PL ISSN 0067-9038

P. G. HOARE* and A. M. McCABE**
Cambridge—Belfast

# THE PERIGLACIAL RECORD IN EAST-CENTRAL IRELAND

Abstract

A variety of periglacial phenomena related to two, or possibly three, cold episodes may be recognised in east-central Ireland. Only the latest event can be dated with any accuracy because of uncertainty concerning the length of time represented by the glacial sediments which form the relative chronological framework.

## 1. INTRODUCTION

This paper considers the features that indicate the former influence of intensely cold, but non-glacial, conditions upon the east-central Irish landscape (i.e. central and southern County Louth, north-eastern County Meath and County Dublin in the Republic of Ireland (Fig. 1c) — an area of approximately 2,000 km$^2$). There have been very few similar studies in the country. COLHOUN (1971) investigated a large range of tundra forms within the Sperrin mountains of Northern Ireland. LEWIS (1977) examined ice-wedge casts in north-eastern County Wicklow immediately to the south of the region now being discussed. Both workers were only able to distinguish a single periglacial period which occurred towards the close of the Midlandian Cold Stage (see Section 2). MITCHELL (1976) presented a general account of tundra phenomena throughout Ireland and, in 1977, provided a further, more detailed, national survey of them with comments upon their palaeoclimatic significance. He identified two Midlandian 'frost cycles', one dating from the early part of the stage, the other following the widespread Late Midlandian glaciation. MITCHELL (1971, 1973) also described presumed pingo scars from County Wexford in south-eastern Ireland. The results in the present article probably justify an extension of the history of cold environments in Ireland, although its length still compares unfavourably with that for eastern England (WEST *in*: PÉWÉ (ed.), 1969).

The term *periglacial* has been used in different ways since being proposed by ŁOZIŃSKI (1909). The problem of definition has been considered by many authors (e.g. DYLIK, 1964; BLACK, 1966; FRENCH, 1976) but continues to defy a unique solution. It is applied here to features believed to denote past cold, non-glacial, conditions which were not necessarily associated with adjacent glaciers. Although there is widespread agreement that periglacial areas do not coincide exactly with

* School of Geography, Cambridgeshire College of Arts and Technology, Cambridge CB1 2AJ, England.

** School of Environmental Sciences, Ulster College, The Northern Ireland Polytechnic, Newtownabbey, County Antrim BT37 OQB; Northern Ireland.

the distribution of permafrost (e.g. BLACK, 1966; PÉWÉ *in* PÉWÉ (ed.), 1969; EMBLETON and KING, 1975), such a relationship would be convenient for palaeoenvironmental studies as the previous existence of permanently frozen ground is easier to prove than are the less precisely defined 'cold climates' with their sometimes equivocal evidence. The significance of each of the periglacial forms under discussion is dealt with at a later stage.

## 2. STRATIGRAPHIC NOMENCLATURE

The Gotian, Munsterian, Midlandian and Littletonian Quaternary Stages of Ireland are thought to be equivalent to the Hoxnian, Wolstonian, Devensian and Flandrian Stages of the British stratigraphical table, and to the Holsteinian, Saalian, Weichselian and Holocene of continental European usage. The term Ipswichian (Eemian) does not have an Irish counterpart (MITCHELL, PENNY, SHOTTON and WEST, 1973). British workers now unofficially divide Late Devensian time into the Windermere Interstadial (PENNINGTON, 1977) and Loch Lomond Stadial (SISSONS, 1974); the corresponding Irish names are Woodgrange Interstadial (SINGH, 1970) and Nahanagan Stadial (COLHOUN, SYNGE and WATTS, In Press). These relatively brief but nevertheless significant episodes are related to the Bölling plus Allerød and Younger Dryas intervals of European stratigraphers; they occupied the periods 13,000—11,000 (14,000—11,000 according to MITCHELL, 1977) and 11,000—10,000 years B. P. approximately (see PENNINGTON, 1977). The integrity of Pollen Zone I (the Oldest Dryas) is being questioned (see, for example, COOPE *in*: WRIGHT and MOSELEY (eds.), 1975).

## 3. THE PHYSICAL FRAMEWORK

The research area is divided into six readily-identifiable regions on the basis of solid geology, topographic expression and the extent of glacial deposits and drift-free outcrops (Fig. 1b). The distinctions are summarised in Table I.

## 4. THE QUATERNARY FRAMEWORK

The glacial history of east-central Ireland provides a relative chronology into which the periglacial record may be fitted. The area has been affected by nine phases of glaciation[1] (Tab. II), but the precise timing of the earlier episodes has not yet been determined (HOARE, 1975, 1977a; McCABE, 1973; McCABE and HOARE, 1978). All the events listed in Table II may have occurred within a congested Late Midlandian period; there is no convincing evidence requiring the older phases to be placed farther back in the Quaternary Era (McCABE and HOARE, 1978). The problem of the length of time represented by the drift succession (and thus of the ages of the tundra intervals) is examined in Section 7.

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[1] A phase of glaciation ranges in magnitude from a major ice-sheet or ice-cap movement to a significant readvance and is associated with a set of deposits classified as a formation (McCABE and HOARE, 1978)

Table I

The physiographic regions of east-central Ireland

| | *Geology* | *Topography and drift* |
|---|---|---|
| 1. Louth lowlands | Silurian siltstones and sandstones | An area which usually lies below 30 m O.D.; bedrock irregularities are generally masked by thick drift. It is drained principally by the rivers Glyde and Dee whose courses are determined by large west-east coursing gravel moraines |
| 2. Louth uplands | Silurian siltstones and sandstones; inliers of Ordovician sediments and volcanics | Prominent west-east striking bedrock ridges rise to 237 m O.D. (Mount Oriel) and 200 m O.D. (White Mountain). Drift rarely extends above 120 m O.D. except where valley bottoms lie above this elevation |
| 3. Boyne lowlands | Carboniferous limestone with Namurian sandstone and shale outliers | An easterly prolongation of the Central Irish Plain often failing to attain 60 m O.D.; few parts exceed 120 m O.D. Thick sheets of till are extensively developed, and fluvioglacial terraces and moraines are also common |
| 4. Balbriggan uplands and the Naul hills | Ordovician and Silurian sedimentaries and volcanics in the north, separated from Namurian shales, sandstones and limestones in the south by a narrow low-lying zone of Carboniferous limestone | Rises inland to 157 m O.D. near Garristown (0 0758); is largely drift-free above 100 m O.D. |
| 5. Dublin lowlands | Principally Carboniferous limestone; occasional inliers of Ordovician rocks; Cambrian sedimentaries make up the Howth promontory | A monotonous landscape relieved by occasional knoll-reefs and the Howth peninsula (171 m O.D.). Drift thicknesses are highly variable, being greatest in the main "pre-glacial" valleys and in coastal sections. Some low-lying level areas are unaccountably drift-free |
| 6. Dublin mountains | Central core of Leinster Granite with metamorphic and Lower Palaeozoic rocks to the west and east; extensive intrusive dolerite in the Tallaght hills (0 0523) | Gently undulating uplands rising to a maximum height of 751 m O.D. in the extreme south of County Dublin. Drift extends into the lower parts of the heads of deep glens on the northern face of the highland region, but most of the area is drift-free |

The Gilltown phase is of considerable importance in that it was the last widespread glaciation to influence the region. The ice-sheet concerned moved south-eastwards across Counties Louth and Meath and much of County Dublin from a centre of dispersion in north-central Ireland (Synge and Stephens, 1960; McCabe and Hoare, 1978) and reached the northern foothills of the Dublin mountains where its limit—the Piperstown moraine or line (Hoare, 1975; Fig. 1a) — may be traced. Thus the southern part of the district was not overwhelmed by this ice and may have

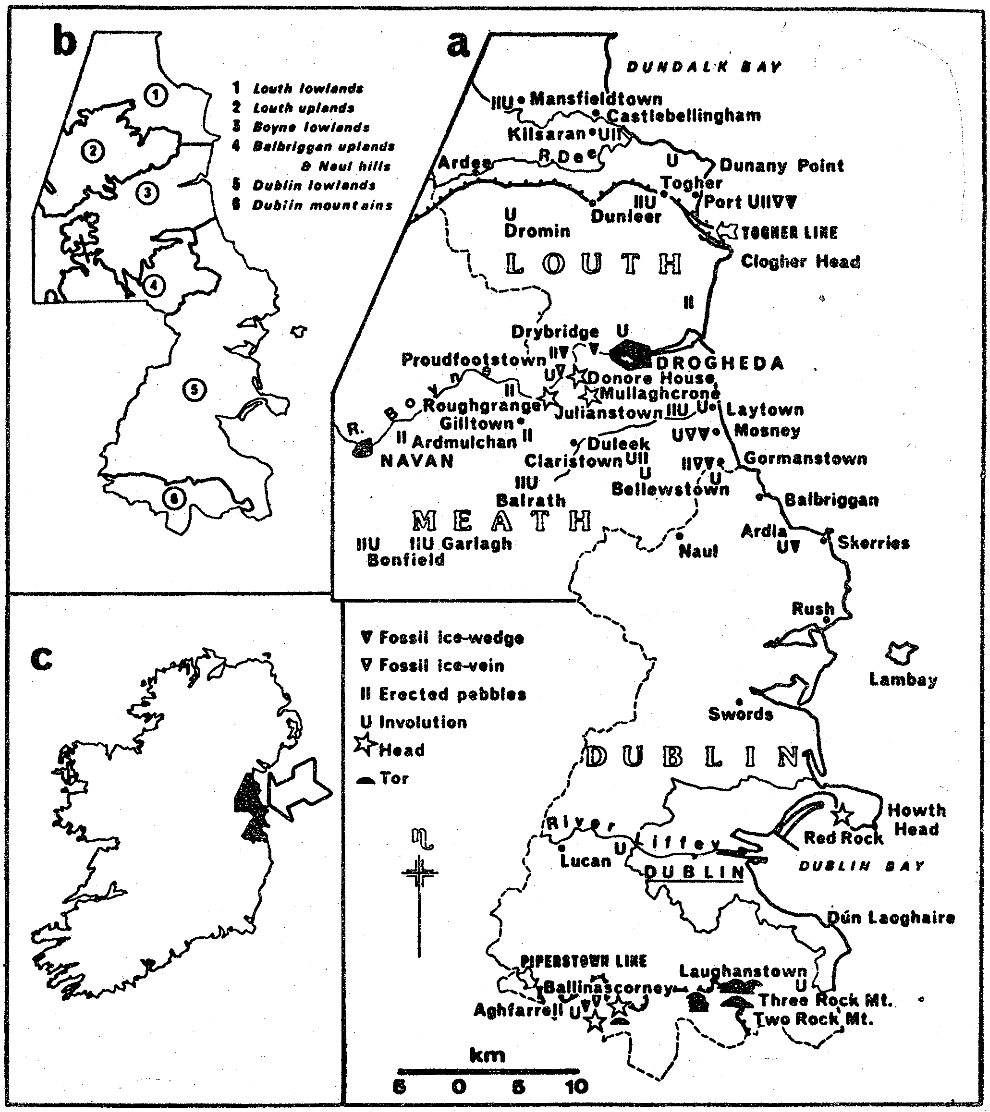


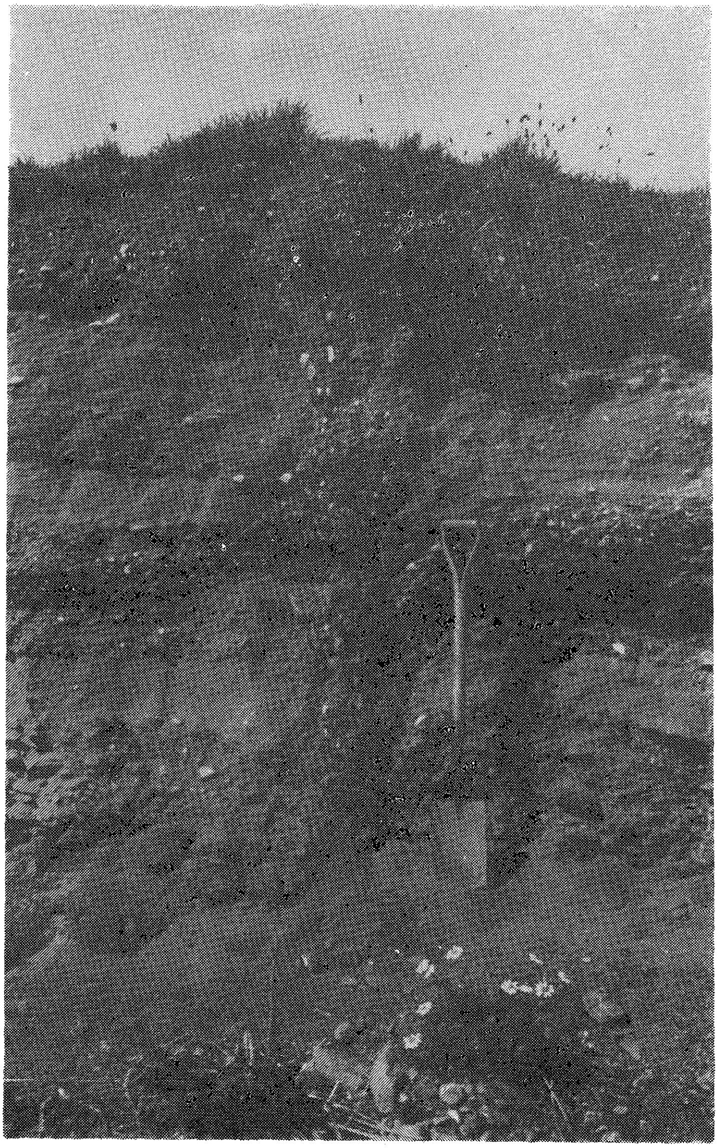

Fig. 1. East-central Ireland: a. distribution of periglacial features; b. physical subdivisions; c. location within Ireland

experienced periglacial conditions for a longer period than elsewhere; however, a certain proportion of the mountainous area was probably occupied penecontemporaneously by the Glenasmole glacier.

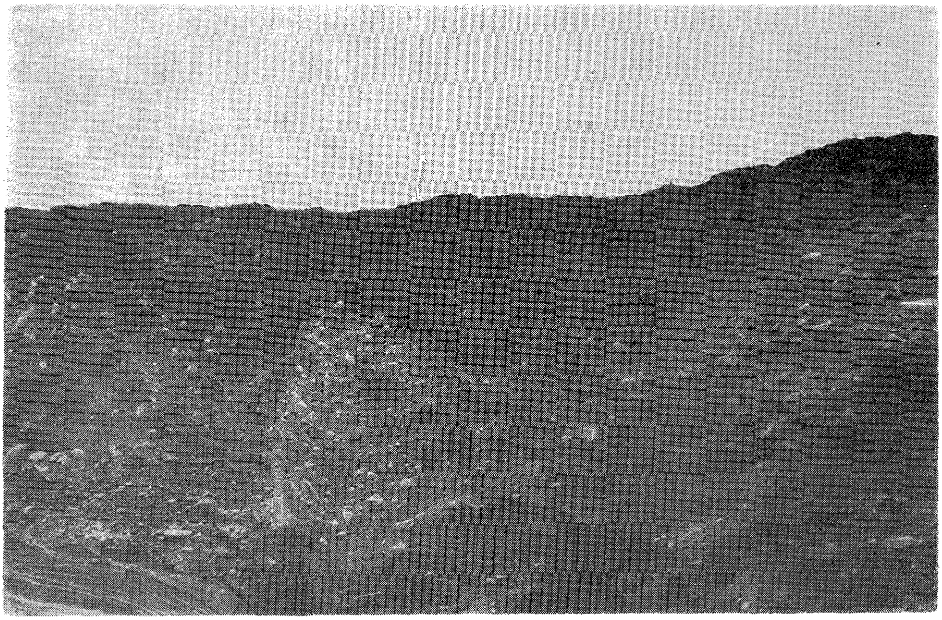
As the Gilltown ice-sheet withdrew northwards and north-westwards across east-central Ireland, extensive deposits of washed sediment were laid down in both ridge and plain form, especially in eastern County Meath and along the river Boyne valley. The numerous moraines and sandar of the Louth lowlands are connected with the decay of this ice following its two major readvances (the Togher and Dunany

Pl. 1. A type C ice-wedge (or ice-vein) pseudomorph penetrating granite-rich outwash gravel of Brittas glaciation age in Ballinascorney towland (0 063214), south-western County Dublin. The feature is at least 4.3 m long and dates from the Ballinascorney periglacial phase

Pl. 2. Festoons in granite-rich sand and gravel of Brittas glaciation age in Aghfarrell townland (0 053215), south-western County Dublin. The timing of the periglacial activity is uncertain



Pl. 3. A type B fossil ice-wedge in Late-glacial raised beach gravel at Port (0 150896), County Louth. Bedding in the enclosing sediment is downturned on the right-hand side of the cast (immediately to the left of the spade handle) and upturned on the left-hand margin



Pl. 4. Cryoturbations dating frcm the Ardla periglacial phase disturb poorly-sorted morainic gravel to a depth of approximately 1.2 m in Barnageeragh townland (0 231608) near Skerries in north-eastern County Dublin

Pl. 5. Cryoturbated till at Kilsaran (0 055935), eastern County Louth, showing two segregations of angular pebbles

Pl. 6. Granite tors and possible core stones on the summit of Three Rock mountain (0 177232), south-eastern County Dublin

phases) which reached Clogher Head (0 173845)[2] (the Togher line is marked on Fig. 1a) and Dunany Point (0 159915) (McCabe and Hoare, 1978). Late-glacial raised beaches and associated features are intimately linked with these limits.

Approximately one-fifth of Ireland was not covered by the Gilltown ice-sheet: it is in this part (almost entirely beyond the southern boundary of the study area) that frost structures are developed on a scale unmatched anywhere inside the maximum extent (where there are said to be "... only very slight signs of periglacial activity..." (Mitchell, 1977, p. 207). (The most southerly fringe of the research region is masked by peat and cannot therefore be examined for tundra phenomena.). Nevertheless, the stratigraphic control offered by the complex but thoroughly investigated sequence of glacial deposits in east-central Ireland provides the best available framework in the country within which to examine the influence and timing of periglacial conditions.

It is not possible to keep entirely separate discussion of the age and type of frost features under consideration. There is a broad subdivision of the text, however, into a description of the evidence necessary to establish a general cold-climate chronology, followed by an examination of the variety of form and palaeoclimatic significance of the information. Although structures such as ice-wedge pseudomorphs are usually exposed for relatively short periods, some have been observed since the original descriptions were made (1968—1971), and a few are visible at the time of writing (October, 1978). They are all referred to as though extant, however, to avoid a confusing mixture of tenses.

## 5. THE DATING OF PERIGLACIAL EVENTS

Two, or perhaps three, separate episodes of former tundra climate may be distinguished.

### (A) THE BALLINASCORNEY PERIGLACIAL PHASE

This phase followed the deposition of the granite-rich Aghfarrell gravel of the Brittas formation at the height of the local glaciation but preceded the fullest development of the Gilltown ice-sheet (Tab. II). The uppermost 4.3 m of the Aghfarrell member are exposed in Ballinascorney townland (0 063214) (type-sites are located on Figure 1a), southern County Dublin, and are penetrated by a fossil ice-wedge of type C (Pl. 1; the morphological classification of these forms is given in Section 6A). The cast increases upwards in width from approximately 1 cm to 15—20 cm between ill-defined margins. The feature is composed of fine to medium calibre pebbles up to 5—8 cm maximum diameter (some arranged vertically), which are set in a light brown, clay-rich matrix; it weathers-out slightly from the surrounding material. The enclosing gravel is of similar grade but the foreset bedding, which

[2] Locations are indicated by six-figure references based upon the Irish National Grid; the initial letter denotes the appropriate 100 km² grid square. The research area occupies parts of Sheets 13 and 16 of the 1:126,720 Series.

Table II

The relationship between the general and local glacial phases in east-central Ireland

| South County Dublin | North County Dublin/ South County Meath | North County Meath/ County Louth |
|---|---|---|
| | | Dunany Readvance[2] |
| Glenasmole ice-cap[3] | | Togher Readvance[2] |
| | | Donacarney Readvance[1] |
| | Gilltown General Glaciation[2] | |
| | (Ipswichian Interglacial?) | |
| Brittas ice-cap[3] | | |
| | Gormanstown General Glaciation[1] | |
| Slievethoul ice-cap[3] | | Drogheda ice-sheet[2] |

(*after McCabe and Hoare, 1978*)

[1] An ice-sheet centred over the Irish Sea Basin.
[2] An ice-sheet originating in north-central Ireland.
[3] All three ice-caps developed over the Dublin mountains and their southerly continuation, and moved northwards into the research area.

elsewhere dips towards the north and east, is locally downturned on both sides of the structure. The Aghfarrell member and the ice-wedge pseudomorph are sealed by limestone-rich washed sediment deposited by the Gilltown ice-sheet as a delta in Glacial Lake Blessington (FARRINGTON, 1957; HOARE, 1975, 1977b).

Gravel deposited during the Brittas glaciation immediately underlies the ground to the south and west of the Ballinascorney delta and is well exposed at the type-site of the member in Aghfarrell townland (0 053215). The bedding is now arranged in elaborate festoon-like structures, pebbles have been pushed into erect positions, and a possible ice-wedge pseudomorph may be traced to a depth of approximately 1.4 m (Pl. 2). These forms cannot be dated more accurately than to a periglacial episode which succeeded the withdrawal of the Brittas ice-cap from the area as the material is beyond the limit of the Gilltown ice-sheet and is therefore not overlain by younger glacial sediments; the features may have developed during the Ardla cold phase (Section 5C).

### (B) THE LAUGHANSTOWN PHASE

The older of two superimposed gravel beds at Laughanstown (0 232236) in south-eastern County Dublin is fine grained, granite-rich and of Gormanstown glaciation age; as well as being broadly cryoturbated, it contains a ball-like segregation of pebbles approximately 18 cm across and 45 cm high (although the top has probably been removed). The vertical stones on the sides of the involution were probably moved into that position by the repeated growth and melting of ground ice during a cold phase of uncertain timing, although this may not have taken place above a permanently frozen layer. Chemical weathering also intervened between the accumulation of the two washed deposits. The upper bed of fluvioglacial material rests unconformably upon the lower; it is coarser, much fresher in appearance, rich in limestone and associated erratics, and is linked with the Gilltown ice-sheet. It is strongly cryoturbated and part of the original horizontal stratification was arranged into festoon-like forms during the Ardla periglacial phase (Section 5C).

Thus the Ballinascorney townland cast dates from a cold interval which separated the Brittas and Gilltown glaciations. Structures at Laughanstown developed during the period between the Gormanstown and Gilltown glacial phases. The imprecise glacial framework does not enable a comparison to be made of the age(s) of the periglacial features at the two sites; they may or may not be of identical date.

### (C) THE ARDLA PERIGLACIAL PHASE

The Ardla phase affected much of the survey area during and after the retreat of the Gilltown ice-sheet. A number of ice-wedge pseudomorphs, as well as several other indicators of tundra conditions, date from this episode, their location largely reflecting the position of sand and gravel pits, and of sections in sea-cliffs and river banks. Their age may be demonstrated where they influence the Gilltown formation; they may also occur within deposits associated with the Gormanstown glaciation as these immediately underlie extensive tracts in the eastern half of the research region. Although the Gilltown ice-sheet passed across this area, the corresponding drift is extremely patchy. (See also discussion of the Aghfarrell exposure in Section 5A). Periglaciation in the lowlands was probably accompanied by the expansion of the Glenasmole ice-cap in the Dublin mountains, and may also have coincided with the restricted Donacarney, Togher and Dunany readvances in the north.

## 6. THE VARIETY OF PERIGLACIAL FEATURES

Four groups of tundra phenomena have been recognised in east-central Ireland; their distribution is shown on Figure 1a.

### (A) ICE-WEDGE PSEUDOMORPHS

Ice-wedge pseudomorphs occur in three distinct forms:

*Type A*

A well-defined cast of this class occurs at Gormanstown (0 175682) in south-eastern County Meath. It penetrates outwash gravel of Gilltown glaciation age grading southwards from the Ben Head moraine, 500 m to the north, and is related to the Ardla phase. The lowest 1.4 m of the pseudomorph has survived commercial extraction of the deposit. The remnant is 30 cm wide at the top and extends down into poorly-sorted gravel and washed sand. The structure is made of an arenaceous matrix containing infrequent stones, only a small proportion of which are arranged vertically. The adjacent strata are downturned near the base of the cast. Similar forms occur at Drybridge (0 060760), Proudfootstown (0 036754) and Irishtown (0 159686).

*Type B*

A distinctive variety, probably of more complex origin, is found in other gravel sections in east-central Ireland. Unlike that at Gormanstown, it consists of a wedge-shaped accumulation of stones nearly all of which are erect. The best example may be seen in Late Midlandian raised beach material at Port (0 150896) in County Louth (Pl. 3). Its top is 50 cm below the ground surface and the vertical feature penetrates horizontally bedded, fine grade, gravel for 2.5 m. The pseudomorph is 40 cm wide at the top and narrows to a fine crack. The stratification of the surrounding sediment is upturned on one flank of the cast and downturned on the other. The infill is composed of stones averaging 3—5 cm across which, as well as being set vertically, are in some cases also fractured. The presence of a large proportion of erect pebbles may indicate a distinct phase of frost action after the fossilisation of the ice-wedge. An alternative, but it is thought less likely, explanation is that the present fabric was inherited from the minerogenic content of the ice (see Section 7).

Pseudomorphs of types A and B occur in washed glacial sediments throughout the area, especially where the gravel is of fine to medium calibre. They average 2.0—2.5 m in length and 30 cm across in their upper part, and are found below approximately 60 cm of soil and/or a cryoturbated layer.

*Type C*

The remaining, narrow, features are more properly termed ice-vein pseudomorphs and may not indicate the former presence of permafrost; WASHBURN, SMITH and GODDARD (1963) recorded modern frost-cracks from a North American mid-latitude area (the State of New Hampshire). They may, however, represent ice-wedges whose development was arrested at an early stage, although it cannot be assumed that the size of the replacement is an accurate reflection of the original thickness of ice. Such forms are generally 0.5—1.5 m long and measure only approximately 8 cm across at their tops which reach to within 50 cm of the surface. The exceptional example in Ballinascorney townland, south-west County Dublin, exceeds 4.3 m in length (see Section 5A). The structures taper vertically downwards to a line of erect and sometimes fractured pebbles. Ice-vein casts always occur in medium to fine grade gravel in east-central Ireland and have never been observed in till. Although it is impossible to base firm palaeoclimatic reconstructions upon them, thermal contraction cracking and repeated freezing and thawing are often suggested by their association with other tundra forms. They have not been reported from Woodgrange Interstadial, Nahagan Stadial or Littletonian material in Ireland, but VAN DER TAK-SCHNEIDER (1968) and SISSONS (1974) described examples of post-Allerød (post-Windermere) Interstadial age in southern Sweden and Scotland, respectively.

The apparent absence of all varieties of wedge cast from tills in the research area may be due to lack of exposure or destruction by solifluction. Alternatively, although ice-wedges are best developed in fine grained deposits, a poor degree of fossilisation in such material may be anticipated as it becomes fluid when thawed and closes as rapidly as the ice melts (BLACK, 1969, 1976). WORSLEY (1966) and MORGAN

(1971), however, described pseudomorphs preserved in till from Cheshire and Staffordshire in England.

Careful examination of pit faces and of the ground in east-central Ireland using aerial photographs at a scale of approximately 1:10,000 showed no trace of fossil tundra polygonal networks resembling those which are faintly seen in north-eastern County Wicklow (LEWIS, 1977) and County Wexford (MITCHELL, 1976), and are clearly defined in certain parts of England (e.g. SHOTTON, 1960; WILLIAMS, 1964; WORSLEY, 1966; MORGAN, 1971; ROSE and ALLEN, 1977); GALLOWAY (1961) was aware of only one example in Scotland. WATSON (1977) provided a map showing the distribution within Great Britain of polygonal markings. Agriculture, which has a long history in Counties Louth, Meath and Dublin, may have destroyed any surface expression.

LEFFINGWELL (1915, 1919), PATERSON (1940) and PÉWÉ (1962, 1966), amongst many others, noted the frequency with which ice-wedges are associated with the upturning of originally horizontal stratification in enclosing sediments. Periodic enlargement of the wedge reduces the extent to which the surrounding frozen ground may expand in summer and thus causes the adjacent beds to become vertical or even overturned. These distorted strata often bend or sag downwards during replacement of the ice, although the former disposition of the beds may be preserved. The Ballinascorney and certain other fossil forms are connected with downturned strata and therefore possess one of the characteristics listed by JOHNSSON (1959) as necessary for the correct identification of ice-wedge pseudomorphs. Those in which the original upturning has been preserved are also known from east-central Ireland (see type B, Section 6A and Pl. 3), although COLHOUN (1971) found none in more than thirty-five casts in the Sperrin mountains of Northern Ireland. GALLOWAY (1961) in Scotland and WATSON (1965) in Wales reported that upturned bedding was rather unusual, and the former worker suggested that it was due to later cryoturbation of the wedge filling. PATERSON (1940) noted that 75% of the fossil features he examined in the Cambridge area of eastern England showed upturning, especially where they penetrated fine gravel and sand, but it has also survived in Cretaceous Gault Clay. The size and shape of individual particles in the parent deposit are important: beds made of coarse and angular fragments are likely to remain in their upturned condition; slumping may accompany thawing in those composed largely of clay and silt. The widest wedges may cause the greatest degree of deformation, and thus enhance the prospect of at least its partial survival.

#### (B) CRYOTURBATION STRUCTURES (INCLUDING INVOLUTIONS), ERECTED AND FRACTURED PEBBLES IN UNCONSOLIDATED MATERIAL

Although it is convenient to consider these forms together, and they are often found in association, the details of their origins may differ appreciably. Fractured stones are omitted from Figure 1a because of their dubious significance.

WORSLEY (*in*: SHOTTON (ed.), 1977, p. 212) considered that fossil involutions are "... undoubtedly the commonest form of supposed periglacial structure to be encountered in the field"; this contention is supported by the authors' observations in east-central Ireland. The phenomenon occurs in many gravel pits but is best developed in fine to medium grade material containing a considerable proportion of fines. Wave-like contortions and loops (the 'festoons' of some workers) disrupt the sediment bedding to a depth of approximately 1.0—1.5 m (Pl. 4). In addition, groups of pebbles have been assembled into distinct, almost semicircular, pockets separated by less disturbed zones, although there is no indication on the surface of patterned ground. Some of the stones in these concentrations are broken along planes of weakness and vertically-aligned pebbles are almost always present. In some cases the stratification of the gravel has been completely obliterated and rearrangement into coarse and fine material is virtually complete. This type of sorting is well seen in the Late Midlandian raised beach at Port (0 150896), County Louth; cryoturbation has influenced the corresponding feature at Laytown (0 165715) in County Meath.

Severe cryoturbation of till was recorded only at Kilsaran (0 055935), eastern County Louth, where an extensive exposure occurs towards the crest of a large morainic ridge. The coarse debris in the till has been gathered into a series of concentrically-layered balls, each approximately 50—80 cm in diameter, surrounded by a sand- and silt-rich matrix (Pl. 5). The depth of disruption is about 1.5 m. The paucity of frost structures in till may be due to the former presence of only a thin active layer compared to that which developed within sand and gravel. The higher thermal conductivity and permeability of washed glacial sediments would encourage deeper thawing during the summer and possibly also give rise to additional freeze-thaw cycles at the beginning and close of an extended melt season. The pervious nature would also allow greater mobility of water towards loci of freezing, thus increasing the size of ground-ice masses and enhancing cryostatic processes.

Many exposures of sand and gravel exhibit some near-surface stones with vertical long axes (not all known occurrences are shown on Figure 1a); the highest concentrations are sometimes along the margins of, and/or within, ice-wedge casts. Such fabrics contrast strongly with the almost horizontal attitude of primary sedimentary structures and individual pebbles in the undisturbed material below. Fractured clasts are also common and are closely associated with other types of periglacial feature (i.e. 'active layer phenomena'). Vertical and broken stones are confined to the topmost 1.5 m of drift and lie below Littletonian soil. Cryoturbation and related forms are therefore somewhat better developed on Gilltown glaciation drift and younger sediments than MITCHELL's (1977, p. 207) "... generally shallow and feebly developed..." might suggest.

### (C) CONGELIFRACTED BEDROCK AND HEAD DEPOSITS

Fractured and cryoturbated bedrock caps too many summits in the Louth uplands for them all to be represented on Figure 1a; Red Mountain (0 060793; 134 m O. D.) may be regarded as typical.

Three accumulations of head occur in the vicinity of Donore (0 045731), 5 km south-west of Drogheda (Fig. 2). At Roughgrange (0 019725) and Donore House

(0 048738) they are exposed at the foot and along the lower flanks of Namurian shale outliers. That at Mullaghcrone (0 059733) is formed of shattered crinoidal limestone which lies at the base of a gentle drift-covered slope.

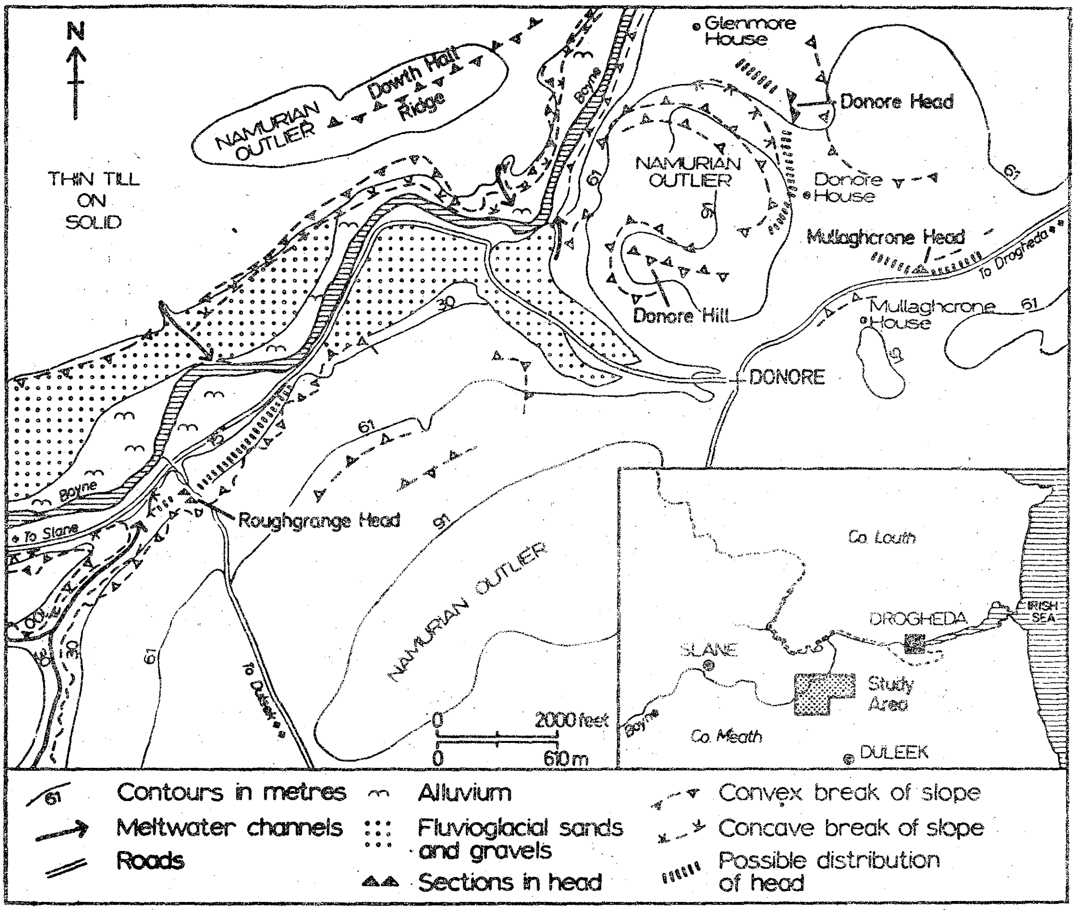



Fig. 2. The head deposits of north-eastern County Meath

*Roughgrange*

Two kilometres west south-west of Donore the river Boyne flows north-eastwards between the Namurian outliers of Dowth Hall (0 020730) and Donore (0 035720). The walls of the valley are steep and composed of rounded rock buttresses separated by small incipient valleys. The Roughgrange head starts between two of these salients at about 30 m O. D. and extends northwards for about 180 m until it merges into fluvioglacial deposits on the floor of the gorge at approximately 20 m O. D. (Fig. 3). Immediately below the shale buttresses the periglacial material is 4 m thick and consists of angular shale particles (90 %) and glacial pebbles (10 %); it rests unconformably upon steeply-inclined bedrock which, although *in situ*, is shattered and in places deeply weathered. The shale fragments range from 2—15 cm across and

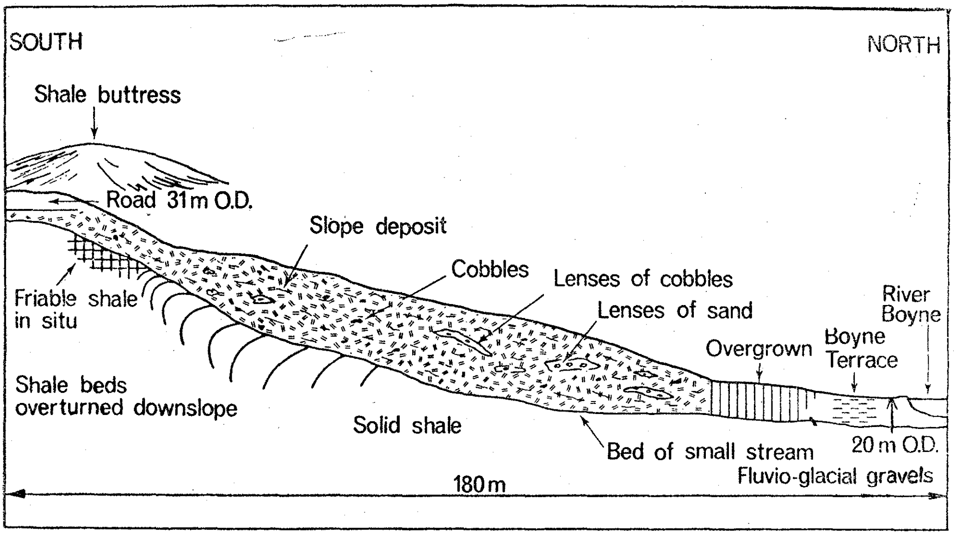



Fig. 3. The Roughgrange head deposit

average about 5—8 cm in diameter. The erraties show a greater variation in size and are made of Carboniferous limestone and sandstone and occasionally of Silurian strata. Immediately above stream level fractured bedrock is overturned to the north in the direction of maximum slope. It passes upwards into approximately 3 m of shale pebbles and numerous glacially-worked stones. Rude stratification is seen as lines of platy particles imbricated towards the principal valley floor, and is best developed towards the toe of the deposit. In places, small isolated lenses of sand, varying in thickness from 3—15 cm and containing infrequent small cobbles, are enclosed within the head. Partial decomposition of the shale has furnished a clay matrix to the material.

*Donore House*

An accumulation similar to that at Roughgrange lies at the base of the north-eastern slope of the Namurian shale outlier of Donore Hill. A stream section 850 m north north-west of Donore House reveals a crudely stratified, 3 m thick, deposit of angular shale fragments with occasional glacial pebbles capped by approximately 1 m of fine hillwash.

*Mullaghcrone*

The material located 400 m north-east of Mullaghcrone House differs in lithology and texture from those at Roughgrange and Donore House. It rests at the foot of a gentle south-facing hillside composed of Carboniferous crinoidal limestone. The head is exposed for about 18 m, is at least 3 m thick, and may be divided into two parts. The lower 2 m is made of angular, locally derived, fragments embedded in a coarse, reddish-brown, sandy matiix. Several erratics of granite, flint and Silurian grit were recorded. Towards the base of the horizon the limestone clasts are up to 0.75 m in length suggesting that bedrock is close by; higher up they are cuboid, average 5—10 cm across, and are contained within a sandy, pebbly matrix. This lower unit is crudely stratified and in places includes lenses of poorly-washed gravel. It is overlain by 1 m of debris made up of small stones set in a sandy substance. This deposit is compact, semi-stratified and heavily iron-stained. Fragment long axes are oriented parallel to the direction of transport but are imbricated both up- and down-slope. The sequence is capped by about 1 m of soil and recently accumulated material with much organic matter of Littletonian age.

Although it is difficult or impossible to separate head-like deposits associated with former periglacial solifluction *sensu stricto* (i.e. gelifluction) from those caused by creep in a less-harsh environment (e.g. BLACK, 1969), the material described above is stable and is not being added to today. Particle shapes and sizes and internal characteristics suggest that severe frost action, possibly under a tundra régime, was necessary for its development. The positions of the Roughgrange, Donore House and Mullaghcrone heads are such that they are unlikely to have survived glacial overriding. It is probable that the material accumulated after the withdrawal of the Gilltown ice-sheet as periglacial processes replaced those of glaciation. They may have been deposited at the same time as ice-wedges and related phenomena were forming elsewhere as the slope deposits appear to represent the last phase of tundra activity in the region. The unweathered fragments in the Mullaghcrone material contrast strongly with the sub-till head at Hollybrook (H 332373)[3], County Fermanagh, Northern Ireland, which is completely decalcified and is thought to be at least as old as the early or middle Midlandian (MCCABE, 1969).

Thin deposits of head were recorded throughout the higher parts of the Dublin mountains but a comprehensive study is hampered by poor exposure due to large tracts of peat and coniferous plantations. These summit areas were buried beneath the Gormanstown ice-sheet but extended above the limit of the Gilltown glaciation (the Piperstown line). It is impossible to be more precise about the age of this periglacial material other than to say that its accumulation presumably post-dated the Gormanstown glaciation.

STEPHENS and SYNGE (1958) described a head in Sutton South townland (0 265375) on the Howth peninsula in east-central County Dublin and suggested that it accumulated during early Midlandian times. The section is now partially obscured but where it can be examined the deposit has been re-interpreted as a 'rip block' (coarse comminution) till forming the base of a lodgement till of Gormanstown glaciation age. The head at Red Rock (0 271368), 800 m south-east of the Sutton South site, is younger than the Gormanstown Formation as it contains erratics characteristic of that advance, but a more accurate age cannot be given.

### (D) TORS

The tors of the Dublin mountains generally rise above gently rounded summit areas and the best known granite examples occur either on or close to the top of Three Rock (0 177232; 451 m O. D.) and Two Rock (0 174220; 518 m O. D.)

[3] Sheet 7 of the Ordnance Survey of Northern Ireland, 1:63,360 Series.

mountains (Pl. 6). Despite its well-established name, six tors may be distinguished on Three Rock mountain: they form a short chain running approximately west-east, and range in height from 1.5 to 8.0 m. Their plan shape is determined by prominent joint directions, and their sides reveal a set of roughly horizontal pseudobedding planes. The three tors on Two Rock mountain vary in height from 3.0 to 4.0 m and are of comparable form to those farther north. Four 'residual' granite features were mapped on Tibradden mountain (0 148223; 469 m); a single example composed of andesite/dolerite lies at about 488 m between Slievenabawnoge (0 080225) and Ballymorefinn Hill (0 085207) on the western flank of Glenasmole.

These mountain summits were overwhelmed during the Gormanstown glaciation (non-calcareous Carboniferous erratics survive from this event) but none was reached by the Gilltown ice-sheet. Some of the granite blocks which lie in large numbers on the higher parts of the Leinster Granite outcrop were probably glacially transported, but others may represent 'core stones' or have resulted from the destruction of former tors (those on Three Rock and Two Rock mountains appear to be in various states of decay).

The theories of tor formation of LINTON (1955), PALMER and NEILSON (1962) and EDEN and GREEN (1971) require the intervention of periglacial conditions, but to varying degrees; the tors described above were not examined in sufficient detail to be able to satisfactorily explain their origin beyond suspecting that cold climate processes played their part (see also WORSLEY *in*: SHOTTON (ed.), 1977). MITCHELL (1976) suggested that granite rotting took place in the last interglacial and that Midlandian solifluction was responsible for removing the solid waste products and for exposing the tors.

## 7. DISCUSSION

The former presence of permafrost in modern temperate latitudes is indicated by correctly identified ice-wedge casts and, with somewhat less certainty, by fossil pingos and related thermokarst forms (see, for example, WEST, 1977; WILLIAMS *in*: WRIGHT and MOSELEY (eds.), 1975; FRENCH, 1976); other features described in Section 6 do not require permanently frozen ground and are not necessarily even associated with the development of sub-surface ice by seasonal or diurnal freezing. Pingo scars and other thermokarst depressions are inexplicably absent from east-central Ireland although they occur farther south in County Wexford (MITCHELL, 1971, 1973). The less diagnostic phenomena shown on Figure 1a are probably of periglacial (*sensu stricto*) origin because of their intimate association with wedge casts, but at best they can only provide qualitative information about previous conditions. The present extent of knowledge concerning the development of all periglacial forms is limited (and the literature too vast to satisfactorily review here); palaeoclimatic conclusions based upon supposed fossil features must be made with considerable caution.

The large majority of frost structures described in this paper (both those of fairly precise environmental significance and of a less helpful nature) lie within the southern maximum of the Gilltown ice-sheet (the Piperstown line) and therefore date from the Ardla phase. The present authors believe that LEWIS (1977) and MITCHELL (1977) were mistaken in thinking that the withdrawal of Late Midlandian (Gilltown) ice was not linked with the development of permanently frozen ground, ice-wedges and other features in the newly exposed areas: "Conditions mild enough to melt away an ice mass could not simultaneously have seen the growth of ice wedges" (MITCHELL, 1977, p. 207). The correct view was expressed by WATSON (1977, p. 188): "In general the evidence suggests that, inside the limit of the maximum extension of the Late Devensian (i.e. Late Midlandian) ice, the area of ice wedge formation extended northwards as the ice cap diminished". The distribution of permafrost is a function of mean annual temperature; relative summer warmth is not inimical to permafrost. Intraformational ice-wedge casts in fluvioglacial gravel such as those near Tempo (H 342467)[4] in County Fermanagh, Northern Ireland (MCCABE, MITCHELL and SHOTTON, in press), demonstrate the contemporaneity of ice withdrawal, meltwater deposition and the establishment of permanently frozen ground. Syngenetic ice-wedges indicate that the accumulation of sediment may be accompanied by the upward growth of permafrost.

There is no discernible variation in the shape and size of each type of periglacial feature dating from the Ardla phase in relation to proximity to the Piperstown line or to elevation. Similar ice-wedge casts occur in Late Midlandian beach gravels and in fluvioglacial sediments produced during the northward retreat of the Gilltown ice. These forms do not immediately suggest more than one major episode of periglacial activity following upon the withdrawal of this ice-sheet. COLHOUN (1971) reached a similar conclusion for the Sperrin mountains of Northern Ireland, as did LEWIS (1977) when describing fossil wedges in north--eastern County Wicklow. Pseudomorphs of type B, however, consist largely of erected pebbles: this is seen not only in east-central Ireland, but throughout extensive areas of the country that were overwhelmed by the Gilltown glacier. Strongly-developed vertical fabrics are unlikely to have formed as minerogenic material gradually replaced the wasting ice-wedge. Published descriptions of 'normal' casts (i.e. those resembling type A) suggest that they contain a relatively small proportion of erect stones. Therefore 'periglacial' conditions must have returned after the fossilisation of these wedges in order to explain the rearrangement of the constituents. The Nahanagan Stadial saw renewed corrie glaciation at one site in County Wicklow (COLHOUN, SYNGE and WATTS, in press) and was probably also associated with the production of permafrost. The (admittedly infrequent) occurrence of fossil wedges within the Loch Lomond Stadial Readvance limit (= Nahanagan Stadial) in Scotland (SISSONS, 1974) suggests that their development took place as ice wastage proceeded. Ice-wedge pseudomorphs have thus been dated to the final part of the last cold stage in Scotland and also in southern Sweden (VAN DER TAK-SCHNEIDER, 1968), and it may be concluded that parts of western Europe were underlain by permafrost during this short period. Some of the east-central Irish ice-wedges and/or

[4] Sheet 7 of the Ordnance Survey of Northern Ireland 1:63,360 Series.

ice-veins may have developed at this stage, but they probably also formed in the early (pre-Woodgrange Interstadial) part of the Ardla periglacial phase and their infills were subsequently modified in the Nahanagan Stadial.

The tops of active ice-wedges lie close to the permafrost table (e.g. LEFFINGWELL, 1915, 1919; BLACK *in*: COATES (ed.), 1974). PÉWÉ (1962, Figs. 2, 5 and 6) reported that those he examined in Alaska do not quite reach this level; his diagrams indicate that the discrepancy never exceeds 0.3 m and is often only a few centimetres. The extent to which this relationship is preserved when wedges are fossilised is difficult to determine. The uppermost parts of upturned strata lying adjacent to ice-wedges may be destroyed, leading to an exaggerated impression of the (apparent) former thickness of the active layer. On the other hand, the collapse of surface or near-surface material into the space left by the melting wedge will suggest that the active layer was thinner than in reality. A further imponderable is the extent to which erosion has occurred following the creation of the pseudomorphs. No rigid relationship can be established because the exact conditions of replacement are highly variable. Nevertheless, in the absence of alternative information, the distance from the surface to the top of ice-wedge casts may provide a useful, if approximate, indication of the degree to which the ground thawed each year.

The more conventional approach to this problem is to establish the maximum depth to which erected pebbles and cryoturbation structures may be traced (e.g. WILLIAMS, *in*: WRIGHT and MOSELEY (eds.), 1975). The somewhat limited data from east-central Ireland indicate that the two procedures lead to rather different results. Most wedge pseudomorphs reach to within 50—60 cm of the surface, whereas active layer phenomena such as vertical stones are found down to approximately 1.5 m.

The following tentative conclusions may be drawn from these observations. Although erected pebbles and involutions may develop with diurnal or seasonal freezing of the regolith, the presence of ice-wedge pseudomorphs shows that permafrost formerly influenced east-central Ireland. The less rigorous requirements of the group of features which includes vertical stones suggests they formed before and after, as well as during, the period of ice-wedge growth. They may have been initiated as the climate deteriorated towards one which was sufficiently cold to produce permafrost, and continued to develop as the permanently frozen ground degraded below an active layer which became increasingly thick; seasonally frozen ground may have played a further part in their evolution. MITCHELL (1977) suggested that re-warming in the latter part of a 'frost cycle' must be rapid if ice-wedge pseudomorphs are not to be destroyed by cryostatic processes in a thickening active layer. WILLIAMS (*in*: WRIGHT and MOSELEY (eds.), 1975) thought that the depth to which fossil involutions may be traced in Britain indicates a climate consistent with the continuous/discontinuous permafrost transition zone; this line represents the southern limit of active ice-wedges in Alaska (PÉWÉ, 1962, 1966; see below).

The palaeoclimatic significance of fossil wedges is based upon a considerable number of recent studies in polar regions. "... there is a difference between a 'permafrost' environment and an 'ice wedge' environment" (PÉWÉ, 1966, p. 70). "It requires a particular environment to produce permafrost, and an even more rigorous environment to produce ice wedges" (PÉWÉ, 1966, p. 71). Observations in North America indicate that the southern limit of continuous permafrost and active wedges roughly coincides with the position of the −6 to −8° C mean annual air isotherm with an average 2,800—5,400 °C days per annum (BROWN, 1960, 1967; PÉWÉ, 1966), although PÉWÉ (1966) considered that some ice-wedges have formed in Alaska in microclimatic situations where temperatures are slightly less severe. BROWN (1967) suggested that the more significant, but less frequently measured, ground temperature is approximately 3.5 °C higher than the corresponding screen value; he demonstrated that unfrozen ground may persist where the mean annual air temperature is as low as −9 °C. BLACK (1963, *in*: COATES (ed.), 1974) stressed that it is not the mean annual temperature that is paramount in wedge formation, but the rate and amount of change in the uppermost 5 to 10 m of the ground, together with the ice content of this material. He noted that a fall of temperature of about 4 °C is sufficient to initiate thermal cracking at Barrow in Alaska. Winter temperatures in the region of −15 to −20 °C are necessary to cause the ice-wedge to crack and thus to allow further growth (LACHENBRUCH, 1966).

The occurrence of wedge casts within sand and gravel deposits in east-central Ireland (their exclusion from till was discussed above) suggests that mean annual air temperatures were considerably lower than the minimum of −6 to −8 °C associated with features which are developed in 'muck' (fetid organic silt) in Alaska (PÉWÉ, 1966); KATASONOV (1973) indicated that a figure of about −12 °C may be essential for active wedge growth in sandy material in central Siberia. However, the Russian worker ROMANOVSKIJ (1973) found that ice-wedges appear in gravel at mean annual air temperatures of −7 to −8 °C. Thus even wedge pseudomorphs, the most accurate indicators of former periglacial conditions, are not as specific in their requirements as might be wished for.

Continuously frozen ground was present in Ireland on two, or possibly three occasions during the Late Pleistocene; it extended down to at least modern sea level. The mean annual air temperature for the research area during the period 1931—1960 was about 9—10 °C; figures ranged from 9.3—9.9 °C (mean = 9.6 °C) for five stations in County Dublin, and the one set of data available for an inland site in County Meath provided a value of 9.2 °C (all measurements were made either in Stephenson screens at a height of approximately 1.2 m above the ground surface, or were appropriately adjusted; *Anon.*, 1971). Thus KATASONOV's work suggests that episodes of ice-wedge formation in the coarse sediments of east-central Ireland were probably at least 21—22 °C colder than now. Mean annual temperatures of about −12 °C, together with a geothermal gradient variously reckoned to be 1 °C per 30—60 m (LACHENBRUCH *in*: FAIRBRIDGE, 1968) or 1 °C per 50 m (GOLD, *et al.*, 1972) imply, by rule of thumb calculation, that permafrost might have developed to a depth of between 360—720 m had sufficient time been available.

Estimates of the rate at which ice-wedges increase in width range from a fraction of a millimetre to several millimetres per annum (e.g. LEFFINGWELL, 1915, 1919; BLACK 1952, 1975; BLACK and BERG, 1963). BLACK (1975) drew attention to the dangers of the widespread application of these values because of the difficulty of assessing the influence of microclimate, the duration of snow cover, local storms and unusually cold periods. MACKAY (1974, 1975) showed that in any one year only 40% of ice-wedges may be split by winter cold, and that at the end of the winter when thawing allows water to enter the crack its original width may have been reduced by up to 20% of its mid-winter size. Thus great care must be taken when extending the results of relatively brief experiments to produce long-term figures. In addition, it may be the exaggerated 'apparent' width of the pseudomorph, exposed in a section cut obliquely across the line of the feature, that is being measured. The estimates of ice-wedge growth rates and ages made by LEFFINGWELL (1915, 1919), COLHOUN (1971) and many other recent workers are based on over-simplified assumptions.

## 8. CONCLUSIONS

The most widely-held reconstruction of glacial events in eastern Ireland owes much to detailed mapping by FARRINGTON (e.g. 1934, 1942, 1944). Recent studies have not required major revision of his work, but three additional ice-sheet readvances are now recognised (MCCABE and HOARE, 1978; Tab. II). The age of the earlier periglacial phase(s) cannot be resolved until the length of time represented by the drift sequence has beene stablished. The latter is traditionally divided into two parts separated by a substantial interval which includes an interglacial (the enigmatic Ipswichian/Eemian) and a prolonged period of periglaciation. Thus FARRINGTON felt that the Enniskerry (Slievethoul of HOARE, 1975), Irish Sea (Gormanstown) and Brittas (Brittas) episodes took place in the Munsterian Cold Stage and that the subsequent glaciations occupied part of the Midlandian. The widespread distribution of 'interstadial' organic deposits in Ireland (MCCABE, MITCHELL and SHOTTON, in press; SCHARFF, SEYMOUR and NEWTON, 1918; COLHOUN, DICKSON, MCCABE and SHOTTON, 1972) and Britain (see COOPE *in* WRIGHT and MOSELEY (eds.), 1975, for a summary) suggests that the early/middle Midlandian/Devensian was ice-free and that extensive ice-masses only developed during the later phase. MITCHELL (1976, 1977), however, proposed that a 'niveogenic' climate led to the formation of a small ice-sheet in the north-western part of the Central Plain of Ireland some time before 41,500 years B. P.). This conventional interpretation of the Late Quaternary glacial history of east-central Ireland remains to be convincingly demonstrated, and all the events may date from Late Midlandian times (MCCABE and HOARE, 1978).

Working within the traditional framework, MITCHELL (1977) considered that Munsterian periglacial phenomena were completely obliterated by 'Ipswichian' deep weathering and the wind-throw of trees. He identified two Midlandian cold periods in the geological record. An early frost cycle — the Saltmills (County Wexford) Stadial (sic) — was responsible for ice-wedges and tundra polygons, erected stones, patterned ground and pingos, all of which are preserved outside the Late Midlandian glacial limit and therefore lie beyond the southern boundary of east-central Ireland. This event was correlated with the tundra episode which (?) immediately succeeded the Chelford 'Interstadial' (= Brorup Interstadial of continental Europe?) in the English midlands towards the close of the Early Devensian (post-60,800 years B. P.). The more recent, short-lived, frost cycle — the Nahanagan (County Wicklow) Stadial — was equated with the Loch Lomond (Younger Dryas) Stadial lasting from approximately 11,000—10,000 years B. P.

The Ballinascorney phase may be equivalent to MITCHELL's Saltmills Stadial but the interval separating the deposition of the lower (Brittas) gravel in Ballinascorney townland and its subsequent modification cannot be determined. The Brittas glaciation is generally regarded as Munsterian in age: the periglacial activity described in Section 5A may have occurred in the same cold period or in the early/middle Midlandian (but see final paragraph). Similar doubt attaches to the Laughanstown event (Section 5B).

The Nahanagan Stadial saw the production of rare ice-wedges and tundra polygons, a few pingos in County Wexford, and generally shallow and feeble cryoturbation and minor solifluction; no patterned ground is thought to have developed (MITCHELL, 1977). The present authors believe that the Ardla phase assumed a rather more complex nature, was longer and somewhat more important than suggested by MITCHELL (see Section 5C). Periglaciation influenced glaciated ground almost as soon as the ice withdrew; it principally took place in the interval leading up to the climatic amelioration of the Woodgrange Interstadial. The latter probably saw the obliteration of permanently frozen ground, but periglacial activity was re-established in the Nahanagan Stadial. Thus the Ardla phase may contain evidence for two frost cycles. COLHOUN (1971) suggested that the ice-wedge pseudomorphs in the Sperrin mountains of Northern Ireland date entirely from the Nahanagan Stadial, as did LEWIS (1977) for those he described in north-eastern County Wicklow. Open-system pingo remains in south-eastern Ireland appear to have formed in the same cold interval (MITCHELL, 1973). SISSONS (1974) showed that permafrost also developed in Scotland at this time.

At least two, and possibly three, periods of cold climate are recorded by periglacial phenomena in the Late Quaternary deposits of east-central Ireland. This represents an increase in knowledge of former tundra conditions in the country, but does not compare with the much fuller record for eastern England (see, for example, WEST *in*: PÉWÉ (ed.), 1969). The Ballinascorney phase followed the maximum extent of the Brittas ice-cap but preceded the fullest development of the Gilltown glaciation; it cannot be dated more accurately. The Laughanstown episode intervened between the Gormanstown and Gilltown glaciations and may be distinct from that recorded at Ballinascorney. Ice-wedges and related phenomena formed in the Ardla phase as the Gilltown ice-sheet retreated, and separate parts of the event may be preserved in the sediments. This episode probably took place in the early part of the Late Midlandian (and again briefly in the Late-glacial) and may have coincided with the growth of the Glenasmole ice-cap over the Dublin mountains and with the ice-sheet readvances farther north. The revised reconstruction of glacial events in east-central Ireland (MCCABE and HOARE, 1978) requires all known periglacial activity to date from the latter part of the Midlandian Cold Stage.

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