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TWO NIVATION CIRQUES NEAR ABERYSTWYTH, WALES

Abstract

In the uplands of Wales, both glacial and nivation cirques occur. In late glacial times, the former were occupied by cirque glaciers which have the ability to move debris out of the cirque. These cirques are characterised by erosion features, usually a lake basin enclosed by a moraine. The nivation cirques on the other hand were occupied by a perennial snow patch, incapable of movement. Their floors are characterised by deposition, for debris, produced by freeze — thaw, moved underneath the snow to the lower part of the snow patch and accumulated there to form a drift platform.

In the drift platform of Cwm Du, stream sections expose these drifts to depths of 50 feet (15 metres) showing beds of unsorted rock debris in a tough matrix of blue-grey silty clay alternating with more stony layers, usually yellow-grey in colour. The former are typical of the solifluction deposits on the local rock type, while the latter are interpreted as poorly washed residues of the deposit from which snow melt has washed some of the muddy matrix.

Sometimes, as in Cwm Tinwen, a protalus or pseudo-moraine occurs, usually associated with a steep high backwall so that debris from the exposed backwall, instead of lodging on the snow patch slides down its steep surface to form a ridge at its foot.

The two cirques, Cwm Du and Cwm Tinwen are situated on the south side of the deep, narrow, fault-guided valley of the River Ystwyth, which is trenched into the High Plateau of Wales, lying here at 1500—1700 feet (about 500 metres) above sea level (fig. 1). Though both cirques have a steep rocky backwall, steeper and more craggy than the normal valley shoulder of the Ystwyth, their basins show none of the erosion features associated with the glacial cirque. Instead, they have thick deposits on their floors. In the case of the larger, Cwm Du, the debris has spread out of the cirque in the form of a fan, across the floor of the main valley and pressed the Ystwyth against its northern valley side.

In this area, tributary valleys on the south side of the Ystwyth are small and few, but the gathering of some of the plateau drainage into Cwm Du suggests that this cirque has developed from a stream gully. Cwm Tinwen receives no streams from the plateau; it is much steeper and shallower than Cwm Du and was probably cut by nivation from the valley side. Its volume, like the volume of debris produced, is much smaller than that of Cwm Du.

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The form of the deposits in the two cases shows marked differences and suggests that the cwms mark the sites of two types of perennial snow patch, one gently sloping and the other steeply sloping.

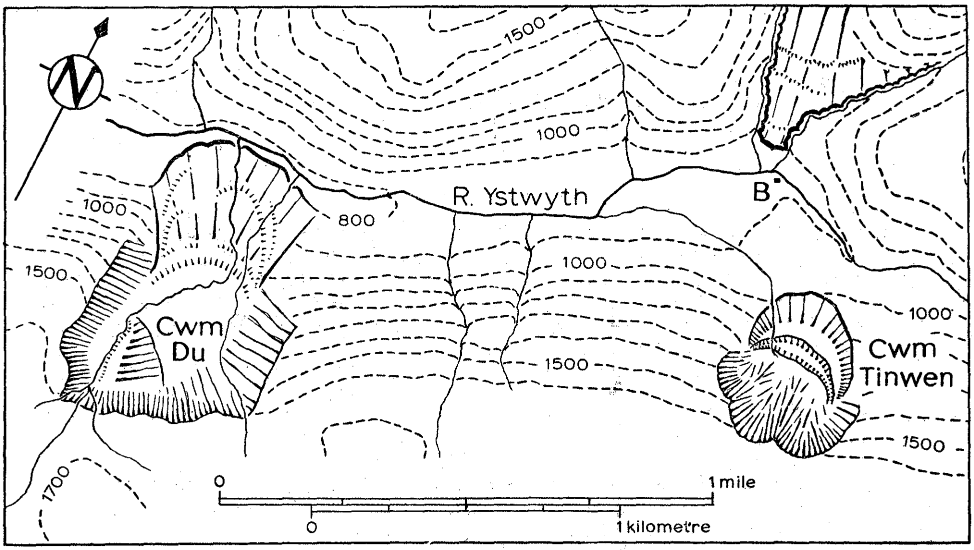

Fig. 1. The Upper Ystwyth Valley, showing the sites of Cwm Du and Cwm Tinwen, in the area of the main watershed of Mid-Wales

Cwm Du is 15 miles (24 kilometres) ESE of Aberystwyth. Contour interval 100 feet; B — Blaen-y-cwm Farm, with the sloping solifluction deposits to the NNW

THE DEVELOPMENT OF NIVATION CIRQUES

The most significant of the early studies of the work of snow patches was that of F. E. Matthès (1900) who believed they enlarge the hollows in which they lie by causing a recession (and steepening) of the slope at their head. This he ascribed to a vigorous thaw—freeze on the margin of the snow. He argued that although "the snow drift acts as a blanket in protecting its bed from oscillations of temperature", the edges of the shrinking snow mass expose new portions of the floor to thaw—freeze (*ibid.*, p. 180). Like most workers, R. J. Russell accepted the conclusions of Matthès for ephemeral snow drifts, but pointed out that "in the case of the perpetual snow drift, a certain zone is always protected by snow cover" (1933, p. 938). The problem of the perpetual snow drift was the mechanism by which frost-shattered material might be removed from under it, in order that its head might be extended.

Matthès (1900, p. 181) had held that the "soil water carries with it a portion of the fine material thus loosened,... but since there are no well-worn channels on any of the sites inspected", inferred that "the water from the upper edges of the drift percolates slowly under the mass in sheets without exerting any appreciable erosive power". The excavation of a snow patch in Iceland by W. V. Lewis (1939) showed that though the ground underneath was frozen, in the lower part the base consisted of waterlogged snow with water passing over the surface of the ground (p. 154), while runnels emerged from underneath the snow at the foot. He concluded that "all the transport (of material from the nivation hollow) was done by melt water", (p. 155). He also believed that caves under the snow produced by melt water "allowed temperature changes to reach many parts of the floor which otherwise might suffer far less frequent frost-shattering", (p. 159). L. H. McCabe (1939), from work in Spitsbergen agreed that water produced at the higher parts of the snow patch might melt its way to the lower end and pointed out that, "owing to nearness of the tjäle to the surface of the ground beneath a snow patch, melt water is restricted to a very thin layer of soil, which thus suffers more intense frost action than the snow-free areas" (p. 454).

Observations in the Urals convinced S. G. Botch that melt water alone is not capable of removing the debris from below a snow patch (1946, p. 216) and that solifluction operates underneath the snow patch "as it does sub-aerially, except that in this case it is under pressure" (*ibid.*, p. 217). He further maintained that the slow general seepage of melt water during the season of thaw is more important than tunnels in raising temperatures above freezing point underneath the snow patch. This seepage proceeds very slowly but it goes on steadily through the summer as variations in air temperatures of short duration are not felt beneath the snow cover. He thought that the ground under a snow patch thaws out entirely, though he admitted that he had no evidence for the larger snow patches in cirques (*ibid.*, p. 216). This thaw affects only a very shallow layer, which melt water saturates to a point where it is capable of flow, so that a semiliquid mud full of rock debris moves towards the lower end of the snow patch. Once begun solifluction continues beneath the snow even if the air temperature falls below freezing for a short time (e.g., by night) so that it is more continuous than on the periphery or beyond the limits of the snow patch.

Botch envisaged freeze—thaw at the upper margins of the snow patch causing the backwall to retreat, the debris falling into the chasm which opens between the head of the snow patch and the rock in summer. There it is further broken up by frost and moves by solifluction beneath the snow. "At the lower edges of the snow the bedrock is protected by a layer of solifluction drift" (Botch 1946, p. 217). This sequence is not, however, true of steeply-inclined snow patches where transport across the surface of the snow may be dominant. Debris produced by frost-shattering of the backwall slides over the surface of the compacted snow forming screes at its foot. The finer fractions are, however, carried down by melt water underneath the snow. In these conditions retreat of the head-wall is accompanied by the removal of debris over the snow as well as under it (*ibid.*, p. 214-5).

On this thesis, there may be said to be two main types of perennial snow patch; the gently sloping, where movement of debris is below the snow so that no moraines are formed at the lower end, and the steeply sloping, where debris slides down the upper surface of the snow and is left as a moraine-like ridge when the snow patch disappears. The latter feature has been described by several authors, in France under the names *moraine de névé* and *pseudo-moraine* (Boyé 1952, pp. 25—27), and in the United States under the name *protalus rampart* (Bryan 1934, p. 656; Sharp 1942, p. 496).

CWM TINWEN

The area shown by the form-lines on figure 2 appears to be the drift accumulation derived from Cwm Tinwen. No rock shows anywhere on it and the stream gully shows drift up to 55 feet (17 metres) thick. Its most distinctive part is the moraine-like ridge which encloses a narrow boggy flat. The height and width of this ridge is much greater in its central part (fig. 2). Its surface falls westward at 3°— 4° and the present drainage from the depression behind it escapes at the western end where the ridge turns upward to merge into the hill-side. The author believes that this ridge is a *moraine de névé* or protalus rampart formed at the foot of a perennial snow patch. The hollow enclosed by it is very narrow because the snow was banked against the steep valley side. This also gave the snow patch a steeply sloping surface so that debris falling on it from the backwall, slid down it to form a protalus at its foot. The curved form of the backwall led to a convergence of this debris towards the centre so that the protalus was most extensive there and thinned away towards the flanks. The rear edge of the rampart bulges out towards the rear (see fig. 2) preserving in a subdued form the original pattern of the debris as noted by Botch in the Northern Urals (1946, p. 215).

Outside this rampart the profile AB shows a platform sloping outwards at 9° to 10° (fig. 3). This ends in a steeper slope of 21° to 22°, which

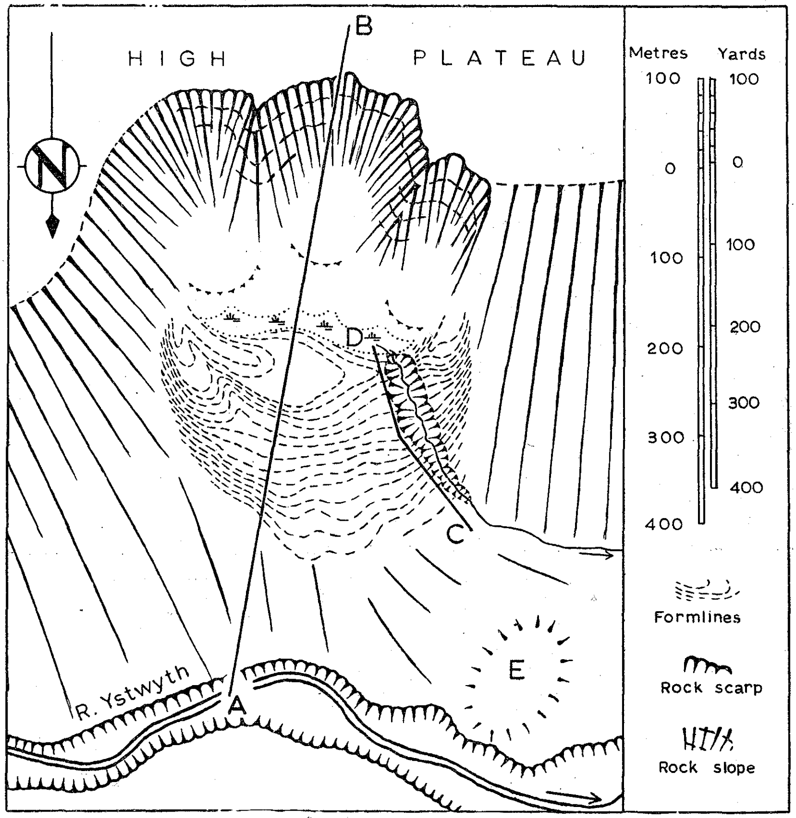

Fig. 2. Cwm Tinwen

The drift accumulation at its mouth is indicated by form-lines at 10 feet intervals, and the marshy strip behind this by conventional marsh symbols. The curved toothed lines above the marsh represent the lower limits of three shallow niches in the backwall. AB and CD show the lines of the profiles shown on fig. 3; E is a rock knoll; as the map shows, the Ystwyth is sunk in a rock gorge at this point

is comparable with the outer slope of the rampart. At the eastern end, however, the upper surface of the platform is replaced by a rounded ridge, which is similar to the rampart and quite distinct from it. West of the profile AB, the platform is replaced by the thickening protalus rampart so that in profile it shows a steady fall to the foot of the drift accumulation. Nearer the gully the protalus rampart narrows rapidly and a convex platform reappears, sloping at 12° to 14° and passing on its lower side into an 18° slope (profile CD, fig. 3). West of the gully the fragment of the drift accumulation is narrow but it does suggest a double ridge structure which merges into one as the valley side is approached. This suggests that the present protalus rampart may be resting on a larger and older protalus accumulation, now represented by the outer ridge and platform (fig. 4).

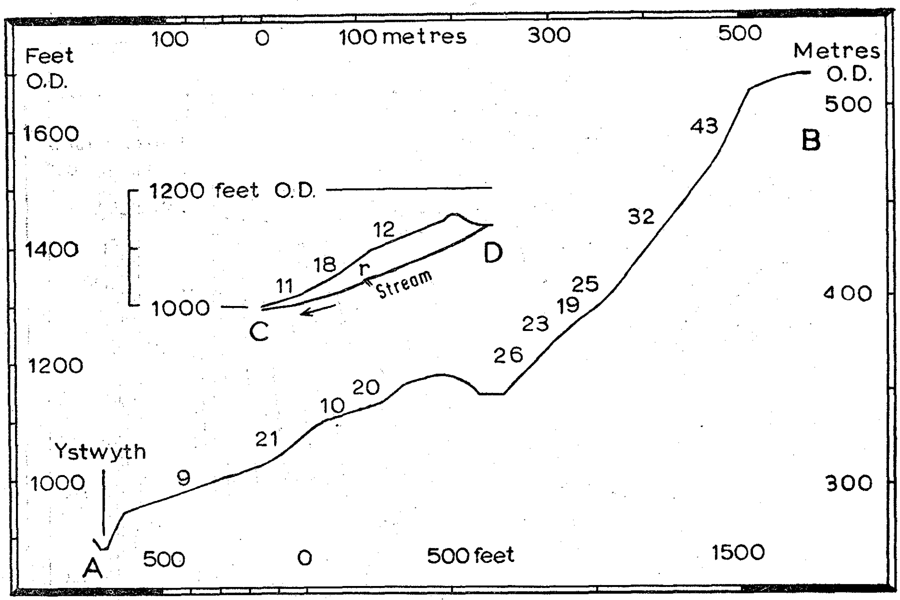

Fig. 3. Profile through Cwm Tinwen along the lines AB and CD on fig. 2

The numbers along the profile indicate the slope in degrees; on CD is also the profile of the stream draining the cwm; rock occurs at one point only in the stream bed, at r; the vertical scale is twice the horizontal

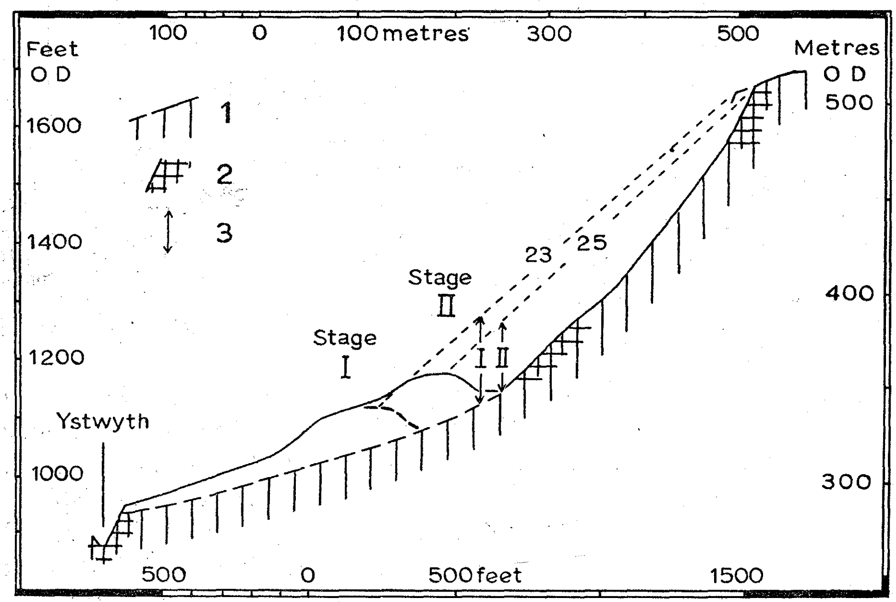

Fig. 4. The evolution of Cwm Tinwen. The profile is that of AB, fig. 3

1. hypothetical surface of bed-rock; 2. rock outcrops; 3. maximum snow thickness at stages I and II. The rim of the backwall, maximum snow thickness and protalus rampart of the last stage are marked II, those of the earlier stage, I. The niche in the backwall at about 400 metres is probably post-stage II

Blocks up to 5 feet (1.5 metres) show through the vegetation especially on the protalus rampart, while exposures in the gully downstream from the peat basin show a grey silty tough head or a yellowish-grey, loose, more gravelly head. Both are crowded with small rock debris, $^1/_4$—$1^1/_2$ inches (5—40 mm) and containing a variable amount of larger stones and boulders up to 5 feet (1.5 metres) long. Drift faces tend to be covered with wash and slip, so that it is difficult to trace an exposure for any distance.

A fresh fall at r, profile CD (fig. 3), in August 1961, showed 10 feet (3 metres) of loose yellowish-grey head with short lenses of muddy grit or sand and irregular seams of yellow silt containing small gravel, and at 5 feet (1.5 metres) above the stream a layer containing large boulders, 2—5 feet (0.7—1.5 metres). This rough stratification dips downstream as would be expected if it were laid down just beyond the toe of a snow-bank (as part of the earlier protalus). The younger protalus rampart exposes 19 feet (6 metres) of muddy, bouldery gravel on grey compact head. Below this at stream level, is the grey head overlain by about 15 inches (38 cms) of loose gravelly head, then 30 inches (75 cms) of muddy fine gravel. Three feet from this, the fine gravel is overlain by 3 feet of brown sand. From their position, they would belong to the earlier protalus accumulation, but one cannot be sure that the deposits at the bottom of the gully are *in situ*. They do indicate the nature of the drifts, however; a succession of head, partly-washed head, and poorly-washed sand and gravel.

CWM DU

Cwm Du has no moraine. Its basin is fronted by a drift scarp, 60 feet (18 metres) high in the centre, which resembles a moraine when viewed from below, but in reality is the front of a drift terrace. The main stream in the cirque has cut a deep gully parallel to this front but instrumental levelling in the area of the profile JK (fig. 5), shows that the top of this scarp is lower than the cirque floor. The gully shows up to 60 feet (18 metres) of head without the bedrock being exposed and the smooth slope rising up to the backwall suggests that this is a solifluction deposit, accumulated beneath a snow patch.

The long axis of the cirque basin is southwest to northeast and its floor falls in the same direction. The snow patch would have sloped from the southwest corner towards the present stream exit. The angle of elevation from the front of the drift platform at the stream exit to the top of tde backwall in its southwest corner is 13 °. The upper limit of the snow patch would be lower than the top of the backwall so that the surface of the snow would

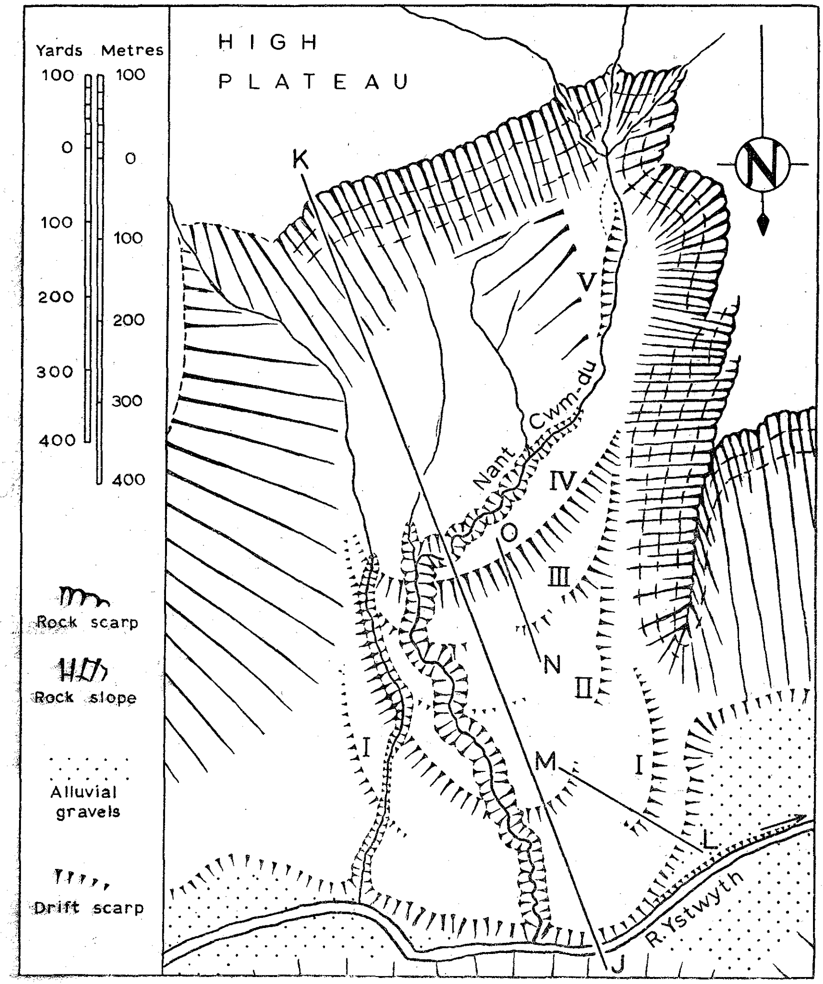

Fig. 5. Cwm Du and its associated fan

The scarps on the latter are numbered I, II and III. Between II and III are traces of another, (IIa on fig. 10) but it is less distinct than the others. IV is the scarp at the mouth of the cirque and V the protalus in its south-west corner. JK, LM and NO show the lines of the profiles on fig. 8. Rock outcrops in the bed of the Ystwyth at J and some 250 yards to east

be less steep than this angle but it is suggested that this reading gives a basis of comparison with other cirques. The absence of a protalus suggests that no superficial debris reached the foot of the gently-sloping snow surface in Cwm Du and that conditions may have resembled those shown in, Botch's block-diagram (1946, p. 221, fig. 7).

The smooth curve of the floor of the lower part of the cirque is replaced towards the head by a drift accumulation which fills the southwest corner of the cirque (see fig. 5 and V, fig. 6). The streams falling steeply into the cirque have filled in the area behind this accumulation at its southern end with bouldery alluvium but downstream (at profile RS, fig. 6) it is seen to be composed of head. This suggests that after the snow patch had disappeared from the cirque, it re-formed, filling only the southwest corner and built up this drift as a protalus. The angle of elevation from the top of this protalus ridge to the rim of the backwall on profile RS of figure 6 is

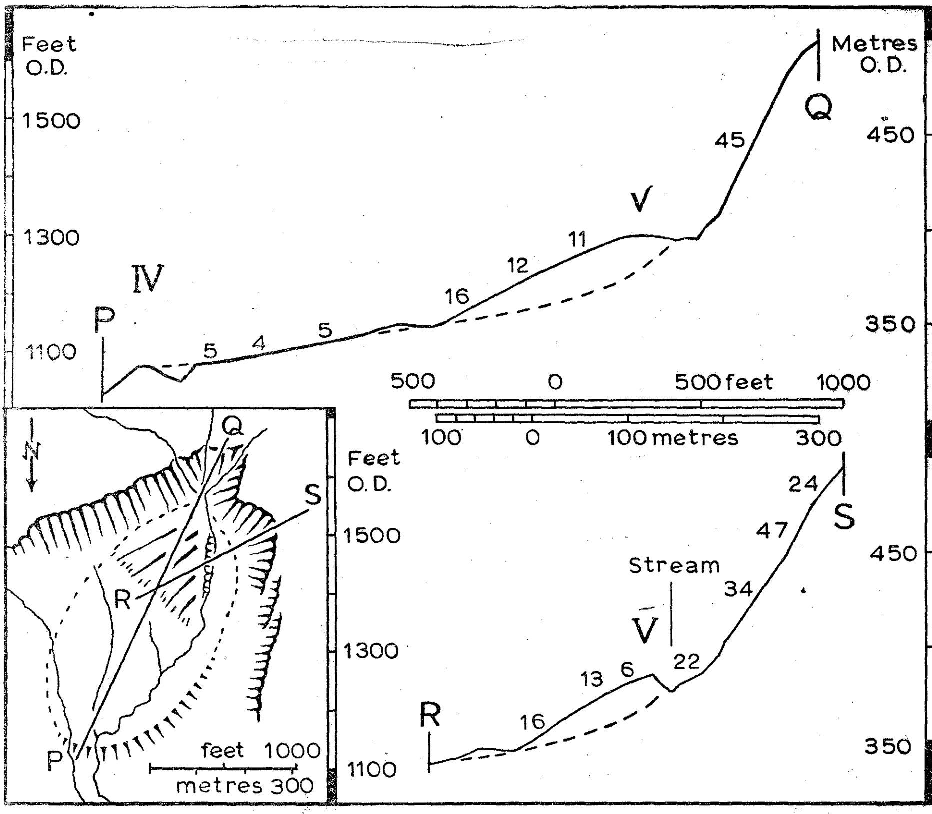

Fig. 6. Cwm Du. Profiles through Cwm Du (cirque only) along the lines PQ and RS on inset map

The Roman numerals IV and V correspond to those on fig. 5. The broken lines show a restoration of the cirque floor at stage IV. The vertical scale is twice the horizontal. The numbers along the profile indicate the slope in degrees

27°, indicating that this final snow patch belonged to the steeply-sloping class, like that in Cwm Tinwen where the comparable angle along profile AB of figure 3 is 25°.

The drifts in Cwm Du cirque as in its associated fan and in Cwm Tinwen, consist of two types of head. One is a tough bluish-grey silty deposit charged with angular and sub-angular rock fragments of all sizes from fine gravel to great boulders. The other is yellowish-grey, loose and charged with similar debris but with a smaller proportion of fines so that it may often be described as a muddy angular gravel. It often shows rusty mottling and in the more open beds manganese staining.

In Cwm Du cirque, exposures in Nant Cwm-du gully (50—60 feet; 15—18 metres deep where it leaves the cirque) suggest that these beds form the whole of the deposits, occurring in distinct layers, between 1 and

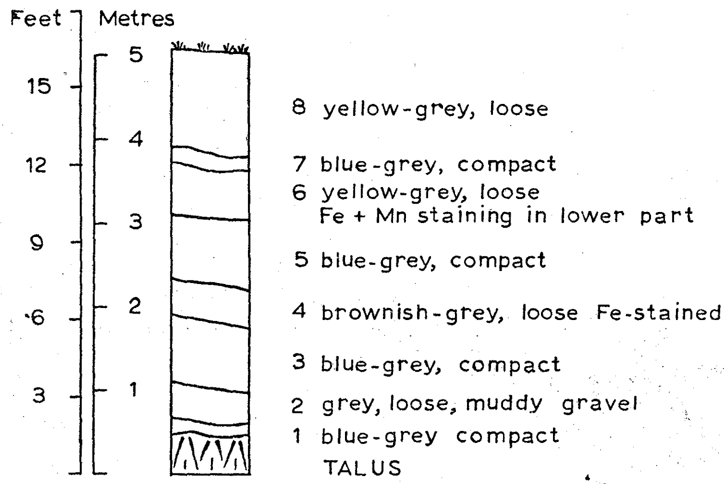

Fig. 7. The sequence of head deposits in Nant Cwm-du gully, 120 metres SW of the point where JK crosses it. The scale begins at stream level

3 feet (0.3 to 1 metre) thick. The bluish-grey type is typical of the solifluction deposits on the greywackes and mudstones of the region and the yellowish-grey type is probably basically the same except that it has suffered some degree of washing during deposition, the yellowish tinge being due to post-glacial weathering accompanying a more ready percolation of water (fig. 7).

The protalus, V, has many boulders scattered over its outer slope, and exposures show these two types of head; on the profile line RS of figure 6, 11 feet (3.3 metres) of the loose yellowish-grey type on 2 feet (0.6 metres) of the compact bluish-grey type, above 17 feet (5.2 metres) of talus.

The exposures of the cirque floor (stage IV) suggest that the drift may have been built up in layers as the theory of Botch states. It must be noted that these exposures occur on the outer edge of the cirque and may represent deposits laid down at the margin of the snow patch. This might account for the increased washing of some of them — in this connection it may be recalled that Botch found "natural pavements" in the area uncovered by the snow in summer, due to the washing away of the fines by melt water (fig. 9).

The building up of such a platform of drift would be due to the fact that the ground below the snow patch is affected by summer thaw only to a very shallow depth and that as the debris derived from the weathering of the backwall moves as a solifluction layer beneath the snow patch it tends to thicken as the gradient lessens. In winter this muddy accretion is frozen to the permafrost below and never thaws out again fully so that summer after summer it is added to. The abrupt limit to the deposit, represented by the scarp 60 feet (18 metres) high, seems to imply that the actual front of the snow patch fluctuated relatively little, otherwise the thawing out of the uncovered ground must have been accompanied by soil flow.

Little data is available on the thickness at which névé becomes ice, but R. F. Flint believes it to be "30 metres or more" (1957, p. 19). J. Tricart accepts this figure — "30 or 40 metres" (1963, p. 157). For slow plastic deformation — the more significant change in this context — "the minimum thickness of ice and firn required is not known... but thought to be 30 or 60 metres in a temperate climate and greater in a polar climate" (Flint 1957). At stage V in Cwm Du, if the snow extended to the top of the backwall, its maximum thickness would be 80 to 100 feet (25 to 30 metres), so that it probably was entirely a mass of snow. The same applies to the younger (protalus) stage in Cwm Tinwen where snow to the top of the backwall would give a maximum thickness of 125 feet (40 metres). The névé mass extending to the outer edge of the cirque in Cwm Du (IV on figure 6) would, if the snow extended to the top of the backwall have a maximum thickness of 230 feet (70 metres), while if it extended half-way up, the figure would be 150 feet (45 metres). In this case, the lower layers of this extensive "snow patch" (1,800 feet or 550 metres in length), may have been ice.

CWM DU FAN

The drift scarp enclosing the cirque basin (IV, fig. 5), appears to be the highest and most continuous member of a series which is developed across the surface of the drift fan below it. This series, marked I, II and III on figure 8 gives the fan a stepped profile. These steps or scarps are not continuous across the fan so that profile JK does not give the complete series; profiles LM and NO restore the missing steps in the general picture. The upper step of the series, III, is parallel to the terrace front of the cirque, IV, and like it falls in elevation towards the east. Unlike IV, it appears to have been worn down at two points as if erosion had lowered the top of the scarp. Scarp II extends as a continuous scarp to the east of the Nant Cwm-du gully except where it is cut by the unnamed stream. West of this stream it appears to have been eroded as in the case of scarp III. Scarp I exists only on the flanks of the fan; in the central area the fan gives the appearance ofhaving been built up so that there is a continuous slope from scarp II to the limiting bluffs of the fan, which are due to erosion by the River Ystwyth.

S. G. Botch in his block-diagram of the features associated with a typical snow patch (1946, p. 221, fig. 7) and in his diagram showing the evolution of a nivation niche (1946, p. 219, fig. 6) shows solifluction debris accumulating underneath the lower part of the snow patch and moving on sub-aerially down the slope as a series of solifluction terraces. The similarity between these two diagrams and the situation at Cwm Du suggests that the steps of the fan may be solifluction terraces (*cf.* fig. 9), but the author has come to believe that these steps — I, II and III — are similar in origin to scarp IV at the mouth of the cirque and that they mark earlier snow patch limits.

One argument against the view that the steps are solifluction terraces is their arrangement in plan. They do not form a series concentric with scarp IV but appear to enclose a series of lobes which have a progressively changing axis. The lobe enclosed by step II has an axis running west of north (about 350°); the axis of the higher lobes swings clockwise until in the cirque (the area enclosed by step IV) it runs north-northeast (about 25°). This would be consistent with an area of snow emerging from a gully which was being extended towards the south and west as freeze—thaw made its maximum attack on the backwall on these sides (fig. 10).

The position of the stream, Nant Cwm-du, on the centre line of a convex fan — not of its own construction but predominantly of head — also favours the view that the steps on the fan mark snow patch limits. Inside the cirque, Nant Cwm-du and the stream to the east occupy positions which would have been sub-marginal to the snow patch of stage IV, and leave it at its lowest point, where one would expect melt water to escape. The present stream appears to be a direct descendant of such a melt water stream, having become entrenched in later times. Downstream of step IV, the stream passes through the lowest point of each crescentic step so that

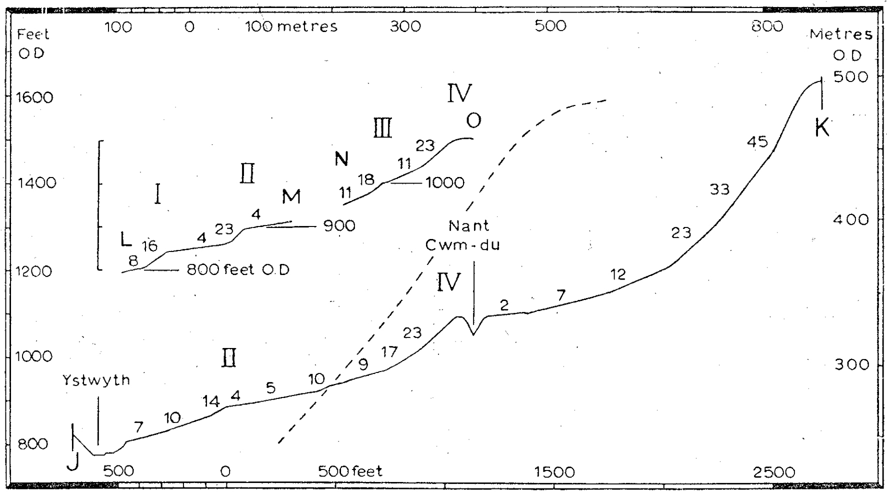

Fig. 8. Profile through Cwm Du and its fan along the line JK on fig. 5 with supplementary profiles along LM and NO

The Roman numerals I to IV correspond to the scarps on fig. 5. The broken line shows the profile of the Ystwyth valley side, obtained by continuing the contours of the valley side across the mouth of the cwm. The vertical scale is twice the horizontal

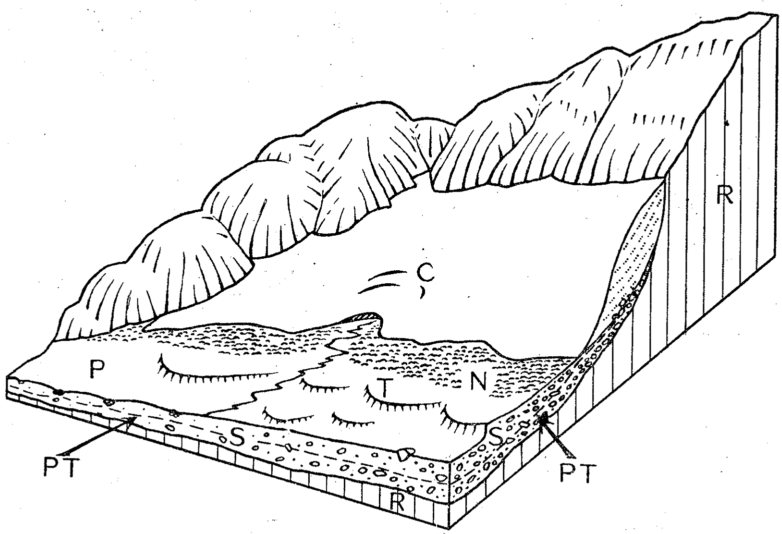

Fig. 9. Block diagram of a snow patch during the melt season, after S. G. Botch (1946, fig. 7)

C — crevasses in the névé above a melt water cave; N — natural pavement; T — solifluction terraces; P — patterned ground (formed by autumn frosts); S — solifluction debris; R — bed-rock; PT — permafrost table, rising quickly at the base of the névé the stream course cuts across the fan to a central position where it joins the Ystwyth (fig. 10).

These arguments are strengthened by a consideration of the tributary valley on the south-facing side of the Ystwyth valley northwest of Cwm Tinwen (see fig. 1). This is drained by two streams and the area of their

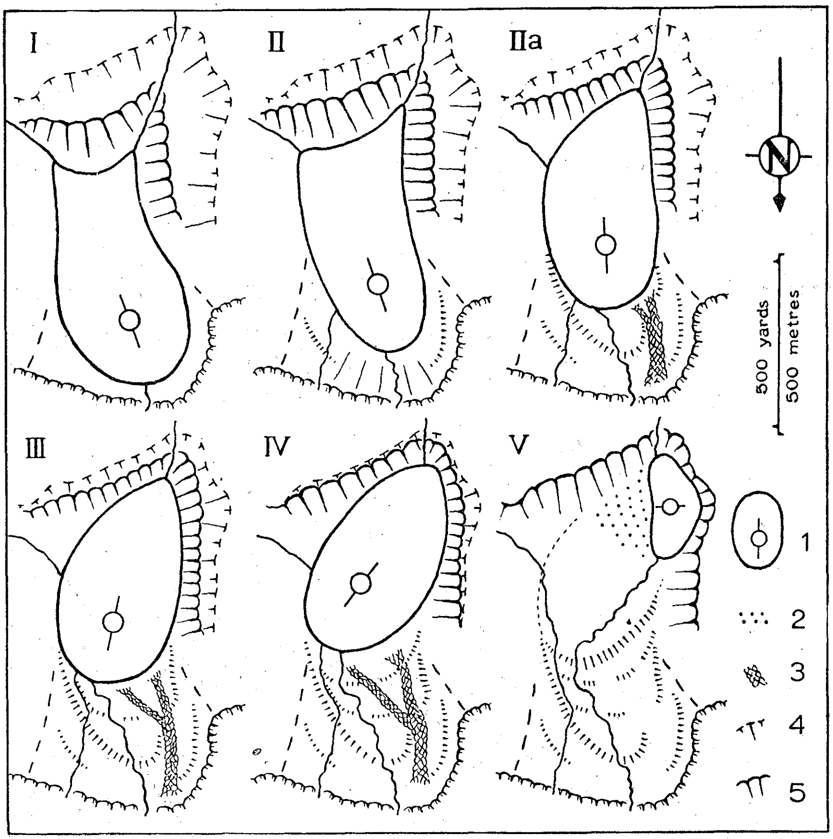

Fig. 10. The evolution of Cwm Du

1. the snow patch showing the axis of the lower part; 2. the protalus of stage V; 3. melt water courses on the fan; 4. existing backwall; 5. the backwall at successive stages. Step IIa (between II and III on fig. 5), is shown here as marking a snow limit; if these steps do represent climatic pauses, research elsewhere in Wales may help to decide the status of IIa

basin would be comparable with that of Cwm Du. Snow must have collected in it during the winter when Cwm Tinwen had a permanent snow patch, but it appears to have melted during the summer as there is no rocky backwall and no clearly defined floor comparable, with Cwm Du. The basin at Blaen-y-cwm is filled with solifluction debris having a surface slope of

7°—9° (fig. 12). This slope is interrupted by low terraces which have lobate fronts and are nowhere so imposing as the steps on Cwm Du fan. Furthermore, although this infilling has not a convex surface, the two streams are on its outer edges flowing between rock slopes and drift scarps 30—40 feet (10—12 metres) high (fig. 11). Both this basin and Cwm Du are

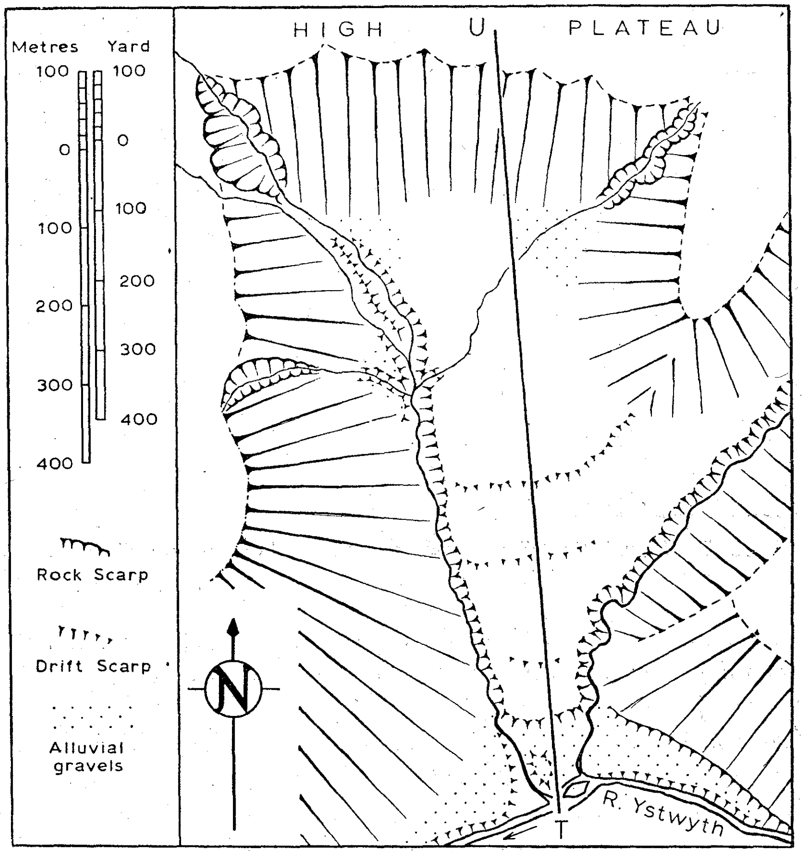

Fig. 11. Solifluction deposits in the valley north-north-west of Blaen-y-cwm. These form a wedge-shaped terraced slope between the two streams

developed on the same rock type; the difference lies in their orientation. It is suggested that at Blaen-y-cwm we have a slope developed by sub-aerial solifluction without a permanent snow patch.

Figure 13 is an attempt to reconstruct the evolution of Cwm Du and its fan by advancing the backwall of the cirque to compensate for the building of the fan, along the profile JK of figure 8. One of the difficulties here is the fact that the cirque was not extending along the axis of the fan. Only a fraction of the material laid down at stage IV came from the backwall on the profile JK; the bulk of it came from the southwest corner of the cirque. This is less true of the earlier stages, but the reconstruction in any case is only very approximate. The "initial" profile shows a nick-point just above 900 feet, as does the Ystwyth and several of its tributaries in the area (Brown 1952). Though no rock is seen in the stream bed, the Nant Cwm-du gully is shallowest at this point, only 25 feet (8 metres)

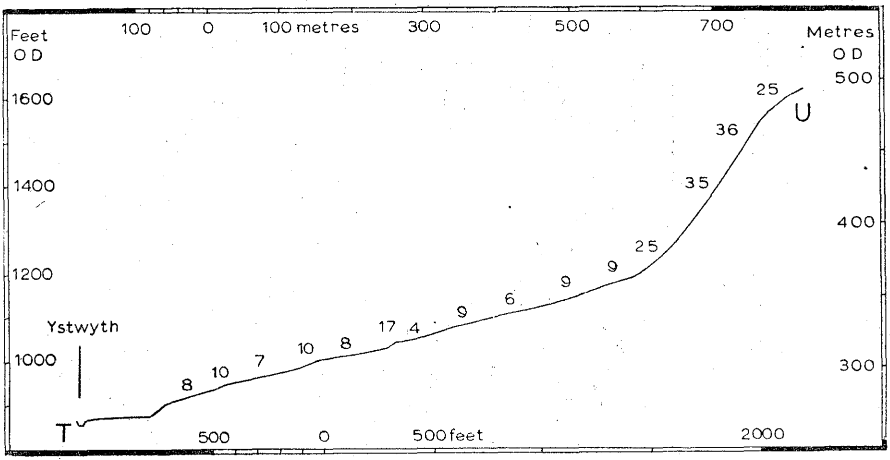

Fig. 12. Profile through the tributary valley north of Blaen-y-cwm, along line TU on fig. 11. The numbers along the profile show the slope in degrees

deep compared with more than 50 feet (16 metres) upstream and downstream of this, and the steepest stretch of the present stream profile in the fan occurs just below this.

From the elevation of the High Plateau here and the position of scarps I, II and III, it seems impossible that a snow patch extending to them, could fall into the steeply-sloping class. On the reconstruction shown in figure 13, the angles from the rim of the backwall are, for scarps I, II and III similar to that for scarp IV, which is 18°. This is in harmony with the fact that each suggested snow limit is marked by a terrace front and not a protalus rampart.

When one tries to estimate the thickness of snow at these stages on the basis of figure 13, the maximum thickness, if the cirque were filled to the top of the backwall, would be 250 feet (82 metres), 250 feet, and 220 feet (72 metres) respectively for stages I, II and III (*cf.* 230 feet, 75 metres, for stage IV). In this respect, the problem of stages I, II and III is the same as that of stage IV. One returns to the question of the thickness reached by snow and ice before it begins to behave as a cirque glacier.

The main exposures of the deposits making up Cwm Du fan are shown on figure 14. The interbedding of tough bluish-grey head and loose yellowish-grey head seen in the floor of the cirque also occurs in the fan just behind scarp II at exposures 2 and 3. At other points, 36 feet (11 metres),

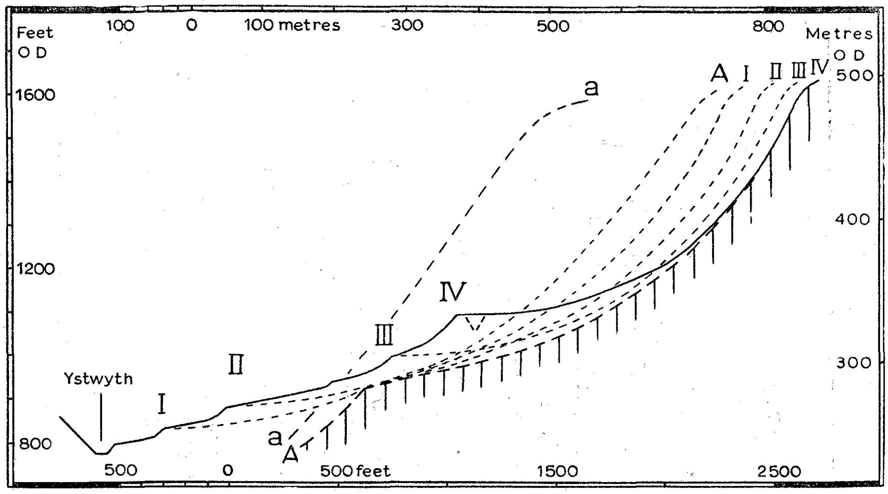

Fig. 13. Stages in the development of Cwm Du profile

The continuous line shows a composite profile along JK of fig. 5. The vertical lines show the bed-rock, in part hypothetical. A — the initial profile of the gully; I—IV — the successive portions of the backwall corresponding to the steps on the fan; a — a — the profile of the main valley side

upstream of exposure 3, the west side of the gully shows only the blue-grey head and at exposure 5 only the blue-grey head is seen for 23 feet (7 metres) above the stream.

In front of scarp II, small calibre waterlaid gravels (less than 2 inches or 5 cms long) interbedded with thin layers of grey silt at the top, from the lower 9 feet (3 metres) of exposure I. Again, in front of scarp III, exposure 4 shows blue-grey head overlain by 7 feet (2 metres) of similar small gravels capped by 1.5 feet (0.5 metres) of sand and silt, on top of which is blue-grey head. In both cases, these water-laid beds might be older than the step behind, having been laid down during a recession phase when summer melting was more pronounced, and then been overwhelmed by the solifluction deposits of the snow patch of the succeeding rigorous phase. They might also represent melt-water deposits laid down while the step behind was being built up. The foımer interpretation is favoured by the sequence in front of scarp IV, where exposure 5 shows 2 feet (0.7 metres) of waterlaid sands, gravels and silt resting on the blue-grey head of step III.

These are overlain by a stony bouldery yellow-grey head (in places a muddy gravel) which thickens when followed upstream (fig. 14), and would appear to be material that has been partly washed by snow melt as it sludged down the face of scarp IV. At exposure 4, the top of the

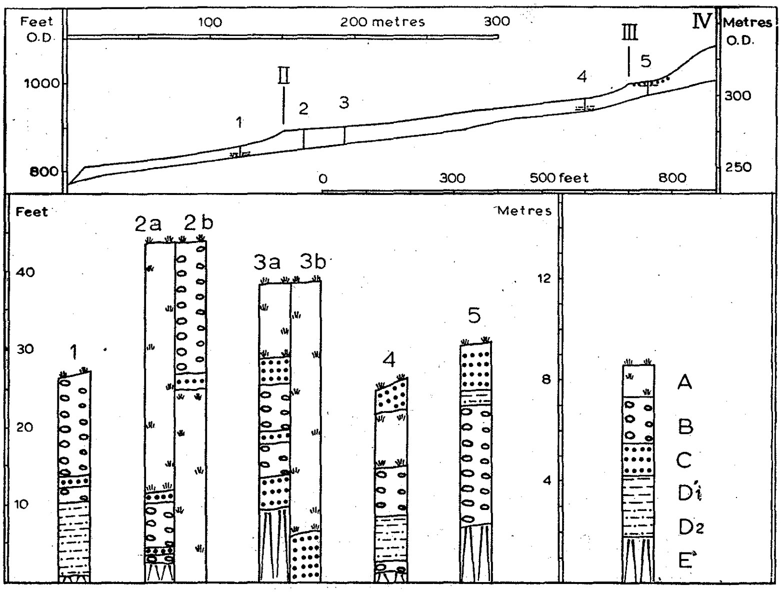

Fig. 14. Exposures of the deposits in Cwm Du fan

A — vegetation-covered slope; B — the blue-grey head; C — the yellow-grey head; D_1 — waterlaid silts and sand; D_2 — waterlaid gravels; E — talus. The sites of the numbered exposures are shown by vertical lines on the profile which represents the west bank of the gully projected on to profile line JK (fig. 5). The profile also shows the position of the waterlaid beds of exposures 1, 4 and 5, those at 5 being overlain by poorly washed yellow-grey head

sequence also shows a gravelly head, roughly stratified parallel to the present surface, showing similar conditions at stage III to those of stage IV.

With this escape of melt water from the snow limit of stage IV, may be associated the fluting of the face of scarp IV suggesting wide shallow gutters leading down to step III. As shown on figure 10, this drainage probably escaped by a shallow channel which breaches scarp II. It may be pointed out that this drainage and the deformation of the scarps is developed on the western, "warmer", side of the fan; the protalus structures of Cwm Tinwen are similarly best preserved on the eastern side, while the western shows considerable deformation.

The exposures in Nant Cwm-du gully show that the material in the fan has been laid down in several stages and that the steps are not a series of terraces formed contemporaneously with the build-up of the platform of head at stage IV. The water-laid gravels and silts seen in three places each one a short distance from a scarp suggests that the building of the steps may have followed on milder climatic interludes.

CONCLUSIONS

S. G. Botch recognized two types of snow patch. The first, the steeply-sloping has been described in North America and Europe, but the second type, the gently-sloping, has not received such widespread recognition. In many parts of upland Wales, some hundreds of feet below the elevation of cirques showing the features of glacial erosion, the protalus ramparts of the first are found, close to steep headwalls. At similar elevations more open cirque-like basins with their terraced superficial deposits are believed by the author to be due to the second.

Cwm Tinwen represents the first type. Its very narrow basin helps to distinguish it from the typical glacial cirque (*cf.* Sharp 1942, p. 496). The estimated thickness of névé, allowing for the fact that it would be considerably less than full to the rim, is less than that generally believed necessary to form a cirque glacier.

Cwm Du, which falls into the second class, has the basin form and steep headwall of a glacial cirque but the existence of a platform of head, 20 metres high on the cirque floor with a surface slope similar to that of solifluction slopes on the same rocks in the Aberystwyth region seems to indicate the operation of a solifluction process beneath an inert mass of névé as suggested by Botch. But the accumulation of head in Cwm Du appears to have been on a much greater scale than that indicated by Botch. Two factors may have operated here. One is the rock type. In this area, the bed rock is the Aberystwyth Grits, a series of greywackes of Silurian age. Under frost weathering, the grits form joint blocks but the well-cleaved mudstones are rapidly broken down to silt so that the whole is very susceptible to solifluction. This undoubtedly influenced the rate of accumulation in Cwm Du and also accounts for the composition of the protalus in Cwm Tinwen which has a greater proportion of silt, grit and small gravel than is often the case. The second factor is the size of Cwm Du; indeed, it may be too large for the accumulation of snow alone. Any reasonable estimate of the thickness of snow at stage IV would be more than the generally accepted depth at which névé becomes ice, but it may be less than that required for plastic deformation and flow. The author submits that this is the critical distinction — that between moving ice which erodes the floor and an inert mass beneath which a soliflual movement of debris takes place. More research on the larger contemporary snow patches is required to test the validity of this.

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DISCUSSION

Professor Linton — Mr Watson must have considered the possibility that both these features were landslip scarps and he must have dismissed this possibility. Could he indicate to us the main types of evidence which led him to dismiss this possible alternative interpretation?

Mr Watson — Probably the main line of evidence bearing upon this is the structure of the cwm itself. The exposures that exist show, quite clearly, bedded material which is dipping downstream. The bedding is apparently undisturbed and could not have developed by slumping. In fact, this is the evidence that made me reject the idea that the deposits were solifluction terraces. The material in the "terraces" is not rolled up as it would have been if it had moved *en masse*. It has been built up steadily, and there is a regular sequence. The only place where there is slipping is at the foot of the scarp.

Mr Andrews — What evidence is there that these features were produced by snowbanks?

Mr Watson — There is none. But the alternative interpretation, mentioned by Professor Linton, does not accord with the evidence, and I do not think that they are glacial. Glacial cirques occur in the area at a much higher elevation or in less favourable situations from the point of view of orientation towards the sun. On Cader Idris a feature described by W. V. Lewis as the most perfect cirque in the British Isles has a rock basin at 1500 feet. About 500 feet lower in the same area, on a north-facing site, there are several protalus ridges each with an oversteepened backwall. There seems to me a strong argument from distribution that features were developed similar to this where conditions were not so severe as in glacial cirques. I suggest that perennial snow patch erosion was responsible.

Mr Andrews — I would like to question your use, without definition, of the terms *snowbank* and *protalus moraine*. How do you differentiate a moraine of this type from a coarse, locally-derived, corrie moraine, and when does a snowbank become a permanent ice patch or slab?

Mr Watson — In the case of a glacial cirque I would expect erosion on its floor, but in these features there is an infilling of at least 60 feet of drift. In Cwm Tinwen the greatest thickness of snow or ice would seem to have been 125 feet. The generally accepted figure at which snow becomes converted to ice is about this amount. So the distinction that we are involved with here is that between moving and eroding ice and motionless névé with some ice in the lower layers of the snow patch. Snow patch is perhaps not the most appropriate term, but I do not know of another which is more suitable. We are dealing with a motionless mass.

Dr Pippan — Was the initial form of this type of feature due to ice?

Mr Watson — The initial landform was probably a gully, and snow from the plateau surface accumulated in the gully head. All these features face north, and in each the final position of the protalus moraine is under the west wall, i.e. in the most shaded situation.

Dr Pippan — Were the walls of the feature controlled by joint or structural planes in the rock?

Mr Watson — No. The valley is excavated along a fault line, and this is why it is steep and very narrow and one of the reasons why it offered this very shaded position for the development of these features.

Professor Péwé — I am still not convinced that they could not be glacial cirques. If the snow line was lowered this could be so and the debris in the bottom could be postglacial I suppose. What about the material itself — is it stratified?

Mr Watson — It is stratified near the stream sections and also in front of the second step of the corrie. In the lower half there is a series of washed sands and small gravels (less than 2 cms in length) laid down by running water. They accumulated to form the basal part of the terrace. This is buried by head, two stages of it. Material in the heart of the step seems to be very largely the blue head material rather than the yellow and blue head which occurs farther up. The semi-washed material was laid down at the margin of the snow patch when the front was oscillating. Further back the material is coarser and the head was produced.

Professor Péwé — If the head were till there would have been glacial erosion. We have the problem of "head" or "till".

In reply to inquiries by Professor Hamelin and Dr Blake, Mr Watson said that no datable material had been obtained, though there were remains of vegetation in the lower part of the drift. Dr Seddon of the National Musseum of Wales had taken samples, but the results of the analysis were still awaited.

Professor Rudberg — In Scandinavia we have observed a complete series of nivation hollows, small to very large, all facing in the same direction.

Mr Watson — In Cwm Tinwen, in addition to the protalus moraine enclosing the main cirque, there are niches on the backwall, and these may record the final position of the snow. Again, out on the main valley side there are similar rounded, dimpled hollows. In the case of Cwm

Du I think that we had a well-marked gully to collect the snow. In the case of Cwm Tinwen there is a slight change in valley direction which makes an elbow which could facilitate snow accumulation.

Miss Edwards — I have found similar features facing east at 1100 to 1200 feet O. D. in the Rhondda valley in South Wales. Again, close to the backwall a protalus is present, composed of coarse, very angular blocky material about 1′6″ in diameter, which contrasts with small calibre material (1″—$1^1/_2$″) in the associated terraces below the ramparts.