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CHRONOLOGY, CLIMATE, AND MARINE RECORD

The Devensian Stage: its development, limits and substages

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The name Devensian for the last glacial stage of the British Pleistocene arose from the attempt of the Quaternary subcommittee of the Stratigraphic Committee of the Geological Society of London to define the divisions of the British Quaternary and to draw up correlation tables. The name of the stage derives from the location of the stratotype. Although the stage is broadly equivalent to the Weichselian of NW Europe and the Wisconsinan of North America, exact equivalence of the boundary limits and of substages in the British sequence to overseas divisions should not be assumed.

As a means of correlation, radiocarbon dating is of great use in the later half of the stage, and a few 'enriched' dates help in a few millennia before 50000 B.P. No other methods of absolute dating have yet been applied, and the possibility of doing these on the land-based Devensian deposits is remote.

Significant recognizable events in a glacial stage are provided by interstadials. Claimed interstadials in the Weichselian of NW Europe are briefly examined, and the evidence for interstadials in the British Isles is summarily presented and compared as far as possible with the continental succession. On the question of when, in the Devensian, the British area was physically 'glacierized', it is claimed that so far there is no evidence for this in the Early Devensian. The timing and duration of the well-established Late Devensian glaciation is discussed, and a word of caution is sounded against regarding this as synchronous throughout the area.

Introduction to the Devensian

Any discussion of the environmental conditions of Great Britain and Ireland during the Devensian demands first an explanation of the stage name which is relevant only to these islands. It labels the period which includes the last glacierization of the country, and the question immediately arises why one of the terms Weichselian or Wisconsinan, which cover roughly the same period of time in Europe and North America respectively, was not used. When a committee of the Geological Society of London undertook the task of producing a correlation of the British Quaternary (Mitchell, Penny, Shotton & West 1973) it attempted:

(*a*) to draw up a fully comprehensive succession of major climatic stages in Great Britain and Ireland,

(*b*) to relate sequences in different parts of the country to this succession, and

(*c*) to provide a framework for the extension of this correlation outside the British Isles.

It followed from this brief that the limits of the major stages and the subdivisions within them should be determined on British stratigraphy, and take British names. The stratotype for the last glacial stage was selected at Four Ashes in Staffordshire, within the area once peopled by the British tribe of the Devenses, and hence arose the now generally accepted stage name. Although Devensian may roughly coincide with the Weichselian as it is known in western Europe, there is no implication that either their upper or lower limits coincide, nor that the smaller climatic divisions within each stage necessarily correspond with each other.

The division of the Quaternary into stages and substages is based wholly on the concept of climatic cycles. In any region it may be possible to work out a succession in time of estimated variations in mean annual temperature, accompanied by other superimposed and less easily quantified fluctuations such as continentality, oceanicity, aridity or pluviality. The colder periods, if accompanied by adequate precipitation, often led to the growth of the continental ice sheets, and then a glaciation or 'Glacial Stadial' may be inferred. If an amelioration of climate leads to shrinkage of the glaciers, this is an 'Interstadial'; but if the decay of glaciers is drastic, this is an 'Interglacial'. Decisions on nomenclature of this kind must be highly subjective, particularly since the nature and extent of climatic change usually have to be deduced from their effect upon biota, rather than from the waxing and waning of past glaciers. If it can be demonstrated to a Briton that glaciers covered most of Scotland, Ireland, Wales and England down to the Midlands as recently as about 16000 years ago, he needs no convincing about the Devensian glaciation. Since he is also well satisfied with the congenial climate in which he lives, he will believe that he is now in an interglacial (Flandrian). It might be less easy to convince an inhabitant of Zaire that his forefathers of 600 generations back lived in a glacial stage, or to persuade a penguin on the Ross Ice Shelf that he is now enjoying an interglacial. When scientists in different parts of the world reach back and attempt to fix the upper and lower limits of the last glacial stage (or, indeed, any earlier one), they find themselves with a choice of the criteria which indicate climatic change, and have to make decisions about their relative importance, and the points in time when they achieved maximum significance.

A region as small as the British Isles has today enough variation in latitude, altitude and proximity to the ocean to produce profound differences in the floral and faunal assemblages of different regions. In the past when climates were changing rapidly these patterns were further distorted by the reaction of plant or animal species to the change. Some would adapt to the new conditions, but many would have to change their areas of colonization in order to continue in an environment where they could thrive. The populations might move northward or southward in search of unchanged temperatures, eastward or westward if precipitation and cloud cover affected their viability, up or down hill to seek unchanged temperatures and precipitation. Interpretations along these lines may still miss the more subtle factors in the tangled pattern of existence. So although the biologist can make sound deductions about ecology, if he chooses some empirical factor to mark a time division – for example, the first arrival of a broad-leaved tree such as oak or alder, or the colonization by a particular beetle, or where the rain of tree pollen exceeds that of herbs – inevitably that postulated boundary will be diachronous. Synchroneity of boundaries biologically deduced cannot really be expected; at the best it can be hoped that the departures from this ideal is small, as it could be if we can assess and make allowance for the effect of geographical position upon the contemporary biota.

The upper and lower limits of the Devensian

If the Devensian limits are to accord with the principles of the Stratigraphic Code, then the base must be clearly defined, but the top merely occurs under a clearly defined base for the overlying Flandrian. Everyone accepts that Pollen Zone III (Younger Dryas of NW Europe), indicating a rigorously cold climate, should be retained within the Devensian. It has been the custom to start the Flandrian with Pollen Zone IV, which begins at a radiocarbon date of about 10250 B.P. (Godwin, Walker & Willis 1957; Godwin & Willis 1959; Hibbert, Switsur

& West 1971). In fact the III/IV boundary is often not easy to fix, and there is a striking vegetation change at the end of Zone IV, when hazel (*Corylus*) spreads with dramatic suddenness and *Pinus* begins to dominate over *Betula*. This occurs at about 9600 B.P., a date which still precedes the advent in force of broad-leaved deciduous trees. Work on beetles at two Midland sites shows that a thermophilous fauna began to move in around 10300 B.P. (Ashworth 1972), and was firmly established at 9500 B.P. (Osborne 1974), in both cases ahead of the woodland vegetation that might have been expected with them. There are thus reasonable grounds to start the Flandrian in lowland England at the III/IV junction which here is around 10250 B.P. Nevertheless, the Quaternary subcommittee felt that there was no reason to expect these zonal boundaries, defined either by plants or insects, to remain fixed in time across the whole length of the British Isles and throughout the great variation in land height. Since there was a good radiometric clock available, to define the beginning of the Flandrian in terms of radiocarbon years avoided any problem of diachronism. A figure of convenience, 10000 years, close to the III/IV boundary of the English lowlands, was chosen because it conformed to the starting date of the Holocene recommended by the Holocene Commission of INQUA. Hence we may say that the Devensian ends at a date of 10000 *radiocarbon years* using the Libby half-life for ^{14}C of 5568 years as the standard for measurement.

The base of the Devensian cannot be so conveniently defined, for here we are beyond the range of radiocarbon. There are alternative methods of absolute dating, applicable with different degrees of reliability to various periods of the Quaternary succession, but none has proved useful or possible at the beginning of the British Devensian. Indirect use of magnetic reversals is impossible, because the whole time range of the Devensian is small compared with the scale of the magnetic changes. Complete lack of volcanic activity (in the whole of the British Quaternary, not only in the Devensian) prevents use of the potassium/argon methods even if these could be used for an antiquity of about 100000 years. For the same reason, fission-track dating need not be considered. The uranium series has rarely been consistent – except in the case of corals – and gives no promise for the Devensian. It is perhaps too early to judge the technique of dating based on the epimerization of amino acids (see Turekian & Bada 1972 for a summary of the method), but as an assumption of constant temperature is basic to the method, its application to the Devensian will be difficult. So we have to look to biological stratigraphy in an attempt to fix the transition from the preceding inter-glacial.

In fact this cannot be done in a satisfactory manner. The last interglacial, which precedes the Devensian, is the Ipswichian. Its type section is at Bobbitshole near Ipswich, but there are about 12 other studied sites east of a line from the Solent to the Wash (see Sparks & West 1970), and a few west of this line. Four floral zones have been set up with changing vegetation marking progress from cool temperate, through climax forest and back to more open woodland associated with declining temperature. If any of these sites continued in an unbroken succession to conditions which could be described as early glacial, the definition of the base of the Devensian would be clear. It would be at the base of this post-Ipswichian zone, however it might be characterized. It is, however, an extraordinary fact that none of the sites includes all Ipswichian zones, the sequence of four zones having been built by up overlap, and only one site (Wretton) is overlain by Early Devensian deposits; and here there is a great gap in which the latest part of zone Ip III, the whole of Ip IV and some of the Devensian is not represented by organic deposits. Deposits at Crayford ascribed to Ip IV might include the Early Devensian, but the age of these is not universally agreed.

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The best stratotype for the Devensian is undoubtedly the Four Ashes section north of Wolverhampton, studied by A. V. and Anne Morgan (Morgan, A. V. 1973; Morgan, Anne 1973). This site is unique in having deposits of Late, Middle, and Early Devensian above an Ipswichian horizon. The only section at all comparable in importance is at Tattershall in Lincolnshire (Girling 1974), which has a fuller development of the Ipswichian, but, within the overlying gravels which may span the whole of the Devensian, fewer diagnostic organic horizons and no Late Devensian till.

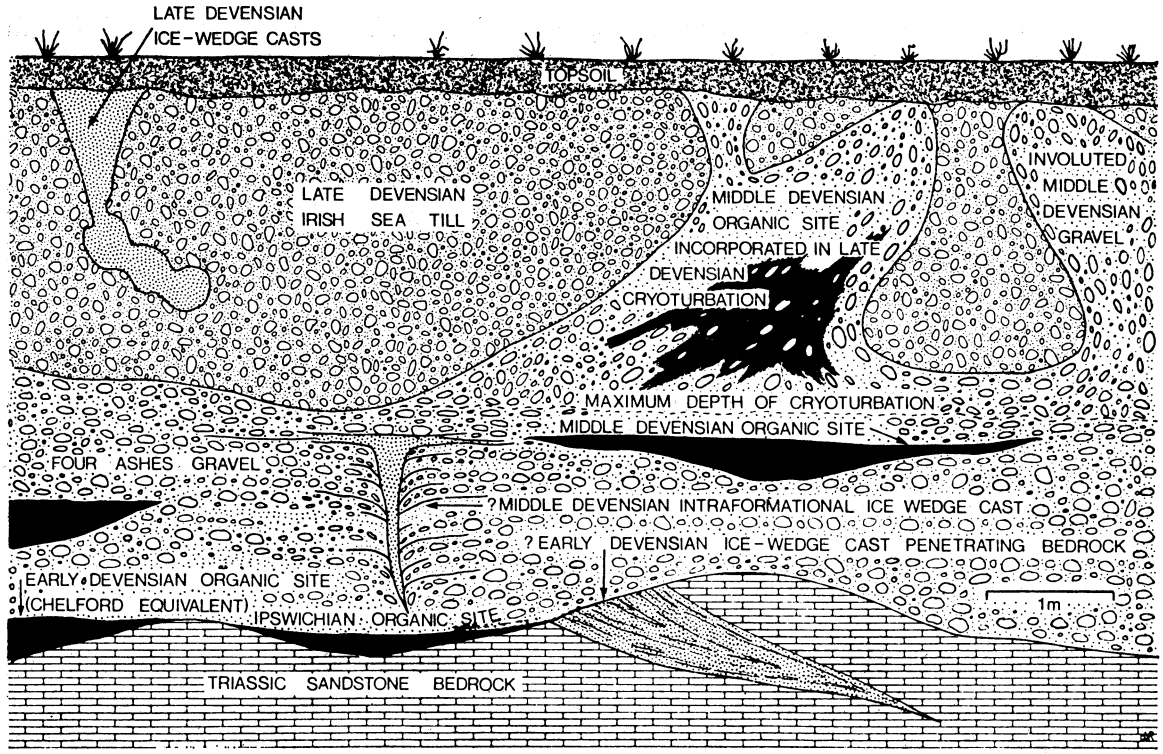

FIGURE 1

The dominant member of the Four Ashes sequence is a gravel varying in thickness between 0.5 and 4.5 m, but containing numerous small lenses of organic silt and peat, which have been subjected to faunal and floral analysis and radiocarbon dating. On the basis of dates alone, the Middle Devensian is well represented (6 determinations between 30000 and 42530 years). Evidence for the Early Devensian depends very much upon the recognition of the Chelford Interstadial (see below), but this is well substantiated. Above the Four Ashes gravel rests the Late Devensian till of the Irish Sea glaciation, and beneath the gravel at one point occurred an undoubted Ipswichian peat. A. V. Morgan summarized the essential features of the succession without attempting to show the 45 separate organic lenses which had been recognized and this diagram, with his permission, is reproduced as figure 1. The implications of this sequence are discussed later.

Interstadials claimed in the Weichselian of NW Europe

Based entirely upon palaeobotany, and almost wholly on palynology, a number of horizons in countries between north France and Denmark have been considered to show relatively short-term ameliorations of climate, and so to be ranked as interstadials. They are shown in table 1, together with the dates which have most recently been ascribed to them.

Table 1

claimed interstadial	dates B.P.
Allerød	numerous, between 11000 and 11800
Bølling	between about 12000 and 13000
Denekamp	*ca.* 30000
Hengelo	*ca.* 39000
Moershoofd	43000–50000
Odderade	*ca.* 58000
Brørup	61000–63500
Amersfoort	65000–68000

The interstadials are not similar in their ecological and climatological implications which are discussed below.

The Allerød Interstadial, as interpreted in Denmark, demands the close proximity of pine and birch woodlands, but the Bølling episode can be interpreted as one of shrub tundra. It is claimed that the pollen record of what is usually called the Older Dryas period, intervening between the Allerød and Bølling, shows a short-lived return to a colder climate which justifies the making of two interstadials. There is some dispute about this concept of two separate interstadials, and also about the date of the maximum amelioration of climate, opinion being less divided on the east side of the North Sea where little but botanical work has been done, than in Great Britain and Ireland where insect studies have supplemented palynology. However, other contributors to this discussion will debate the relation of the British Late Devensian Interstadial (or interstadials) to the Late Weichselian oscillations of NW Europe. What is not disputed is that Bølling, Older Dryas and Allerød together constitute a major interstadial between the rigours of the preceding glacierization and the return to arctic conditions in Zone III.

In the earlier third of the Weichselian (Early Pleniglacial) three interstadials are claimed, and the lower two (Amersfoort and Brørup) are well substantiated (Andersen 1961; Zagwijn 1961). At Amersfoort in the Netherlands and Brørup Bog in Denmark, there are two organic horizons which lie above the Eemian, and which each show a strong increase of tree pollen which must indicate contemporary boreal forest. The lower one is dominated by *Betula* and *Pinus*, the upper by *Betula*, *Pinus*, *Picea* and *Alnus*. The sequences in the two localities parallel each other, and the Danish name has been accepted for the later interstadial and the Dutch name for the earlier.

Both these interstadials are beyond the normal reach of radiocarbon dating but the Gröningen laboratory, using the enrichment technique, gave them positive dates. Recently Grootes has made new determinations on newly collected material in the hope that the older ones might be confirmed, or at least corrected for the minimal contamination that may have been present.

These dates are listed below, the earlier series being shown in italics and any given with the 'greater than' symbol being unenriched. Grootes has not yet fully published his dates but a short abstract (Grootes 1976) gives a diagram from which they may be read with reasonable precision. They are quoted below without standard deviations or laboratory numbers.

Brørup I/S.	At Brørup	*58740 ± 1000* GRO 1729
		59430 ± 1000 GRO 1470
	At Amersfoort	*> 53000* GRO 1280 and 1285
		61000 at the end, 63000 at the beginning.
Amersfoort I/S.	At Amersfoort	*> 53000* GRP 1221
		63500 ± 1100 GRO 1398
		66500 at the peak, 68000 at the beginning.

These 'enriched' old dates must still be treated with caution, and regarded only as minima. It is perhaps not generally realized how little of its original radioactivity is retained in a piece of organic matter 68000 years old. It is 0.024 %. Broecker (1965, p. 749) raised doubts about the accuracy of the original Amersfoort date of 63500, on the grounds that the 'date' of the alkali-extracted humate gave a positive figure of 42300, which indicated that there had been contamination originally. The new Gröningen determinations were done to examine this criticism, and it is claimed that the slightly enhanced figures now presented are probably close to the truth.

The Odderade Interstadial claimed by Averdieck (1967) in Schleswig Holstein depends to some extent upon acceptance of the Brørup Interstadial below it. The date of 58000 appeared at first sight to offer little chance of distinguishing it from the Brørup by absolute dating alone, but now that the latter's age has been advanced to around 64000 years, separate identities appear more probable.

Within the Middle Weichselian (the Interpleniglacial of some authors) three interstadials are claimed, but they are different in character from those of the Early Weichselian. In no case does the pollen indicate anything but a shrub tundra environment, and the main justification for regarding them as interstadial (which implies a measurable amelioration of climate) is that the organic horizons are separated from each other by mineral sediments which are cryoturbated. No great claims are made for the extent of the climatic amelioration in these interstadials, van der Hammen, Maarleveld, Vogel & Zagwijn (1967) postulating an improvement in mean July temperature from 5 to 10 °C. Zagwijn (1974) regards the Moershoofd Interstadial as requiring more pollen analyses before its interstadial nature can be accepted without question.

Radiocarbon dates for the Moershoofd period range between 43000 and 50000 years. The two later interstadials are more closely defined, though in the case of the Hengelo, there is still an apparent spread in dates. Seven dates taken in the three localities of Hengelo, Ruigekluft and Denekamp range between 36000 ± 600 and 40500 ± 1500, but the youngest date may be affected by contamination. Nevertheless, the range of this relatively minor interstadial would be from about 37500 to 40000, with its peak around 39000. The Denekamp Interstadial is dated around 30000 B.P.

One of the characteristics of NW Europe is the paucity of datable organic deposits between the Denekamp period and the Oldest Dryas around 13000 B.P. This period, which embraces the maximum advance of the North European Ice Sheet, is interpreted ecologically as polar desert, and clearly invites comparison with the same length of time in Britain and Ireland.

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Devensian interstadials

(a) *Evidence for the Amersfoort Interstadial*

The only British deposits which might be in the Amersfoort Interstadial occur in Zones C and D of Wretton in Norfolk, and they have been labelled as the Wretton Interstadial (West *et al.* 1974). The pollen diagrams suggest the lower half of an interstadial, in that over the short range of the sediment, there is an upward increase in tree pollen and a decline in grasses. There seems little doubt from the stratigraphy that this horizon is post-Ipswichian, and also low in the Devensian, but the argument that it coincides in time with Amersfoort is not conclusive. The pollen diagram for site WX is interpreted as beginning in Ipswichian Zone II, and then passing without obvious break into the possibly Amersfoort horizon. There must, however, be a considerable sedimentary gap if Ip III and Ip IV are absent, and in this case one cannot deduce how close the interstadial is to the bottom of the Devensian. Support for an Amersfoort age is given by the tree pollen (see West *et al.* 1974, p. 403), which is predominantly *Betula*, *Pinus* and *Alnus* with very little *Picea*, and, if the next overlying tree pollen-rich zone is to be correlated with Brørup, the case for equivalence between the Wretton and Amersfoort interstadials is strengthened. However, there is a division of opinion about the correlation of this higher zone (Coope, in appendix to West *et al.* 1974). No radiocarbon date has been attempted on the Wretton interstadial. It could only be done after diffusion-enrichment, and in view of the doubts about the accuracy of the Amersfoort measurement, it is doubtful whether any result would be conclusive.

(b) *Brørup Interstadial and the Chelford Interstadial*

The well-known bed of peat with trunks and other macro-remains of birch, pine and spruce in the yellow sands of Chelford, Cheshire, was the first deposit to be correlated with the Brørup Interstadial (Simpson & West 1958). It demonstrably antedates the Upper Boulder Clay of Cheshire, now known to be Late Devensian, but it cannot be proved to be post-Ipswichian by superposition on Ipswichian organic deposits. Simpson & West described the flora, with *Betula* cf. *pubescens* and cf. *verrucosa*, *Pinus sylvestris* and *Picea abies* the dominant trees, and considered correlation with Brørup to be the most likely possibility. At the time, the Gröningen laboratory had not finished the calculation of an 'enriched' ^{14}C date, but shortly after this was given as 57 000. It has since been recalculated at 60 800 ± 1500 (GrN 1480). This has been taken as additional proof that the Chelford Interstadial of England is the same as the Brørup of Holland and Denmark. Coope (1959) described the abundant insect fauna, and so established an independent assemblage zoning for the Chelford Interstadial. As might be expected, the insect record agreed with the palaeobotany in evaluating the climate, and was consistent with the vegetational environment.

It is because the two types of evidence conflict at Wretton that there is doubt about the horizon attributed there to the Chelford Interstadial. The pollen is interpreted to mean an amelioration of climate resulting in birch-conifer woodland, whereas Coope (in appendix to West *et al.* 1974) interprets the beetles as indicating a deterioration in climate leading to treeless tundra.

There seems no doubt that the Chelford Interstadial is recognizable in the type Devensian site at Four Ashes (Morgan, Anne 1973), even though the evidence is somewhat circumstantial.

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The many small sporadically occurring, organic lenses included:

(*a*) A group with an arctic insect fauna, all in the upper part of the gravels, and three of them dated at 30500 ± 440 (Birm-195), 30655 ± 730 (Birm-25) and 36340 ± 730 (Birm-24).

(*b*) A group with mixed fauna but including a number of warm climate stenotherms, and a great reduction in the cold stenotherms. Three samples here gave dates of 38500^{+1300}_{-1100} (Birm-170), 40000^{+1400}_{-1200} (Birm-196) and 42530^{+1345}_{-1115} (Birm-56). This group was correlated with the Upton Warren Interstadial (*sensu stricto*).

(*c*) A small number of lenses in the lowest metre of the gravel, in two of which the beetle fauna was conspicuously arctic, closely resembling group (*a*), but older than group (*b*), since one sample gave a date of > 43500 (Birm-74).

(*d*) Two organic lenses at the base of the gravel, and presumably therefore older than (*c*). They gave a beetle fauna which closely resembles that of Chelford, including species dependent upon the presence of trees of birch and pine and/or spruce, and the two species *Scolytus ratzeburgi* and *Blastophagus piniperda* which were hitherto only known from Chelford. Professor West (personal communication) states that the palynology confirms a Chelford horizon.

(*e*) A third lens also at the base of the gravels, devoid of insects but with abundant thermophilous plants. Clearly an interglacial, it has been confirmed as Ipswichian by Professor West (personal communication). A 'precautionary' radiocarbon date was done (Birm-171), which was, as expected, > 45000.

The Chelford Interstadial (and that of Brørup, assuming synchroneity) is thus clearly represented at Four Ashes. A flora from Beetley in West Norfolk, worked on by Dr Linda Phillips, is stratigraphically not much later than Ipswichian. Pollen of *Betula*, *Pinus* and *Picea* and an abundance of *Picea* needles indicate the existence of woodland of Chelford type. The site is therefore ascribed to this interstadial.

The only other possible claimant to Brørup status is in Borehole V 050 which penetrates the infilling of the 'Fosse Dangeard' in the English Channel, and which can use its position well within British territorial waters to justify its reference here. Morzadec-Kerfourn (1975) considered that the pollen of the organic deposits indicated a period towards the end of the Brørup Interstadial, but did not exclude the possibility of a later date with the pollen largely reworked. If the age is truly Brørup, then the occurrence of salt marsh deposits (for that is how they are interpreted) as low as −89 m N.G.F. provides an interesting figure for an Early Devensian sea level (if there has been no subsequent tectonic disturbance).

(*c*) *The Upton Warren Interstadial*

The Middle Devensian was defined between the radiocarbon age limits of 26000 and 50000 years (Mitchell *et al.* 1973). It lies between the Late Devensian which includes the manifestations of British glacierization, and the Early Devensian with broadly corresponds to the 'Early Würm' of Europe. Because an episode of interstadial nature had already been established at an age of about 42000 years at Upton Warren in Worcestershire (Coope, Shotton & Strachan 1961), the Middle Devensian has been alternatively referred to as the Upton Warren Interstadial Complex, and would be deemed to include additional climatic ameliorations such as equivalents of the Hengelo and Denekamp. Further work has substantiated the existence of a short but marked interstadial in the Devensian between about 43000 and 40000 B.P., in marked contrast to the later part of the Middle Devensian which was consistently very cold.

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So the label of Upton Warren Interstadial is used in a limited sense here for this shorter period.

The Upton Warren site lies on a river terrace correlated with the Main Terrace of the River Severn. There are three organic bands lying within gravels which show clear evidence of contemporary cryoturbation. A sample from the middle organic bed sent to Gröningen was dated at 41 500 ± 1200 (GRO 595) after acid pretreatment only. A second portion of the same sample was dated after alkali-treatment at 41 900 ± 800 (GRO 1063), and the alkali extract was dated at > 40 000. This indicated the absence of contamination, and an age near to 42 000 years may be considered to be reliable.

Nothing in the fauna or flora suggested a climate which approached interglacial. The abundant mammals included *Bison*, *Coelodonta antiquitatis*, *Mammuthus primigenius*, *Rangifer tarandus* and *Dicrostonyx torquatus*. Pollen indicated a treeless environment, but there were several plant taxa which belied the description of this as tundra. Mollusca favoured the interpretation of a cold climate, but the insect list included species now restricted to north Scandinavia and north Russia along with others now south of latitude 60°. Fauna and flora therefore both included taxa seemingly incompatible, a fact which could be explained if adjustment to a rapidly changing climate was taking place.

The Upton Warren Interstadial has been recognized now at five other places. It has already been indicated how Anne Morgan established this at Four Ashes, by recognizing the appearance of warm stenotherm beetles between dates of $38\,500^{+1300}_{-1050}$ and $42\,530^{+1345}_{-1115}$. Frances Bell (1970) compared the flora of a silt bed at Earith with other Devensian floras, and considered it closest to Upton Warren and Sidgwick Avenue, Cambridge (which is undated). She also classified it as interstadial on the grounds that some of the plants demanded summer mean temperatures up to 16 °C. The ascription to the Upton Warren Interstadial is supported by the radiocarbon date of $42\,140^{+1890}_{-1530}$ (Birm-88).

The beetle fauna described by Coope & Angus (1975) from the Upper Floodplain Terrace of the Thames at Isleworth is considered by them to be more thermophilous than any which have been mentioned above, necessitating summer temperatures around 18 °C, and winter temperatures only slightly below those of the present day. They would regard it as marking the peak of the Upton Warren Interstadial, fitting to a radiocarbon date of $43\,140^{+1520}_{-1280}$ (Birm-319). Characteristically, the environment appears to have been treeless.

Finally, the work of Maureen Girling (1971) at Tattershall in Lincolnshire, only as yet summarily reported on, brings out the great rapidity of the climatic change which led up to this interstadial. Two silt beds occur in the post-Ipswichian gravels, very close to each other in direct upward succession. The lower has a conspicuously cold beetle fauna and two radiocarbon dates, $42\,100^{+1400}_{-1100}$ (Birm-398) and $44\,300^{+1600}_{-1300}$ (Birm-408). The large standard deviations overlap, but a figure between 43 000 and 44 000 is likely. The fauna in the upper silt has changed dramatically with the introduction of typical Upton Warren thermophiles. Radiocarbon dates are $43\,000^{+1300}_{-1100}$ (Birm-341) and 42 200 ± 1000 (Birm-409), which are not statistically separable from the two in the lower bed, but they illustrate how rapid the climatic change up to the interstadial must have been. This, and the short duration of the mild period, evidently conspired to inhibit the establishment of trees.

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(*d*) *The latter half of the Middle Devensian*

It is clear that the Upton Warren Interstadial does not fit with the date given to Hengelo, but is rather earlier, though there is some overlap. There is a growing body of evidence that the climate deteriorated very rapidly after the Upton Warren Interstadial to become arctic, and eventually to pass to polar desert before the advent of the Late Devensian glaciers. There are now many dates between about 39000 and 26000 measured in deposits which contain fauna and/or flora leading to climatic deductions. No. 2 Terrace of the Warwickshire Avon, and its correlative in the tributary Carrant Brook, have at least eight dates on organic horizons ranging from 38000 to 26000 years. In the Trent drainage we have three for Four Ashes (36340, 30655 and 30500), and one in the Tame Valley (32160). Standlake Common in Oxfordshire gave 29500, Queensford in Oxfordshire 39300, Sutton Courtenay in Oxfordshire 33190 (with a very large standard deviation), Syston in Leicestershire 37420, Thrapston in Northants 25780, Great Billing in Northants 28230, Kirkby-on-Bain in Lincolnshire 34800, Oxbow in Yorkshire 38500 (on a mammoth tusk), Leadenhall Street, London, on a bone of *C. antiquitatis*, 29450, and as far afield as Derryvree, Co. Fermanagh, 30500 and Castlepook Cave, Co. Cork, 33500. In all these cases wherever flora has been studied, tundra is indicated, and where fauna has been worked on, an arctic environment can be deduced. It would be misleading to affirm that the small Denekamp oscillation does not exist in the British record. Before this could be said, one would have need to study a continuous sequence extending between, say, 32000 and 28000 years, and such a sequence is as yet unknown. All that we are entitled to say is that none of the mid-Weichselian interstadials of the continent has yet been recognized in the British Isles, and that our one clear interstadial appears to lie between the claimed dates for the Moershoofd and Hengelo.

Glaciation in the Devensian

With the increase in the number of, and knowledge about, the organic beds of the Devensian and radiocarbon dates extending back towards 50000 years, there is now no evidence for an Early Devensian glaciation in Great Britain or Ireland. There are situations, as at Derryvree (Colhoun, Dickson, McCabe & Shotton 1972), where two tills are separated by Middle Devensian sediments, but so far nowhere that a lower till is underlain by deposits of Chelford, Amersfoort or Ipswichian date. Till of Late Devensian age is widespread in Ireland, Wales, Scotland and England north of the Midlands, and it is of interest to examine what we know about the duration of the main glaciation, as distinct from late readvances.

It is possible, even probable, that the spread of ice over the country did not occur in a single surge, but was effected by lobes which advanced and retreated over different areas at different times. Such appears to have been the case in the Late Wisconsinan of North America. If, however, we hope to date these glacial episodes, it can only be done by obtaining limiting dates on organic deposits above and below tills, or associated with fluvioglacial sediments emanating from the glaciers. We are still far from having enough conclusive information on this score. One of the most surprising dates was effected on the Dimlington moss layer, which occurs in silt-filled pools on the weathered surface of the Basement Till, and is overlain by the layered Drab and Purple Tills of the Yorkshire coast. American dating produced a figure of 18500 ± 400 (I-3372) (Penny, Coope & Catt 1969). A second determination on independently collected

material strikingly confirmed this figure, 18240 ± 250 (Birm-108). This has led to a widespread quoting of a duration for the main Late Devensian glaciation as lying between 18000 and about 15000 years ago. This may not be the whole story. The problem of the relation between the 'Irish Sea Glacier' of the Midlands and the Severn Main Terrace still remains an unsolved puzzle. The Main Terrace is, because of its erratics, clearly the outwash below the Ironbridge Gorge of the Irish Sea Glacier. It has no radiocarbon dates. Topographically it grades with Avon No. 2 Terrace (which is not glacial outwash) and in this there are numerous dates, none newer than 32000, though there are figures as late as 26000 from the same terrace along the Carrant Brook. Admittedly many of these dates refer to organic material near the base of the terrace deposits. Even more confusing is the Upton Warren date of 42000, in the middle of terrace gravels on the River Salwarpe, tributary of the Severn and apparently grading into the Severn Main Terrace. It must also be recalled that of the seven dates from the gravels underlying the till at Four Ashes, the youngest was just over 30000. Much of this evidence is negative, and we urgently need to find datable material within gravels of the Severn Main Terrace which carry the characteristic Lake District and Scottish erratics of the Irish Sea Glacier. Until we do this, we are unlikely to know whether the ice advance down the Irish Sea and across the Cheshire Plain was earlier or synchronous with that along the Yorkshire coast. It may be significant that a layer of the moss *Drepanocladus revolvens* at Glen Ballyre in the Isle of Man has four determined dates, three of them separate measurements on one sample (Birm-270, a, b, c) and one on a sample collected at a different time (Birm-213). The four dates are bracketed between 18400 ± 500 and 18900 ± 330 and something close to 18650 must be correct. The deposit is near the base of a succession which post-dates the Late Devensian glaciation, yet the date is slightly older than the one which antedates the East Yorkshire tills. The possibility of 'hard water error' has been suggested (Shotton & Williams 1973), since the moss is capable of photosynthesis under water as well as subaerially. Even so, the correction would have to be considerable to abolish the suggestion of non-synchronous advances and retreats of lobes of the Late Devensian glacier.

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