A STUDY OF FLANDRIAN GLACIER FLUCTUATIONS IN TUNSBERGDALEN, SOUTHERN NORWAY

DEREK N. MOTTERSHEAD & R. LINDSAY COLLIN


Variations in the extent of Tunsbergdalsbreen over the last 9200 years are considered, drawing on evidence from a variety of sources. Stratigraphy, radiocarbon dates, lichenometry, and a variety of historical data are reviewed. It is shown that the glacier receded rapidly between 9200 and 8100 B.P., shrinking to a size smaller than the present between the latter date and 3800 B.P. A subsequent readvance culminated in the mid-eighteenth century, since which time there has been a generally increasing rate of recession.

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The Tunsbergdalsbreen, a valley glacier some 10 km long, is the largest outlet glacier of the Jostedalen icecap in southern Norway (Fig. 1). It has been visited and studied by several previous authors. In 1868 it was visited by C. de Seue, who published two years later a rough map and a description of the lower part of the glacier. During the first decade of the present century the writings, photographs, and records of Rekstad (1901, 1903, 1905, 1910, 1911) afford much valuable evidence as to the state and fluctuations of the glacier at that time. Rekstad also organised the measurement of the annual recession of the snout over the period 1900–1947. The results of this work are quoted by Fægri (1948). The glacier was visited by various parties of the Brathay Exploration Group during the period 1956 to 1966, and associated with their work Howarth (1963) offers a discussion of the geomorphology of the proglacial area. Kick (1966) produced maps of the glacier as it was in 1937 and 1957 by photogrammetric methods. Håtling (1967) has produced a more recent description and a morphological map of Tunsbergdalen. Finally Vorren (1973) has described features of deglaciation in Leirdalen, the lower part of Tunsbergdalen.

General description
Tunsbergdalen (Fig. 2) is trough-like in form, 1 km broad and incised to a depth of up to 1000 m below the surrounding divides. The valley floor beyond the glacier snout consists of several distinct types of terrain.
Fig. 1. Tunsbergdalsbreen – general location map.
Fig. 2. Tunsbergdalen – topography and prominent moraine ridges. Peat samples for radiocarbon dating were taken from sites A and B.
In 1973 the glacier terminated on the upvalley side of a large amphitheatre cut in solid rock which contained a lake some 200 m across (Fig. 3). This amphitheatre is formed by a rock bar, composed of granite-gneiss in common with the rest of Tunsbergdalen. The rock bar is trenched deeply by the main proglacial stream which drains the amphitheatre lake. Much of the rock bar and amphitheatre is coated with a thin and inconsistent veneer of glacial sediments, the only major exception being the sheet of till across the western slopes of the latter.

At a distance of 1 km from the snout, bedrock plunges abruptly beneath a valley infill of glacial and fluvioglacial sediments. For a distance of 1.5 km down valley from the rock bar there is a series of neoglacial recessional moraines, recording several stages in the retreat of the glacier snout. The morphological pattern here is complicated by the presence of the Tverrdalen, a side valley which hangs some 200 m above the west side of Tunsbergdalen, approximately 0.5 km south of the rock bar. The Tverrdalen contains streams which are fed by the melting of icefields on the surrounding plateau. The main stream from Tverrdalen plunges down into Tunsbergdalen, where it splits into five and sometimes six distributaries which flow to join the main proglacial stream. The Tverrdalen streams have clearly had a great influence on the moraine deposits of Tunsbergdalen, and several moraine ridges have been destroyed, breached, or trimmed by these streams, which have also deposited alluvial gravels in great spreads in the intermoraine areas. The surface morphology in this zone therefore consists entirely of moraine ridges and spreads of alluvial gravels.

Fig. 3. View across the amphitheatre in Tunsbergdalen, showing the position of the glacier snout in August 1973. The lake in the foreground is some 200 m across.
The moraine system of Tunsbergdalen thus consists of a dissected series of arcuate ridges. The larger ridges reach a maximum height of 7–9 m in the centre of the valley, generally declining towards the valley sides. Whilst in their central parts these moraines are comprised of material ranging from fine sand to boulders, they tend to decline to small boulder ridges at the extreme lateral margins beneath the rock bar.

The degree of destruction of the ridges varies over the valley. The terminal ridge system is breached only by the present outwash stream and at the western margin by a channel now dry. This dry channel presumably represents the outlet of the Tverrdalen stream diverted along the margin of the ice when the glacier obstructed its entry into the main valley. The only other moraine ridge in a comparable state of preservation is the youngest one of the series. This lies just upvalley of the Tverrdalen confluence and is breached only by the proglacial stream. The intervening moraines are in varying degrees of preservation. Almost complete destruction has taken place on the western side of the valley immediately in front of the youngest moraine. On the eastern side of the main channel destruction has been less severe, although several large areas of outwash channel are evident. The discharge of the proglacial stream is augmented not only by the waters of the Tverrdalen stream, but has in the past also been increased by the periodic release of water from an ice-dammed lake, Brimkjelen, up-glacier. The pattern of stream activity has therefore varied considerably, and Rekstad’s photographs show the main river channel to be following a course rather different from its present one.

The valley moraines are quite complex in form, and all of the more important ones are multiple ridge features. The terminal moraine, for instance, consists of at least three, and sometimes four, distinct ridges, separated by marked troughs. This pattern is typical of the eighteenth century terminal moraines throughout the region. The other major moraines are also multiple features, but in these cases the ridges are piled up more closely upon one another. The intricate pattern of ridge crests is shown in generalized form in Figs. 2 and 4.

The general nature of the glacial deposits in Tunsbergdalen is very coarse. Nowhere was a significant quantity of material finer than silt observed. The valley moraines and the veneer of till on the rock bar both consist of stones and boulders set in a sandy matrix. This lack of fines ensures that the deposits are always loose and unconsolidated, which renders it extremely difficult to cut a section through a moraine and retain the cut face. Observations of moraine fabric are thus strictly limited.

The great contrast between the volume of glacial deposits below the rock bar, and those on the rock bar, prompted a consideration of the origin of the material comprising the moraines. Accordingly samples of 100 stones larger than 30 mm long axis were taken for analysis. The derivation of the samples and their characteristics are set out in Table 1, and the information is displayed graphically in Figs. 5 and 6.
Fig. 4. Detailed map of the proglacial area in Tunsbergdalen, showing recessional moraines and lichenometric dates.
Table 1. Valley moraine sediment characteristics

<table>
<thead>
<tr>
<th>Material</th>
<th>Sample</th>
<th>Mean length (mm)</th>
<th>Mean flatness</th>
<th>Mean roundness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent till</td>
<td>UTL</td>
<td>59.6</td>
<td>64.6</td>
<td>93.6</td>
</tr>
<tr>
<td></td>
<td>LTL</td>
<td>64.8</td>
<td>54.9</td>
<td>78.0</td>
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<tr>
<td></td>
<td>SNT</td>
<td>58.9</td>
<td>59.8</td>
<td>61.6</td>
</tr>
<tr>
<td>Moraine</td>
<td>MT 1</td>
<td>58.4</td>
<td>51.2</td>
<td>190.7</td>
</tr>
<tr>
<td></td>
<td>MT 2</td>
<td>65.0</td>
<td>43.5</td>
<td>165.9</td>
</tr>
<tr>
<td>Outwash gravel</td>
<td>GR 1</td>
<td>74.1</td>
<td>41.8</td>
<td>239.0</td>
</tr>
<tr>
<td></td>
<td>GR 2</td>
<td>76.9</td>
<td>39.1</td>
<td>150.5</td>
</tr>
</tbody>
</table>

In the case of both characteristics – the Cailleux roundness index and the Cailleux flatness index – the valley moraine fabric has a closer affinity with the outwash gravels than with recent glacial deposits. It is both more rounded and less flat than material currently and recently deposited from the ice. Clearly since it was originally released from the ice the valley moraine fabric has undergone a considerable degree of rounding.

It is considered therefore that the material comprising the valley fill was deposited as outwash gravel during a previous recession of the glacier. During a readvance the glacier reworked the pre-existing deposits and pushed up the moraine ridges. This hypothesis offers an explanation of why the valley moraine fabric differs so markedly from that of moraines currently forming. If these valley moraines were formed by pushing, clearly a substantial push would be required. The task was probably facilitated by the loose unconsolidated nature of the gravels, but the multiple nature of many of the larger moraines suggests that several pushes were responsible for their formation perhaps over a period of two or more years. Downvalley of the terminal moraine ridge the outwash gravels extend for a distance of some 4 km to the head of Tunsbergdalsvatnet, a lake ponded up by an outcrop of solid rock. The outwash deposits are cobbly in calibre immediately outside the moraine, gradually becoming finer downvalley. They form a nearly flat valley floor, with a downvalley gradient of ca. 2 m/km across which outwash streams braid widely.

At the rock bar which impounds the Tunsbergdalsvatnet, the valley turns abruptly and runs eastwards for some 3 km. It then comes to its confluence with the main valley, Jostedalen, above which it hangs by some 300 m. In this lower section the valley is known as Leirdalen.

On the valley sides high above Tunsbergdalsvatnet and Leirdalen there is a series of older moraines. These have been previously described by Håtling (1967) and Vorren (1973), and are represented in generalised form on Fig. 2.

On the east side of the valley, on the gentle slopes at the crest of the divide in the angle between Tunsbergdalen and Leirdalen, there are two major lateral moraine ridges. The larger one at 960–880 m is over 1 km long, the smaller one runs from 930–880 m. At least four fragmented subsidiary ridges are present also. The largest ridge has a relief of up to 10 m.
Fig. 5. Moraine fabric – roundness values. Samples as follows: Recent till (UTL, LTL, SNT), Moraines (MT1, MT2), Outwash gravel (GR1, GR2).
Fig. 6. Moraine fabric – flatness index. Sample identification as in Fig. 5.
On the western side of the valley where Tunsbergdalen turns to join Leirdalen up to twelve lateral moraine ridges are present, ranging in altitude from 1040 m down to 730 m. Major ridges occur at altitudes around 840 m and 800 m.

It would be unrealistic to attempt a direct correlation between moraines on opposite sides of the valley on the basis of moraine altitude and size, on account of the complex form of the glacial trough at this point as it turns through a right angle. It is clear, however, that they represent a series of recessional moraines of broadly similar age. They all possess a silty matrix and show well developed soil horizons, leached grey to a depth of 4–8 cm., with a ferruginous illuviated horizon beneath. They have a continuous vegetation cover of Vaccinium, Empetrum, grasses, and shrubs. In terms of location, morphology, fabric, horizonation, and vegetation cover, they are clearly of a different generation than the moraines on the valley floor.

Adjacent to the valley-side lateral moraines on the western side above Tunsbergdalsvatnet, three sets of moraines are at present associated with high-level icefields. These moraines consist generally of free boulders, usually angular, and often exceeding 1 m across. The largest of these ridges associated with the central tongue of ice descending from the Såta icefield attains a relief of 6–7 m and descends to an altitude of 900 m. Multiple ridges are present in the central and northern tongues. The lack of fines precludes soil development and the moraines are well covered with lichens.

**Dating of glacier fluctuations**

Several sources of dating information were employed, and these will be treated in turn.

**Radiocarbon dates**

A radiocarbon date of 9154 ± 62 B.P. (SRR-265) was obtained from the basal 2 cm of peat at a site adjacent to the major moraine of the eastern high valleyside series. The site was a small mire developed in a hollow on the proximal side of the moraine, where 1.3 m of peat overlies stony silt grading down into till. Clearly the peat could not have begun to form until the glacier had started to recede away from the moraine, and it thus postdates the formation of the moraine. Of critical importance is the relationship of the date of formation of the basal peat to the age of formation of the moraine. In this connection it is pertinent that the peat has accumulated in a topographic hollow in an ill-drained site, and it seems reasonable to assume that no great span of time elapsed between the two events. On the rock bar at an altitude of 500 m, a depth of 2 cm of peat has in places accumulated since 1937. Allowing 100 years or more for the development of peat at 100 m altitude in Boreal time, then the glacier presumably began to recede from the moraine prior to 9200 B. P.
The presence of erratic peat in the amphitheatre has been described previously (Mottershead, Collin & White 1974). On the south side of the amphitheatre a bed of peat up to 2 m thick was seen sandwiched between two tills. This is interpreted as representing a non-glacial interval at this point of duration at least as long as the period of formation of the peat. The base of the peat was dated as 8083 ± 100 (SRR-50) whilst a sample from the top layer of the peat yielded a date of 3850 ± 55 (SRR-87). It thus appears that by ca. 8100 B.P. the Tunsbergdalsbreen snout had receded to a position at least as far up valley as its present position, and it did not readvance beyond the amphitheatre for over 4000 years. The post 3850 B.P. readvance is presumed to have culminated in the eighteenth century terminal moraine.

**Historic information**

In this section we will deal with evidence that enables us to reconstruct the position of the glacier snout with at least reasonable certainty at particular points in time.

It is recorded by Rabot (1900) and Rekstad (1901) that glaciers in the Jostedalen area advanced between 1730 and 1742. Rekstad quotes contemporary evidence that the nearby Nigardsbreen was in retreat after 1748, and accordingly dates the formation of terminal moraines of several glaciers in this district, including Tunsbergdalsbreen, as 1743. In the absence of any further evidence, we accept Rekstad's interpretation of the formation of this moraine.

The position of the snout is described by Rekstad (1905) in relation to two marks he made on the rock bar. In addition a photograph taken on 6th September 1900 immediately in front of the ice (Fig. 7A) shows a small moraine which can be positively identified in the field at present by comparison with the photograph. It is reasonable to assume that this moraine was formed in 1900.

A reasonable estimate can be made of the age of the innermost moraine of the recessional series in the proglacial zone. Discussion by Mottershead & White (1973) of the evidence shows that this period following 1903 was a time of complex changes of the ice margin as the glacier accommodated itself to recession around a major bend in the valley. Fægri's (1948) figures of annual recession for the period indicated that a major recession of 67 m took place during 1911–12. Thus the moraine concerned must predate this movement.

The position of the margin in July 1937 is mapped by Finsterwalder and quoted by Kick (1966). It lay at this time across the lower part of the rock bar, where distinctive topography enabled the line to be traced in the field without difficulty.

The 1957 and 1966 ice margins were plotted photogrammetrically from aerial photographs. In both these years the glacier terminated on the upper part of the rock bar.
The terminus in July 1971 and July 1973 was surveyed in the field by parties from Portsmouth Polytechnic to a high standard of accuracy.
Thus we have a reasonable picture of the terminal position of the Tunsbergdalsbreen at several points in time. Clearly the most accurate information relates to 1937 and the years following. These fixed positions are shown in Fig. 4.

Lichenometric data
The lichenometric dating of glacier recession in Tunsbergdalen has been outlined elsewhere (Mottershead & White 1972, 1973). This subject has subsequently seen some discussion (Worsley 1973, Webber & Andrews 1973, Matthews 1974), and accordingly a few further remarks may now be pertinent.

Three points in particular are worthy of emphasis. First in relation to lichen sampling, the present authors support Matthews in employing the average of largest lichens present. This approach is explicitly rejected by Webber & Andrews, who argue that it will underestimate the lichen growth rate. As Matthews rightly points out, however, the assumptions used by Webber & Andrews differ from those of Mottershead & White, and himself. The latter authors are concerned in establishing an empirical curve, relating lichen size to age of substrate, as defined by the sampling methods used. The latter is designed to minimise sampling error and variability and establish an age/size relationship which can then be used for predicting ages of unknown substrates. Webber & Andrews, on the other hand, mistakenly interpret this as a functional growth curve of the optimally growing lichen, which it does not claim to be.

Secondly, serious doubt was cast by Worsley on the general form of lichen growth curve described for Tunsbergdalen. Subsequently Denton & Karlén (1973) have shown a decelerating growth rate and Matthews has demonstrated for the Jotunheimen area an age/size relationship of identical form to that from Tunsbergdalen over a similar range of ages. Privately Mottershead & White were of the opinion that their previously published curve may have represented the upper part of a sigmoidal growth curve, for which they lacked the evidence of the early years. Interestingly Miller (1973) has produced a sigmoidal curve for the growth of Alectoria miniscula based on direct observations in Baffin Island. These observations cause the present authors to retain faith in the approach previously employed in Tunsbergdalen.

Thirdly, Matthews (1974) experimenting with his data, produces a family of nine lichenometry curves, and uses these to predict a range of ages for unknown moraines. His nine curves are based on the principle of using the largest single, largest five, and largest ten lichens from one, three, or five sample plots per moraine. The previous data from Tunsbergdalen were reanalysed along these lines, with the exception that there were insufficient data to consider the largest ten lichens per sample plot. Of the six curves so
produced, the one used previously, using the largest five lichens from each of five sample plots, provided the best fit to the data as recorded by the correlation coefficient. In addition it produced ages for the intervening moraines which most closely approximated the mean predictions of the total family of curves. Accordingly its use is retained.

On the basis of information which has come to light since the original curve was published, there are grounds for minor reassessment of the moraine dates. Whilst the terminal moraine may well have been formed at the height of the glacier advance in 1743, Fægri (1934) has argued critically in respect of Nigardsbreen that recession from this position did not begin until 1748. Since the assumption behind lichen dating is that lichen size reflects the age the substrate was revealed it may well be more appropriate to accept a date of 1748 for this moraine in the lichen curve. Employing 1911, as argued earlier, as the date of the youngest recessional moraine, the lichen curve is amended to the following:

$$\log (x + 28) = 0.0094 y + 1.52$$

when \(x = \) age of substrate
\(y = \) lichen size

On the basis of this curve the dates in Fig. 4 are obtained for the intervening moraines. These dates differ but marginally from the ones originally published.

Lichen were measured also on the icefield moraines, and gave values comparable with those on the terminal moraine on the valley floor.

The lichen sizes and corresponding dates, the latter quoted with one standard error, are presented in Table 2. Recession rates are calculated by dividing the distance between two moraines by the difference in age between them. Clearly this gives only a mean rate of recession between the two points in time, for it is possible that fluctuations took place on a smaller time scale, which are masked by the present data.

Table 2. Lichen sizes, moraine dates and axial recession rates

<table>
<thead>
<tr>
<th>Lichen size (1971) (mm)</th>
<th>Date</th>
<th>Recession (m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>93.4</td>
<td>1748</td>
<td></td>
</tr>
<tr>
<td>82.5</td>
<td>1802 ± 3</td>
<td>0.7</td>
</tr>
<tr>
<td>76.4</td>
<td>1826 ± 2</td>
<td>4.2</td>
</tr>
<tr>
<td>69.4</td>
<td>1850 ± 2</td>
<td>13.3</td>
</tr>
<tr>
<td>65.1</td>
<td>1864 ± 2</td>
<td>7.9</td>
</tr>
<tr>
<td>60.9</td>
<td>1875 ± 2</td>
<td>19.1</td>
</tr>
<tr>
<td>54.5</td>
<td>1891 ± 2</td>
<td>8.7</td>
</tr>
<tr>
<td>53.2 *</td>
<td>1895 ± 2</td>
<td></td>
</tr>
<tr>
<td>51.6</td>
<td>1900</td>
<td></td>
</tr>
</tbody>
</table>

--- omitted due to fragmentary nature of moraine precluding estimation of axial line.
Recent surveys
Recording of the annual recession of Tunsbergdalsbreen was started in 1900 by Rekstad, and continued by Fægri, and more recently by Norges Vassdrags- og Elektrisitetsvesen. The recession data collected in this way are illustrated in Fig. 8. Unfortunately the exact lines along which these measurements were recorded are not known to the present authors, and do not tie up with our measurements of axial recession. Accordingly they are of limited value only. Of greater value are Rekstad's published data re-
Fig. 9. Map of lower rock bar area of Tunsbergdalen, showing the position of the glacier snout in 1900 and 1903, as derived from the photographs and surveys by J. Rekstad.

In the years following 1956 the glacier was visited by parties of the Brathay Exploration Group, who marked with paint on the rock bar successive positions of the ice margin. Two lines of marks, designated A and B, were surveyed by us (Fig. 10) and the recession along these two lines is shown in Fig. 11. Despite their being only 100 m apart the rate of recession clearly differs substantially along these transects. This is for two reasons. First the subglacial surface here is irregular, and the ice is often retreating across a reverse slope which Price (1971) has shown to reduce the recession rate. This is particularly the case with line B. Secondly the lines are be-
coming tangential to the ice margin as the latter retreats, and thus are departing progressively from the line of axial recession. The variability shown by these data underlines the importance of expressing recession figures along a known line, preferably standardised as the axial line.

Fig. 10. Map of the snout of Tunsbergdalsbreen, showing former positions, and surveyed lines of recession A and B.
Discussion

The results put forward in this paper will now be discussed in relation to previous observations and work by other authors. The present work complements that of Vorren (1973) since the oldest features described here are the youngest ones dealt with by him. This small overlap thus provides a degree of continuity between the two studies.

The high valleyside moraines at the southern end of Tunsbergdalen are clearly those described by Vorren and related to his Gaupne Stadial. He traces these moraines through Leirdalen down Jostedalen to a frontal deposit at Gaupne. If this morphological correlation is correct (and the present authors have not worked in the intervening part of Jostedalen), then the date derived for the valleyside moraines calls into question Vorren's
dating of 9700 B.P. for the Gaupne Stadial. The date of 9100 ± 200 which he ascribes to the subsequent Høgemo Stadial would appear to be more applicable to the Gaupne event, whilst the Høgemo frontal deposit and the associated valleyside moraines below the highest one dated here represent more recent episodes as the glacier falteringly receded from its Gaupne position.

Subsequent to ca. 9200 B.P. recession from the Gaupne position would appear to have taken place, slowly at first with intermittent stillstands indicated by the Høgemo frontal deposit and the high valleyside moraines of Tunsbergdalen and Leirdalen. Between 9200 and 8100 BP the Tunsbergdalsbreen must have severed itself from confluence with Jostedalen glacier and receded right up Tunsbergdalen to a position upvalley from the amphitheatre, a distance of some 20 km. How far the glacier shrank is impossible to tell, but it is clear that the minimum value indicated above represents a very considerable wastage in this period.

The Tunsbergdalsbreen remained smaller than its present size from at least 8100 BP until 3800 BP. This is consistent with the assertions by Rekstad (1903) and Liestøl (1969) that glaciers in Norway wasted away almost completely at this time. The evidence put forward here does not support a readvance during the climatic optimum as suggested by Page (1968) for Svartisen, nor readvances at 8000 and 5000 B.P. tentatively suggested by Karlin (1973) for glaciers in the Kebnekaise area.

Evidence for events in Tunsbergdalen between 3850 B.P. and the mid-eighteenth century A.D. is very sparse. It is clear that at some time in this interval (possibly more than once) glacier expansion took place. Liestøl suggests that Norwegian glaciers were regenerated at the beginning of sub-Atlantic time (2500 B.P.), and this period is postulated as a period of glacier expansion in Kebnekaise by Karlén, and it may be that these dates are paralleled by a readvance of Tunsbergdalsbreen. Whether there were one or more readvances in this period is not known, but the next clear expansion for which there is evidence culminated in the mid-eighteenth century. No evidence was found in Tunsbergdalen to suggest that the terminal valley moraine is of substantially different age from the others in the series, as has been shown by Karlén in Kebnekaise and Østrem (1965) for Jotunheimen.

The dates calculated for the recessional moraines from lichenometric evidence show good agreement with historic data, particularly when the recession rate is considered. The gradually increasing rate of axial recession suffers a setback in the period 1850–64. During the early years of this interval, according to Hoel & Werenskiold (1962), cold and wet weather occurred and was associated with glaciers advancing. In the coastal districts of Norway glaciers then shrank markedly till ca. 1870, which tallies with a high mean rate of recession of 20 m/yr for 1864–1875 in Tunsbergdalen. It is interesting to note that the largest of the recessional moraines in Tunsbergdalen is dated at 1875, which is precisely the date attributed on
historical evidence to the largest moraine of a similar series in Nigardsdalen (Andersen & Sollid 1971).

There is apparently some degree of discrepancy between the results put forward here and the annual recession measurements of Rekstad. It is clear, however, that the position of the ice margin fluctuated in a complex manner during the first decade of the twentieth century, as the glacier slewed round a major bend in the valley. Fægri (1948) presents mean values of annual recession at this time which are clearly based on Rekstad's measurements along either side and in the centre of the glacier. Rekstad's photographs of 1903 and 1907 show a clear recession between these two dates, and yet his paper of 1910 tabulates an advance of the middle part of the glacier front of 33.5 m. It is clear, therefore, that conflicting evidence exists as to the behaviour of the glacier at this time. We have argued earlier for a limiting date of 1911 for the innermost recessional moraine, and used this in a calculation of the recession rate for the period 1900–1911, which shows a general slowing down of recession consistent in general terms with Rekstad's date and with the known climatic deterioration of the time.

![Fig. 12. Cumulative axial recession of Tunsbergdalsbreen, 1743–1973.](image-url)
Summary of glacier fluctuations during Flandrian time

The general pattern of fluctuations of Tunsbergdalsbreen during Flandrian time is shown to be as follows. The evidence suggests that prior to 9200 B.P. the glacier extended down into Jostedalen where it was confluent with a trough glacier which extended down to Gaupne. Between that time and 8100 B.P. the terminus receded up valley at least as far as the amphitheatre and possibly further. This rapid shrinkage involved a retreat of the snout at a mean rate of 20 m/yr over a period of 1000 years. At the same time a depth of at least 500 m (the height above the present valley floor of the high valleyside moraines) of ice was wasted from Tunsbergdalen.

The peat in the amphitheatre indicates that at no time between 8100 and 4000 B.P. did Tunsbergdalsbreen exceed its present extent. Subsequently a readvance saw the glacier extend again over the rock bar to form a terminal moraine in the mid-eighteenth century. This readvance was accompanied by extensions of the glacier tongues descending from the Såta icefield above the west side of Tunsbergdalen.

The recent period of shrinkage over the last 200 years is well recorded in a series of recessional moraines, photographs, and records left by previous workers. The recession since 1748, measured along the axial line of the glacier, is shown in Fig. 12, from data tabulated in Table 3. This information is based upon the lichenometric dating of moraines for the period 1748–1891, on Rekstad’s surveyed ice margin positions of 1900 and 1903, Kick’s 1937 position, and our plots of subsequent years.

The initial recession from the 1743 position is shown to have taken place slowly, at a mean rate of 0.9 m/yr throughout the latter part of the eighteenth century. Recession rates are generally higher throughout the nineteenth century, with the exception of the periods 1850–1864, and 1875–1891, which were years of more severe climatic conditions. During the present century recession has generally increased after the first decade, and since 1957 the mean rate has always been at least 30 m/yr, culminating in a value

Table 3. Total axial recession

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean rate (m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1748 – 1802</td>
<td>0.7</td>
</tr>
<tr>
<td>– 1826</td>
<td>4.2</td>
</tr>
<tr>
<td>– 1850</td>
<td>13.3</td>
</tr>
<tr>
<td>– 1864</td>
<td>7.9</td>
</tr>
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<td>– 1875</td>
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<td>– 1911</td>
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</tr>
<tr>
<td>– 1937</td>
<td>17.3</td>
</tr>
<tr>
<td>– 1957</td>
<td>21.0</td>
</tr>
<tr>
<td>– 1966</td>
<td>34.4</td>
</tr>
<tr>
<td>– 1971</td>
<td>30.0</td>
</tr>
<tr>
<td>– 1973</td>
<td>37.0</td>
</tr>
</tbody>
</table>
of 37 m/yr for the central part of the margin between 1971 and 1973. Throughout the last 230 years, therefore, the recession of Tunsbergdalsbreen has, with the exception of three short periods, been generally increasing.

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