PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Periglacial Ireland [and Discussion]

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Periglacial Ireland

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During the colder parts of the Last Cold Stage at some times there were large ice masses, and at others there were periglacial conditions apparently without ice masses. It is a matter of doubt whether ice masses did form early in the Cold Stage, or whether periglacial conditions were dominant for the greater part of the stage, with ice only appearing at a relatively late date; some evidence from Ireland does not appear to tally with that from England.

The paper presents a hypothetical frost cycle, and suggests that all the periglacial features created during the Last Cold Stage that have so far been recognized in Ireland could have been formed in two such cycles. The first cycle, which was very severe, perhaps took place at the end of the Early Devensian; the second cycle, which was sharp but short, occurred at the end of the Late Devensian, between 11000 and 10000 B.P., and corresponds with Pollen Zone III.

Nearly all the types of periglacial features that are to be seen in Britain also occur in Ireland, and therefore this paper will concentrate on the possibility of drawing climatic inferences from fossil periglacial structures, rather than provide a catalogue of the features themselves. But, as Washburn (1973) has warned, any such attempts, in the present limited extent of knowledge, can only be very tentative and highly subjective.

During the Last Cold Stage three types of environment seem to have developed in Ireland:

(A) Interstadial conditions too warm for snow or frost;

(B) Glacial conditions suitable for snow accumulation, and leading to the development of ice masses; on the areas that were not buried by ice, tundra vegetation of some variety probably continued to grow; and

(C) Periglacial conditions too dry or too cold for snow accumulation, but suitable for frost action, and leading to the formation of frost structures; any vegetation would have been sparse and open.

Condition A gave rise to park-tundra with scattered trees and bushes, sometimes with large mammals. A mammoth bone from the cave at Castlepook, Co. Cork, was dated to 33500 B.P. (Mitchell 1976†), and if the faunal remains from the cave were contemporaneous, then in Middle Devensian time giant deer, reindeer, woolly mammoth and spotted hyena were wandering in the Blackwater valley. Giant deer and reindeer flourished in the Woodgrange Interstadial, between 14000 and 11000 B.P.

In Co. Fermanagh two organic deposits (with arctic vegetable remains, beetles and molluscs) lie between tills, and below a topography of drumlin form. That at Derryvree (Colhoun *et al.* 1972) has been dated to 30500 B.P., and that at Hollymount to greater than 41500 B.P. Two mountains in northwest Ireland, Ben Bulbin (530 m) in Sligo, and Slieve League (600 m) in Donegal, which appear to have stood as nunataks above the Devensian ice masses, today

† Much of the material of this paper is discussed in Mitchell (1976), and constant reference to that book is omitted. Again, where full details of a publication referred to in this paper are given in the references in Mitchell, Penny, Shotton & West (1973), the details are not repeated here.

carry clusters of arctic plants which probably survived the accompanying glacial conditions in or near their present locations. Many of the same plants also characterize the deposits at Derryvree and Hollymount, and perhaps these deposits can do no more than tell us that the plants and animals they record could coexist with ice masses in Ireland; they do not tell us that conditions were interstadial, in the sense of Sparks & West (1972), who require 'a climax dominated by a conifer such as pine or, in the case of a shorter amelioration, a phase of birch woodland between phases of Arctic treeless vegetation' (p. 28).

We have thus only unequivocal evidence for two interstadials in the Last Cold Stage in Ireland, in the Middle Devensian at Castlepook (33500 B.P.), and in the Woodgrange Interstadial (14000–11000 B.P.) in the Late Devensian.

Condition B perhaps occurred three times. As we have seen, at Derryvree the organic deposit (30500 B.P.) lay below Late Devensian till which had been moulded into drumlin form; it rested on a lower till which showed no signs of weathering or of cryoturbation. What appeared to be the same upper till – again in drumlin form – also buried the nearby deposit at Hollymount, where the record (in exposed section and by drilling) was:

0–1000 cm	till moulded in drumlin form
1000–1200 cm	gravel
1200–1665 cm	laminated sandy silt with arctic vegetable debris of age greater than 41500 years
1665–1695 cm	brown silt
1695–1740 cm	black silt with arctic vegetable debris and lamellibranchs
1740–1670 cm	varved clay
at 1760 cm	calcareous till

This record strongly suggests that the lower part of the sequence – till, varved clay, lacustrine deposit with vegetable debris – was deposited without interruption, and that there was no opportunity for the till either to be subaerially weathered, or to be disturbed by frost action, before the arrival of the vegetable debris. Thus unless the vegetable debris is Late Wolstonian in age – and it could hardly have survived the weathering of the Ipswichian Warm Stage – it must be of Devensian age, and if so that underlying till must also be of Devensian age, and formed before 41500 B.P. In Britain there is no accepted record of till so early in the Devensian.

If we accept this interpretation of the Hollymount evidence, Condition B will have occurred for the first time in the Devensian before 41500 B.P. The second occurrence was in the Late Devensian, as drumlins of the type that occur at Derryvree must be of this age, because they overlie material dated to 30500 B.P., while the closed basins between them contain lacustrine deposits of Woodgrange age (14000–11000 B.P.). The third occurrence was only on a very small scale, and confined to ice partly reoccupying older corries. Lough Nahanagan (at 500 m in the Wicklow Mountains) held a corrie glacier in the Devensian, but this melted away in the Woodgrange Interstadial, and a lake occupied the corrie hollow; muds accumulated on the lake floor. Small glaciers then formed on the corrie walls, and ploughed up the lake muds, thus clearly demonstrating their post-Woodgrange age. They thus fall into the final cold snap of the Devensian, formerly called Zone III, but now named in Ireland the Nahanagan Stadial (11000–10000 B.P.). Their moraines are buried by muds of Flandrian age.

It is more difficult to say how often condition C occurred. When the Devensian ice sheets were at their greatest extent in Ireland (figure 4*b*) about one-fifth of the country, chiefly in the south, was not covered by ice. In this area marked periglacial structures are to be seen. It seems fair to assume that if the end of the Wolstonian Cold Stage had left periglacial structures imprinted on the country, these would have been dissipated by the deep weathering of the Ipswichian Warm Stage. Obliteration would have been aided by the deep penetration of tree-roots, and by the wind-throw of trees. At the opening of the Devensian Cold Stage, the soils would have shown no signs of relict features. It can of course be argued that if tree-roots can destroy periglacial soil structures, then the roots of the Flandrian forests should have destroyed Devensian periglacial structures. But the Ipswichian soils and forests ran a full interglacial cycle, whereas in Ireland man began the destruction of the postglacial forests no more than five thousand years after the woodlands had first developed.

We must next ask 'Can in fact "periglacial" features form in the vicinity of an ice mass?' This question at once throws up the modern misuse of the term 'periglacial' which originally referred to the climate and related geological features peripheral to ice sheets. For Tricart (1969) glacial and periglacial conditions coincide. But ice masses, just like the snow from which they derive, blanket the surface of the Earth, and greatly reduce loss of heat by radiation, a loss that is essential, if deep freezing, and the structures it produces, are to develop. Once temperatures fall to the level necessary for deep freezing, the air will be too cold to hold the quantities of water necessary for massive snowfalls. Flint (1971) considers it was possible for the ice sheets to have been built up by precipitation at today's rates, provided only that temperatures were moderately lower, and notes (p. 268) that 'important sectors of former ice sheets seem not to have been fringed with extensive features created by frost action'. Embleton & King (1968) see the formation of snow and ice flourishing in temperatures 5–7 °C cooler than those of today. Condition B, which encourages the accumulation of snow and ice, should perhaps be called 'niveogenic'.

Parts of the periphery of a large ice sheet, which was nourished by distant snowfalls, might advance into an area which was already in the grip of deep frost, or frost might come to dominate an area already occupied by an ice sheet, whose growth would then have to stop, but ice sheets of themselves cannot induce deep freezing. Where frost conditions obtain, ice masses cannot melt away; thus if we find ice-wedge casts in meltwater gravels, the ice wedges must have formed in a phase of cold later than that that produced the ice from whose melting the gravels derived.

Sparks & West (1972) have warned against the use of synthetic jargon, but we might do better to speak of 'cryogenic' or 'cryokinetic', rather than 'periglacial', processes, because the structures that are formed are the result of the energy reactions of water as it freezes and thaws. A wealth of frost structures certainly formed in the Last Cold Stage, and when we try to see how many cycles of frost conditions are involved, we must remember that today it is being shown more and more clearly that an ice sheet in decay can produce a suite of deposits of different facies superimposed on one another. In the past the deposits composing such a suite have often been attributed to more than one ice sheet; a single frost cycle as it grows in intensity and then ebbs away may produce several structures of different facies.

We can construct a diagram (figure 1) to represent a hypothetical frost cycle. As the cycle develops, the winter cold freezes lakes, and produces a relatively thin frozen layer of soil: there may be a phase of heavy snowfall. For a time the frozen layer melts completely in the following summer, and so we have 'seasonally frozen ground'. But as long as a watertight sheet of frost – however thin – survives, it prevents the downward movement of water, and if the slope of the ground is less than 2° an 'active layer', a layer of supersaturated soil, will develop above the frozen horizon. Convectional disturbances in the active layer may bring about the erection of contained stones.

As the cold grows further in intensity, snowfall drops away, the winter freezing-front moves deeper down into the ground; the weaker heat of summer can no longer penetrate so deeply, and the active layer gets shallower. Ultimately very severe winter frost brings the mean annual air temperature (m.a.a.t.) below 0 °C, summer heat can no longer pierce the frozen layer, and permafrost is firmly established, while the active layer becomes negligible. For Péwé (1969) the permafrost zone is the periglacial zone. If m.a.a.t. falls below −7 °C, then ice wedges will develop, arranging themselves in polygonal patterns.

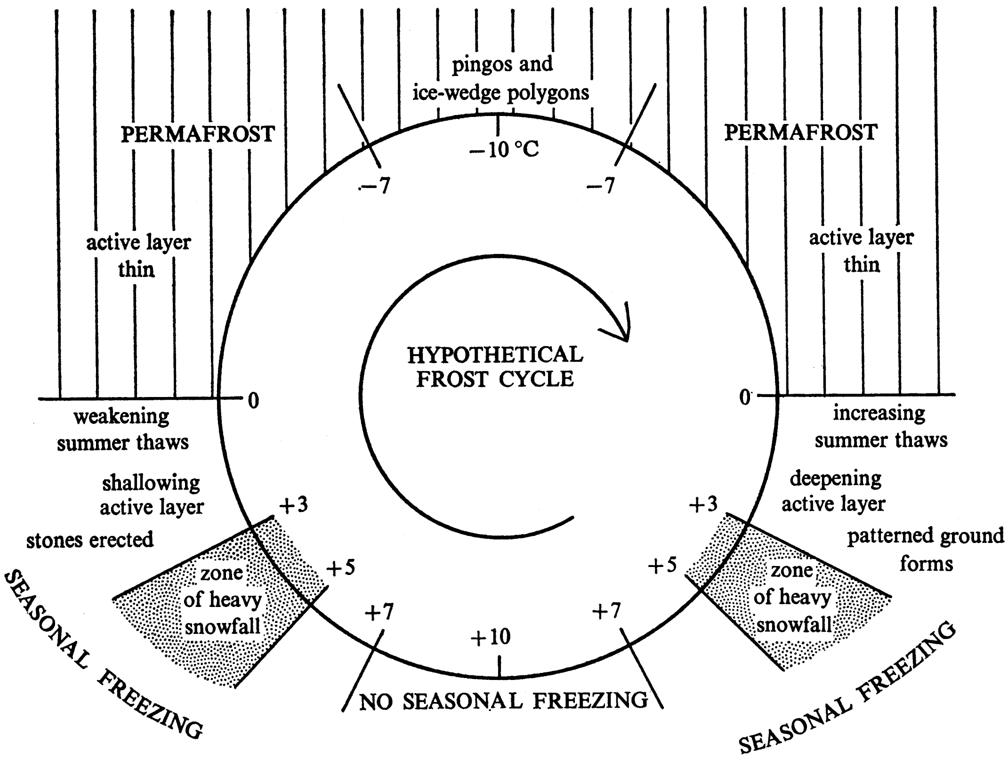

Figure 1. A hypothetical frost cycle.

Warmer conditions then begin to return, winter frosts ebb away, and the active layer deepens again. As it becomes deeper and warmer, movements analogous to convection currents in cell-like patterns develop in it, and these sort the contained debris, drawing the coarser material up to form the walls of honeycomb-like cells, and filling the cells with the finer fragments. As the active layer deepens, the polygonal patterns become more prominent and more perfect, until one summer the basal sealing-layer of frost completely melts, the water of the active layer drains away downwards, while its contained polygonal structures become immobilized, and survive to form polygonally patterned ground. It must be noted that patterned ground produced in this manner is quite different to the patterned ground produced by ice-wedge polygons. A phase of heavy snowfall may reoccur.

Thus the one cycle of frost may leave in one place erected stones, in another ice-wedge casts, and in a third polygonally patterned ground, and it may be difficult to interpret the record.

Also, we cannot assume that the frost cycle will always rotate at a constant speed, or complete a full circle. The tendency towards cold can be reversed at any point, and parts of the cycle can be speeded up or retarded, or even short-circuited.

But at one locality in Ireland, Ballymakegogue, Kerry (Mitchell 1970, Figs. 1 and 5), we appear to see a fairly complete cycle in deposits of Wolstonian age. Here the local rock is a brecciated Namurian shale, which is particularly susceptible to frost action.

When seasonal freezing of the ground set in at the beginning of the Wolstonian Cold Stage, the countryside was essentially free from trees, even though some pollen from warmth-demanding trees still lingered in the soil. Frost action broke up the plant cover, and as soil was moved downslope it brought derived pollen with it. Solifluxion then became more vigorous, and coarser debris was moved downslope to form a thick deposit of head. Developing permafrost then checked solifluxion, and as the frost cycle reached its coldest level, ice wedges formed. Material primarily ice-borne in origin, and rich in striated stones, rests on the head, but it is not clear whether this material was introduced by a contemporaneous glacier, or was soliflucted down from an older deposit upslope. At any rate solifluxion was resumed, as rising temperature allowed an active layer to establish itself once more, and a further thick layer of head was deposited. As the head grew thicker and thicker, the slope on its upper surface will have got less and less, and cryoturbation will have replaced solifluxion. The upper layers of the head are deeply disturbed by cryoturbation, and involutions are well developed in it. It is very probable that these involutions belong to a later frost cycle of Devensian age, because as we have already seen any structures that were in the upper layers of the head as the Wolstonian Cold Stage ended, would probably have been obliterated by weathering during the following warm stage.

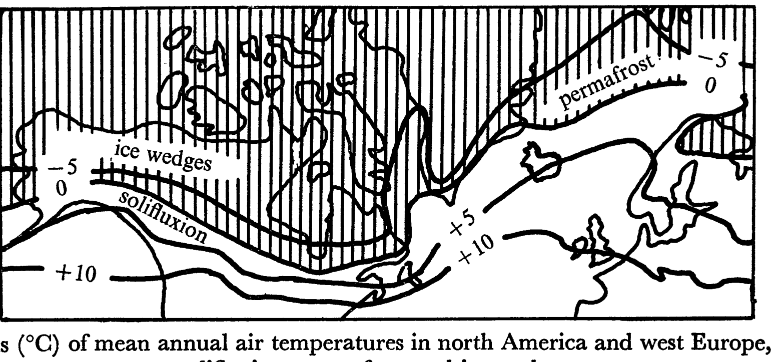

Figure 2. Isotherms (°C) of mean annual air temperatures in north America and west Europe, showing zones of solifluxion, permafrost and ice wedges.

We can also get a contemporary view, because the climatic conditions from temperate to extreme cold that develop in the first half of the frost cycle can be paralleled as we move from south to north, particularly in western North America (figure 2). We pass from the frost-free Pacific west coast to the solifluxion lobes of the Seward Peninsula, to the permafrost around Fairbanks, and to the ice wedges and pingos of the coastal plain around Point Barrow. But when we think about the active layer in these areas, we must remember that the long summer days of the arctic north may well bring about a deeper melting than the shorter days further south.

As noted at the opening, we have in Ireland a wide range of Devensian periglacial features on deposits of different ages. How many frost cycles do they represent? If we take an arbitrary horizontal scale, with five levels of mean annual air temperature, we can construct a very tentative curve (figure 3) to suggest how climate may have changed from one level to another during the Devensian. The levels are: +10 °C, the temperature of the British Isles today; +5 °C, the level at which seasonally frozen ground starts to appear, and some cryoturbation and solifluxion will take place; 0 °C, when permafrost becomes established; −5 °C, when the contraction-cracking that leads to the development of ice wedges will start; −10 °C, a temperature at which ice wedges may continue to grow, but little else will happen, as the ground is too solidly anchored by frost for much summer movement to take place. In addition it is accepted that when the temperature falls to below 7 °C cooler than at present – say to +3 °C – the air will be too cold to hold the water that is necessary to provide snow, if ice masses are to build up. As temperature falls from +5 to +3 °C, there may be a phase of heavy snowfall.

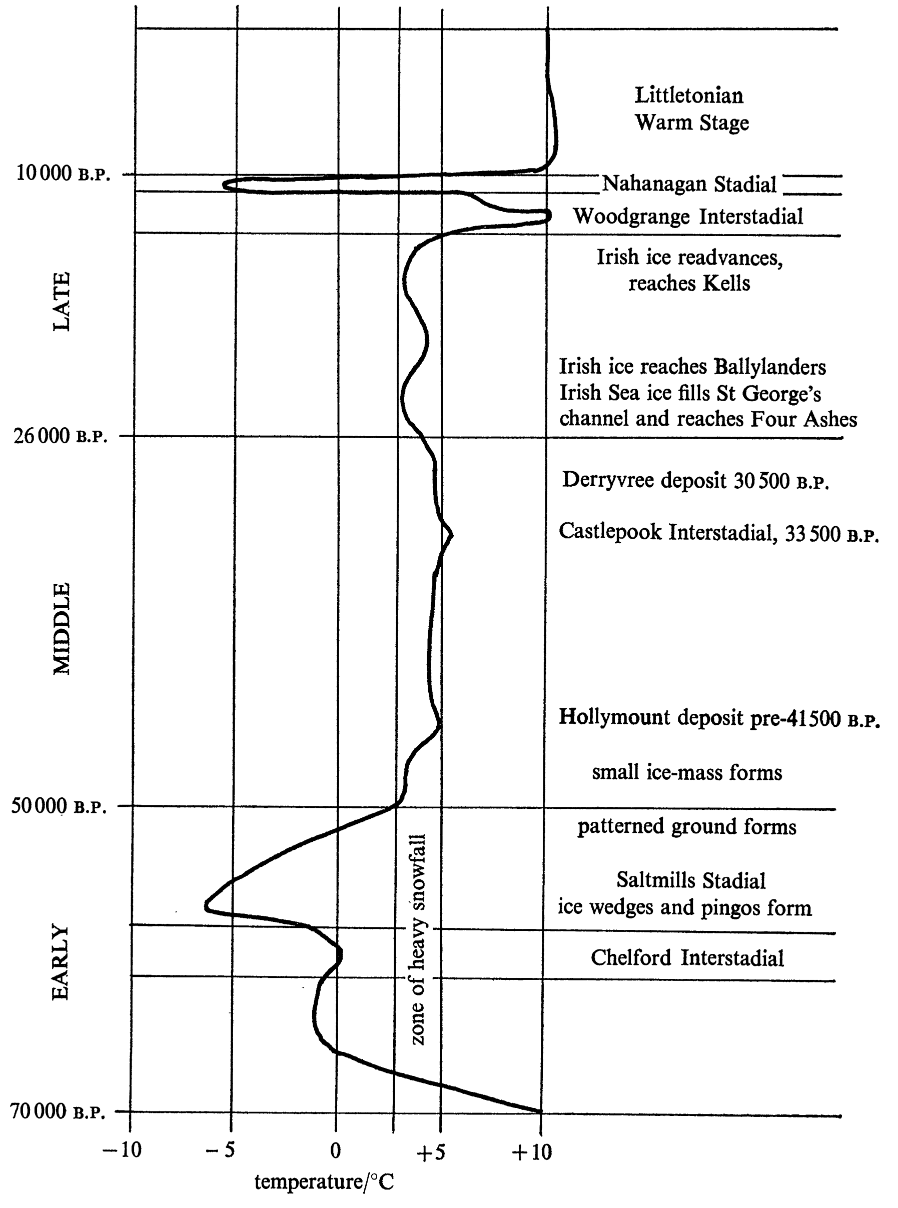

FIGURE 3. Hypothetical curve to suggest the movement of mean annual air temperatures from one level to another during the Devensian Cold Stage.

In Ireland, about one-fifth of the country, chiefly in the south, was not covered by ice at any stage of the Devensian (see figure 4), and it is in this ice-free area that we have our best development of periglacial structures, on a scale unmatched anywhere on deposits of Devensian age. If we accept the position set out above, that the surface of the Wolstonian deposits was free of any periglacial structures at the opening of the Devensian, then these structures will have developed over the whole area of Ireland, and have been subsequently destroyed or buried by the action of ice in those parts of the country where Devensian ice masses did later form. Outside those ice limits we have:

(i) fossil ice-wedge polygons, and numerous fossil pingos, both indicating temperatures below -7 °C,

(ii) well-developed patterned ground, with disturbance extending to 2 m below the surface, indicating easy cryoturbation in a deep active layer, and

(iii) where the ground was sloping, a landscape with concave slopes, where solifluxion on a massive scale has moved large quantities of material down into the valley bottoms.

In Britain we get our first view of Devensian climatic conditions at Chelford in Cheshire (Simpson & West 1958), where an organic mud whose fossils suggest a mean annual air temperature between $+2$ and -3 °C is contained in current-bedded sand, perhaps deposited in a braided river channel. The sand above the mud is penetrated by ice-wedge casts (Worsley 1966), which show that severe frost conditions developed after the mud had been formed.

It may well have been this cycle of cold that produced the massive frost structures of the south of Ireland, and so figure 3 places the cycle at the end of the Early Devensian. The deeply developed patterned ground, and the large quantities of solifluxion-earth or 'head' suggest that a deep active layer must have persisted for some time. As we have seen, we do not know how long our frost cycle took to complete a revolution, nor if it rotated at a constant rate. The massive features just referred to suggest that on this occasion the process of re-warming, and the deep active layer it produced, may have lasted for a considerable length of time, and to emphasize this possibility the curve has been drawn asymmetrically at this level. To achieve the survival of ice-wedge casts the converse would have to hold; re-warming would have to have had been rapid, and no deep active layer could have formed. At Saltmills in Co. Wexford erected stones can be traced down to a considerable depth, and patterned ground is also suggested; there are fossil pingos and ice-wedge polygons in the immediate vicinity, and so this cycle of cold and frost could be called the Saltmills Stadial (for location, see figure 4*a*).

We now arrive at a major problem. As we have seen, at both Hollymount (pre-41500 B.P.) and Derryvree (30500 B.P.) in Co. Fermanagh there is no indication in the materials that underlie the organic deposits that they had been either deeply weathered during the Ipswichian Warm Stage, or severely disturbed by frost action during the Saltmills Stadial. In each case the organic material seemed to rest on an unweathered undisturbed till, which should be older than 41500 B.P. This position is accepted here, and it is envisaged that at the beginning of the Middle Devensian a small ice mass formed in the northwest part of the Irish midlands (see figure 4*a*), and deposited a layer of till. The deposits of this small early ice mass were later completely buried by a larger Devensian ice mass, which either removed the earlier till, or concealed it beneath its own deposits. In England there is no record of ice being formed at this time.

The relatively mild Middle Devensian continued, and just as in England we have interstadial conditions recorded in the Upton Warren Complex, so in Ireland we have the Castlepook Interstadial at 33500 B.P. We have also the organic deposits at Hollymount and Derryvree, but these may do no more than indicate a landscape with arctic plants and invertebrates, of which a record has happened to survive because the deposits were later buried by till.

The Late Devensian opens at 26000 B.P., and ice masses gradually built up in Ireland, Wales and Scotland. A powerful flow down the basin of the Irish Sea developed, and this carried material of marine origin as far as St David's Head in Wales, and Carnsore Point in Ireland; on the east the ice pushed into the English midlands as far as Four Ashes, Staffs, where its

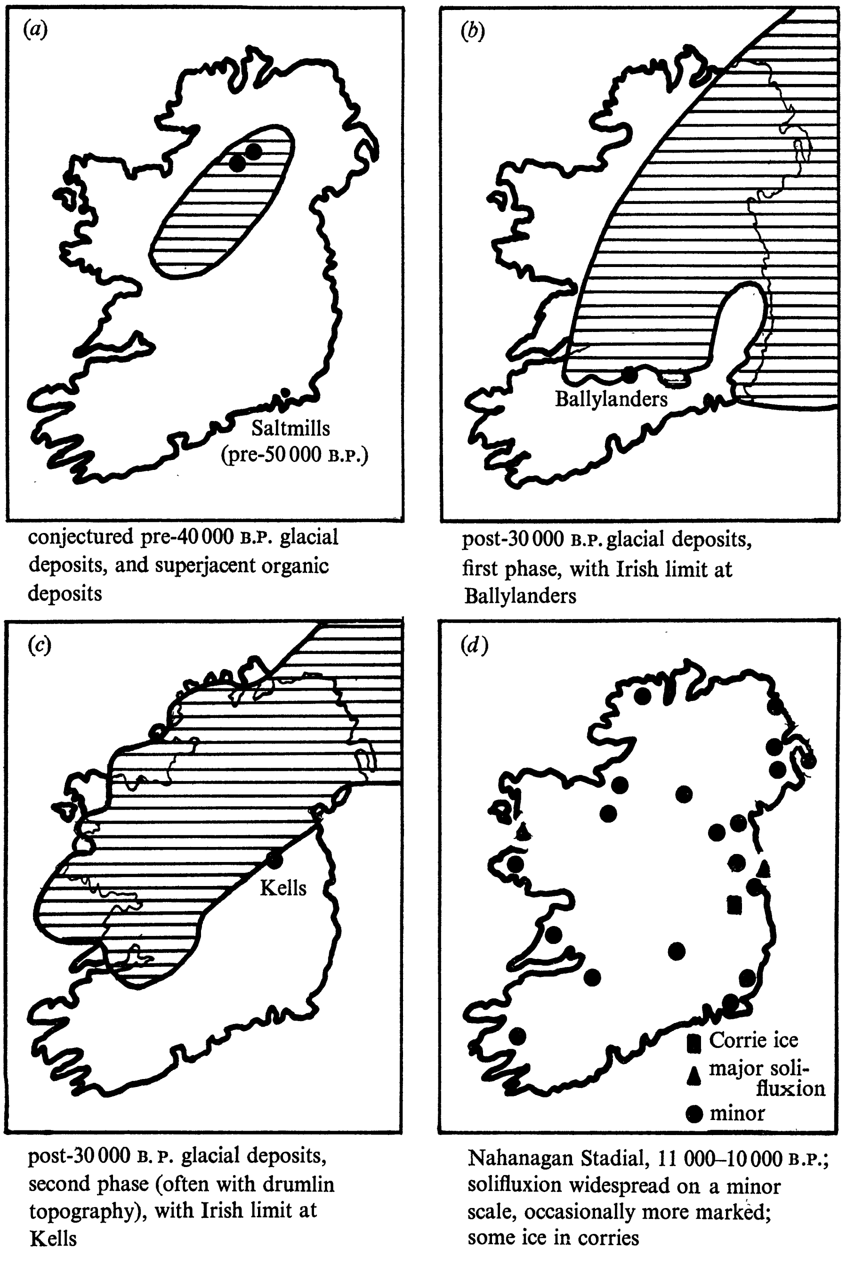

FIGURE 4. Devensian glacial deposits in Ireland.

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deposits rest on organic deposits of the Upton Warren Complex; on the west it kept ice from the Irish midlands pressed against the western shore of the Irish Sea. On the south, the Irish ice reached as far as Ballylanders, Co. Limerick (figure 4*b*).

At first the axis of this Irish ice mass ran approximately from Belfast to Limerick, but it later migrated slightly northwest, to run from the lower Shannon Estuary to Fair Head (figure 4*c*). Parts of western Ireland, hitherto free of ice, now became buried, while in the southeast some areas emerged from beneath the ice. The ice then began to melt away, revealing numerous drumlins as it did so, and had probably completely disappeared by 14000 B.P.

We thus have in the central midlands two areas of glacial deposits of slightly different ages, separated along a line that runs northeast/southwest through Kells, Co. Meath. Both areas show only very slight signs of periglacial activity, in marked contrast to the south of the country; rare ice-wedge casts and ice-wedge polygons occur in both areas; pingos are unknown in the younger northwest area, but do occur just inside the morainic limit in Co. Wexford, in the southeast area: patterned ground is unknown in either area; cryoturbation, if it can be recognized, is generally shallow and feebly developed: solifluxion is generally on a minor scale, and has nowhere produced concave curves; primary depositional features are still preserved in essentially mint condition. It seems clear that the two phases of the ice mass cannot be separated by a cycle of frost, neither are any organic deposits known to occur between the glacial materials of the two phases.

About 14000 B.P. a very dramatic amelioration of climate began, and convincing beetle evidence (Coope in Colhoun & Mitchell 1971) shows that temperature climbed quickly to a level at least as warm as that of today. However, the burst of heat was short-lived, and temperatures began to fall again, at first slowly. But about 11000 B.P., or perhaps a little later, temperature crash-dived to a very low level. In Scotland an ice mass of relatively modest size formed, and glaciers flowed south to the basin of Loch Lomond, and also the Lake of Menteith.

In Ireland so far ice at this time has been proved in only one corrie basin – Lough Nahanagan at 500 m in the Wicklow Mountains, and here the basin was only partly reoccupied. The emphasis seems to have been on cold, rather than ice. In the north of Ireland the Late Devensian ice mass surrounded, and perhaps buried, the Sperrin Mountains, and the dissolution of that ice can only have come late in the Devensian. Conditions mild enough to melt away an ice mass could not simultaneously have seen the growth of ice wedges. But the outwash gravels laid down by the decaying ice sheet are penetrated by ice-wedge casts (Colhoun 1971), which must be younger than the gravels, and probably formed in the Nahanagan Stadial.

When a pingo collapses, a central hollow is formed, and this is often occupied by a pond. Investigations of the muds in such ponds in Wales have not been able to produce mud older than 10000 B.P. (Watson 1975), and less detailed investigations in Ireland (Mitchell 1973) point in the same direction. Some pingos may thus have formed in the Nahanagan Stadial. In case it is thought that the duration of the stadial, probably less than 1000 a, was too short for the extensive development of pingos, recent studies (Ryckborst 1975) have shown that pingos up to 15 m in height – and there is no reason to think that many of the pingos in Ireland were on a much larger scale – can form in no more than 75 a.

When solifluxion begins to affect a slope whose soil is bound by the roots of grasses and herbs, lobate masses contained by plant roots begin to move down the slope. In the process mats of vegetation become buried, and may be preserved beneath the lobes of soil. At sea level in a cliff-section at Old Head, Co. Mayo, mats of vegetable debris lie below 2 m of 'till'. The plant material was first thought to be of interglacial age (Synge 1968), but a radiocarbon determination gave it an age of 10000 years, and therefore the solifluxion that buried it must have taken place in the Nahanagan Stadial. At Howth Demesne, Co. Dublin, also, a 'till' 2 m thick rested on a mud of Woodgrange age, with a ^{14}C date of 12000 B.P.; while in this case it is not impossible that the 'till' reached its present position in the course of landscape gardening, it may have been emplaced by solifluxion.

In the Nahanagan Stadial solifluxion on a minor scale was universal in Ireland, even out to the Atlantic coast, as is shown by figure 4*a*. At one site recently reinvestigated, Drumurcher, Co. Monaghan, the solifluxion-earth, which had a ^{14}C age of 10500 B.P., contained remains of about 100 species of beetle (Coope & Mitchell, in prep.). Many of the beetles indicated an arctic or sub-arctic regime, such as occurs today in the lower alpine regions of the mountains of Scandinavia, or the tundra regions of the far north. The site also produced the first seed so far found in Ireland of the arctic poppy (*Papaver radicatum* s.l.); today the distribution of this plant is strictly arctic-circumpolar.

The temperate muds that rest on the Nahanagan deposits have a ^{14}C age of 10000 years, and therefore this stadial lasted no more than 1000 years. Nevertheless in that short time, a frost cycle ran its full course from temperate conditions to conditions that allowed ice wedges and pingos to develop, and back to temperate conditions once more.

We can now give at least a tentative answer to the question we have posed, and we can say that the current limited amount of evidence that we have suggests that periglacial conditions occurred in Ireland twice during the Devensian Cold Stage. The first frost cycle, the Saltmills Stadial, came relatively early in the stage, after the Chelford Interstadial, and seems to have been prolonged and severe. The second cycle, the Nahanagan Stadial, came at the very end of the stage, between 11000 and 10000 B.P.; though short, its conditions were sufficiently severe for ice wedges to form. No Devensian periglacial features are known in Ireland whose stratigraphical position would suggest that they had formed in a frost period, other than one of the two described.

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Discussion

R. J. O. Hamblin (*Institute of Geological Sciences, 5 Princes Gate, London SW7*). I was interested to hear Professor Mitchell suggest a lower as well as an upper Devensian till, as we have found the same in the I.G.S. survey of Telford, Salop. Here the Upper Devensian till as at Four Ashes is underlain by lacustrine and fluvioglacial sands, clays and gravels and then by a lower Irish Sea till. The 'Middle Sands' run out into the Main Terrace of the Worfe and hence of the Severn, and as Upton Warren Interstadial dates are known from tributaries of the Severn Main Terrace at Upton Warren and Fladbury we believe that our Middle Sands and Lower Boulder Clay indicate an ice advance immediately preceding the interstadial and probably younger than the Chelford deposit.

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