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CHARACTERISTICS OF ICE-WEDGE CASTS IN WEST CENTRAL WALES

Résumé

La majorité des remplissages de fentes en coin ont été observés dans des dépôts de pente caillouteux et des graviers fluvatiles et fluvio-glaciaires. Les formes les plus grandes atteignent une largeur de 2 à 3 m et une profondeur de 3 à 5 m. Les couches de graviers encaissants sont soulevées en bordure des coins, spécialement lorsque les formes sont très larges. Des structures de glissement et d'affaissement apparaissent seulement dans le remplissage lorsque les graviers sont aplatis; dans les autres graviers, le remplissage du coin est caractérisé par l'inclinaison très forte des éléments caillouteux. Bien qu'aucune datation précise des fentes de gel ne soit disponible, l'auteur pense que ces formes sont apparues dans la dernière partie de la dernière glaciation.

Abstract

Most of the wedge casts occur in angular slope gravel, fluvial or fluvio-glacial gravels, the largest reaching a width of 2–3 m and a depth of 3–5 m. Upturning of the host gravel occurs, especially with the larger casts. Slump or sag structures in the fill are limited to platy gravels; in other gravels, the wedge fill is characterized by very steeply dipping clasts. Though no means of precise dating is available, it is thought that the wedge casts formed in the latter part of the last glaciation.

INTRODUCTION

The area under discussion lies within 25 km of Aberystwyth. A map of approximately the same area published in 1965 (WATSON, 1965a), showed only 7 sites; Fig. 1 shows 23, and it probably still does not reflect accurately the distribution of ice-wedge casts. Instead it shows the areas of investigation by the author and A. POTTS (1971). It is for instance, unlikely that the absence shown in the Dovey basin is real.

The bedrock consists of Ordovician and Silurian turbidites, mudstones and shales, with plate, blade and rod-shaped clasts dominating the superficial deposits. Almost all of the recorded wedge casts occur in two types of host material, angular gravel of slope deposits and waterworn gravel of fluvial or fluvio-glacial deposits. These are not well stratified and usually it is the orientation of the maximum projection (or a/b) planes which gives the structure of host deformation or of the wedge fill. In Table I the wedge casts have been grouped by the type of host, but for ease of reference the sites have been continuously numbered on Fig. 1, reading from N.W. to S.E.

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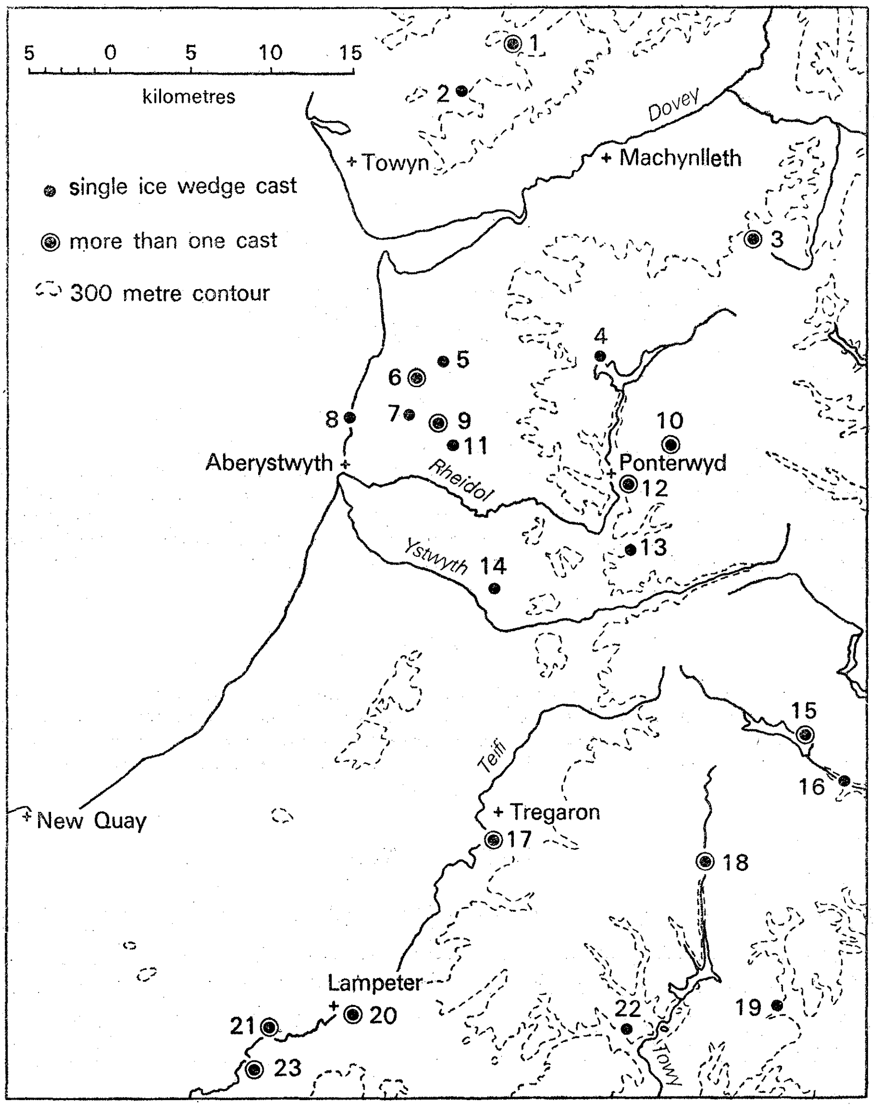


Fig. 1. Location of ice-wedge casts in west central Wales, numbered as in Table I

THE IDENTIFICATION OF ICE-WEDGE CASTS

In contemporary permafrost ice wedges are best known in plan as polygonal patterns which are occasionally cut by the coast or river banks showing them to be the surface expression of a net of ice veins. Thus casts should be identified not only in vertical section, they should continue in a horizontal direction to form a polygonal net. Two main criteria have been given for the recognition of ice-wedge casts in vertical section. The first is deformation of the host. Since the time of LEFFINGWELL it has been observed that the summer expansion of the permafrost tends to produce an upward curvature of the bedding adjacent to the ice wedge "to the vertical and

Table I

1	2 Grid Ref	3 alt	4 width	5 height	6 sag structures	7 host arched	8 host sags	9 Cover
Group A: wedges in angular slope gravel								
2	SH655050	73	1.25	2.75	×	—	×	1.0
3a	SN836958	480	1.85	4.25	—	×	×	1.5
b		480	>0.9	>2.1	—			
6	SN626870	45	0.3	>1.0	—	—	—	1.2
10a	SN785829	345	1.32	1.60	×	×	—	1.5
b		345	2.33	3.00	×	×	—	2.0
c		345	2.20	3.75	×	×	—	1.3
11	SN648830	122	>0.2	>0.6				
12a	SN757806	305	1.00	3.20	—	—		1.5
b		305	2.40	>3.8	—	×	×	1.6
13	SN763763	410	1.70	2.40	×	×	—	1.0
15a	SN869645	380	0.90	4.30	—	—	×	3.2
b		380	1.00	4.60	—	—	×	1.4
16	SN895619	275	1.75	>1.5	×	—	—	1.8
18a	SN807566	325	0.85	>1.5	×	—	×	0.5
b		325	0.75	>1.1	×	—	×	0.6
c		325	0.15	>1.2				
19	SN851482	267	0.36	>0.6	×	—	×	>0.5
22	SN760460	305	1.55	>1.2	—	×	—	1.5
Group B: wedges in water-worn gravel								
1a	SH684076	40	1.30	2.75	—	×	×	1.60
b		40	0.60	>1.1	—			0.6
c		40	1.40	>1.0	—			0.5
d		40	0.50	>1.3	—	—	×	2.4
e		40	0.25	>1.2	—	—	×	2.3
f		40	0.50	1.20	—	—	—	0.3
5	SN645880	53	0.40	>1.1	—	—		0.4
7	SN623848	30	0.25	0.90	—	—		
8	SN586841	18	0.55	>1.2	—	×	×	0.3
9a	SN643842	45	0.20	1.00	—	—	—	0.4
b		45	0.60	0.80	—	×	—	0.6
14	SN674739	76	1.05	2.88	—	×	—	0.3
17a	SN673582	69	0.60	3.50	—	×	—	0.3
b		69	0.60	2.80	—	—	×	0.3
c		69	0.50	3.00	—	—	—	0.3
20a	SN587475	122	0.50	>1.8	—	×	—	0.4
b		122	0.80	>1.6	—	—	—	0.5
c		122	0.20	1.20	—	—	—	0.5
21a	SN537468	122	0.40	>1.2	—	×	—	0.3
b		122	0.50	1.30	—	×	—	0.2
23a	SN527443	105	0.30	2.1	—	—	×	0.3
b		105	0.25	1.5	—	—	×	0.3
Group C: wedge in silt								
4	744876	325	>0.9	>0.7		—	×	

Cols. 2, National Grid Reference; 3, altitude above sea level; 9, undisturbed overlying beds. 3, 4, 5 and 9 are in metres. 6, 7 and 8, × present, — absent, or no data.

even beyond", (1919, p. 208). This "should be preserved locally adjacent to *some* wedges in a group", (BLACK, 1976a, p. 11). Its presence has been recorded in Table I, col. 7. The second criterion suggested by BLACK is that in the wedge fill, "slump fabrics should show stratification arcuate downward across wedges" (*ibid*), This is indicated in Table I (col. 6), as "sag structure".

ICE-WEDGE CASTS IN ANGULAR SLOPE GRAVEL

LOCALITY 10, PONTERWYD

The most instructive of recent exposures was produced by the widening of the A44 road, 20 km east of Aberystwyth in 1975, (WATSON, 1976, pp. 99—100). The section, (Fig. 2), showed the bedrock overlain by a blocky stony clay on which rested platy angular slope gravel. Two of the casts were wedge-shaped but one was almost rectangular in generalized outline. Shallow excavations of the casts showed that their sides were approximately normal to the face so that the outlines represented fairly accurate cross-sections. Both the wedge fill and host consisted of angular gravel but the fill was generally less coherent and fell readily to produce a depression in the cast area.

Wedge C

Below the 2.5 m level, (Fig. 2), a brown silty-clay band 5—20 mm thick, formed almost continuous walls which were used to delimit the lower wedge cast. It could not be traced in the wider upper part and may have been related to the generally more muddy character of the lower gravel at this point.

Host deformation was striking on both sides of the cast above a depth of 2.75 m, where the a/b planes of the host gravel curved up towards the cast margins, almost becoming vertical on the right. Below this level, the host contained short lenses of very silty gravel within the generally open gravel. These lenses showed much more deformation than the open gravel indicating a differential response to pressure. In loose open gravel this might be made by closer packing, by a reduction in voids, whereas in the silty lenses few voids existed; (*cf.* SHUMSKII, 1964, p. 196, "the enclosing frozen rock must *consolidate or extrude upwards*"). The silty lenses also responded to pressure by thickening at the wedge boundary, (*cf.* BLACK, 1976a, p. 12). The silty shell of the lower part of the cast may have resulted from extrusion of silt by compaction of the open but somewhat muddy lower gravel. Immediately outside this silty shell the a/b planes tended to be oriented nearly parallel to the wedge margin, probably by pressure. This was well developed on the right below 3.5 m (Fig. 2). That it was outside the cast and not part of the fill was shown by a similar reorientation of gravel in the thickened silty lenses at 3 and 3.25 m. Again the band at the top left where the upturned a/b planes were bent downwards towards the cast, is interpreted as being part of the host as the same downbending also occurred outside the silty shell at about 2.50 m.

Though there was no bedding in the wedge fill, the alignment of the a/b planes suggested a sagging collapse pattern. At the sides they were parallel to the wedge

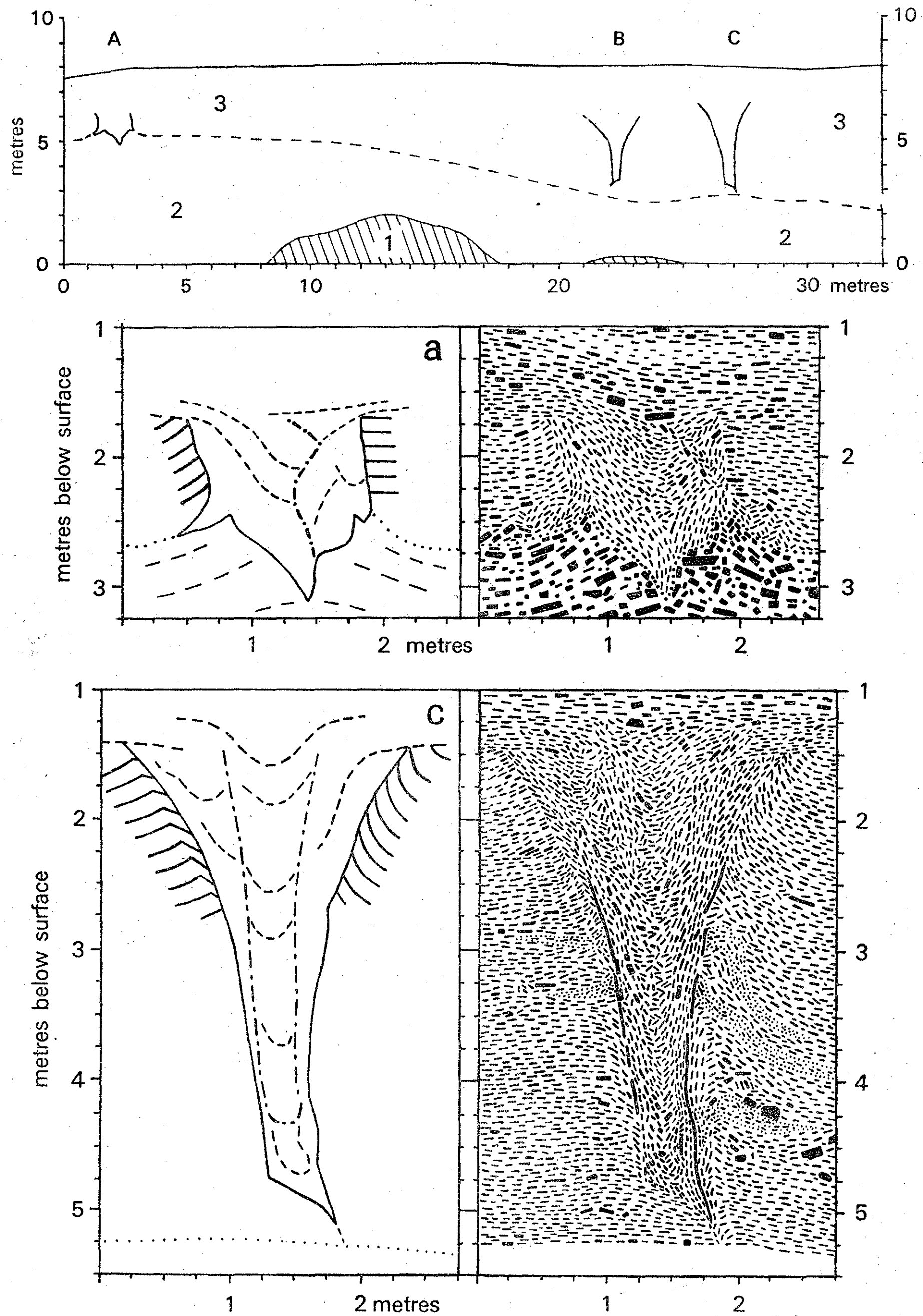


Fig. 2. Locality 10, N.E. of Ponterwyd, showing wedge casts A, B and C

Above, vertical exposure: 1. bedrock; 2. stony clay; 3. angular slope gravel
Centre, wedge cast A: dotted line, boundary between beds 2 and 3 (see Plate 1)
Below, wedge cast C: dotted beds, silty gravel; brown silty shell shown in black (see Plates 2 and 3)

outline, becoming vertical in the lower part. Towards the central axis of the wedge the dips decreased and tended to become horizontal, producing a general synclinal pattern. This was more clearly seen in wedge B (Fig. 3a). In wedge C this central zone (delimited on Fig. 2 down to 4.25 m) consisted of looser gravel than the rest of the fill (*cf.* Plates 2 and 3). It is suggested that this represents the final collapse, possibly into a large void produced in the lower cast as the ice thawed. The relatively narrow top of the lower part of a wedge must ensure that collapse generally continues longest in the centre and affects the highest of the overlying beds here (as also in wedge B, Fig. 3a).

Wedge B

This was of the same form as wedge C, though the silty shell could be traced only in a small part, from 2.75 to 3.25 m on both sides, (Fig. 3a), possibly because the host gravel had generally a lower silt content. The definition of the cast therefore depended on the orientation of the clasts. In the host the a/b planes turned up clearly on both sides above 3 m, with some tendency to downturning and alignment parallel to the wedge margins between 3 and 4 m. The sag structures in the fill were clear down to about 4 m below which there were sub-vertical dips to the base.

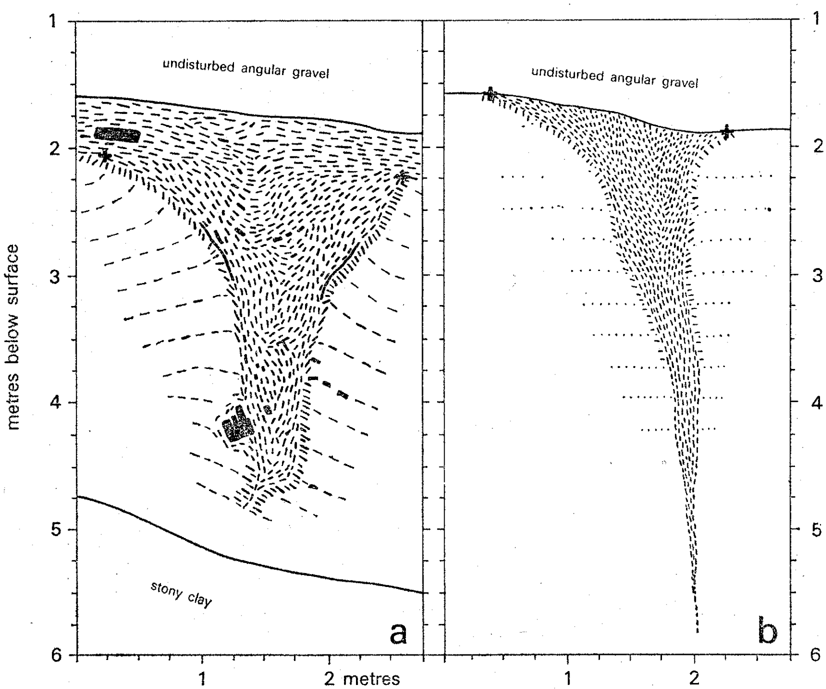
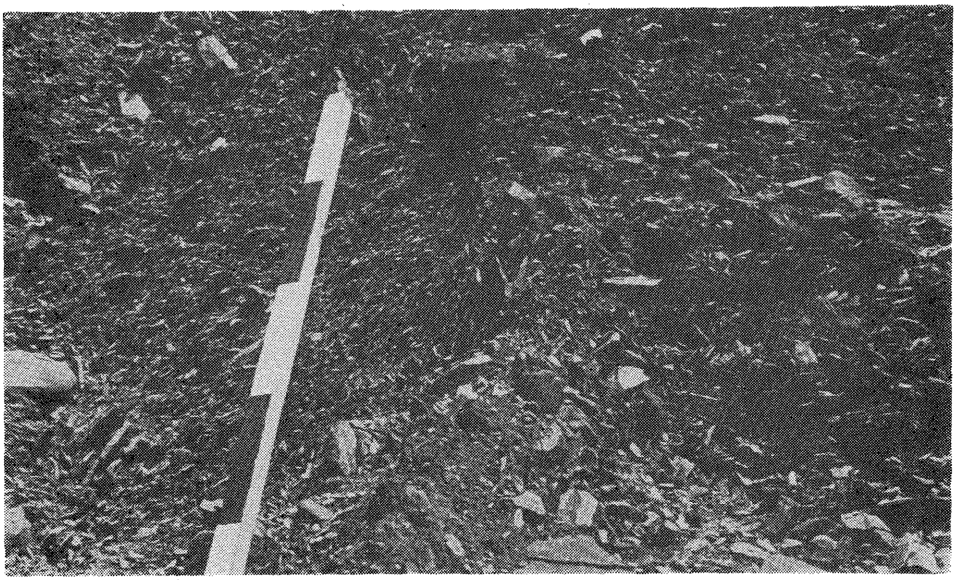


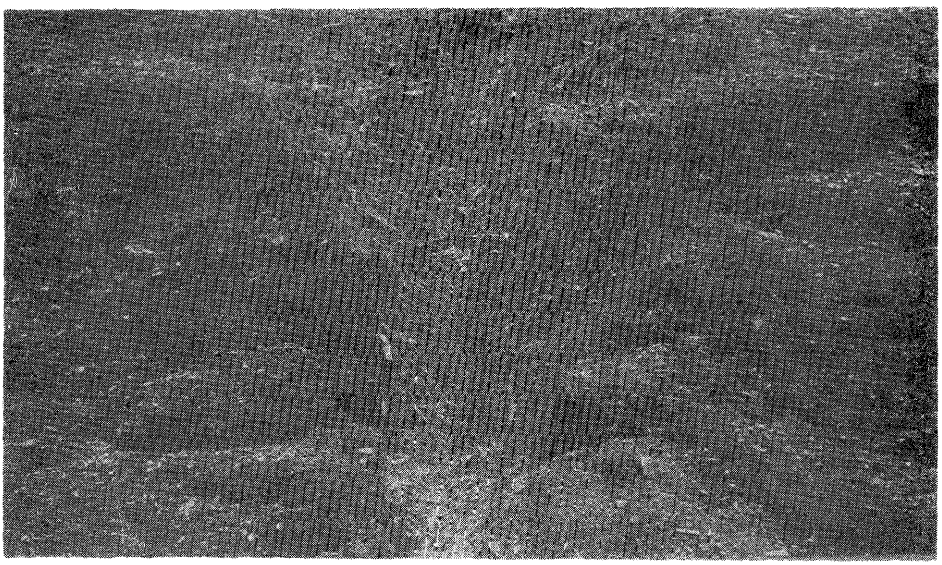
Fig. 3. Wedge casts in angular slope gravel

a: cast B, locality 10, in platy gravel. Plate 10, WATSON, 1976, shows some detail
b: cast 2, locality 3, in smaller rod-shaped gravel, 1978. The deeper casts are in the finer gravel
The orientation of the clasts in the host is shown in outline. The crosses show the measured width of the casts, at the junction of deformed host, fill and undisturbed overlying beds



Pl. 1. The lower margin of cast A, locality 10

The lower centre of the photo, shows the ridge of stony clay 2 m right and 2.7 m down on Fig. 2a, above which is the boundary between the fill (left) and the highly disturbed gravel of the host. The sag structure in the fill is seen left of the top of the scale which shows decimetres

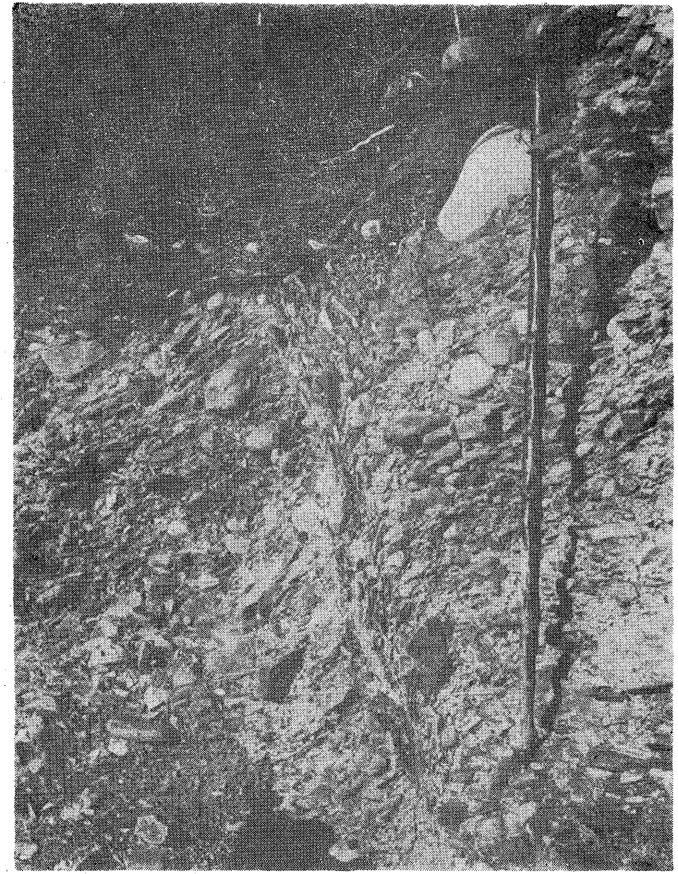


Pl. 2. The upper part of cast C, locality 10

This photo was taken obliquely upwards (*cf.* Fig. 2c). Note the deformation of host and sag structure in fill

Pl. 3. Lower part of cast C, locality 10

The pale area left of centre is due to the accumulation of fine particles (soil mostly) at the bottom of the hollow coinciding with the loosest fill. Note the deformation of the silty gravel lenses, upper right. Scale shows decimetres



Pl. 4. Cast in terrace gravels, locality 8 (Clarach), 1966

Stick, 90 cm long, but photo oblique to face, from right (*cf.* Fig. 5b)

Pl. 5. Part of wedge cast in alluvial gravel, locality 20 (a)

The fill is generally finer than the host which shows upturning of the a/b planes on its margins (see Fig. 5c). Scale shows decimetres

Pl. 6. Wedge cast almost parallel to face at locality 20 (a)

The cast is at 20° to face and appears as an area of structureless gravel where the larger pebbles have fallen away leaving casts. Continues Plate 5, on the same scale

Wedge A

The form of wedge A is exceptional in the region, but the alignment of the sides and base of the cast suggested it was a true cross-section. It was clearly confined to the loose angular gravel, having failed to penetrate the more compact diamicton underneath, apart from a narrow extension at its centre. At the bottom corners it also extended along the contact of the two beds. It showed many features comparable with wedges B and C. The relatively loose fill fell away to leave the more cohesive host in clear outline. To the left the a/b planes of the host were gently arched up, to the right they remained almost horizontal, but at both sides, the a/b planes of the fill dipped steeply inward. The upper part of the fill suggested a ruptured syncline from which the loose gravel poured into the lower extensions.

LOCALITY 13, DEVIL'S BRIDGE

The single cast 2.5 km east of Devil's Bridge was also in platy gravel; excavation of the cast in plan, 1977, showed the horizontal axis to be at 70° to the face, so that the outlines shown in Fig. 4 differ little from a true cross-section. The first bed laid down on top of the shrinking ice wedge was a very muddy gravel (matrix of silt and fine sand), which formed a lining to the cast and in places filled the lower part, as in 1966, (Fig. 4a). In 1964, when the exposure was several metres further downslope the muddy gravel bed occurred only in the upper wider part of the wedge, thinning downwards to end at about 2.50 m below the surface. The lower part of the cast was filled with loose gravel (*cf.* WATSON, 1965a, p. 458). At both dates this muddy bed was truncated by the overlying undisturbed beds (a and b in Fig. 4a, b in Fig. 4b), showing erosion of the upper flanks of the wedge. The host showed vertically oriented clasts in places outside the wedge fill (Fig. 4a), similar to that accompanying wedge C at locality 10 (Fig. 2). When this wedge cast (13) was excavated in the horizontal plane in 1977, these vertical a/b planes were again seen outside the muddy gravel fill, parallel to its edge, as if re-oriented by pressure against the wedge.

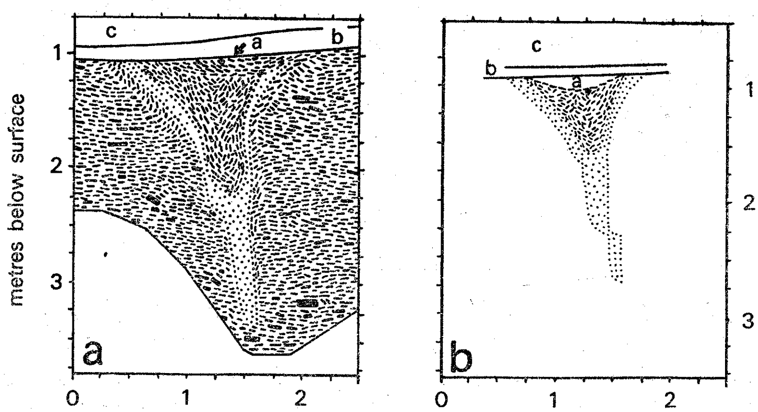


Fig. 4. Wedge cast in platy gravel at locality 13

a: 1966 b; 1977. Dotted areas represent very muddy gravel in wedge cast; Bed a, open gravel which has lightly sagged into the cast; b, very muddy gravel; c, open gravel

Wedge casts B and C at locality 10 have a blunt base with a narrow fissure continuing downwards from one corner. The profile of cast 13 in 1977 showed the same blunt base and a further development of the continuing fissure which was filled with the muddy gravel (Fig. 4b). This extension has also a blunt base. So far flat bottomed wedges of this type have been recorded only in very platy gravel, probably because fissures near the limit of penetration tend to stop against a plate especially where coarser debris in the form of slabs is fairly common as at the base of cast 13. Widening takes place by sliding between clast surfaces.

LOCALITY 3, RHIW FAWR

When first recorded, in 1968, there were two casts in the gravel pit, but with further exploitation the site of 3b has disappeared. Cast 3a which still survived in 1978, (Fig. 3b), illustrates a second pattern, characteristic of closely cleaved shales which disintegrate to small rod-shaped clasts. The host is *grèzes litées*, like casts 12a and 12b (WATSON, 1965b, photo 1a), which in central Wales are best developed on these rocks.

The host showed relatively slight deformation, the upturning of the finer beds and of the a/b planes of the coarser beds being limited to a very narrow band (about 10 cm wide), and to a small part of the upper wedge. This is general in this type of gravel; consolidation of the host seems to have been more important than upward extrusion on the wedge margins. The fill lacked any suggestion of downward sagging but was characterized by vertical to near-vertical clasts. The lower two-thirds consisted of vertical a/b planes which contrasted sharply with the horizontal clasts and bedding of the host. In the wider upper part, convergent streams of steeply dipping clasts met at acute angles. These steep dips continued up to the base of the overlying undisturbed gravel where there was a marked discordance of dips. The overlying beds may sag slightly (as here, over the deeper part of the cast), but the change in the a/b dips remains abrupt.

These features, the long tapering wedge with a fill of vertical clasts are represented by 13a, 12a and 12b in the same type of gravel, and also by 6, 11, 15a and 15b in a gravel of fairly uniform small platy clasts. This pattern dominates casts in slope gravels; though wedge fills with sag structures have been discussed more fully, there are only six such casts in the area, 3 at locality 10, one at each of localities 13, 2 and 16 (POTTS, 1971, Fig. 10).

ICE-WEDGE CASTS IN WATERWORN GRAVELS

LOCALITY 8, CLARACH

The single wedge in the cliff top north of river contracts rapidly downward to a narrow fissure, some 5—6 cm wide filled with sand, grit and small gravel, (Fig. 5b and Plate 4). The a/b planes of the host gravel are upturned around the upper wedge to a limited extent. There are no overlying undisturbed gravels: the cast is in a terrace some distance from the hill slope. The host and cast are covered only by the modern soil, as is true for almost all sites in this group, Table I (B). The fill

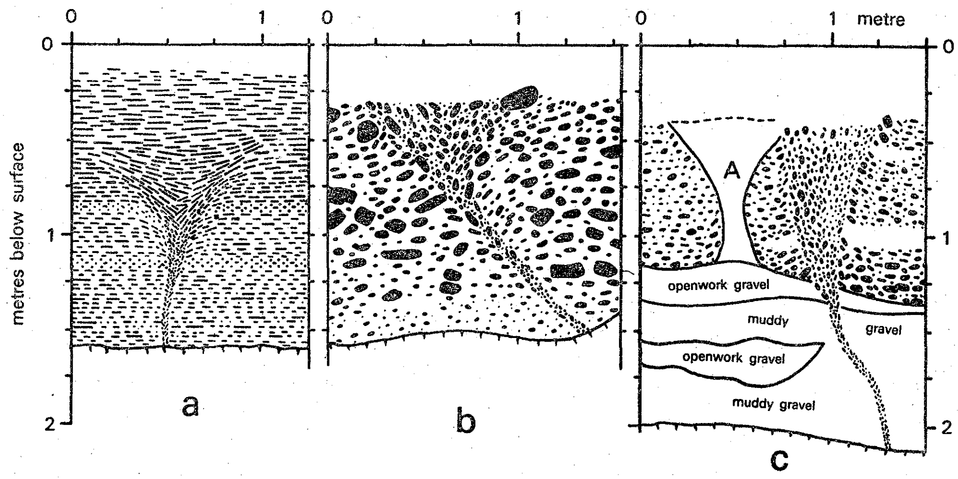


Fig. 5. Wedge casts in *grèzes litées* and fluvial gravels

a: locality 18, in *grèzes litées*, overlain by coarse angular gravel, 1978
b: locality 8, in coarse alluvial gravel, 1978, (see Plate 4)
c: locality 20, in alluvial gravel, 1977. A is the trace of a narrow wedge cast which meets the face at about 20°; it stops abruptly at the openwork gravel

consists of steeply dipping gravels, inclined towards the centre, and shows no indication of a sag structure. Removal of part of the fill shows the wedge meets the cliff face at about 45°, and the apparent width of 80 cm represents a true width of about 55 cm (*cf.* Table I).

This funnel-shaped wedge about 50 cm wide at the top and narrowing at a depth of about 50 cm to a fissure some 5—10 cm wide which continues a further 2 to 3 m seems common in fluvial gravel, and in the fluvio-glacial gravels of the Teifi valley, as in localities 17a, b and c and 23a and b. It may be suggested that the rapid widening of the top of the cast is due to collapse of the host. The absence of the larger clasts occurring in the host seems against this but much of the fill is similar in calibre. Clearer evidence is provided by casts of similar form in slope deposits such as 18a and 18b. The slope deposits consist of fine *grèzes litées* overlain by a coarse angular gravel of very thin plates (Fig. 5a). The latter have sagged into the upper cast and though they do not fill it completely, show that the wide top already existed. Between the fill of coarse plates and the cast margins there is a zone some 5 cm wide of finer gravel from the wedge sides; 0.8 m below the surface the total width of the cast is 0.40 m, 25 % of which is derived from the wedge sides. The fill in the lower narrow part of the fissure is derived from the *grèzes litées* forming the sides,

LOCALITY 20, LAMPETER

The wedge cast in the bank of the River Hathren has a longer relatively narrow V-shape in its upper part, also common in waterworn gravels. Indeed its width is 0.50 m, less than it appears in the exposure, (Fig. 5c), as it cuts the face obliquely. The wedge fill seems not to have been derived from the sides as it is generally of narrowest cast (locality 6) has a form resembling that in Fig. 5a. Many flared casts occur in waterworn gravels (e.g. Fig. 5b). About half are not; as these are amongst the narrower casts, this feature may be related to width.

The great majority taper downwards to a narrow crack (as Fig. 3b), both in angular and rounded gravels. Wedges known to have a broad flat bottom (as Figs. 2c, 3a and 4) are rare, being limited to these examples which are in platy debris. Three casts split at the base and are continued downwards as two diverging narrow fissures (sites 14, 20c and 21b). No round-bottomed casts have been recorded.

HEIGHT

In angular gravel, the 9 fully exposed casts have heights between 0.80 and 4.60 m, 5 of which exceed 3 m and 8 (89 %) exceed 2 m. Those in waterworn gravels are shorter, only 1 out 13 exceeding 3 m and 6 (46 %), exceeding 2 m.

WIDTH

Widths range from 2.40 to 0.20 m, Table I suggesting there is also a correlation between the wider wedges and angular gravels. Table II (a) shows that of a total of 16 casts in angular gravel, 11 (69 %), are wider than 1 m compared with 3 (14 %) out of 22 in waterworn gravels. The samples are small but the contrast is marked.

Table II

Relationships between width of wedge cast, elevation and host

(a) *Width of wedge cast and host*

Host		Width of wedge cast			
	Total	2 m	1–2 m	0.5–1 m	0.5 m
Angular gravel	16*	3	8	3	2
Waterworn gravel	22	0	3	11	8

(b) *Elevation and host*

Host		Elevation in metres			
	Total	300	200–300	100–200	100
Angular gravel	16*	12	2	0	2
Waterworn gravel	22	0	0	7	15

(c) *Width of wedge cast and elevation*

Elevation		Width of wedge cast			
	Total	2 m	1–2 m	0.5–1 m	0.5 m
48–480 m	38	3	11	15	9
300 m	12	3	6	3	0
200–300 m	2	0	1	1	0
100–200 m	7	0	0	3	4
100 m	17	0	4	8	5

* Wedge casts 3b, 11 and 18c are truncated and therefore omitted.

Table II(b) sets out the relationship between elevation and wedge casts grouped by host type. Those in angular gravels are relatively high lying; 14 out of 16 are above 200 m, 12 are above 300 m. In contrast, all 22 casts in waterworn gravels are below 200 m; none is higher than 125 m. This may reflect the fact that fluvial and fluvial-glacial gravels have a dominantly lowland distribution while slope gravels occur to relatively high levels.

Table II(c) suggests a strong correlation between cast width and elevation, and this may be more important than host type. If this is true the width of casts at low elevations should be similar in both slope and waterlaid gravels. Only two are recorded in slope gravels below 200 m and their evidence is somewhat contradictory; at site 6 the width is 0.30 m but at 2 it is 1.25 m.

HOST DEFORMATION

In contemporary ice wedges this is often related to width and generally decreases in intensity down a wedge as it thins. In west central Wales it is best developed with the widest casts, being most pronounced with the three that are more than 2 m wide, (10b, 10c and 12b) and in one other, 13, which is 1.70 m wide. It is less developed in 3a, width 1.85 m; and 1a, 10a, 14 and 22 showing comparable deformation, are between 1.05 and 1.55 m. Deformation is slight with 8, 9b, 17a, 20a, 21a and 21b, all of which are between 0.40 and 0.60 m. The widths of casts accompanied by no clear deformation range from 1.75 to 0.20 m, suggesting that other factors such as the possibility of compaction of the host under pressure may have operated.

Where three casts are exposed in the same host as at locality 10 (Fig. 2), the deformation at A, which is 1.30 m wide, is less extensive than at B and C, measuring 2.33 and 2.20 m respectively. Of two in fluvial gravel, 9a, 0.20 m wide, was accompanied by no deformation, while 9b, 0.60 m wide, showed a slight but distinct upturning of the host.

WEDGE FILL

In order that a fill may show "stratification arcuate downwards", (BLACK, 1976, p. 11—12), it must have a stratification to deform by collapse. Ice wedges on sloping sites where slope deposits were laid down during the period of thawing and subsequently, offered the most favourable conditions in central Wales for this. But these overlying beds of open angular gravel rarely have a true stratification and it was only in the case of markedly platy clasts that the beds had enough cohesion to preserve a sag structure. Where the slope deposits consist of rod-shaped or small platy gravel, the fill is characterized by "vertical clasts" whose a/b planes dip at 60—90°. Casts in fluvial or fluvio-glacial gravels are in flat or gently sloping sites where overlying beds are absent. Here again the fill consists of steeply dipping clasts, as well as in the rare casts in hosts other than gravels, such as silt or bedrock.

Thus the dominante pattern of wedge fill consists of an outer zone where the a/b planes of clasts dip parallel to the sides. In the narrow part of the cast or, all of it in the narrower ones, this produces a fill of vertical clasts. In the upper part of the wider casts several "streams" may occur abutting on one another at steep angles.

Virtually all wedge casts that have been recorded have been perpendicular to the exposure face or cut it at a fairly large angle. If they were parallel to it or nearly so they would be impersistent and the chance of their being recorded would be slight. Some such cases are known, as at locality 20, where A (see Fig. 5c) cuts the exposure face at an angle of 20° and appeared as an area of vertical stones with their a/b planes nearly parallel to the face (Plate 6).

Although the recorded casts in slope deposits are almost all of wedges aligned sub-parallel to the slope, there is no evidence that they formed gullies, no evidence of the erosion forms and depositional structures associated with water flow. The explanation may be found in contemporary ice wedges on slopes which do not produce a surface pattern of troughs, "snow cracks being the only indication of ice wedges below" (MACKAY, 1974, p. 1376).

EVIDENCE FOR HORIZONTAL EXTENT

Evidence that these casts are part of a polygonal net is lacking. Crop markings have not been identified on aerial photographs, and evidence of horizontal extent at the sites is limited. The gravels are of low value and little exploited, with small pits showing only one or two casts. The occasional building excavation or road widening usually shows no more than two or three. Eleven of the 23 localities on Fig. 1 have single casts, seven (3, 9, 12, 15, 21 and 23) show two in a continuous face and five (6, 10, 17, 18 and 20) show three or more. Only the latter twelve locations give data on the distance between casts. The mean is 10 m with values from 38 to 1 m. A line of section drawn randomly through an area of polygons will give any value from 0 to the maximum diagonal; a very large number of readings is necessary to obtain a realistic mean. A value of 10 m would fall within the range expected.

Cast 4 was seen for a length of 5.2 m (WATSON, 1965a, p. 456–8) and 13 was excavated for 2.5 m, while four others were seen on opposite sides of trenches or small excavations. In five other cases the fill was excavated for a short distance back from the face to reveal the wedge sides and seven recorded in the 1960s have persisted during the retreat of the vertical face, sometimes over several metres. In one of these, 20a, the retreat of the stream bank has shown the replacement of one wedge (1961) by two as it branched, the left-hand wedge (A on Fig. 5c), cutting the face at 20° (1977). Proof of a polygonal pattern of fossil ice-wedge casts "requires expensive long-term investigations" (DYLIK, 1966, p 243). The task has only begun.

PALAEOCLIMATIC SIGNIFICANCE

It is generally accepted that ice wedge growth on a regional scale occurs only in continuous permafrost (BLACK, 1976b, p. 81). PÉWÉ (1966) concluded from a distribution study in Alaska, that though many occur in discontinuous permafrost, they are inactive and survive only in fine-grained sediments. Those in gravels have already thawed: they have not survived the change to discontinuous permafrost. The period when ice wedges formed in gravels in central Wales must have been one of continuous permafrost.

The duration of this period of growth may, in general terms, be estimated from the width of the ice-wedge casts. At Point Barrow in Alaska measurements of ice wedges suggested a "round figure growth rate" of 1 mm a year, while on Garry I. near the Mackenzie delta, it was found that "most grew at far less than 1 mm a year" (MACKAY and BLACK, 1973). In Victoria Land, Antarctica the mean growth rate over 6—8 years was 0.84 mm a year (BLACK, 1973). At a mean growth rate of 1 mm a year ice wedges 2.20, 2.33 and 2.40 m wide would require 2200—2400 years, at 0.84 mm about 2750 years, or in round terms 2000—3000 years. The width of a wedge cast, however, is not likely to be the width of the ice wedge that occupied it. The relation between the two is difficult to establish and undoubtedly varies with the host. The amount of survival of host deformation in these, the largest wedges suggests that widening of the cast after thawing may not be serious though some erosion of the upper sides by the collapsing fill seems probable. Against this factor tending to exaggerate the width, some erosion of the upper wedge cast probably occurred reducing its width, as in most casts overlain by slope deposits. The amount probably varies with the slope. As was pointed out this erosion is clear at site 13 (Fig. 4; cast width, 1.70 m) with a surface slope of 20°. At 10c and 10b (Figs. 2c and 3a; widths, 2.20 and 2.33 m), the deformation of the host is truncated with a slope of 25°. The unqualified application of contemporary process rates in Antarctica demands comment: it seems unlikely that the thermal contraction of permafrost in winter or the frequency of cracking in Pleistocene Wales would exceed that of present-day Antarctica. The round figure of 2000—3000 years seems likely to be an underestimate.

With regard to age no means of precise dating is available at present. The casts are obviously younger than the fluvial terraces and fluvio-glacial gravels and also younger than most of the slope deposits. They probably date to the Late-glacial, but are older than the Younger Dryas (WATSON, 1977, p. 194—5).

References

BLACK, R. F., 1973 — Growth of patterned ground in Victoria Land, Antarctica. *In*: *Permafrost, N. American Contribution to 2nd Int. Conf. on Permafrost*; p. 193—203. Nat. Acad. Sci., Washington, D.C.

BLACK, R. F., 1976a — Periglacial features indicative of permafrost: ice and soil wedges. *Quat. Research*, 6; p. 3—26.

BLACK, R. F., 1976b — Features indicative of permafrost. *Ann. Rev. Earth Planet. Sc.*, 4; p. 75—94.

DYLIK, J., 1966 — Problems of ice-wedge structures and frost-fissure polygons. *Biul. Peryglac.*, 15; p. 241—291.

LEFFINGWELL, E. DE. K., 1919 — The Canning River Region, northern Alaska. *U.S. Geol. Survey Prof. Paper* 109.

MACKAY, J. R., 1974 — Ice wedge cracks, Garry Island N.W.T. *Can. J. Earth Sci.*, 11; p. 1366—1383.

MACKAY, J. R. and BLACK, R. F., 1973 — Origin, composition and structure of perennially frozen ground: a review. *In*: *Permafrost, N. American Contribution to 2nd Internat. Conf. on Permafrost*; p. 185—192. Nat. Acad. Sci., Washington D.C.

PÉWÉ, T. L., 1966 — Palaeoclimatic significance of fossil ice wedges. *Biul. Peryglac.*, 15; p. 65—73.

POTTS, A. S., 1971 — Fossil cryonival features in central Wales. *Geogr. Annlr*, 53A; p. 39—51.

SHUMSKII, P. A., 1964 — Principles of structural glaciology. New York.

TABER, S., 1943 — Perennially frozen ground in Alaska: its origin and history. *Bull. geol. Soc. Amer.*, 54; p. 1433—1548.

WATSON, E., 1965a — Periglacial structures in the Aberystwyth Region of Central Wales. *Proc. Geol. Assoc. London*, 76; p. 443—462.

WATSON, E., 1965b — Grèzes litées ou éboulis ordonnés tardiglaciaires dans la région d'Aberystwyth. *Bull. Ass. Géogr. Franç.*, 338—9; p. 16—25.

WATSON, E., 1976 — Field excursions in the Aberystwyth region, 1—10 July, 1975. *Biul. Peryglac.*, 26; p. 79—112.

WATSON, E., 1977 — The periglacial environment of Great Britain during the Devensian. *Phil. Trans. Royal Soc. London*, B280; p. 183—198.