Late Holocene glacier variations and climate at Jan Mayen

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Jan Mayen is a small (373 km^2) remote island in the Norwegian Sea. One third of it is covered by glaciers, all located on the Beerenberg volcano. There have been at least two Holocene periods of glacier expansion at Jan Mayen. The first may have taken place around 2500 B.P. Some glaciers had their maximum extent during the second period, around 1850 A.D. They have subsequently shown an oscillating retreat, with marked expansion around 1910, and with a minimum extent around 1950. Many glaciers advanced again around 1960. The advance of Sørbreen probably culminated around 1965. The climate appears to have been more arctic-continental than today during these two periods of glacier advances, caused by expanded pack ice cover in the East Greenland current and strong influence from the Greenland–Arctic high pressure area. The interplay between the high pressure area and the low pressure tracks in the North Atlantic Ocean determines the climate over the north-western part of the Atlantic, and this results in parallel climate and glacier variations within this region. We conclude, contrary to previous reports, that the advances of the glaciers around 1960 were caused by reduced summer temperatures and ablation, and not by increased precipitation.

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Jan Mayen is the most northerly island on the Mid-Atlantic Ridge, located at 71°N, 8°W. The island covers an area of 373 km^2, and consists of two different landscapes, Nord-Jan with the 2277 m high Beerenberg volcano cone, and the lower and narrow Syd-Jan (Fig. 1). Jan Mayen lies on the boundary between the cold East Greenland current and the warm Atlantic currents in the Norwegian Sea. The island is surrounded by pack ice during winter and spring, while the ice retreats west of the island in the summer (Vinje 1976). Meteorological observations from 1922 show that the climate is cool oceanic with a mean (1951–1980) annual temperature near sea level of −1.2°C and a mean (1963–1980) yearly precipitation at the present meteorological station of 685 mm (Steffensen 1982).

The island consists of young volcanic rocks (Fitch et al. 1965; Imsland 1978). Nearly 20% of the area is covered by postglacial lavas (Imsland 1978; A. Hiksdal, pers. comm.). The most recent eruption occurred in 1970 on the north-eastern side of Beerenberg (Siggerud 1972). Glacial geologic studies by A. Hiksdal (pers. comm.) and J. Mangerud show that the island has been covered by glaciers during several phases of the Weichselian.

Altogether 113 km^2 of Nord-Jan is covered by glaciers, some of which extend to sea level (Fig. 2). Several of the glaciers show undulating surface topography. Supraglacial material covers large parts of the ablation area on some of the glaciers. There are no glaciers on Sør-Jan, where the highest mountain is 769 m a.s.l.

Mass balance studies (Orheim 1976; Anda 1980) indicate that the equilibrium line elevation varies from 600 m a.s.l. on the NW-facing glaciers to 950 m a.s.l. on the S-facing glaciers, probably mainly due to variations in winter accumulation. This comes mostly with north-north-westerly winds (Steffensen 1969, 1982; Anda 1980) giving most precipitation on the windward side of Nord-Jan. Measurements at Sørbreen show that the winter balance is around 1–2 m water equivalent, and that there are large local variations because of much wind drift and the hummocky topography of the glacier surface. Convection and condensation account for most of the heat transfer to the surface in the ablation season. Measurements

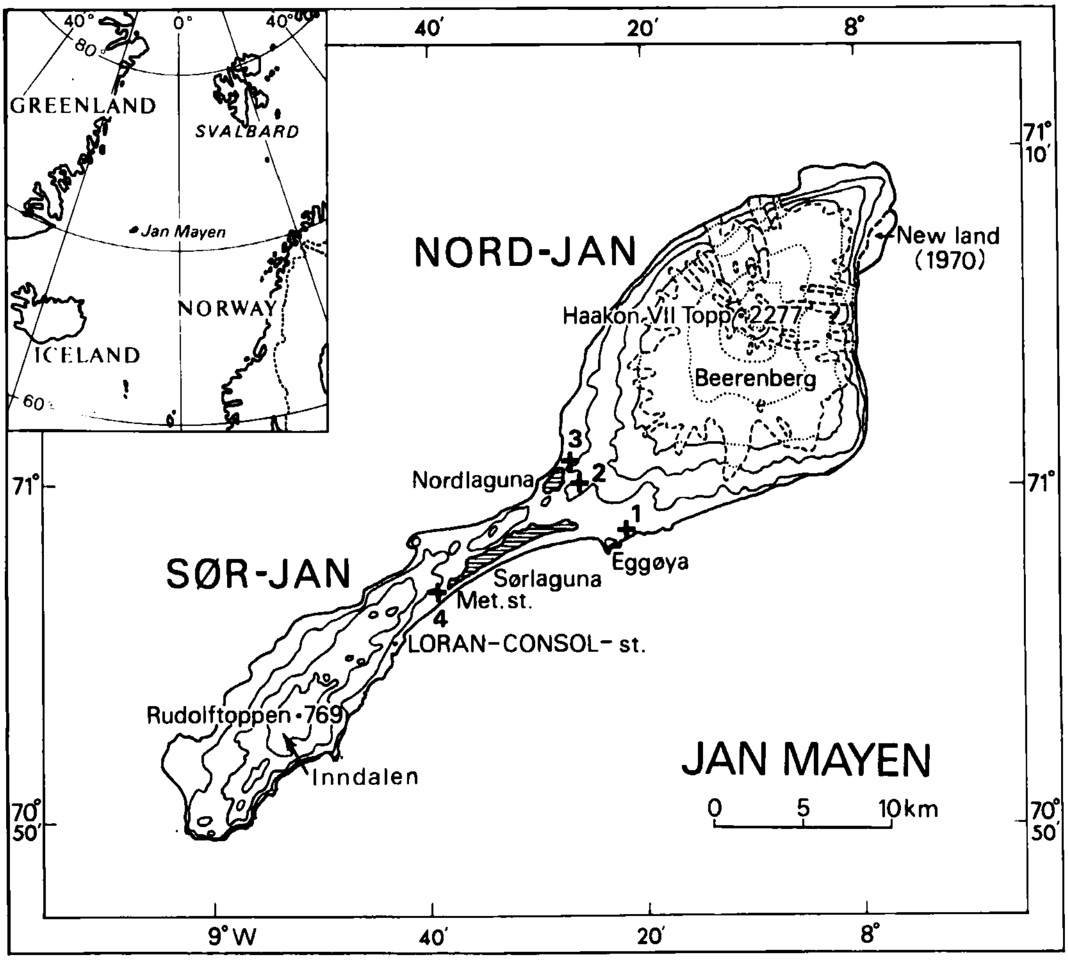

Fig. 1. Index map of Jan Mayen. The numbers refer to the locations of the meteorological station at various periods. 1: 1922–1940; 2: 1941–1946; 3: 1946–1962; 4: 1962 to present.

show the abnormal phenomena that the ablation increases with elevation over lower parts of Sørbreen. This is caused by long-lasting advection fog which reduces both incoming radiation and temperatures over the lowest section. This phenomenon is probably less important on the NW glaciers. Calving is an important ablation mechanism for some of the glaciers around the northern sector of Nord-Jan.

Little previous work has been done on the Holocene fluctuations of the glaciers. Fitch et al. (1965) described ground moraine deposits and terminal moraine stages at Nord-Jan which they correlated to glacial phases around 4000 and 2000 B.P. A. Hiksdal (pers. comm.) assumes that these moraines are from the last main glaciation. Moraines formed during the last few centuries have been described by Boldva (1886), Jennings (1939, 1948), Flint (1948), Fitch et al. (1962), Lamb et al. (1962), and Kinsman & Sheard (1963). The last three assume that the glacier advances culminated during the 18th century, based on correlation with Scandinavia. They also described a marked advance of Sørbreen around 1960. Lamb et al. (1962) and Fitch et al. (1962) claim that changes in precipitation have been the main reason for the glacier fluctuations during the past two centuries.

We have investigated the Holocene glacier and climate variations by (1) mapping and lichenometric dating of moraines, (2) reconstruction of glacier fluctuations from historic sources, and (3)

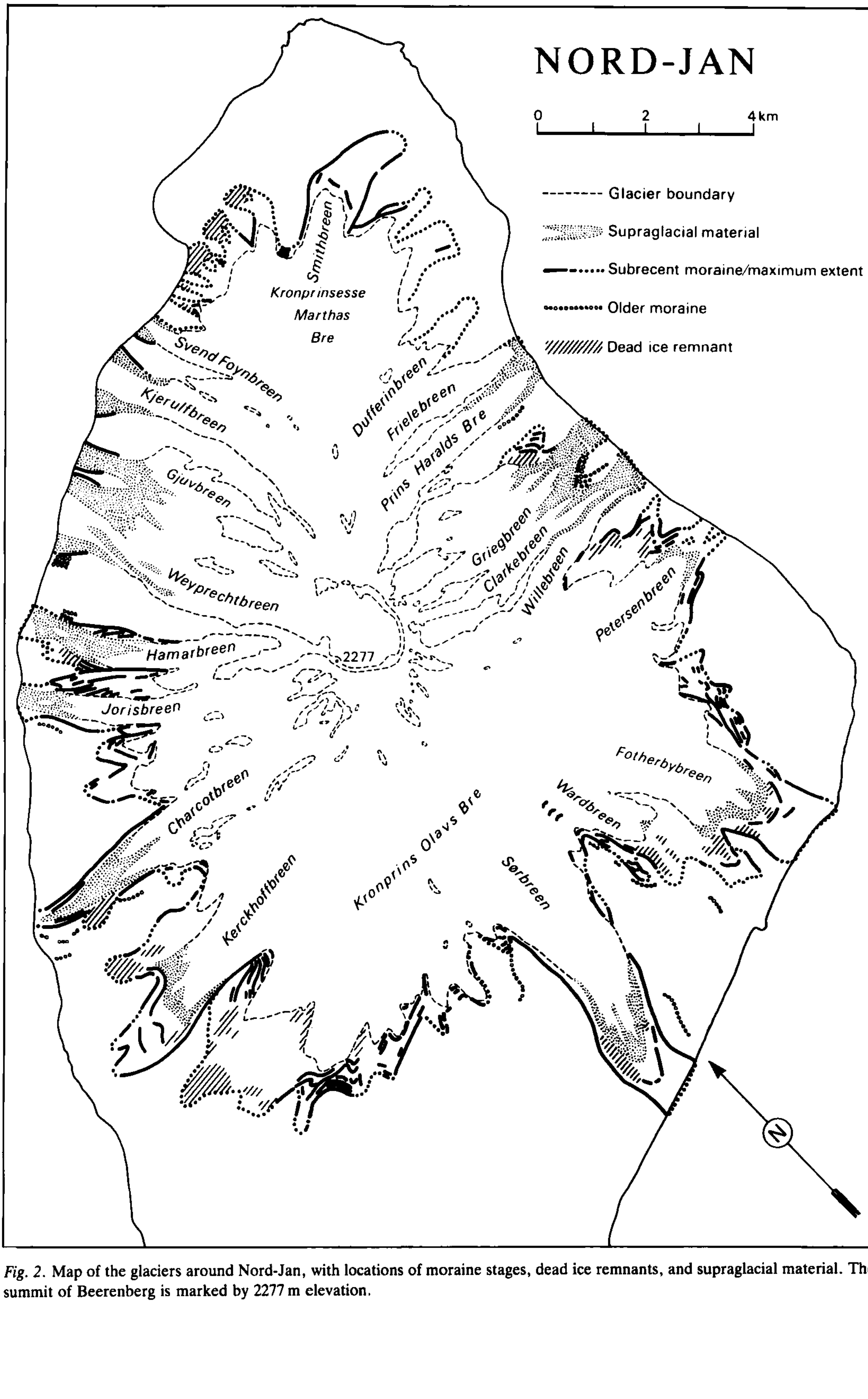

Fig. 2. Map of the glaciers around Nord-Jan, with locations of moraine stages, dead ice remnants, and supraglacial material. The summit of Beerenberg is marked by 2277 m elevation.

evaluation of the glacier and climatic changes in a regional context. The field work was carried out during the summers of 1976, 1977 and 1978.

Holocene moraines and marginal stages

All certain Holocene moraines are located at Nord-Jan. They can be divided into (1) moraines formed during the last few centuries, hereafter termed the 'subrecent', and (2) considerably older moraines. The subrecent landscape (Fig. 2) is characterized by sharp and little modified moraines (Fig. 3), and by a poorly developed vegetation cover. Some lateral moraines are up to 50 m high. Dead ice appears at several places in the moraines (Fig. 2). The number of subrecent moraines varies, probably mainly because of varying depositional mechanisms. Terminal moraine ridges are less developed when there is much supraglacial material on the glacier tongues, and when there have been advances against dead ice deposits. In both cases an irregular terrain of low hummocks is formed, making it difficult to identify specific end moraines.

Moraine ridges are in several places located outside the subrecent moraine landscape. These have more subdued, rounded forms (Fig. 4), and the vegetation cover is also markedly better developed.

One possible moraine ridge is located at Sør-Jan, south of Inndalen. This was identified on aerial photographs after the field work had been terminated. The ridge may also be of volcanic origin. The terrain in the higher parts of Sør-Jan should be favourable for the formation of small local glaciers. There are several cirque-like forms associated with the highest peaks. However, the fact that there are no finite traces of Holocene glacial activity indicates that the glaciation limit during the entire Holocene has been above the highest peaks, i.e. above 769 m elevation.

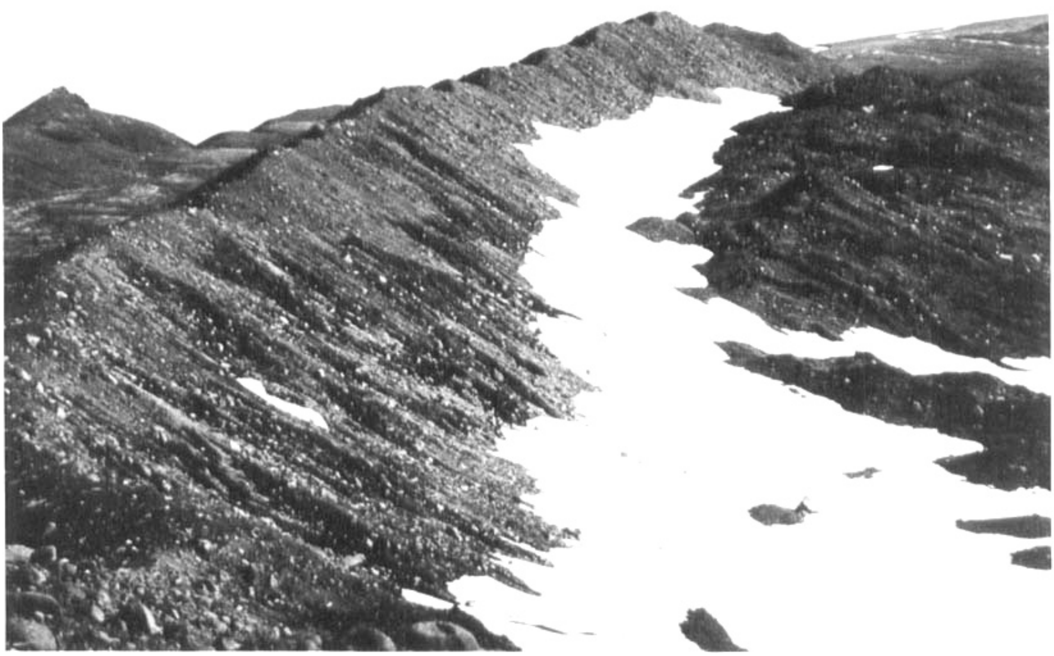

Fig. 3. Moraine on eastern side of Sørbreen, below 350 m elevation. The moraine is probably deposited around 1850, and is an example of subrecent moraine ridge. Photo: E. Anda.

Fig. 4. Moraine ridge, east of Sørbreen, stage I, older than subrecent. Photo: A. Hiksdal.

Reconstruction of the glacier front variations from historic sources

The reconstruction concentrates on Sørbreen (Fig. 5). This is the most visited glacier on the island, and the proglacial area is a key area for the lichenometric study.

Maps and descriptions from 1632 (Blaeu 1662) and from 1817/18 (Scoresby 1820), indicate that the glacier did not reach the sea at these periods and was smaller than during its maximum subrecent extent. However, these descriptions cannot be considered wholly reliable.

Sørbreen was near its maximum subrecent extent during 1861 (Vogt 1863). A detailed sketch shows the glacier reaching the sea, and the glacier surface nearly level with the high lateral moraines. A second sketch shows that Sigurdbreen and Smithbreen, on the NE side of Beerenberg, were also near their maximum subrecent extent. The observations of Smithbreen are important because this glacier did not reach the sea; Sørbreen terminated in the sea also in 1878 (Mohn 1878, 1882), but the elevation of the glacier surface cannot be estimated from this source.

A map of the island and descriptions of several glaciers were made by the Austrian expedition in 1882/83 (Boldva 1886). At this time the front of Sørbreen disappeared under moraine material 80 m from the sea. The glacier surface was 30 m below the top level of the lateral moraines at elevation of 150 m a.s.l.

Flint (1948) described Sørbreen after a short visit in 1937. The front was then about 600 m from the sea. The lowest part of the glacier tongue, which was covered by supraglacial material, was gently-sloping and seemed stagnant. The following year Jennings (1939, 1948) stated that the glacier front was 960 m from the sea. Comparison of the sketch maps made by Flint and Jennings suggests that the latter misinterpreted the boundary of moraine-covered ice as the glacier front.

Norsk Polarinstitutt constructed a topographic map of Jan Mayen in 1959, based on aerial photographs taken during 1949 and 1955. The glaciers were mapped from the 1949 photography. Sørbreen was at this time 1200 m from the sea, which is the smallest recorded extent of the glacier. This was also the case for many other glaciers. However, the areas north and west of Beerenberg

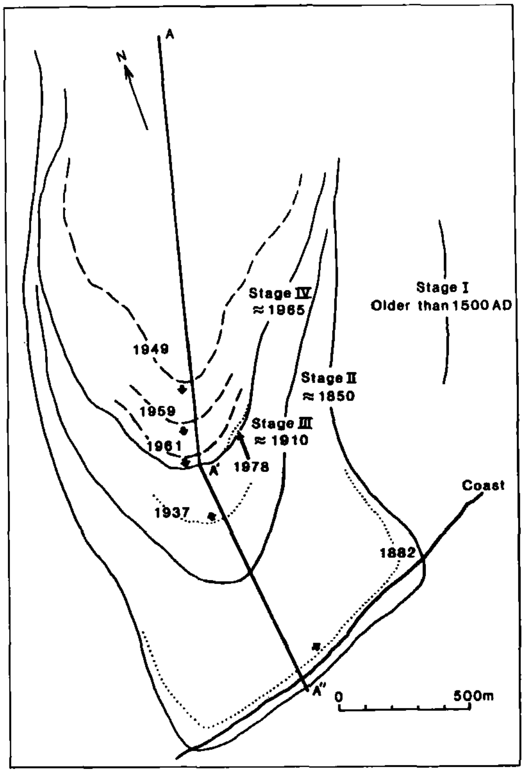

Fig. 5. The frontal position of Sørbreen at different times. Solid lines indicate culmination of advances, dashed lines intermediate position during advancement, dotted lines intermediate during retreat. The arrows indicate whether the glacier was advancing or retreating.

were covered by new snow during the 1949 photography, which makes it difficult to determine the exact position of the glacier fronts here.

University of London expeditions made extensive studies of Sørbreen in 1959 and 1961 (Fitch et al. 1962; Kinsman & Sheard 1963). The glacier had advanced 100 m between 1949 and 1959, and the front was steep. The glacier had advanced an additional 124 m during the next two years, but the front was now more gently sloping. The velocity of the glacier tongue at 310 m elevation had decreased during this time from around 1 m/day to only 0.07 m/day. They also observed that several other glaciers had advanced after 1949.

Aerial photographs from 1975 (Norsk Polarinstitutt) show that Sørbreen had advanced further after 1961. The front part of the glacier seemed to be stagnant and the glacier front had probably been in the same position for several years. This suggests that the advance culminated around 1965. The supraglacial material had reduced the surface ablation and thus slowed the retreat of the glacier front (Anda 1980). This situation persisted until 1978, when only a small part of the glacier front had ablated back compared with the position in 1965 (Fig. 5).

The results of the reconstructions are shown in Figs. 5 and 6. These indicate that Sørbreen is sensitive to climatic change, and seems to be representative of the other glaciers around Nord-Jan.

Table 1. Frontal position of Jan Mayen glaciers at various times. Numbers give distance from the sea (c. = approximate), except in the case of Dufferinbreen, where they give elevation at the front. The coastline by this glacier was changed by the volcanic eruption in 1970, which also caused extra melting of the glacier. References are given in the text.

	Maximum	Year A.D.									
	extent	1632	1817	1861	1876	1882	1937/8	1949	1959	1961	1975
Sørbreen	0	>0	>0	0	0	<80	600	1200	1040	920	890
Petersenbreen	0	0	0	0	0	0	c. 400				550
Willebreen/ Clarkebreen	0	0	0	0	0	0	0	0		0	25
Griegbreen	0	0	0	0	0	0	0	c. 780	0	0	50
Prins Haralds Bre/Frielebreen	0	0	0	0	0	0	0	0	0	0	0
Dufferinbreen m a.s.l.	0	0	0	0	0	0	150	250		200	400
Svend Foynbreen	0				0	0	0	0	0	0	0
Kjerulfbreen & Weyprechtbreen	0				0	0	0	0	0	0	0
Hamarbreen	0										25
Jorisbreen	0										25
Charcotbreen	0					100	c. 180				130
Kerckhoffbreen	700					1500		2250			2150

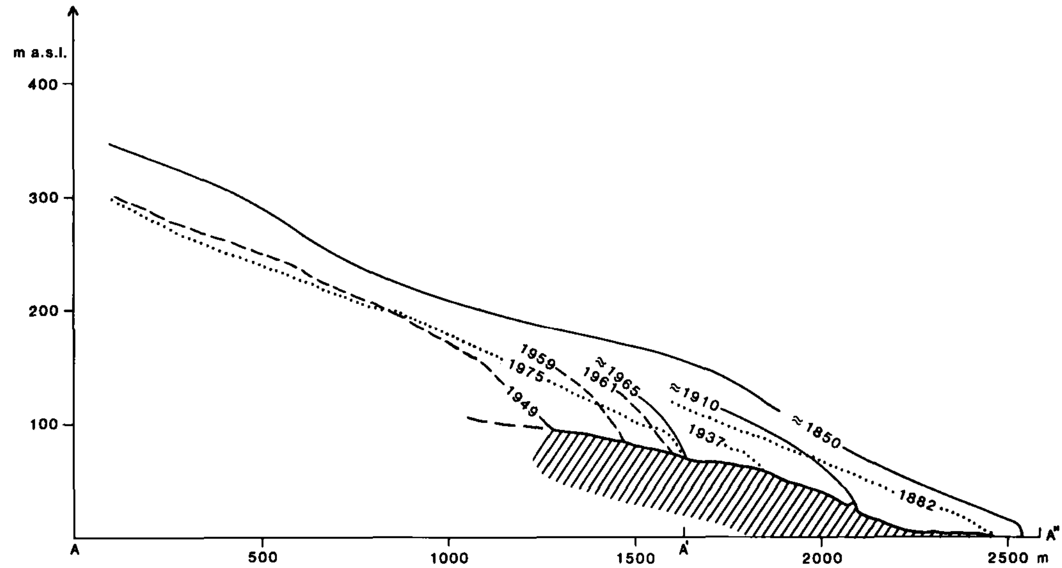

Fig. 6. Length profiles of Sørbreen along A–A'–A" (Fig. 5) at various times.

Lichenometric dating of the moraines

Lichenometric datings had not previously been done at Jan Mayen. Thus a growth curve had to be established. *Rhizocarpon geographicum* was used for this study, this is a common lichen on Jan Mayen (Lynge 1939). The study followed the methodology of Webber & Andrews (1973), by measuring the dimensions of the largest lichen found on each surface. The measurements were done during the 1978 summer.

Point A on the growth curve is from a basal moraine just in front of Sørbreen (Figs. 7, 8). The glacier retreated from this surface between 1937 and 1949. The locality lies closest to the glacier position from 1937, and the glacier was then stagnant. On this basis the surface is taken to have been exposed around 1940. Maximum lichen size on this surface was 11 mm.

Point B on the growth curve is moraine stage III in front of Sørbreen (Figs. 7, 8). This was deposited between 1883 and 1937. Fitch et al. (1962) suggest that the moraine was deposited around 1910. This seems reasonable, as considerations of the glacier profiles and annual lowering indicate that the moraine was deposited between 1900 and 1920. The maximum size of lichen here was 19 mm.

Point C on the growth curve is a lava formation in Schmelckdalen-Laguneflya, located 5 km west of Sørbreen (Figs. 7, 8). This was probably formed by a volcanic eruption in 1818, although it may also have been from an eruption in 1732 (Imsland 1978). Maximum size was here 38 mm.

According to this the growth rate of *Rhizocarpon geographicum* on Jan Mayen is one-third the growth rate on South Iceland (Jaksch 1975), half of that at Jostedalsbreen/Jotunheimen in Norway (Andersen & Sollid 1971), and three times that at south-west Greenland (Pitman

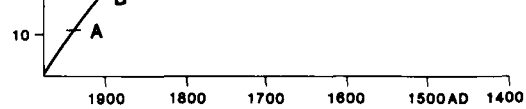

Fig. 7. Growth curve of *Rhizocarpon geographicum* at Jan Mayen, in terms of diameter of largest lichen. The curve gives minimum ages above 55–60 mm.

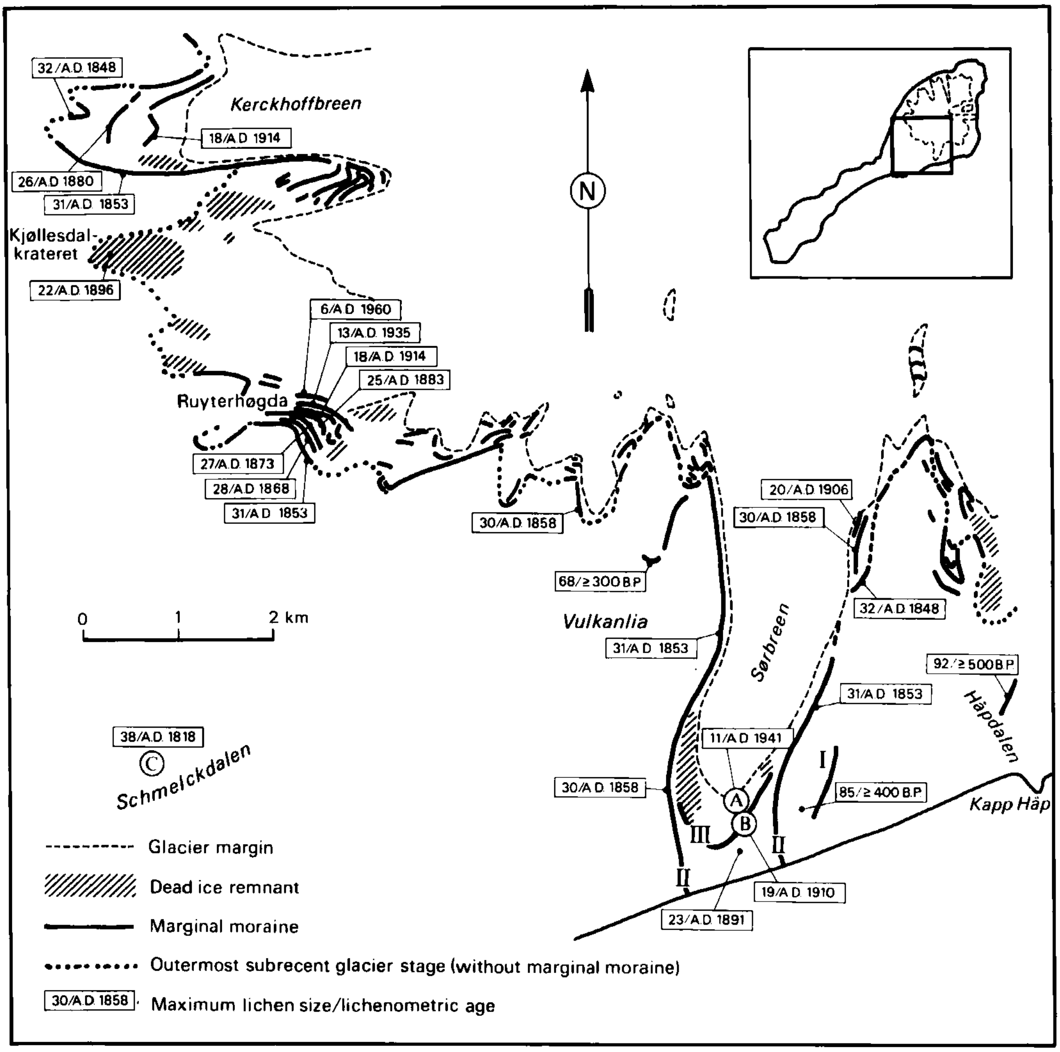

Fig. 8. Localities of moraines dated by lichenometry. The growth curve (Fig. 7) is based on localities A, B, and C.

1973). The method can only be used for a short time span at Jan Mayen. Measurements at surfaces known to be of old age show that the growth rate decreases/stagnates at 55–60 mm, corresponding to a lichenometric age of around 300 years. Lichen larger than this thus shows only minimum ages. The largest lichens found were nearly 100 mm, corresponding to a minimum age of 500 years. The main reasons why the growth rate stagnates are probably solifluction processes, frost action, moss vegetation, and in some cases wind erosion.

The size of the lichens indicates minimum ages of 500 years on three moraine stages at terminal/lateral moraine in Håpdalen (Fig. 8), 400 years at moraine stage I (lateral moraine) by Sørbreen, and 300 years at terminal moraine in Vulkanlia. Even though all these ages are uncertain they show that there has been a glacier advance older than 300 years. All these moraines lie outside the outermost subrecent glacier deposits.

Dating of the other moraines gave lower ages. The outer subrecent terminal stages were dated to 1850 A.D. over the whole studied region. One exception was surface moraine over dead ice remnants by Kjøllesdalkrateret. The maximum lichen size here was 22 mm, corresponding to around 1900 A.D. The growth here has probably stagnated because of thermokarst, which causes unstable terrain.

The other well-developed terminal stages were dated to A.D. 1910–1920 and 1960–1965, and the less-developed stages to around A.D. 1860–1880 and 1935.

It is difficult to quantify the uncertainties in the datings. We have already mentioned the uncertainties in the growth curve. The measurements were done on the south and south-western side of Nord-Jan in the elevation interval 0–700 m. Similar maximum lichen sizes on the outer subrecent stage suggest equal growth rates throughout the studied area. The growth is constant over a considerable elevation interval also in the Jostedalsbreen/Jotunheimen region (Andersen & Sollid 1971; Matthews 1974).

Some potential errors are as follows. Older lichen may be included in younger moraines in several ways: blocks with lichen may be incorporated in push moraines, mass transport may carry blocks with lichen down to younger moraines, and lichen may grow on supraglacial material (Griffey 1978; Andersen & Sollid 1971). The latter phenomenon is in particular a likely source of error on Jan Mayen. The datings may give too low ages if the ground is unstable. This occurs especially on ice cored moraines (Griffey 1978), thus this is also a likely source of error.

Comparison of glacier fluctuations and meteorological data

Following Liestøl (1967) we take the winter precipitation and the summer temperature as the principal meteorological elements that determine the mass balance of the glacier. These give a measure of the winter and summer balances (accumulation and ablation). In this connection 'winter' is taken as the accumulation season, and is defined as all the year apart from July and August. 'Summer' refers to the ablation season, and is taken as the months June to September. This means two months of overlap and transition, which is a reasonable approximation to the complex reality, with varying lengths of season from year to year and with location on the glacier.

The meteorological station has been moved several times since it was established in 1922. The four main locations are shown in Fig. 1, but it was also moved shorter distances several times in the first three periods. Parallel temperature measurements show that a continuous temperature curve can be constructed, whereas this can not be done for the precipitation (Steffensen 1982). Analyses of precipitation and wind data suggest that most winter precipitation arrives with winds from the north-northwest (Steffensen 1982; Anda 1980). Brinken and Libergsletta (No. 3 in Fig. 1) are then on the windward side, while the other localities are on the lee side. It is therefore likely that the precipitation recorded for Brinken and Libergsletta should be reduced to obtain a homogeneous curve for the Jan Mayen precipitation. The lack of longer parallel series, in particular for the precipitation in the form of snow, prevents a quantification of this reduction.

Lamb et al. (1962), Fitch et al. (1962), and Sheard (1965) concluded that the glacier advances around 1960 were caused by increased precipitation from 1947 through the 1950's (Fig. 9). This was the period the meteorological station was located at Brinken and Libergsletta and, as referred above, the apparent increase in precipitation is probably not real. Lamb et al. (1962) also suggest that low temperatures in the 1940's may have contributed to the glacier expansion, and refer to low mean annual temperatures. Sheard (1965) considers seasonal trends in temperature and precipitation, but unfortunately uses the 0°C temperature at sea level to define the ablation season on the glaciers, which makes this unreasonably long, from May to October. None of these authors seem to have considered the changes in location of the meteorological station to have been of importance for the meteorological record.

We believe there is good correlation between summer temperature at sea level and the ablation of the glacier even though this is complicated by the particular temperature distribution over the glaciers, with frequent inversions in the lower layers (Anda 1980). The summer temperatures (Fig. 9) were very high during the 1930's. This may have caused the glacier retreat from 1910–1920 to near 1950. We conclude that the reduction in summer temperatures from around 1940 to the mid-1960's is the main cause for the glacier expansion around 1960.

This explanation is also supported by mass transport considerations. Mass balance measurements of Sørbreen are available for the lower half of Sørbreen, up to 1100 m elevation (Orheim 1976). It seems likely that the upper reaches of the glacier have no proper summer season, and that practically all precipitation here is in solid form. Over the lower parts of the glacier the

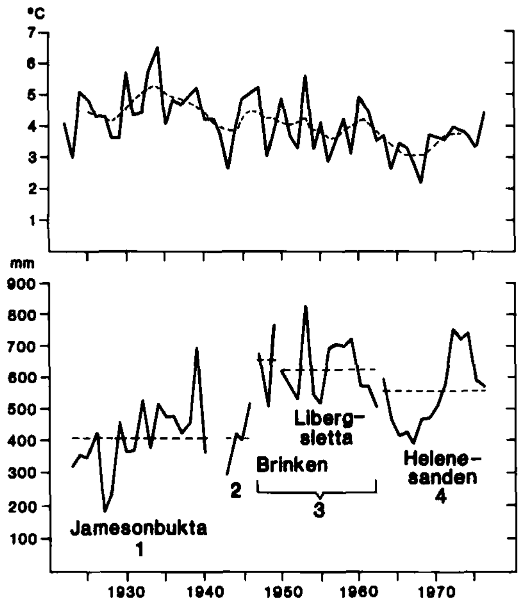

Fig. 9. Above: Mean temperature for the months June–September. The dashed curve is averaged using the formulae

$$Tn = 1/16(Tn - 3 + 2Tn - 2 + 3Tn - 1 + 4Tn + 3Tn + 1 + 2Tn + 2 + Tn + 3),$$

where Tn – 3 refers to the temperature three years before year n, etc. *Below:* Precipitation for the months September–June (accumulation season). The horizontal lines show the mean precipitation at the various localities. The numbers for the meteorological stations correspond to the numbers given in Fig. 1. Data: Steffensen (1969, 1982) and the Norwegian Meteorological Institute.

temperature variations may cause large variations in the amount of precipitation which falls in solid form. This glacier, which covers an elevation interval of nearly 2000 m over a length of 8 km, will have a varying response to different changes in mass balance. The glacier front will respond much quicker to changes in summer temperatures and net ablation than to changes in precipitation, because the former influences mostly the lower parts of the glacier, whereas the precipitation variations are most important around the central and upper part (1000 to 2000 m a.s.l.). Using the concept of Nye (1958) and Weertman (1958) that a travelling wave will move at four times the ice velocity, we find from the velocity measurements in 1961 (Fitch et al. 1962) that a wave from 910 m elevation would take 10–20 years to reach the frontal zone of Sørbreen, and effects from mass balance changes from higher on the glacier would of course arrive later. Thus, if the glacier advance that had started by the late 1950's was caused by increased precipitation, then this increase should have occurred prior to 1947.

The main features of the glacier and climatic variations in the NW region of the North Atlantic Ocean

The main feature of the climate in the Iceland and East Greenland region is the Greenland–Arctic high pressure area, and the North-Atlantic low pressure tracks (Petterssen 1969; Steffensen 1982).

Two neoglacial phases are described from Iceland (Thorarinsson 1964; Bergthorsson 1969). Some glaciers had their greatest Holocene expansion around 2500 B.P., but the majority had their largest expansion during 1750–1900 A.D. The most marked advances culminated around 1750, 1850 and 1890, with the largest expansion around 1850. The glaciers have since retreated considerably, especially after 1930. Several glaciers have advanced again after 1960. A reconstruction of the temperature variations over the past 1000 years based on the sea ice variations shows particularly low temperatures during the 18th and 19th centuries (Koch 1945; Bergthorsson 1969).

Little is known of the Holocene glacier fluctuations in East Greenland. Marginal stages from around 6700 B.P. and from historic time are described from Innlandsisen (Funder 1978). Accumulation rate curves from deep ice cores in Greenland show that there was less precipitation east of the ice divide during 1550–1720 A.D., and more on the west side, indicating fewer low pressure passages along East Greenland at this time (Reeh et al. 1978).

We assume from the limited data available that the climatic variations in Iceland, East Greenland and Jan Mayen were parallel during the last few thousand years. The variations are results of the interplay between the Greenland–Arctic high pressure area and the North Atlantic low pressure tracks. The extent of the high pressure area is determined by the land mass of Greenland together with the surrounding ice covered seas (Jonsson 1978). The subrecent glacier advance probably resulted from a more Arctic-continental climate than at present with expanded high pressure area and increased sea ice cover. The ablation was reduced as a result of short and cold summer seasons with more northerly winds.

Dibben (1965) has shown for Sørbreen that the surface ablation is smallest during non-frontal weather patterns. The expanded high pressure area probably resulted in less precipitation than at present, but with a larger proportion in the form of snow.

Conclusions

Two phases of Holocene glacier expansion are identified at Jan Mayen, one during the past few centuries, and one considerably older. The latter may have occurred around 2500 B.P., based on assumed correlation with glacier expansion in Iceland. All mapped moraines are on Nord-Jan and no evidence has been found for glacier activity at Syd-Jan in postglacial times.

During the subrecent the glaciers had their maximum expansion around 1850 A.D. Glacier retreat started after 1910, and accelerated after 1930, and the glacier extent was minimum in historic time around 1950. A subsequent glacier advance culminated around 1960–1965.

Climate during the subrecent period of glacier expansion was probably more arctic-continental than today, with fewer low pressure systems. The glacier advances at this time were mainly caused by reduced ablation resulting from short and cold summer seasons. Also the most recent advances, around 1960, seem to have been caused by reduced ablation resulting from lower summer temperatures.

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References

Anda, E. 1980: *En glasiologisk og glasialgeologisk undersøkelse på Jan Mayen.* Unpublished Cand. real. thesis. University of Bergen. 65 pp + 65 pp maps & Figs.

Andersen, J. L. & Sollid, J. L. 1971: Glaciological chronology of and glacial geomorphology in the marginal zones of the glaciers Midtdalsbreen and Nigardsbreen, south Norway. *Nor. Geogr. Tidsskr. 25,* 1–38.

Bergthorsson, P. 1969: An estimate of drift ice and temperature in Iceland in 1000 years. *Jökull 19,* 94–101.

Blaeu, 1662: Insvla quæ a Ioanne Mayen. Nomen Scripto. In *Atlas Major Vol. 1,* 19–21, + map. Amsterdam.

Boldva, A. A. B. von 1886: Aufnahme und Beschreibung der Insel Jan Mayen. Beobachtungen über Gletscherbewegung . . . In *Die Österreichische Polarstation Jan Mayen, v. 1, part 2 (Kaiserlichen Akademie der Wissenschaften).* K. Gerold's Sohn, Wien. 50 pp.

Denton, G. H. & Karlen, W. 1973: Holocene climatic variations – their pattern and possible cause. *Quaternary Research 3,* 155–205.

Dibben, P. C. 1965: A heat-balance study at Sørbreen, Jan Mayen. *Journal of Glaciology 5,* 793–803.

Fitch, F. J., Kinsman, D. J. J., Sheard, J. W. & Thomas, D. 1962: Glacier readvance on Jan Mayen. IUGG/IASH Obergurgl Symposium, 10–18 Sept. 1962. *Intern. Association of Scientific Hydrology Publ. 58,* 201–211.

Fitch, F. J., Nairn, A. E. M. & Talbot, G. J. 1965: Paleomagnetic studies on rocks from North Jan Mayen. *Norsk Polarinstitutt Årbok 1973,* 49–60.

Flint, R. F. 1948: Glacial geology and geomorphology. The coast of Northeast Greenland. With hydrographic studies in the Greenland Sea. The Louise A. Boyd Arctic Expedition of 1937 and 1938. Pp. 91–210 in Boyd, L. A. (ed.): *American Geogr. Soc. Publ. 30.*

Fredskild, B. 1969: A postglacial standard pollendiagram from Peary Land, north Greenland. *Pollen Spores 11,* 573–583.

Funder, S. 1978: Holocene stratigraphy and vegetation history in the Scoresby Sund area, East Greenland. *Bull. Grønlands geol. Unders. 73.* 66 pp.

Griffey, N. J. 1978: Lichen growth on supraglacial debris and its implications for lichenometric studies. *Journal of Glaciology 20,* 163–172.

Griffey, N. J. & Matthews, J. A. 1978: Major neoglacial glacier expansion episodes in Southern Norway: Evidence from moraine ridge stratigraphy with C dates on buried palaeosols and moss layers. *Geografiska Annaler 60A,* 73–90.

Imsland, P. 1978: The geology of the volcanic island Jan Mayen, Arctic Ocean. *Nordic Volcanological Institute 78 13.* University of Iceland, Reykjavik, 74 pp.

Jaksch, K. 1975: Das Gletchervorfeld des Solaheimajökull. *Jökull 25,* 34–38.

Jennings, J. N. 1939: The glaciers of Jan Mayen. *Geogr. Journal 94,* 128–131.

Jennings, J. N. 1948: Glacier retreat in Jan Mayen. *Journal of Glaciology 1,* 167–181.

Jonsson, T. 1978: *Drivis og negative temperaturavvik i Island.* Unpublished Cand. real. thesis. University of Bergen. 155 pp.

Kinsman, D. J. J. & Sheard, J. W. 1963: The glaciers of Jan Mayen. *Journal of Glaciology 4,* 439–448.

Koch, L. 1945: The East Greenland ice. *Medd. om Grønland 130 (3),* 195 pp.

Lamb, H. H., Probert-Jones, J. R. & Sheard, J. W. 1962: A new advance of the Jan Mayen glaciers and a remarkable increase of precipitation. *Journal of Glaciology 4,* 355–365.

Liestøl, O. 1967: Storbreen glacier in Jotunheimen, Norway. *Norsk Polarinstitutt Skrifter 141.* 63 pp.

Lynge, B. 1939: Lichens from Jan Mayen. *Skrifter om Svalbard og Ishavet 76.* 55 pp.

Matthews, J. A. 1974: Families of lichenometric dating curves from Storbreen gletcheroverfeld, Jotunheimen, Norway. *Norsk geogr. tidsskr. 28,* 215–238.

Mohn, H. 1878: Den norske Nordhavsexpeditions Reise til Jan Mayen. *Naturen 2,* 153–157.

Mohn, H. 1882: Geografi og naturhistorie. *Den Norske Nordhavs-Expedition 1876–1878,* 3–29.

Nye, J. F. 1958: A theory of wave formation in glaciers. IUGG/IASH Chamonix Symposium, Sept. 16–24, 1958. *Intern. Association of Scientific Hydrology Publ. 47,* 139–154.

Orheim, O. 1976: Bremålinger på Jan Mayen. *Norsk Polarinstitutt Årbok 1974,* 249–252.

Petterssen, S. 1969: *Introduction to Meteorology.* McGraw-Hill Book Co., N.Y. 333 pp.

Pitman, G. T. K. 1973: A lichenometric study of snow patch variations in the Frederikshaab district, south-west Greenland. *Bulletin Grønlands geol. Unders. 104.* 31 pp.

Reeh, N., Clausen, H. B., Dansgaard, W., Gundestrup, N., Hammer, C. U. & Johnson, S. J. 1978: Secular trends of accumulation rates at three Greenland stations. *Journal of Glaciology 20,* 27–30.

Scoresby, W. jr. 1820: *An Account of the Arctic Regions, with a History and Description of the Northern Whale-fisheries. A.* Constable & Co. Edinburgh, 2 vols. 653 & 582 pp.

Sheard, J. W. 1965: Seasonal weather trends in relation to fluctuations of the Jan Mayen glaciers since 1920. *Journal of Glaciology 5,* 805–811.

Siggerud, T. 1972: The volcanic eruption on Jan Mayen, 1970. *Norsk Polarinstitutt Årbok 1970,* 5–18.

Steffensen, E. 1969: The climate and its recent variations at the Norwegian Arctic stations. *Meteorologiske Annaler 5,* 215–349.

Steffensen, E. 1982: The climate at Norwegian Arctic stations. *Klima 5,* 3–44.

Thorarinsson, S. 1964: On the age of the terminal moraines of Bruarjökull and Halsajökull. *Jökull 13,* 67–75.

Vinje, T. 1976: Sea ice conditions in the European sector of the marginal seas of Arctic, 1965–1975. *Norsk Polarinstitutt Årbok 1975,* 163–174.

Vogt, C. 1863: *Nordfarth entlang der Norwegischen Küste, nach dem Nordkapp, den Inselen Jan Mayen und Island auf dem Schooner Joachim Hinrich unternommen während der Monate Mai bis Oktober 1861.* Carol Zugel, Frankfurt am Main. 429 pp.

Webber, P. J. & Andrews, J. T. 1973: Lichenometry: A commentary. *Arctic and Alpine Research 5,* 295–302.

Weertman, J. 1958: Travelling waves on glaciers. IUGG/IASH Chamonix Symposium, Sept. 16–24, 1958. *Intern. Association of Scientific Hydrology Publ. 47,* 162–168.