate the position of the niches made by nivation processes.

being caused by nivation and excludes springs or slides as the geomorphologically responsible processes.

Some of the snowpatches, especially those on the north-western side of the moraine ridges, were probably perennial. Nivation processes (Thorn, 1988) at and around snowpatches are assumed to have formed niches. Such niches have also been called nivation hollows (Rapp, 1984). The preferred north-western orientation of the niches on the lee-side slopes of the moraine ridge most probably was caused by the favoured shady position of this area. Preliminary computing of the areas that have had the best possibilities of experiencing the longest periods with shadow on a yearly basis showed that exactly the north-western slopes of the moraine ridges were most favoured (Christiansen, 1991).

PERSPECTIVES

The presentation of periglacial landelements existing in the Bjergsted area clearly stresses the importance of highlighting and understanding the periglacial processes of the Late-Glacial palaeoenvironment and climate when interpreting the geomorphological evolution of the landscape. The results of the geomorphological investigation of the Bjergsted landsystem obviously indicate that periglacial processes were able to modify the glacial landscape in certain places.

The next step in the development of the deglaciation model for the Bjergsted landsystem will be an attempted

determination of the melting rates of the dead-ice by reconstructing the depositional rates of the kame-hills. By the use of a stereo model technique on a pair of aerial photographs from the nivation niches, future investigations on the quantification of the nivation processes will be implemented and combined with luminescence dating of sediment deposited by nivation processes.

ACKNOWLEDGEMENTS

Financial support to the field investigations was given by the Institute of Geography, University of Copenhagen. The Nordic Laboratory for Luminescence dating, Risø Research Centre has also provided financial support by letting me undertake the dating at their laboratory, and giving me good instruction in the dating procedure. I am also very grateful to my colleagues; O. Humlum and H. Svensson, for helping with the field-work and for inspiring discussions on periglacial geomorphology.

References

- Brehmer, A.C. (1990): En sedimentologisk og geokemisk undersøgelse samt magnetostratigrafisk datering af en sen Mellem-Weichsel issøaflejring i Istedbjerg lergrav, NV-Sjælland. Dansk Geologisk Forening, Årsskrift for 1987-89, 49-54.
- Christiansen, H.H. (1991): Senglacielandskabsudvikling i et randmoræne-hedeslette miljø ved Bjergsted Bakker og Bregninge Hedeslette i Vestsjælland. Unpub. master thesis, Institute of Geography, University of Copenhagen, 144 p.
- Jørgensen, M. (1988): TL-dated Weichselian deflation surfaces from Northern Jutland, Denmark. Norsk Geografisk Tidsskrift, Vol. 42, 225-229.
- Krüger, J. (1985): Bemærkninger om dal-dannelser i smeltevandsterrasser med eksempler fra Island og Danmark. Dansk Geologisk Forening, Årsskrift for 1984, 7-13.
- Mejdahl, V. (1991): Thermoluminescence dating of Late-Glacial sand sediments. Nuclear Tracks and Radiation Measurements, Vol. 18, 71-75.
- Milthers, V. (1943): Nordvestsjællands Geologi. Danmarks Geologiske Undersøgelse, 5. Rk., No. 6, 185 p.
- OSU-MAP-for-the-PC (1989): OSU-MAP-for-the-PC ver. 3.0 User's Guide. GIS Lab. Dept. of Geography, Ohio State University, Columbus, Ohio, USA.
- Rapp, A. (1984): Nivation hollows and glacial cirques in Södera-sen, Scania, southern Sweden. Geografiska Annaler, Vol. 66A, No. 1-2, 11-28.
- Rørdam, K. & Milthers, V. (1900): Beskrivelse til Geologisk Kort over Danmark. Kortbladene Sejro, Nykjøbing, Kalundborg og Holbæk. Danmarks Geologiske Undersøgelse, 1. Rk., No. 8, 143 p.
- Svensson, H. (1992): Wind-Blasted Erratics in Southern Sweden. In Billwitz, K.; Jäger, K.-D. & Janke, W. (eds.) Jungquartäre Landschaftsräume, 105-109, Springer-Verlag.
- Thorn, C.E. (1988): Nivation: A Geomorphic Chimera, in Clark M. J. (ed.) Advances in Periglacial Geomorphology, 3-31, John Wiley, Chichester, England.

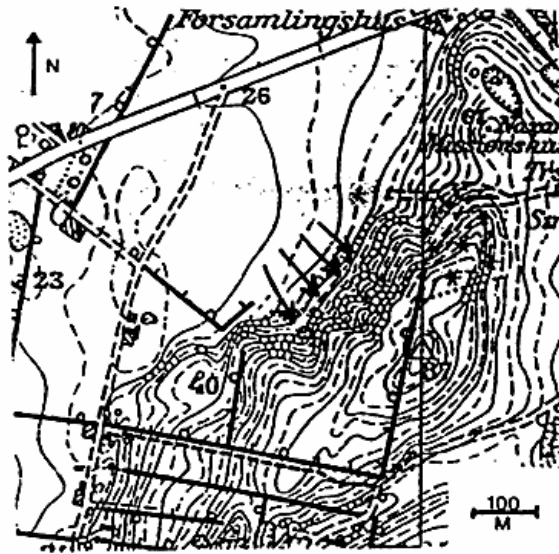


Fig. 8. Map showing the steepest front of one of the terminal moraine ridges and the most proximal part of the Bjergsted cone. The arrows indicate the position of the niches made by nivation processes.

being caused by nivation and excludes springs or slides as the geomorphologically responsible processes.

Some of the snowpatches, especially those on the north-western side of the moraine ridges, were probably perennial. Nivation processes (Thorn, 1988) at and around snowpatches are assumed to have formed niches. Such niches have also been called nivation hollows (Rapp, 1984). The preferred north-western orientation of the niches on the lee-side slopes of the moraine ridge most probably was caused by the favoured shady position of this area. Preliminary computing of the areas that have had the best possibilities of experiencing the longest periods with shadow on a yearly basis showed that exactly the north-western slopes of the moraine ridges were most favoured (Christiansen, 1991).

PERSPECTIVES

The presentation of periglacial landelements existing in the Bjergsted area clearly stresses the importance of highlighting and understanding the periglacial processes of the Late-Glacial palaeoenvironment and climate when interpreting the geomorphological evolution of the landscape. The results of the geomorphological investigation of the Bjergsted landsystem obviously indicate that periglacial processes were able to modify the glacial landscape in certain places.

The next step in the development of the deglaciation model for the Bjergsted landsystem will be an attempted

determination of the melting rates of the dead-ice by reconstructing the depositional rates of the kame-hills. By the use of a stereo model technique on a pair of aerial photographs from the nivation niches, future investigations on the quantification of the nivation processes will be implemented and combined with luminescence dating of sediment deposited by nivation processes.

ACKNOWLEDGEMENTS

Financial support to the field investigations was given by the Institute of Geography, University of Copenhagen. The Nordic Laboratory for Luminescence dating, Risø Research Centre has also provided financial support by letting me undertake the dating at their laboratory, and giving me good instruction in the dating procedure. I am also very grateful to my colleagues; O. Humlum and H. Svensson, for helping with the field-work and for inspiring discussions on periglacial geomorphology.

References

- Brehmer, A.C. (1990): En sedimentologisk og geokemisk undersøgelse samt magnetostratigrafisk datering af en sen Mellem-Weichsel issøaflejring i Istedbjerg lergrav, NV-Sjælland. Dansk Geologisk Forening, Årsskrift for 1987-89, 49-54.
- Christiansen, H.H. (1991): Senglacielandskabsudvikling i et randmoræne-hedeslette miljø ved Bjergsted Bakker og Bregninge Hedeslette i Vestsjælland. Unpub. master thesis, Institute of Geography, University of Copenhagen, 144 p.
- Jørgensen, M. (1988): TL-dated Weichselian deflation surfaces from Northern Jutland, Denmark. Norsk Geografisk Tidsskrift, Vol. 42, 225-229.
- Krüger, J. (1985): Bemærkninger om dal-dannelser i smeltevandsterrasser med eksempler fra Island og Danmark. Dansk Geologisk Forening, Årsskrift for 1984, 7-13.
- Mejdahl, V. (1991): Thermoluminescence dating of Late-Glacial sand sediments. Nuclear Tracks and Radiation Measurements, Vol. 18, 71-75.
- Milthers, V. (1943): Nordvestsjællands Geologi. Danmarks Geologiske Undersøgelse, 5. Rk., No. 6, 185 p.
- OSU-MAP-for-the-PC (1989): OSU-MAP-for-the-PC ver. 3.0 User's Guide. GIS Lab. Dept. of Geography, Ohio State University, Columbus, Ohio, USA.
- Rapp, A. (1984): Nivation hollows and glacial cirques in Söderåsen, Scania, southern Sweden. Geografiska Annaler, Vol. 66A, No. 1-2, 11-28.
- Rørdam, K. & Milthers, V. (1900): Beskrivelse til Geologisk Kort over Danmark. Kortbladene Sejro, Nykjøbing, Kalundborg og Holbæk. Danmarks Geologiske Undersøgelse, 1. Rk., No. 8, 143 p.
- Svensson, H. (1992): Wind-Blasted Erratics in Southern Sweden. In Billwitz, K.; Jäger, K.-D. & Janke, W. (eds.) Jungquartäre Landschaftsräume, 105-109, Springer-Verlag.
- Thorn, C.E. (1988): Nivation: A Geomorphic Chimera, in Clark M. J. (ed.) Advances in Periglacial Geomorphology, 3-31, John Wiley, Chichester, England.