Landslides and relict ice margin landforms in Adventdalen, central Spitsbergen, Svalbard

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Sawagaki, T. & Koaze, T. 1996: Landslides and relict ice margin landforms in Adventdalen, central Spitsbergen, Svalbard. *Polar Research 15(2)*, 139–152.

Two characteristic landforms, landslide blocks and drainage channels, were investigated in Adventdalen, central Spitsbergen. The landslides in the middle reaches of Adventdalen comprise large-scale bedrock slumps which form a hummocky surface on the south slope of Arctowskifjellet. The fourteen recognised landslide blocks are divided into upper and lower sections, according to altitude. The drainage channels consist of tributary rivers to Adventelva which flow in two distinct directions, either parallel with or oblique to the direction of the main river. Glacial deposits were found to cover the ridges between these tributary channels. The upper and lower landslide divisions may indicate former positions of the ice surface, and the channels appear to have originated during the existence of lateral moraine ridges with high ice content. These geomorphological findings have allowed reconstruction of former ice marginal positions, and they strongly suggest the existence of stagnant ice or minor re-advance phases during the course of deglaciation in Adventdalen.

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Introduction

In the large valleys of central Spitsbergen, such as Adventdalen, Reindalen and Sassendalen, distinct moraines delineating the pattern of deglaciation have not previously been recognised except for a complex series of moraines outside of the mouth of Isfjorden (Ohta 1982; Mangerud et al. 1992). Additionally, it has been stated that Younger Dryas moraines seem to be completely absent in Svalbard (Salvigsen 1979) and that the ice dissipated rapidly in the warming climate of the early Holocene age (Feyling-Hanssen 1955, 1965; Forman 1989; Mangerud et al. 1992). As most of the studies on the Quaternary glaciation in Svalbard are based on research along the coastal areas, where glacial till and uplifted former shorelines are easily found (e.g. Boulton 1979; Troitsky et al. 1979; Mangerud et al. 1987; Forman 1989; Miller et al. 1989; Mangerud & Svendsen 1990; Salvigsen et al. 1981; Mangerud et al. 1992), the Quaternary history of the inland area is less well understood. It is difficult to find thick glacial till layers due partly to the possible presence of former cold-based, non-scouring ice. In addition, the lack of historical record of glacial fluctuations and absolute ages for moraines and glacial deposits have prevented studies in the inland area up to now.

The Japanese Geomorphological Expedition to Svalbard carried out field work in 1988 and 1989 (Ono et al. 1991) and was followed by the Japanese Svalbard Expedition in 1990. As part of the latter expedition, a geomorphological study was carried out in August 1990 and in the period of June–August 1991 to identify the geomorphological evidence for glacial fluctuations in Adventdalen, an inland area of central Spitsbergen. The investigated area is situated between the ice margin of Drønbreen and the junction of Foxdalen and Adventdalen.

Two characteristic landforms, landslides and drainage channels were investigated. The causes and times of failure for the landslides were evaluated. Regarding the drainage channels, this study shows how the distribution of till and channels allow reconstruction of the former ice margin landforms in the Adventdalen area.

As large-scale topographic maps suitable for the purpose of this study are not available, two basic maps on the scale of 1:10,000 and 1:25,000 with a contour interval of 10 m were drawn, using

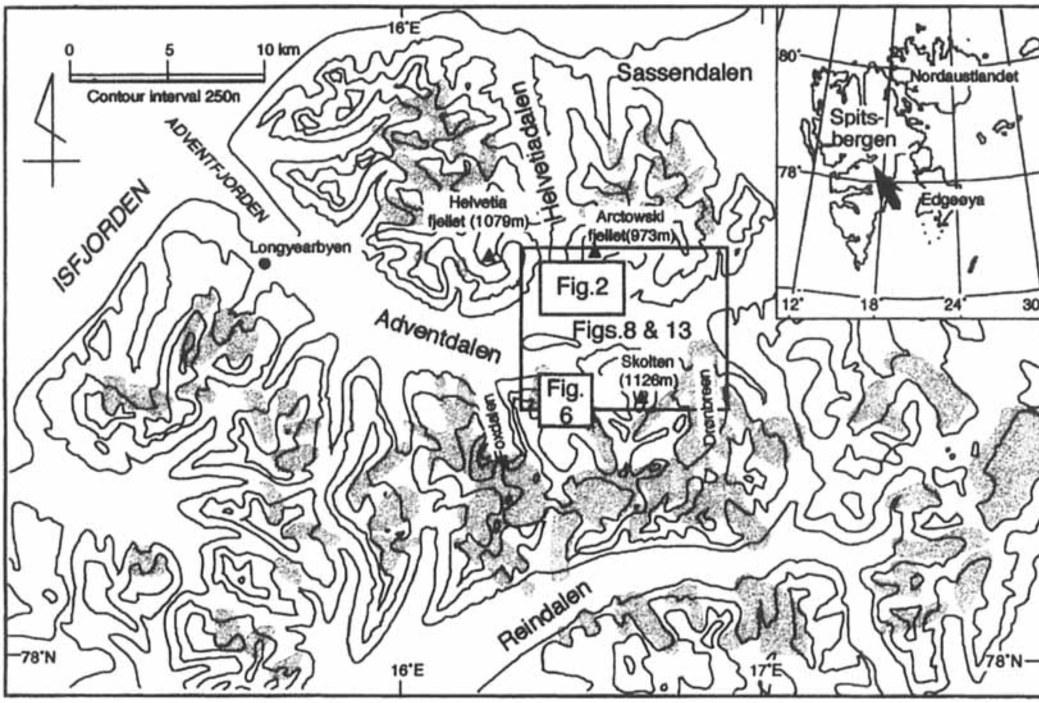

Fig. 1. Location map of Adventdalen, Spitsbergen. Present glaciers are shaded. Inner squares indicate the sites of Figs. 2, 6, 8 and 13.

the Analytical Photogrammetric System (Wild Aviolyt BC 2) of the National Institute of Polar Research, Japan. Data on morphometry were obtained by interpretation of air photographs in the scale of 1:15,000 taken by the Norwegian Polar Institute in August 1990.

The study area

Adventdalen is an ESE–WNW trending glacial valley which terminates in Adventfjorden, a tributary to Isfjorden, central Spitsbergen, Svalbard (Fig. 1). The valley is approximately 45 km long and 4 km wide. The upper reaches of the valley are connected with Sassendalen to the northeast and Reindalen to the south through low passes at altitudes of about 400 m a.s.l., forming a network of interconnected valleys. The valley is surrounded by ice-capped mountains ranging in altitude from 1000 to 1100 m. The highest summit is that of Mt. Skolten (1128 m). Drønbreen, the largest glacier, occupies the valley head, and other small glaciers terminate in the tributary valleys.

Adventelva, the main stream of this valley, drains westward from Drønbreen into Adventfjorden. It has formed braided channels and an outwash plain in front of Drønbreen. From the upper reaches to the middle reaches of the valley, the river has dissected Late Quaternary sediments and the underlying Jurassic shale bedrock to form terraces about 10 m high which dominate the valley bottom. In the lower reaches of the river, the stream spreads out to form complicated braided channels. In the investigated area, three large tributaries in Helvetiadalen, Janssondalen and Foxdalen flow into Adventelva. Wide alluvial fans have formed at their confluent points.

Polygons of various sizes have developed both on river terraces along Adventelva and on the hill slopes. Ice wedges were found beneath some of the polygons (Svensson 1988; Ono et al. 1991) and some pingos were present on the riverbed. Few direct measurements of the permafrost thickness have been made in this area. According to the measurements reported by Liestøl (1975),

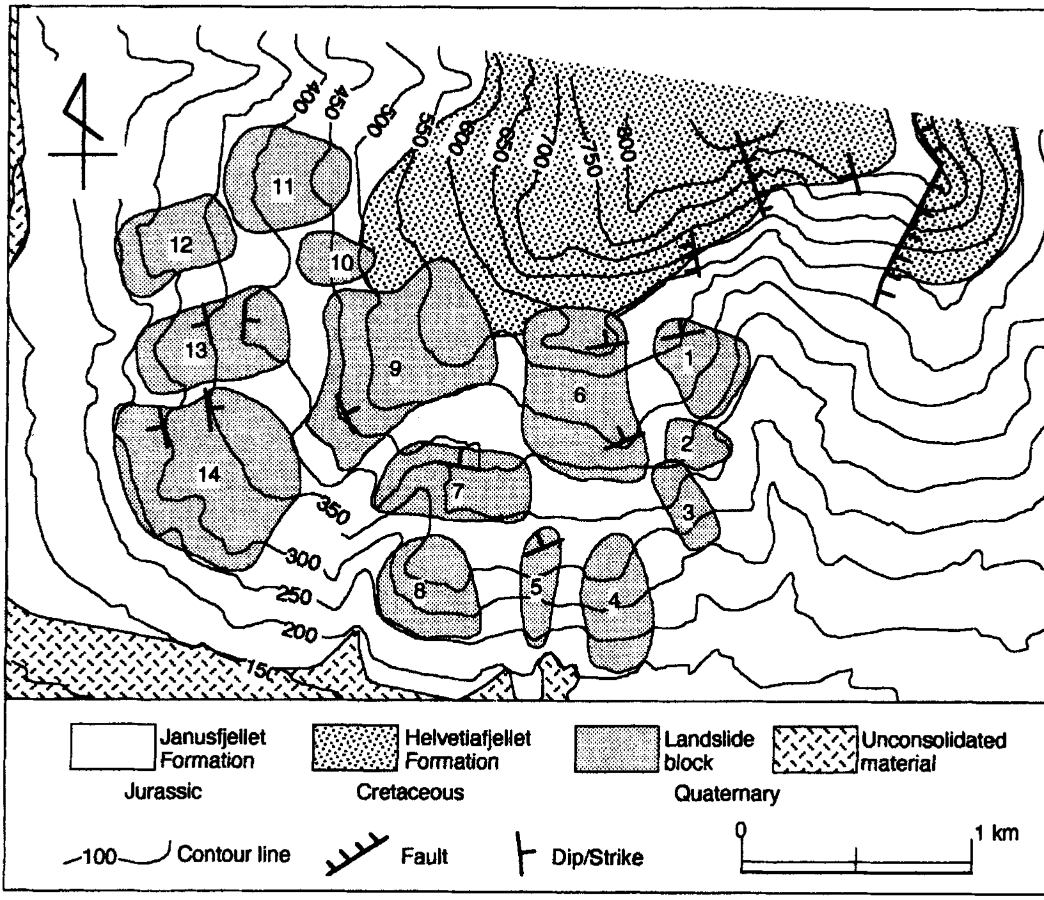

Fig. 2. Distribution of the landslide blocks on the southern slope of Arctowskifjellet (cf. Fig. 1).

the permafrost thickness on the southern side of Adventdalen was 450 m. In summer, a seasonal thawed layer 40–100 cm thick was observed, and the active layer saturated by water collapsed in many places on the valley slopes. As this type of failure is limited to the surface, it is not discussed in this article.

The bedrock geology of Adventdalen is shown on a 1:100,000 map (Major & Nagy 1972). A major part of the investigated area is underlain by Jurassic and Cretaceous sedimentary rocks which dip gently towards the southwest. Progressively older rocks are exposed from south to north. These deposits are lithologically divided into the Janusfjellet, Helvetiafjellet and Carolinefjellet Formations in ascending order.

The Janusfjellet Formation consists predominantly of dark-gray shale and siltstone. The Helvetiafjellet Formation consists of a lower Festningen Member and an upper Glitrefjellet Member (Parker 1967). The Festningen Member is a light-gray, fine- to coarse-grained sandstone forming distinctive cliffs. The Glitrefjellet Member is a medium- to coarse-grained sandstone interbedded with shale and siltstone. The Carolinefjellet Formation consists of shallow marine sediments with alternating beds of sandstone and shale (Major & Nagy 1972).

The most characteristic structures in the studied area are two north-south trending anticlines, the Skolten Anticline and the Tronfjellet Anticline, which are separated by Drønbreen Syncline (Major & Nagy 1972; Haremo et al. 1990). The Skolten Anticline in this area has a trend of about N160°E and a plunge of less than 5°SSE (Haremo et al. 1990, fig. 6). In a river section along

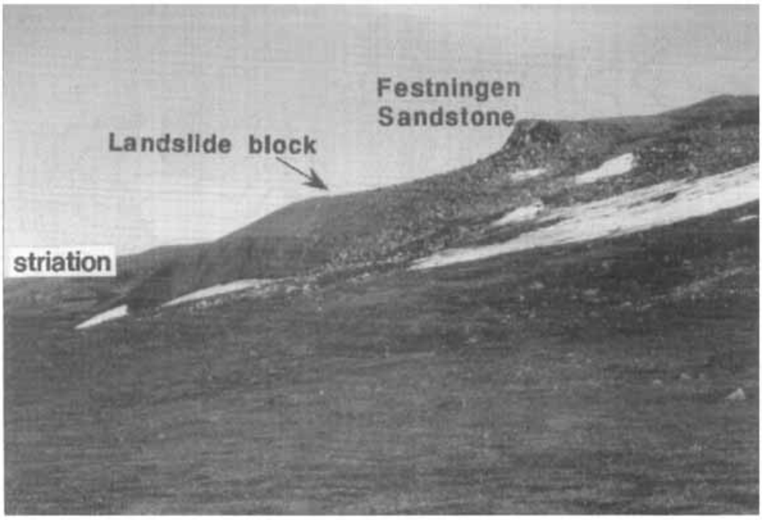

Fig. 3. Landslide block location (No. 14) on the west of Arctowskifjellet.

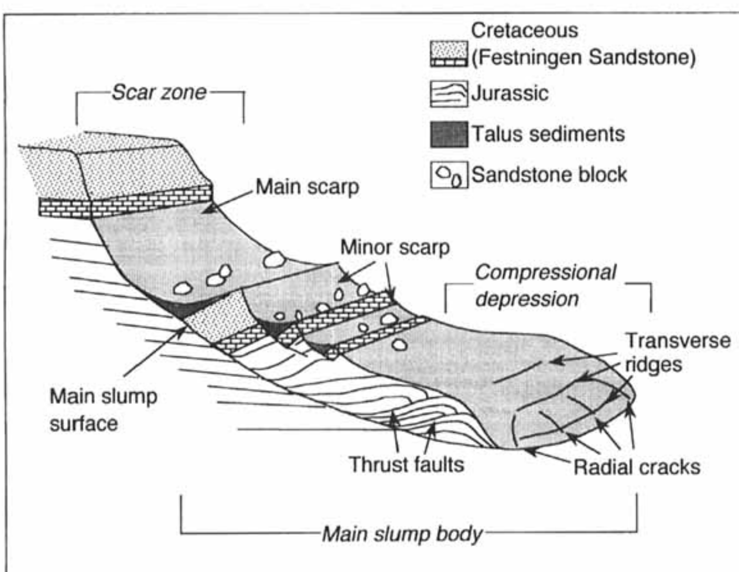

Fig. 4. Idealised sketch of the internal structure and features of the landslide blocks.

Adventelva, the upper part of a duplex structure with a northward fold axis crops out (Haremo et al. 1990). Normal faults with minor (0.1–1 m) offset have been identified in the Janusfjellet Formation. Haremo et al. (1990) suggest these as young faults associated with landslides. They note that cleavage and joints are generally not characteristic deformation structures and that joint orientation is highly variable in this area (Haremo et al. 1990).

Landslides

Identification of the landslides

According to the geological map of the Adventdalen area (Major & Nagy 1972), a multitude of smaller and larger landslides termed 'landslips' had occurred in areas where the mountain slopes were comprised of a combination of the Janusfjellet and Helvetiafjellet formations. These slopes

Table 1. Features of the landslide blocks.

No.	area ($\times 10^4 m^2$)	orientation (m)	length (m)	width (m a.s.l.)	base (m a.s.l.)	top (m)	height (m a.s.l.)	old (m a.s.l.)	new (m)	dH (m)	dL
1	12.61	S46E	400	400	430	572	142	600	550	50	275
2	6.15	S64E	280	200	380	480	100	600	480	120	625
3	7.03	S30E	370	150	300	450	150	600	450	150	675
4	15.12	S06E	550	275	210	390	180	600	390	210	1000
5	7.77	S06W	55	150	230	390	160	600	390	210	825
6	34.42	S08E	730	500	430	623	193	600	500	100	325
7	20.12	S08W	270	675	400	450	50	500	450	50	300
8	16.06	S10W	440	475	250	373	123	–	–	–	–
9	48.84	S46W	1010	600	380	587	207	540	450	90	325
10	6.28	W	320	200	410	520	110	–	–	–	–
11	20.11	W	550	425	360	480	120	520	450	70	200
12	15.56	S72W	470	450	250	360	110	–	–	–	–
13	21.19	S72W	670	350	270	410	140	540	400	140	700
14	48.02	S58W	730	780	230	380	150	540	360	180	875

No = Number of each block.
area = Area of the block.
orientation = Downward orientation of the long axis of the block.
length = The maximum horizontal length of the block.
width = The maximum horizontal length of the block, right-angle to the orientation.
base = Altitude of the lowest point of the block
top = Altitude of the highest point of the block.
height = The relative height of the block calculated by an equation: (height) = (top)–(bottom)
old = The original altitude Festningen Sandstone.
new = Altitude of the Festningen sandstone in the block.
dH = The differential height between 'old' and 'new' (vertical travelling height of the Festningen Sandstone).
dL = The differential horizontal length between 'old' and 'new'.

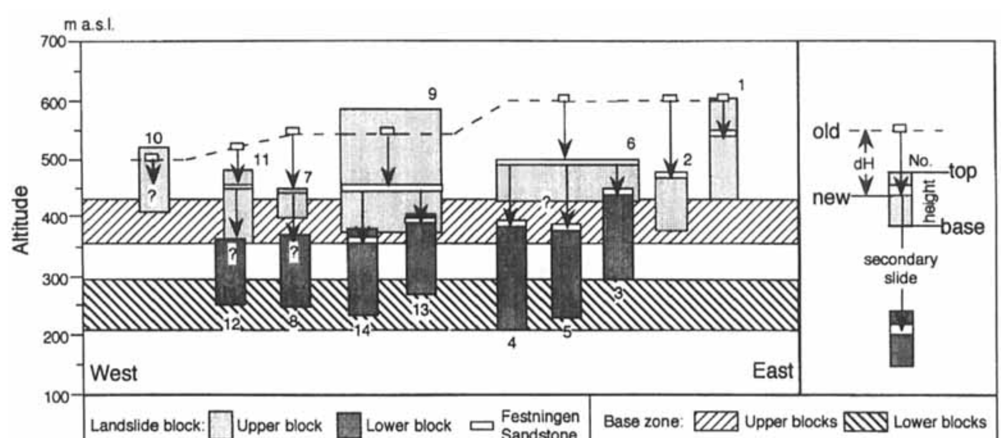

Fig. 5. Vertical distribution of the landslide blocks.

are commonly underlain by shale, which is loose and crumbles easily. Conversely, sandstone, especially the quartzitic sandstone of Festningen Member, is hard and remains as caprock forming cliffs.

Using aerial photographs together with detailed field observation, fourteen landslide blocks have been identified on the convex southeast to southwest facing slopes of Arctowskifjellet (Fig. 2). In the field, most landslides were recognised as slide blocks (as shown in Figs. 3 and 4) with the following characteristics:

The inner stratification of massive sandstone which forms the top of the block has not been disturbed, and the block surface is tilted back toward the upper part of the slope at a gentle angle. The edge of the Festningen Sandstone generally forms a steep cliff. Gentle slopes composed of shale occur in the middle part of the block. A number of sandstone blocks have fallen down from the cliffs and lie scattered on the slope surface. Although the bedding in the underlying shale is difficult to identify, the bedding plane occasionally remains. In such cases, most of the bedding planes are complexly folded and faulted.

A landslide on the highest part of the slope on the south of Arctowskifjellet has the largest scarp in this area. The height of the scarp is about 150 m, and the slope angle is nearly 40°. The foot of the scarp is covered by talus and the landslide blocks spread downward from the talus slopes. On the blocks, sandstone layers of the Helvetiafjellet Formation tilt upslope to form small hillocks. This tilting results in a transverse depression between the landslide scarps and the blocks. Both sides of the depression are smoothed by solifluction.

Positions of the Festningen Sandstone beds within the blocks were confirmed by field observation. They are good markers and indicate displacement of the landslide blocks. Features of the individual blocks are listed in Table 1. Vertical traveling height (dH) and differential horizontal length (dL) of the Festningen Sandstone were calculated using the original altitude of the sandstone (old) and the current altitude of the sandstone (new).

Vertical distribution of the landslide blocks

As shown in Figs. 2 and 5, the landslide blocks may be divided into two groups according to their vertical distributions, an 'upper block group' (Nos. 1, 2, 6, 9, 7, 11, 10) and a 'lower block group' (3, 5, 4, 13, 14, 8, 12). The base zone of the upper block is higher than 360 m a.s.l., and the lower block extends to below 300 m a.s.l. The 'height' and 'dH' of the upper block group seem to be variable. However, the 'base' of the individual landslide blocks within the upper block group seem to be between 360 and 430 m. In the case of block No. 6, the base is undefined, because the lower part of the block seems to have been disturbed and is obscured by secondary landslides (Nos. 3, 5 and 4). The bases of landslide blocks in the lower block group may be limited to between 210 and 300 m a. s. l. In the upper block group, the Festningen Sandstone is commonly found in the middle, whereas in the lower block group, it occurs in the uppermost part of the block. The deformation structures and displacement of the Festningen Sandstone suggest that the lower block group originated from the upper block group as secondary landslides (Fig. 5).

Causes of landslides

The landslides in the studied area have been classified as 'rock slumps' (after Varnes 1978). A rock slump is a type of slide characterised by a rotational component. The term 'slide' signifies the existence of a single surface or several surfaces of shear displacement. None of these features were recognised in the Adventdalen landslides, but this may be because the shear planes occur at depth, below the ground surface, or because shear may have occurred within a diffuse zone. However, a backward rotational movement is indicated by the tilting sandstone strata on the blocks. Rotation occurs due to forces that cause a turning moment about a point above the centre of gravity of the unit. The less firm shale underlying the sandstone has been pushed ahead forming lobate pressure ridges in front of the block.

The valley walls of Adventdalen are believed to have been eroded by glacial activity. However, the slopes in the studied area are not U-shaped, but rather form gentle hummocky shapes; Helvetiadalen, a tributary of Adventdalen, has the same shape. These hummocky slopes may have been produced by the landslides which were associated with the side wall steepening as a result of the former glacial erosion. The Jurassic shale is loose enough to be denuded, while the sandstone remains on top of the shale. Consequently, loading of the sandstone and over-steepening of the slope have occurred, resulting in the failure of the sandstone overlying the shale.

In Svalbard, most of the glaciers are subpolar glaciers (Hagen 1987). Subpolar-type glaciers reach melting point in high accumulation areas, below which continuous permafrost appears. Thus, melt water sinks into the ground producing a groundwater stream which flows downwards under the permafrost layer (Liestøl 1975). The bedrock on the valley slopes should freeze after the glacier retreated, thus it is possible for the groundwater stream to act as slump surface

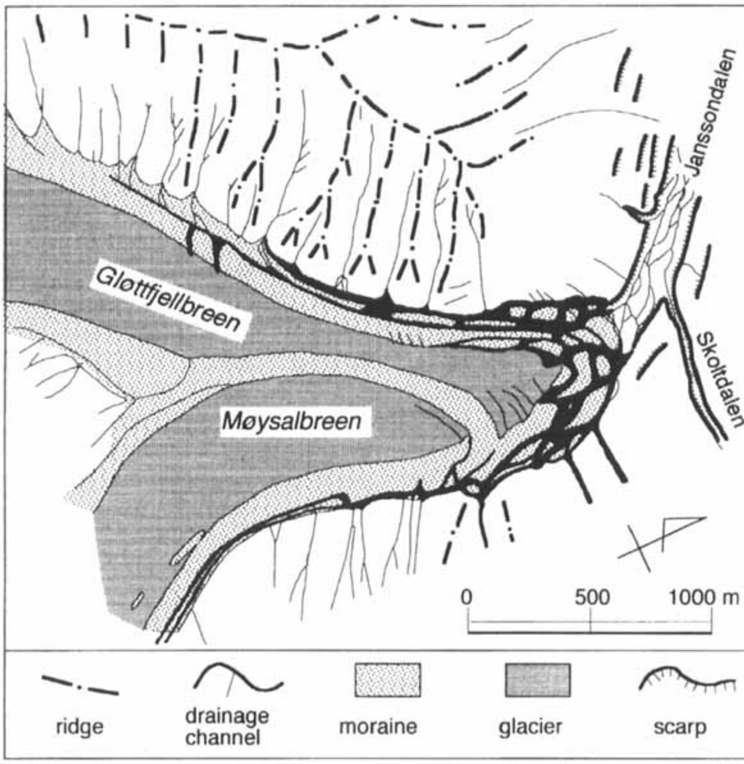

Fig. 6. Recent glacial margin landforms in the upper part of Janssondalen (cf. Fig. 1).

between the upper frozen bed and the lower thawed bed.

We assume three principle causes of the landslides in Adventdalen: (1) a caprock structure, composed of Helvetiafjellet sandstone above and Janusfjellet shale below, causes loading of the sandstone onto the shale; (2) glacial erosion produces the over-steepening of the valley wall; and (3) the groundwater stream under the frozen bedrock has resulted in hydrologic change.

Time of occurrence

Owing to a lack of empirical evidence in the field, it is difficult to assess the exact time of the landslides and deposition of its surface materials. However, since glacial erosion is considered to be one of the causes of the landslides, the time of occurrence of the landslides should correspond to the deglaciation.

In the middle part of the lobe of block No. 14 (Fig. 2), the shale is exposed, striking N20°W and dipping 48°W. Glacial striae were locally observed on unweathered and polished surfaces (Fig. 3). The SSW orientation of the glacial striae coincides with that of the current main drainage in Adventdalen. The lobe was formed as a bulge in front of a sliding block, and the striae are believed to have been originally formed on the horizontal bedding plane of the shale before the landslide occurred. Because shale is very susceptible to erosion, it is hard to believe that the shale could have survived another glaciation. Therefore, the landslide blocks are not believed to have experienced glaciation since formation of the striae.

The landslides caused by deglaciation seem to have been intercepted by the glacier ice remaining in the valley. In fact, some of the landslides which are located along the present ice margin are indicated in the geological map of Adventdalen (Major & Nagy 1972); for example, Tellbreen and Fangenbreen at the north of Helvetiafjellet, Arnicabreen to the east of Arctowskifjellet. These landslides are commonly restrained by lateral moraines or glacier ice.

The two groups of landslide blocks which are based on the two fixed base levels (Fig. 5) can then be considered to indicate the former levels of the surface of the glacier ice. This means that the occurrence of the landslides coincides with two

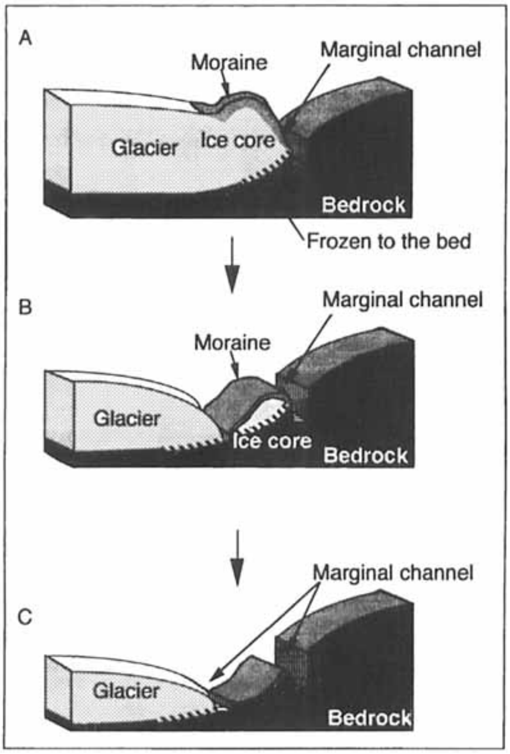

Fig. 7. Development of two glacier margin hillside channels during deglaciation. A. Glacier advance forming the ice-cored moraines. B. Thinning of the ice-core during glacial retreat. C. Extinction of the ice-cored moraine remaining the superficial deposits.

different stages of deglaciation. At first, after the surface of the glacier had dropped considerably to one level, the upper blocks slumped. Later, when the ice surfaces further lowered, the lower blocks slumped from the upper blocks.

Ice marginal landforms

Recent ice marginal landforms in Adventdalen

The most distinct moraines around the margin of Drønbreen and other glaciers in Adventdalen are considered to have formed during the Little Ice Age (e. g. Warner 1989; Mangerud & Svendsen 1990; Shiraiwa et al. 1991). As is usually the case in Svalbard, these moraines are ice-cored.

The Gløtfjellbreen and Møysalbreen glaciers, which converge to the west of Mt. Skolten, show a typical example of present ice margin features (Fig. 6). The moraine ridges in front of these glaciers are approximately 10 m high and have been cut by streams in several places. Tributary stream courses on the valley walls have been blocked by the ice-cored lateral moraines of the glacier and diverted along the margins of the moraines, incising into the shale underlying the moraines and forming narrow, deep marginal channels (Fig. 6).

The outermost parts of the subpolar glaciers are frozen to the bed preventing the water from draining in and out. Thus it is also likely that similar ice marginal channels along the high moraine ridges were formed at various times in the past. Since these channels formed, the ice cores in the moraine ridges have melted and the ridges have decreased in height, leaving only surface deposits. Once a channel was established, the stream continued to cut into the relatively soft shale bedrock. Thus each channel was incised and remained long after the ice retreated, in contrast to the degraded ice-cored moraine ridges.

Flint (1971) presented an idealised sketch showing the development of glacier-margin hillside channels during deglaciation. In the present study, another idealised sketch is proposed based on the investigation of Grøtfjellbreen (Fig. 7). This sketch shows that a pair of marginal channels develop on either side of the ice-cored moraine during a stagnation in the deglaciation.

Drainage pattern and distribution of glacial deposits in Adventdalen

The river system in the middle reaches of Adventdalen shows a feather-like drainage pattern (Fig. 8). The upper part of major tributaries and their branches are mainly aligned in a north-south direction according to slopes. However, major tributaries turn their courses in the lower part below about 200 or 300 m a.s.l., from north-south to northeast-southwest on the north side and to southeast-northwest on the south side of the valley, oblique to the general inclination of the valley walls. These stream channels join the main river channel at an angle between 45° and 90°, following former courses in their lowest parts. The tributaries on both sides are confluent to the main river at almost the same place, like a three-pronged fork. Topographic profiles presented in Fig. 9 show that these tributaries flow at the same altitude on both sides of the main river and that the tributaries on each side make a pair.

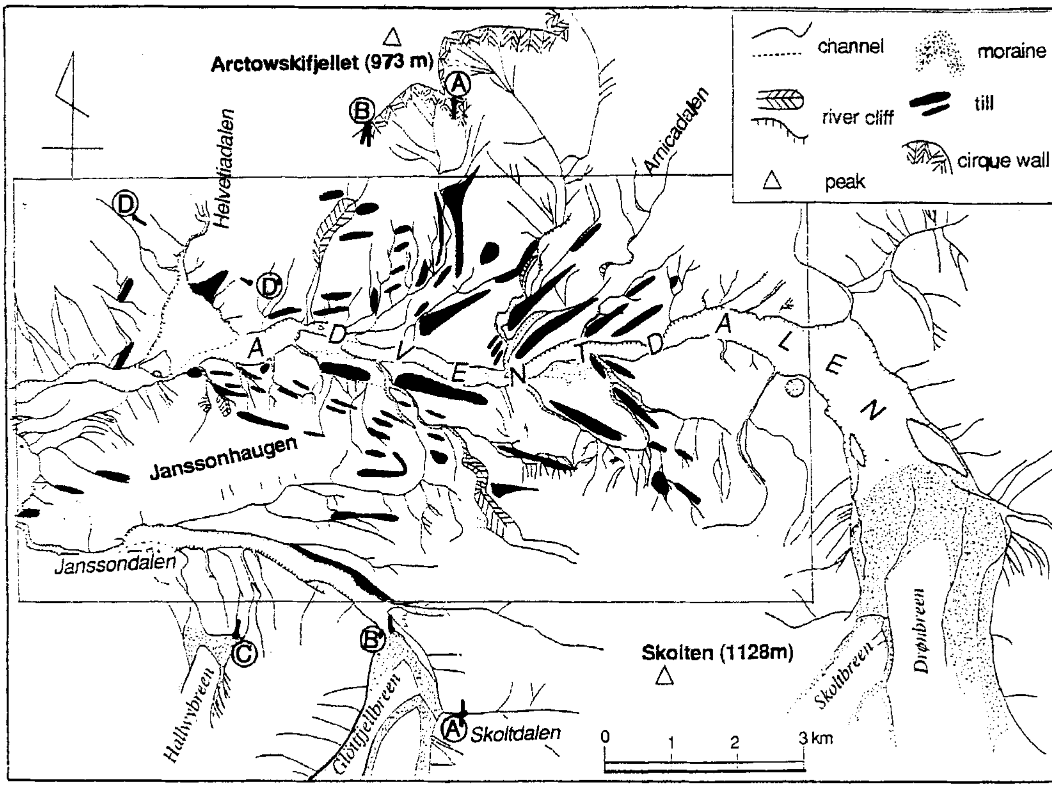

Fig. 8. Drainage system and till distribution in Adventdalen (cf. Fig. 1).

The azimuth of the orientation and the total length of the tributaries in each direction were measured as defined by lines joining the nodes and head of stream segments after the method of Morisawa (1964) and Jarvis (1976) (Fig. 10B). Two distinct directions, northeast on the right bank of the valley and east-southeast on the left bank, oblique to the principal slopes of the valley, are indicated on Fig. 10A. Generally, the drainage patterns are influenced by both geological structure and lithology. In particular the parallel or preferred orientation of the stream courses is usually influenced by geological structure. The structural geological data of this area collected along the Skolten Anticline and the duplex structure along Adventelva (Haremo et al. 1990) show that the orientation of the dominant structure is NNW–SSE. According to these data, no relation between bedrock structure and the channel directions is apparent.

Except for the distinct moraines in front of the glaciers, the till and other superficial deposits over bedrock in this area are generally only a few metres or so thick. The till and sandstone erratics are distributed on interfluves between the tributary channels and on the terraces of the trough at definite levels (Fig. 8).

The drainage pattern and the distribution of the till in Adventdalen (Fig. 8) are interpreted as evidence showing that the glacial marginal channels and ice-cored moraines remain as relict landforms. The parallel-running tributaries and interfluves should be developed in the same manner as shown in Fig. 7; the till on the interfluves was originally deposited on the ice-cored moraine and the channels were formed as marginal channels.

Relationship between the landslides and the channels

The vertical distribution of the landslide blocks, ice marginal channels and till are shown in Fig. 9. In the main valley, the landslide blocks are

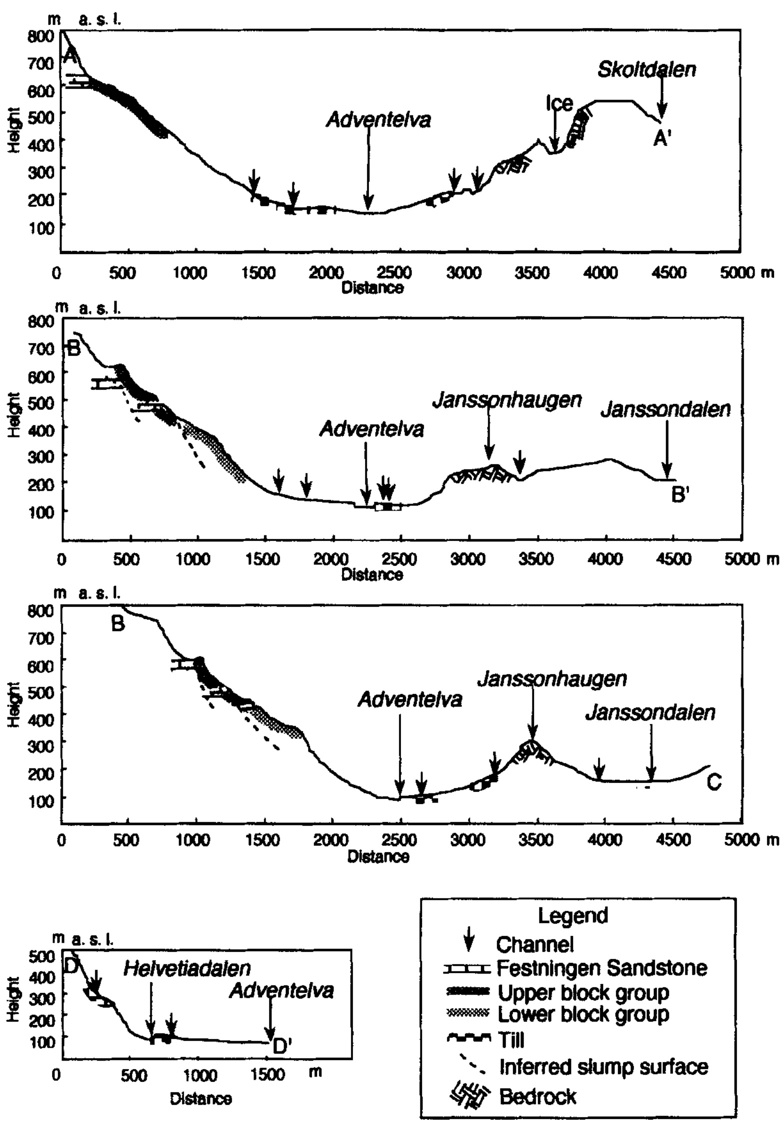

Fig. 9. Topographic profiles of Adventdalen. Locations of the profiles are indicated in Fig. 8.

situated at higher altitudes and do not reach the valley bottom. The channels, however, are mainly distributed on the lower part of the valley slopes or on the valley bottom. It is therefore difficult to find a direct connection between the two in the main valley. However, at the confluent point of Helvetiadalen, on the southeast of Helvetiafjellet (Fig. 1), a landslide block has come into contact with a channel and its lateral ridge (Figs. 11 and 12). The ridge and the block are connected. The ridge continues to the southwest, though it is partly interrupted by the alluvial fan flowing down from above. Some erratics and till were deposited on the ridge, and a few erratics can be seen on the landslide block. An alluvial fan spreads out at the place where Helvetiadalen joins with Adventdalen. At the fan top, in a river section of Helvetiadalen, a well-layered section of flat-lying and alternating beds of fine sand and coarse gravel is exposed. The section appears to

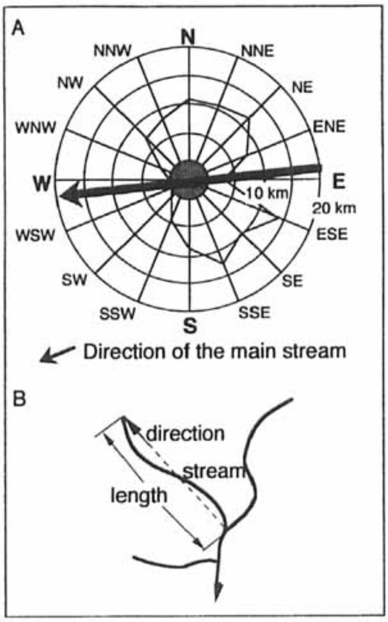

Fig. 10. Orientational data of the tributaries of the Adventelva. The measurement was applied to the inner square in Fig. 8. A. Total length and orientation of the tributaries in Adventdalen. B. Angles were defined by joining ends of stream segments or links.

have a gradational contact with a diamicton which includes striated boulders within a fine sand and clay matrix.

These features are believed to demonstrate that the ridge and the channel were formed before the landslide because the slope instability was increased by undercutting in the channel.

Discussion

As previously stated, ice marginal channels and landslides intercepted by the former glacier ice are well developed in the Adventdalen area. The Jurassic argillaceous rocks dominating this area are weak and susceptible to weathering and erosion. The soft shale exposed extensively on the lower slopes and valley is subject to erosion and transport by glacial meltwater. Thus, this rock type is unlikely to form distinct moraine ridges. Although moraine ridges were once formed, because they were high in ice content, they subsequently decreased drastically in size. On the other hand, erosional landforms incised into the shale layer are likely to remain intact.

It also seems likely that the angle of the slope at the interface between rock and ice is critical. Flint (1971) stated that an ice-margin stream should easily be able to cut through the ice to the base of the slope in the case of a nearly vertical interface. With a flat-lying interface, as on a bedrock spur, a similar stream would more likely incise its channel into the bedrock. In the case of Janssondalen, the slope on the southern side of the valley is steeper than that on the northern side. Ice margin channels develop on the northern slope but not on the southern side (Fig. 8). Regarding other areas where ice margin channels are absent, such

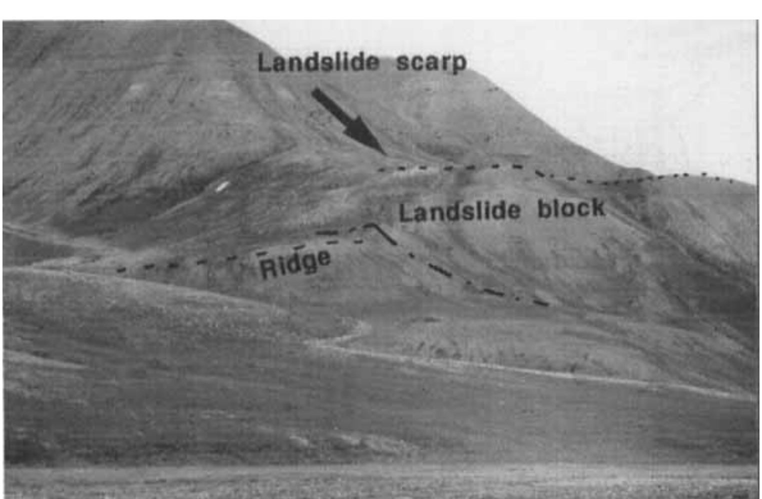

Fig. 11. Landslide block and ridge distribution at the mouth of Helvetiadalen.

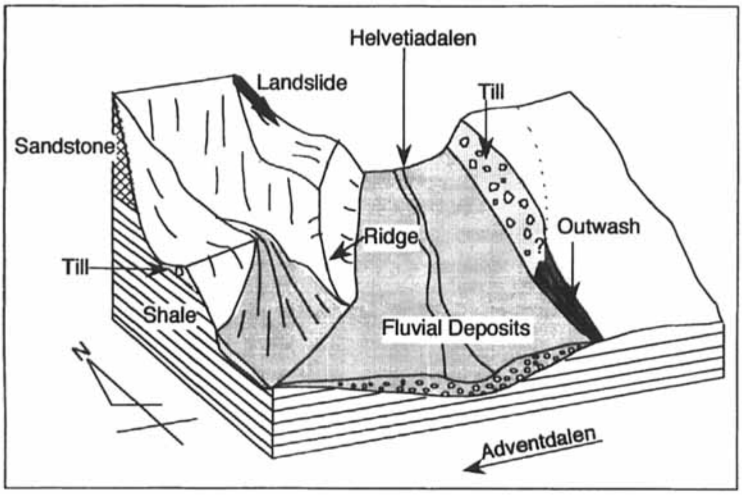

Fig. 12. Schematic sketch of the landforms and surface material development at the mouth of Helvetiadalen.

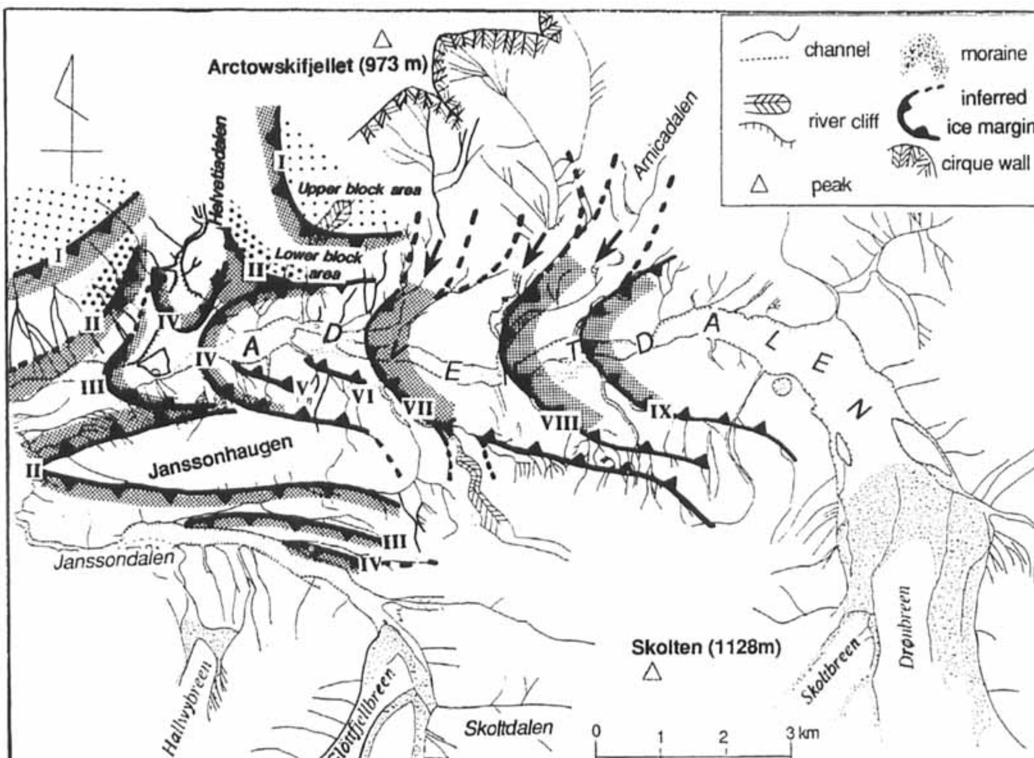

Fig. 13. Inferred position of the former ice margin in the middle part of Adventdalen (cf. Fig. 1). Each ice margin inferred is identified by numbers of I, II......, VIII and IX. Arrows in the figure are described in the text.

as Reindalen or the lower reaches of Adventdalen, both sides of the valley could be steep enough to prevent meltwater streams from incising into the bedrock, which is made up of horizontally bedded sandstones.

As the present ice front features show, channels are formed at the edge of the thin ice which is thought to be receding. Even a small advance or a short stagnation of the ice during the course of deglaciation could be enough to form the

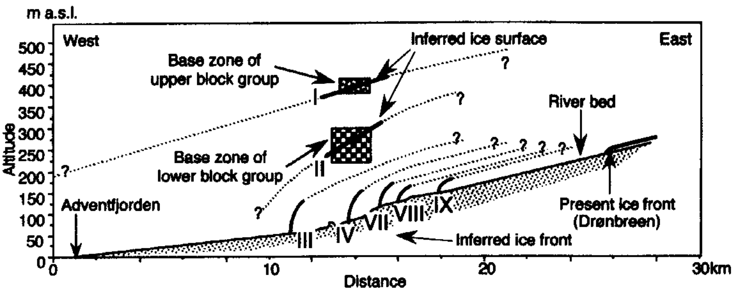

Fig. 14. Inferred profile of the former ice surface along Adventdalen. The reconstruction of ice surfaces I and II is based on the altitude of the base of the upper and the lower landslide blocks.

channels. On this assumption, these landforms indicate former positions of the glacier margin in the intervals of stagnation or at small re-advances.

Former position of the ice margin

The former position of the ice margin and the former ice surface profile have been reconstructed in Figs. 13 and 14, respectively, under the assumption that the till on the interfluves was originally deposited on the ice-cored moraine and that the channels were formed as marginal channels. The altitudes of the bases of the upper and lower landslide blocks are utilised for the reconstruction of ice surfaces I and II. Although absolute ages for the various ice margin positions are not available, the correlative recessional sequences of the glaciers are traceable. The main glacier retreat can be traced as I, II, III, IV, V, VI, VII, VIII and IX in Figs. 13 and 14. Retreat of the tributary glacier in Helvetiadalen is denoted by I, II, and IV. As for the Janssondalen, positions II, III and IV are inferred. As for stages I and II, the former position of the ice front is uncertain. However, the ice of stage-I could have terminated in Isfjorden to form the terminal moraines reported by Ohta (1982), assuming that the ice surface corresponds to the last glacial maximum in this area.

On the right bank of the valley, some of relatively large tributaries other than the river in Helvetiadalen flow into the main river. A cirque has been formed at the upper end of each valley. A small glacier, Arnicabreen, presently occupies the head of Arnicadalen. Taking these present-day features into consideration, these tributary valleys were probably filled with ice, and the glaciers likely joined Drønbreen at the time of glaciation (arrows, Fig. 13).

The reconstructed positions of former ice margins suggest that some intervals of stagnation or small re-advances occurred during the course of deglaciation. However, it has been stated that the ice in Spitsbergen dissipated rapidly in the warming climate of the early Holocene age (Feyling-Hanssen 1955, 1965; Forman 1989; Mangerud et al. 1992), and there is widespread evidences for this throughout the arctic. In present day Spitsbergen, surges are frequent phenomena and a common form of glacier advance (e.g. Liestøl 1969; Schytt 1969; Drewry & Liestøl 1985; Dowdeswell 1986a,b; Hagen 1987; Dowdeswell et al. 1991). Glacial surge is thus most likely to have caused the stagnation and re-advances during the course of deglaciation.

Conclusions

Fourteen landslide blocks are recognised on the southern slope of Arctowskifjellet; they are divided into two groups based on the altitudes of the base of the blocks. The two levels of the landslide blocks seem to be related to the former ice surface levels, assuming that landslide blocks were intercepted by the glacier ice. The geomorphic changes produced by glacial erosion and glacial retreat are the causes of the landslides. These landslides are classified as belonging to the rotational bedrock slumps.

The present-day ice marginal landforms, the development of drainage patterns and the distribution of till in Adventdalen may reflect former ice marginal positions. The crumbly and erosive nature of the soft Jurassic shale aided in channel incision. Former positions of the glacier tongues were reconstructed on the basis of the relict ice marginal landforms. The landforms suggest that several episodes of stagnation or small re-advance phases occurred during the course of deglaciation.

Since few exact dating methods were used in this study, the deglaciation history in Adventdalen remains difficult to date.

Acknowledgements. – We would like to thank Y. Ono, Graduate School of Environmental Earth Science, Hokkaido University, for many helpful suggestions, advice and encouragement during the course of this work. We also thank K. Moriwaki, National Institute of Polar Research, Japan, for permission and instruction in using the Analytical Photogrammetric System of that institute. For assistance in the field work, sincere thanks are extended to members of the Japanese Svalbard Expedition in 1990: K. Hirakawa, Hokkaido University, N. Matsuoka, Tsukuba University, and S. Sawaguchi, Meiji University. We express our gratitude to Y. Ohta, O. Salvigsen, T. Siggerud and other staff of Norsk Polarinstitutt for their logistical support for the expedition, and for their valuable help in preparing the manuscript.

References

Boulton, G. S. 1979: Glacial history of the Spitsbergen archipelago and the problem of Barents shelf ice sheet. *Boreas 8*, 31–57.

Dowdeswell, J. A. 1986a: Drainage-basin characteristics of Nordaustlandet ice caps, Svalbard. *J. Glaciol. 32*, 31–38.

Dowdeswell, J. A. 1986b: Remote sensing of ice cap outlet glacier fluctuations on Nordaustlandet, Svalbard. *Polar Res.*. *4 n. s.*, 25–32.

Dowdeswell, J. A., Hamilton, G. S. & Hagen, J. O. 1991: The duration of the active phase on surge-type glaciers: contrasts between Svalbard and other regions. *J. Glaciol. 37*, 388–400.

Drewry, D. J. & Liestøl, O. 1985: Glaciological investigations of surging ice caps in Nordaustlandet, Svalbard. *Polar Rec. 22*, 359–378.

Feyling–Hansen, R. W. 1955: Stratigraphy of the marine late Pleistocene of Billefjorden, Vestspitsbergen, *Norsk Polar-inst. Skr. 107*, 187.

Feyling-Hansen, R. W. 1965: Shoreline displacement in central Vestspitsbergen and a marine section from the Holocene of Talavera on Barentsöya in Spitsbergen. *Norsk Polarinst. Medd. 93*, 1–34.

Flint, R. F. 1971: Drainage; Eolian features. In: *Glacial and Quaternary geology*, New York, John Wiley & Sons Ltd., 227–226

Forman, S. L. 1989: Late Weichselian glaciation and deglaciation of Forlandsundet area, western Spitsbergen, Svalbard. *Boreas 18*, 51–60.

Hagen, J. O. 1987: Glacier surge at Usherbreen, Svalbard. *Polar Res. 5 n. s.*, 239–252.

Haremo, P., Anderson, A., Dypvik, H., Nagy, J., Elverhøi, A., Eikeland, T. & Johansen, H. 1990: Structural development along the Billefjorden Fault zone in the area between Kjellstromdalen and Adventdalen/Sassendalen, central Spitsbergen. *Polar Res. 8 n. s.*, 195–216.

Jarvis, R. S. 1976: Stream orientation structures in drainage networks. *J. Geol. 84*, 563–582.

Liestøl, O. 1969: Glacier surges in west Spitsbergen. *Can. J. Earth. Sci. 6*, 895–897.

Liestøl, O. 1975: Pingos, springs, and permafrost in Spitsbergen. *Norsk Polarinst. Årbok 1975*, 7–29.

Major, H. & Nagy, J. 1972: Geology of the Adventdalen map area. *Norsk Polarinst. Skr. 138.*

Mangerud, J. & Svendsen, J. I. 1990: Deglaciation chronology inferred from marine sediments in a proglacial lake basin, western Spitsbergen, Svalbard. *Boreas 19*, 249–272.

Mangerud, J., Bolstad, M., Elgersma, A, Helliksen, D., Landvik, J. Y., Lycke, A. K., Lønne, I., Salvigsen, O., Sandahl, T. & Sejrup, H. P. 1987: The late Weichselian glacial maximum in western Svalbard. *Polar Res. 5 n.s.*, 275–278.

Mangerud, J., Bolstad, M., Elgersma, A, Helliksen, D., Landvik, J. Y., Lønne, I., Lycke, A. K., Salvigsen, O., Sandahl, T. & Svendsen, J. I. 1992: The last glacial maximum on Spitsbergen, Svalbard. *Quat. Res. 38*, 1–31.

Miller, G. H., Sejrup, H. P., Lehman, S. J. & Forman, S. L. 1989: Glacial history and marine environmental change during the last interglacial-glacial cycle, western Spitsbergen, Svalbard. *Boreas, 18*, 273–296.

Morisawa, M. E. 1964: Development of drainage systems on an upraised lake floor. *Am. J. Sci. 262*, 340–354.

Ohta, Y. 1982: Morpho-tectonic studies around Svalbard and northernmost Atlantic. Embry, A. F. and Balkwill, H. R. (eds.): Arctic geology and geophysics. *Canad. Soc. Petrol. Geol. Mem. 8*, 415–429.

Ono, Y., Matsuoka, N., Sawaguchi, S., Shimokawa, K., Fukuda, M., Takahashi, N., Shiraiwa, T., Hasegawa, H., Yoshikawa, K. & Muto, H. 1991: Geomorphological results of the Japanese Expedition to Svalbard, 1988–1989. *Mountain Res. Dev. 11*, 259–269.

Parker, J. R. 1967: The Jurassic and Cretaceous sequence in Spitsbergen. *Geol. Mag. 104*, 487–505.

Salvigsen, O. 1979: The last deglaciation of Svalbard. *Boreas 8*, 229–231.

Salvigsen, O., Eligersma, A., Hjort, C., Lagerlund, E., Liestøl, O. & Svensson, N. O. 1981: Glacial history and shoreline displacement on Erdmannflya and Bohemanflya, Spitsbergen, Svalbard. *Polar Res. 8 n. s.*, 261–273.

Shiraiwa, T., Sawaguchi, S., Hasegawa, H., Sawagaki, T. & Ono, Y. 1991: Timing of the Little Ice Age glaciation in Reindalen, western Spitsbergen, reconstructed by lichenometry. *Proceedings of the International Symposium on the Little Ice Age Climate, September, 1991. Tokyo Metropolitan Univ., Tokyo, Japan.*

Schytt, V. 1969: Some comments on glacier surges in eastern Svalbard. *Can J. Earth Sci. 6*, 867–873.

Svensson, H. 1988: Ice-wedge casts and relict polygonal patterns in Scandinavia. *J. Quat. Sci. 3*, 57–67.

Troitsky, L. S., Punning, J. M., Ht, G. & Rajamae, R. 1979: Pleistocene glaciation chronology of Spitsbergen. *Boreas 8*, 401–407.

Varnes, D. J. 1978: Slope movements and types and processes. In: *Landslides: Analysis and Control*, Transportation Res. Board, Nat. Ac. Sci., Washington Spec. Rep. 176, 11–33, (cited by Hansen, M. J. 1984).

Werner, A. 1989: Holocene glaciation and climatic change, Spitsbergen, Svalbard. Ph. D. Thesis, University of Colorado.