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LICHEN GROWTH ON SUPRAGLACIAL DEBRIS AND ITS IMPLICATIONS FOR LICHENOMETRIC STUDIES

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ABSTRACT. Lichens were found growing on some of the supraglacial debris of six small, active, retreating valley glaciers in southern Norway. The circumstances permitting their growth are discussed, as is the possibility of their surviving pro-glacial deposition under current and past conditions. Their occurrence does not appear to present a problem to careful lichenometric surveys of Holocene glacial and fluvio-glacial deposits.

RÉSUMÉ. *Croissance des lichens sur des blocs supraglaciaires et conséquences pour les études lichenométriques.* On a trouvé des lichens en cours de croissance sur quelques moraines supraglaciaires de six petits glaciers de vallées actifs en retrait, dans le Sud de la Norvège. On discute les conditions ayant permis cette croissance ainsi que la possibilité qu'ils aient survécu après un dépôt proglaciaire sous les conditions régnant autrefois et actuellement. Leur présence ne semble pas poser un problème pour les observations lichénométriques minutieuses des dépôts de l'Holocène, glaciaires et fluvio-glaciaires.

ZUSAMMENFASSUNG. *Flechtenwachstum auf glazialem Oberflächenschütt und seine Bedeutung für lichenometrische Studien.* Der Schutt auf sechs kleinen, aktiven, zurückgehenden Talgletschern in Südnorwegen ist teilweise von Flechten bewachsen. Die Umstände, die dieses Wachstum ermöglichen, werden diskutiert, darunter die Frage, ob die Flechten eine voreiszeitliche Ablagerung unter derzeitigen und früheren Bedingungen überleben können. Ihr Auftreten scheint kein Problem für sorgfältige lichenometrische Messungen auf holozänem glazialem und fluvioglazialem Schutt zu bieten.

INTRODUCTION

Lichenometric studies can be used to attempt to estimate the time lapse since the deglacierization of surfaces or the glacier-marginal deposition of glacial and fluvio-glacial landforms. One of the basic assumptions of such studies is that when substrates are deglacierized or landforms produced they do not bear any living lichens. Many studies have supported this assumption but there have been no systematic investigations of supraglacial and pro-glacial debris associated with different types of glaciers in various activity states.

A study of the medial moraine and the recently deglacierized area in front of Storbreen, a short valley glacier in the Jotunheim area of southern Norway (Fig. 1), showed that under certain circumstances lichens can grow on medial moraine debris, survive its deposition on till plains and continue to grow (Matthews, 1973). As these results represent a challenge to the previously mentioned assumption of the lichenometric technique, the natural progression from Matthew's study was to determine whether the Storbreen results were exceptional and, if they were not, to attempt to define the conditions under which they were likely to recur. As a contribution to this task, studies were made of Storbreen and three other central Jotunheimen valley glaciers that had well-developed medial moraines and, in addition, reconnaissance studies were made of two valley glaciers with significant supraglacial debris covers in the Hurrangane area of Jotunheimen (Fig. 1). Since lichens were found to be growing on some of the supraglacial debris on all six glaciers, this paper is able to consider the conditions that permitted their growth, whether they survived the pro-glacial deposition of the debris (recently and in the past), how these results might relate to other glaciers and the consequent implications for lichenometric studies of glacial and fluvio-glacial deposits.

SUPRAGLACIAL DEBRIS

The supraglacial debris on all six glaciers covered very small percentages of the glacier surfaces and was largely concentrated as solitary medial moraines up to 1.8 km long, the remaining debris being small numbers of isolated cobbles and boulders and short debris lines at the fronts of the glaciers (Figs 2 and 3). The current supraglacial debris cover is probably no smaller than it had been during the Holocene; there was certainly no geomorphological evidence to indicate otherwise.

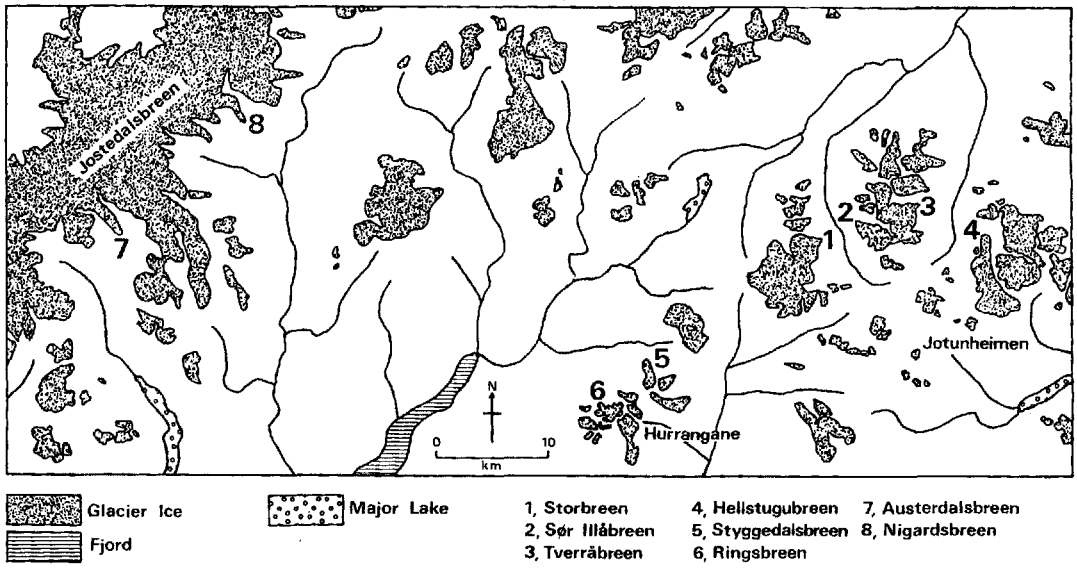

Fig. 1. The location of certain southern Norwegian glaciers (based on Østrem and Ziegler (1969)).

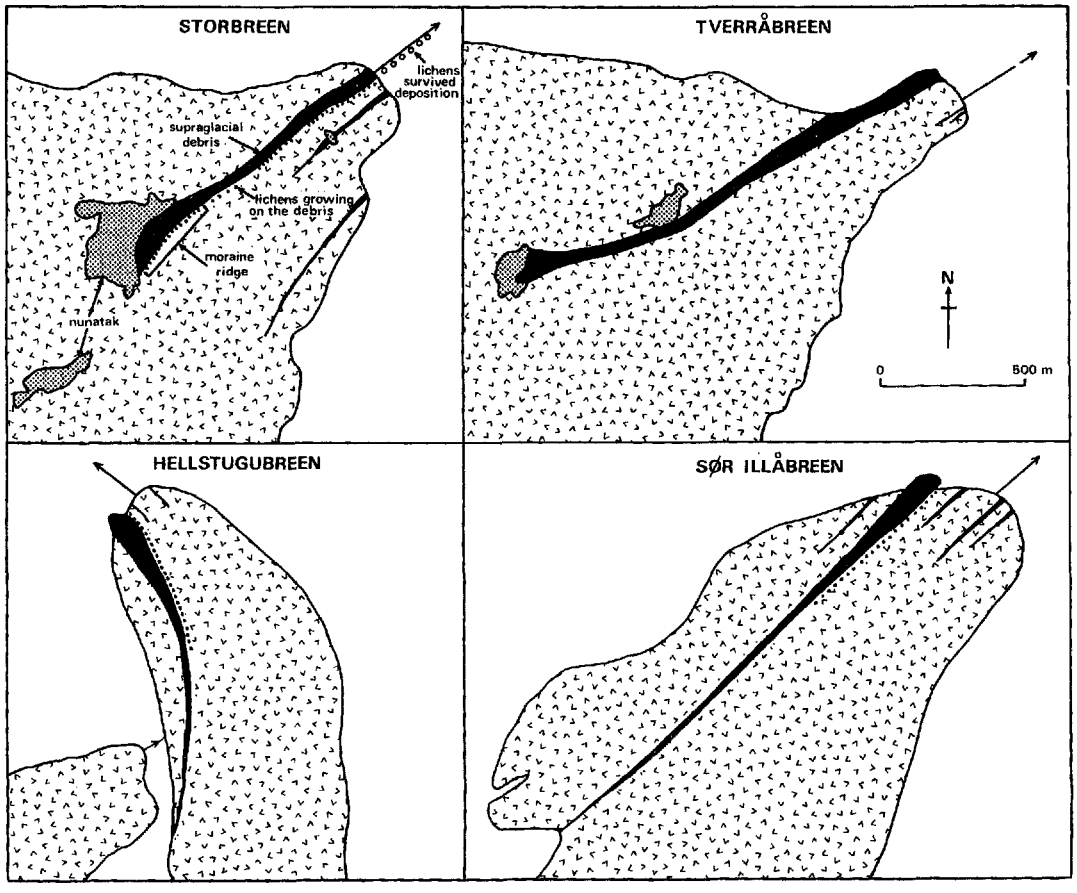

Fig. 2. The supraglacial debris cover of the four Jotunheimen glaciers.

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Fig. 3. The supraglacial debris cover on Hellstugubreen.

Regardless of whether they originated at nunataks or the confluences of ice streams, the medial moraines were morphologically very similar. The only major differences were in respect of their upper sections, where the confluence medial moraines of Hellstugubreen and Sør Illåbreen were reduced to narrow boulder lines. This appeared to have resulted from recent decreases in the flow of the subsidiary ice streams which had reduced the debris supply to the medial moraines. On Storbreen and Tverråbreen, the textural composition of the medial moraines was very similar throughout their entire lengths. The middle sections of all four medial moraines had near constant widths. Farther down-glacier the widths increased gradually, finally widening considerably on the steeper slopes at the glacier snouts, which was the only place where they had developed pronounced ridge forms (Fig. 3).

The widths of the medial moraines were generally below 40 m with maxima of 60 m and, except on Tverråbreen, long stretches of 30 m or less. The debris ranged in size from silt up to boulders 3 m across, with cobble sizes predominating and little silt and sand. The two medial moraines that originated from nunataks included very few boulders and more fine sediment than the other two medial moraines, though, like the other medial moraines, the debris cover was always very thin and boulders were usually perched on very low ice pedestals. In parts of the two former medial moraines the lack of boulders and the thin debris cover gave a "pavement" effect (Fig. 4). On all four medial moraines the amplitude of relief was usually about 2 m, increasing at the snout up to a maximum of 20 m. At the present time, large ridges do not occur at the snouts of Storbreen and Tverråbreen because the main subglacial river emerged beneath the supraglacial debris, and because of the occurrence of a rock knoll at the side of the medial moraine, respectively. The formation of these ridges appeared to be enhanced by the melt-out of limited quantities of sediment from the ice beneath the medial moraines. This englacial sediment was usually fine-grained and was aligned along the longitudinal foliation of the glacier ice which paralleled the medial moraines.

Fig. 4. The "pavement" surface of the middle section of the medial moraine of Tverråbreen. The width of the medial moraine is about 50 m.

The continuity of the medial moraines was enhanced by the smooth, low-angle longitudinal glacier profiles which have resulted from several decades of glacier recession and the absence of strong subglacial bedrock relief. Over most of their lengths the medial moraines had longitudinal gradients of 5–8°, while at the glacier snouts they increased to about 15°. Consequently, they were not affected by crevassing except for two adjacent crevasses in the middle section of the medial moraine of Tverråbreen. There was also little disturbance by the small supraglacial streams which usually flowed parallel to the medial moraines. However, on Storbreen and Sør Illåbreen, low-angle transverse glacier surface gradients have enabled them to cut across a few short sections of the medial moraines.

The boulder lines which occurred on the steep frontal slopes of all four glaciers have, in some instances, produced very low, narrow unstable ridges. Those shown in Figure 3 are typical of their kind, except one on Storbreen which was broader and was associated with a very small nunatak, but was no more stable than the others. A few scattered, non-aligned angular cobbles and boulders occurred on the glacier surfaces apparently as a result of small rock falls on to the glaciers.

Lichen growth on the supraglacial debris

Lichens were found growing on all four medial moraines, though their distribution patterns and concentrations differed considerably. The lichen species were dominated by *Umbilicaria*, *Lecidea*, and *Rhizocarpon*, which studies of pro-glacial areas have shown to be rapid colonizers of deglacierized surfaces (Fig. 5). As lichens are intolerant of unstable surfaces, such as those found on ice-cored end moraines, steep-sided end moraines and rock glaciers, their occurrence on medial moraines can be interpreted as indicating areas of

Fig. 5. A lichen-covered boulder on the lower section of the medial moraine of Sør Illåbreen. Scale is 0.3 m.

relative stability, either at the present time and/or in the immediate past. On all the medial moraines the lichens occurred in areas of cobbles and boulders which were resting against each other, or appeared to have recently been so doing. Through such contact they appeared to have been able to avoid much of the instability that would be expected to result from the differential ablation of ice that is debris-covered and that which has only a very thin cover or none at all.

On Tverråbreen the only lichens on the medial moraine occurred in a very small area close to the glacier's snout, where there was a small group of boulders in the middle of the medial moraine (Fig. 2). The remainder of the medial moraine was dominated by "pavement" surfaces which contained very few boulders. On Sør Illåbreen and Hellstugubreen there were no lichens on the unstable boulder-line upper sections of the medial moraines. They do occur lower down and their frequency increases down-glacier, though there were interspersed areas with no lichens (Fig. 2). On Storbreen, lichens occur from the nunatak to the snout, except where there was a "pavement" section and, to a lesser extent, where supraglacial streams had cut a series of channels across the medial moraine (Fig. 2). Matthews (1973) suggested that some of the lichens found immediately in the lee of the Storbreen nunatak may have initially grown on the nunatak. Examination of this area revealed that this part of the medial moraine was a moraine ridge that appeared to be largely, if not wholly, resting on bedrock (Fig. 6). Further, not only did large lichen specimens occur but also a sparsely distributed variety of vascular plants, grasses and mosses, which were absent on the medial moraine proper, where the debris cover is much thinner and less stable. Therefore, although it is still possible that some of the lichens at this site began their growth on the nunatak, it is quite conceivable that they all began their growth on the moraine ridge.

Fig. 6. The uppermost section of the medial moraine of Storbreen and the moraine ridge in the lee of the nunatak. The medial moraine is about 30 m wide and the top of the nunatak is 150 m above the medial moraine.

The distribution of lichens across medial moraines was related closely to the size of the debris and the amplitude and width of the medial moraines, which are themselves related in part to the debris size and its quantity. Where the amplitude was low ($<c.$ 2.0 m) and the debris was very bouldery and closely packed, stable conditions can exist that permit lichen growth almost completely across the medial moraines. Such conditions were not common. When the amplitude increased ($>c.$ 5.0 m) as a result of the presence of a thin cover of fine sediment on the medial moraines, lichen growth was concentrated on the crest of the moraine ridge where stable conditions can persist. Lichens also occurred on boulders and cobbles that were rolling and/or sliding down the side slopes of the medial moraines. Inspection of boulders and cobbles at the bottoms of these slopes showed that these movements eventually resulted in the destruction of the lichens.

The debris lines were too narrow and contained too little debris to permit the establishment of stable conditions. Consequently, no lichens were growing on the debris. Isolated boulders and cobbles also had no lichens growing on them.

Lichen survival after the pro-glacial deposition of the supraglacial debris

Matthews (1973) recorded the survival and continued growth of lichens on medial moraine debris deposited on the pro-glacial area immediately in front of Storbreen (Fig. 2). Now the medial moraine intersects the glacier snout at the emergence point of the main melt stream, so no lichens are currently surviving their pro-glacial deposition. Judging from the apparent subglacial course of the melt stream, this situation is likely to persist while Storbreen continues to retreat. At Hellstugubreen and Sør Illåbreen the medial moraine debris was

being deposited away from the main melt streams, but the melting of considerable glacial ice masses beneath the debris was progressively destroying the lichen cover on the debris. Surveys of the medial moraine debris that now lies some distance from the glaciers and was no longer underlain by ice produced no evidence for the survival of lichens that had begun to grow when the debris was in a supraglacial position. At Tverråbreen, subglacial streams had eroded caverns beneath the lowest section of the medial moraine into which it was collapsing. This collapsing will soon destroy the very few lichens that were growing on the medial moraine. The part of the pro-glacial area where the retreating glacier had deposited medial moraine debris has been repeatedly washed by glacier melt streams and no lichens had survived their pro-glacial deposition.

The possibility of lichens being deposited on end moraines

When the possibility of lichen survival on the deposition of supraglacial debris is considered in the context of its implications for lichenometry, it is essential to assess the likelihood of such lichens surviving on the surfaces of end moraines, because lichenometric studies have usually been concentrated on lichens growing on end moraines. End moraines are favoured because their formation has sometimes been historically recorded, they provide readily identified "synchronously" created surfaces in most cases, and they often afford undisturbed post-depositional environments relative to inter-end moraine areas. Matthews (1973) partially considered this problem with respect to the most recent end moraine produced by Storbreen which appears to have been formed between A.D. 1925 and 1928 (Liestøl, 1967). No evidence was found for lichen survival from the deposition of supraglacial debris. This may be explained by one or a number of the following factors:

1. *The nature of the glacier snout.* When the glacier was advancing or was relatively stationary following a short recession episode such as Storbreen experienced before the formation of this end moraine, the snout would have been steeper and probably more crevassed than today, since Storbreen has been retreating for the last four decades. The crevassing of the snout of Storbreen at that time was probably accentuated through being affected by two large rock knolls (see Liestøl, 1967, figs 31 and 33). These conditions would militate against the possibility of the relatively "gentle" deposition of lichen-covered supraglacial debris which had occurred recently.
2. *Snow cover on the glacier.* During the glacier-advance episode the snow cover would have been more persistent on the lower parts of the glacier and so could have precluded lichen growth on parts of the medial moraine. The size of the largest lichens on the medial moraine suggest, by comparison with those growing on historically dated end moraines in the Jotunheim, that they began to grow this century. Considering their favourably moist environment and the limited snow cover on the medial moraine during the current glacier recession episode, it is just conceivable that they did not start to grow until as recently as the 1930's, following the last glacier-advance episode. Alternatively, the limited lichen dimensions may simply reflect the medial moraine attaining a degree of stability great enough to allow lichen growth to commence.
3. *The stability of the end moraine.* With the possible exception of relatively small end moraines composed solely of boulders, an end moraine will not be a stable surface as soon as it is formed, so that any lichens deposited with supraglacial debris would probably be destroyed by overturning, abrasion or burial of the debris. At the site where the medial moraine of Storbreen intersected the end moraine in the 1920's (and on either side of this site), the end moraine contains a high proportion of fine material and very few boulders, so it would have presented a particularly unstable surface. Even today, very few lichens grow at this site and their dimensions are far smaller than those attained on the more stable sections of the same end moraine.

Lichenometric surveys along all the end moraines of Tverråbreen, Sør Illåbreen, and Hellstugubreen also failed to find any evidence to suggest that lichens now growing on them had started to grow on supraglacial debris. If any of these end moraines would have been expected to provide any such evidence, it would certainly have been the outermost end moraine of Hellstugubreen, because it is relatively low, composed of boulders and lies above the old pro-glacial melt-water channels. Also, when it was formed, the lower section of Hellstugubreen would probably have been very little affected by crevassing, if at all, as the valley has a very low gradient and remains a constant width, while the medial moraine would have been as bouldery and favourable for lichen growth as its lower section is today. The failure to find any evidence for lichen survival on this end moraine suggests that if lichens do survive their deposition on end moraines it is probably a very rare occurrence.

Discussion

It has been demonstrated that the growth of lichens on supraglacial debris on active glacier ice is not only possible but also may be a much more widespread phenomenon than had previously been thought. In Norway, lichens have been found growing on supraglacial debris on six Jotunheim glaciers and the Jostedalsbreen outlet glacier, Austerdalsbreen (personal communication from A. M. Tvede, 1976) (Fig. 1). Elsewhere there is very little relevant data. In Switzerland, Hambrey (personal communication, 1976) and Small (personal communication, 1977) have observed lichens growing on the medial moraines of the Unteraar and Tsidjiore Nouve glaciers, respectively. In Vestspitsbergen, Drozdowski (1977, fig. 3) has photographed lichens growing on coarse supraglacial debris near the snout of Aavatsmarkbreen and has observed similar occurrences on other Vestspitsbergen glaciers (personal communication, 1977). In New Zealand, Burrows and Orwin (1971) recorded lichen growth on the supraglacial debris near the snout of Mueller Glacier, though the lower part of this glacier is stagnant and heavily debris-covered and therefore is not comparable with the previous glaciers. Loomis (1970) and Eythórsson (1951) have reported moss growing on sections of medial moraines on Kaskawulsh Glacier in the Yukon region of north-western Canada and Breiðamerkurjökull in southern Iceland, respectively, indicating that stable conditions had been established and that lichens might also possibly occur at these sites.

In addition to lichen growth on medial moraines, lichen cover could also develop on debris that had fallen, slid, or flowed from adjacent slopes on to a glacier, or on debris brought to a supraglacial position from a subglacial one. Under certain cirumstances, it is possible for lichens to survive on debris brought on to the glacier surface by mass-movement processes. A small example of such conditions occurred on the western side of the snout of Styggedalsbreen (Fig. 1), where lichen-covered boulders and cobbles from Holocene glacial deposits on the steep slope above the glacier had slid over the early summer snow cover on to the glacier. Nearly all the boulders and cobbles involved were not overturned and lichen growth appears likely to continue since the debris will very shortly be deposited at the front of the glacier. Such slides appear to have occurred previously as lichen-covered boulders were found embedded in the surface of ice-cored fluvio-glacial deposits immediately in front of the glacier. These lichens, plus those on the glacier, will almost certainly be destroyed either as a result of the collapsing of the ice-cored deposits or through washing by the pro-glacial melt-water streams.

Given that lichens can grow on supraglacial debris under certain conditions and that some of these may reach the glacier snout having avoided destruction through the action of crevasses, supraglacial streams, and instability related to the differential ablation of glacier ice, few can be expected to survive for long after their pro-glacial deposition. They will be destroyed b fluvial action or slope instability or be buried by debris or sediment. Of those that do surviv it appears probable that, as in the Storbreen example, they will survive on fluted till surfaces

particularly near-horizontal ones, because these areas have not been greatly affected by fluvial action and mass-movement processes since their deglacierization. Nevertheless, it is possible that some may survive on deposits that were ice-cored for some time after their deposition.

Having established that lichens can be deposited successfully when glaciers are receding, it does not appear very likely that this will occur when they are advancing or when their frontal margins are near-stationary following an advance episode, when their lower regions will usually be more crevassed and their snouts will be steeper. It is not therefore likely that this problem will affect lichenometric studies of end moraines, particularly as the surface of a newly formed end moraine will usually be unstable and so constitute an unfavourable environment for the survival and continued growth of lichens.

Perhaps a more significant problem, and one that could easily be confused with the previous one, is that posed by the incorporation into end moraines of lichen-covered boulders from older deposits distal to the end moraines. This might occur in several ways. One way is through mass movements of older deposits down on to younger end moraines. This possibility was noted by Jochimsen (1973) with reference to Alpine end-moraine sequences, though no examples were quoted. However, as in the case of Styggedalsbreen, it could be possible for boulders to slide over a snow cover and come to rest on a moraine ridge leaving no geomorphological indications that the movement had occurred. Another way whereby older lichens can be incorporated in a moraine ridge, and one that has been documented at Nigardsbreen (Andersen and Sollid, 1971; Griffey, 1977) (Fig. 1), is where lichen-covered boulders have been included in the distal side of the moraine ridge during its formation. This can be achieved when boulders have been pushed short distances by the glacier or where they already rested at the end-moraine site. The boulders in this particular instance have avoided burial partly by virtue of their size and number, though they are no larger than many others on the moraine ridge and could readily be confused with them.

In conclusion, it can be recommended that workers carrying out lichenometric surveys should exercise caution when sampling past intersection points of medial moraines and end moraines, and be wary of possible supraglacial debris if inter-end-moraine areas are being sampled, especially fluted till surfaces. Glaciers which have or have had greater supraglacial debris covers than the Norwegian ones examined here may be more problematical in this respect. Certainly, it is a problem that could reward further investigation. Finally, workers must also beware of the potential presence on end moraines and inter-end-moraine areas of lichens that began their growth on older pro-glacial surfaces.

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