Chapter 4 The pre-Devensian glacial and interglacial record The Lower Quaternary

Introduction

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In northern England the major landforms and sediments that can be recognized in the landscape are largely a response to environmental changes that have taken place over the past 150 000 years, through the last interglacial and glacial cycle, into the current interglacial. This is because, with the exception of parts of South Derbyshire and Yorkshire, the region lies wholly within the limits of the Late Devensian glaciation. Consequently, glacial landforms and sediments from this glaciation dominate the region and most of the pre-Devensian deposits have been removed or reworked.

Through all the glacial phases of the Quaternary Period the region was strongly affected by ice from Scottish sources that passed over offshore marine basins, crossed onshore along the Lancashire, Cumbrian, Northumberland, Durham and Yorkshire coasts and coalesced with local ice that radiated from the Pennines, Lake District and Cheviot uplands. The type of Quaternary deposit was determined largely by the region's upland Palaeozoic rocks and surrounding Mesozoic sedimentary basins in the Irish and North Seas. Nevertheless, the cave environment is a favoured location in northern England for the preservation of pre-Devensian deposits and by reference to events that took place in other areas of the country, an extremely fragmented Early and Middle Pleistocene development for the region can be pieced together. This fragmentary evolution is discussed below but the evidence is sparse and the dating almost nonexistent.

Traditionally, the Quaternary deposits of Britain have been divided into Lower, Middle and Upper divisions and for convenience of treatment this approach is simplified and maintained here. Deposits of the Lower Quaternary are essentially restricted to East Anglia and comprise marine and terrestrial sediments deposited on the western margin of subsiding North Sea sedimentary basins. Although displaying alternating cold and temperate faunal characteristics they are free of evidence of extensive glaciation. The Middle Quaternary, also exposed mainly in East Anglia, records similar repeated climate changes that include, traditionally, evidence for two extensive phases of glaciation, the Anglian and the Wolstonian cold stages and two intervening interglacial stages, the Hoxnian and Ipswichian. The Upper Quaternary covers the last interglacial–glacial cycle of the Devensian cold stages and the current temperate interglacial stage, the Holocene. Many of the stages in the Lower and Middle Quaternary have not yet been matched to the oxygen isotope stages defined from ocean records. Consequently, traditional stratigraphical stage names and marine oxygen isotope stages (OIS) are used in this discussion of pre-Devensian events in northern England.

The Lower Quaternary

Probably the earliest terrestrial Quaternary deposit in northern England comes from a cave site in Derbyshire. Victoria Quarry cave at Dove Holes was discovered during quarrying and it contained a series of deposits, now removed, of stratified, yellowish-red clay containing limestone and irregularly distributed bones and teeth, described by Dawkins (1903). He suggested from the weathered state of some of the bones, and possible teeth marks, that the material had accumulated in a hyaena den at a higher level and subsequently had been washed deeper into the cave. Work by Spencer and Melville (1974) on the surviving fauna shows that it contains hyaena (*Crocuta* sp.), sabre-toothed tiger (*Homotherium sainzelli*), gomophothere mastodont (*Anancus arverensis),* extinct elephant (*Archidiskodon meridionalis*), extinct horse (*Equus cf. bressanus*) and a deer (*Dama* sp.). This warm temperate fauna suggests an open grassland. The reassessment rejects hyaena denning as the bone accumulating mechanism. They assigned a Lower Pleistocene (Villafranchian, Plio-Pleistocene transitional faunas in Europe (see Zeuner, 1953 and Bowen, 1978)) age to the fauna, whilst Stuart (1982) noted that the presence of *Anancus arverensis* indicated an age not later than the Bramertonian temperate stage. West (1980b) had added the pre-Pastonian and Bramertonian stages to the climato-stratigraphical stages in Britain (compare (Table 2.3), Chapter 2) but as Jones and Keen (1993) suggest, the timing of the Bramertonian is both problematical and controversial. It is suggested as a warm temperate stage after the Baventian.

The earliest suggestion for glaciation in northern England is in the Thurnian cold stage (see (Table 2.3), Chapter 2). It appears to have had a climatic environment colder than those that currently exist in this country. Jones and Keen (1993) suggest that temperatures may have been low enough to allow the accumulation of at least localized ice in the northern and western highland regions of Britain during this phase. However, there is no evidence for this. The ice limits drawn on Catt's (1981) map (Figure 4.1) are nothing more than conjecture, as that author acknowledges, and there is no real evidence for direct glacial deposition.

Baventian cold stage

There is perhaps marginally more evidence for the younger Baventian cold stage in northern England. Catt (1981) considered it possible that ice may have entered the North Sea basin during this phase, possibly for the first time. Certainly there is evidence for low temperatures from the pollen record (Turner, 1975) and Hey (1976, 1980) reported the presence of *Rhaxella* chert likely to be from the Jurassic deposits in eastern Yorkshire as a component of Baventian marine gravel at Easton Bavents. Discussion in Mottram (1999) suggests that the evidence allows only speculation as to the precise provenance and that it is possible that the specimens represent more than one outcrop area, for example offshore Yorkshire and Lincolnshire (Cameron *et al.,* 1992) and the Moray Firth (Andrews *et al.,* 1990). West (1980) cited too the occurrence of metamorphic minerals, with Norway the probable provenance, in Baventian sediments in Suffolk. The likelihood is that these components were brought to Suffolk either by icebergs in a glaciomarine environment or by glacial outwash. The pollen and foraminiferal record had already allowed Funnell and West (1962) to suggest that 'glaciers were present not far from East Anglia'. Scattered remnants of weathered sediment that resembles till in Oxfordshire (Shotton *et al.,* 1980) and Hertfordshire (Catt, 1981; Jones, 1981) may be evidence for Early Pleistocene glacials. Hey (1991) reviews this type of evidence and suggests that although Shotton *et al.'s* (1980) striated clasts in the Northern Drift could have been carried by ice-floes and this would account for the glaciated sand grains of the Kesgrave Formation, the glacial origin is not unequivocal. It does not explain the variations in composition noted by Hey (1986) in the Northern Drift and its supposed downstream equivalents, and it does not explain why the Northern Drift contains very few, highly durable, Palaeozoic clasts from the Midlands. Hey (1991) suggests that the Northern Drift was deposited by a river issuing from an ice-front situated some distance to the north of the present Cotswold scarp. The upper course of such a river might well have been confined largely to Triassic outcrops, and therefore its bedload may have been dominated by Bunter pebbles. Nevertheless its bedload composition might have varied in response to changes both in the ice sheet itself and in the non-glaciated areas drained by its outwash. Erratic content was used by Catt (1982) to imply that residual glacial sediments on the Yorkshire Wolds could be of Baventian age.

Pastonian temperate and Beestonian cold stage stages

There is some evidence from dinoflagellate and pollen and spore data to suggest that the Bridlington Crag along the Yorkshire coast may be of the Pastonian temperate stage (Reid and Downie, 1973; Gibbard *et al.,* 1991). The following Beestonian cold stage, with evidence of ice-wedge casts in river sediments in East Anglia (West, 1980), indicates at least discontinuous permafrost and mean annual temperatures not exceeding 6°C, although there is no evidence of glacial activity in that region. However, the presence of far-travelled, presumably glacially derived, gravels in the Thames river terraces, which may have formed in the Beestonian, has been reported by Green and MacGregor (1980) and glaciers being present in Northern England, Scotland and Wales seems likely. Catt (1981) produced a tentative ice-limit and he suggested that the Northern Drift of Oxfordshire could be the result of a Beestonian glaciation. The lower of two tills in the Kettering and Buckingham areas (Hollingworth and Taylor, 1946; Horton, 1970) may be of equivalent age.

In the central North Sea, glaciomarine sediments were deposited in this phase (Figure 4.2) (Cameron *et al.,* 1987; Long, A.J. *et al.,* 1988). The sediments of the Kesgrave Formation from inland East Anglia were noted earlier and they have been recognized in many localities (Rose and Allen, 1977; Hey, 1980). Many of the members of this Formation were probably deposited in a braided, ancestral Thames under a periglacial climatic regime. As some of the gravels contain Triassic conglomerate clasts derived from the western English Midlands and from North Wales volcanic rock, it seems likely that they were derived from glaciation to the west and north-west (Bowen *et al.,* 1986) and some are likely to be Beestonian in age (Zalasiewicz and Gibbard, 1988).

There has been a detailed interpretation of the Kesgrave Group, the pre-Anglian terraces of the River Thames, in Essex and Suffolk by Whiteman (1992) and Whiteman and Rose (1992). Within this Group, which spans a long time period from the pre-Pastonian to the early Anglian, they recognize ten terraces and a major subdivision into the quartz-rich Sudbury Formation and the flint-diluted Colchester Formation. They believe that the Thames rose in Wales during the deposition of the highest terraces forming the Sudbury Formation and that it had lost its headwaters west of the Cotswolds by the time the Colchester Formation was deposited. Their interpretation implies glaciation in upland Wales, and by implication in northern England, during the pre-Pastonian, and a West Midland glaciation during the deposition of the Waldringfield Member of the Colchester Formation. This suggested to Gibbard *et al.* (1991) that glacial episodes can be taken back to 1.2–1.4 Ma, and quoting Bowen *et al.* (1986) they state 'it appears that the Kesgrave Formation is associated with five glacial events in western Britain between the Baventian and the Cromerian (*sensu stricto*)'.

Recent work has shown that the Pastonian is Early Pleistocene in age and is separated from the Cromerian by a huge time interval (Preece, 2001). It is clear from northern England that we know little from this Lower Quaternary period.

Cromerian temperate stage (Oxygen Isotope Stages 13–21)

The succeeding Cromerian interglacial is possibly marked by deposits in northern England at Blackhall, County Durham that contain plant, molluscan and vertebrate fossils possibly representing this warm stage (Kennard and Woodward, 1919, p.200; Trechmann,1919; Reid, 1920). It is also worth noting that a water vole, *Mimomys* (Hinton, 1919, p. 201), and an elephant, *Archidiskodon meridionalis* (Andrews, 1919), have been reported from these County Durham fissure deposits, one of which may be Cromerian in age. Both animals have been recorded in Cromerian deposits in the British Isles, with the elephant becoming extinct in the early Middle Pleistocene (Stuart, 1982). There is further discussion of this in the description of the Warren House Gill GCR site. The correlations between the northern England deposits and oxygen isotope stage stratigraphy are given in (Table 4.1) from Thomas (1999), where it can be seen that the Blackhall Colliery Formation is categorized as pre-stage 9. In the Derbyshire caves some of the earliest evidence comes from high-level systems such as Water Icicle Close Cave above the Lathkill valley, where there is speleothem development associated with the Cromerian (Burek, 1991) and the Group V system from Derbyshire (Ford *et al.,* 1983) dates to 350 Ma, which also suggests the Cromerian warm stage.

However, Preece (2001) suggests that the single Cromerian interglacial is an oversimplification and that the molluscan evidence points to as many as five distinct stages within the 'Cromerian Complex'. Similarly Stuart and Lister (2001) present mammalian evidence for an additional temperate stage in the early Middle Pleistocene, distinct from that reconstructed from the West Runton, Cromerian type site. They suggest that sites of 'Cromerian Complex' age may be coarsely grouped into those containing the ancestral water vole, *Mimomys savini,* or those containing its probable descendent, *Arvicola terrestris cantiera.* They propose that as many as four separate temperate episodes may be represented by sites with *Mimomys,* whereas at least two distinct temperate episodes are represented by sites with Arvicola. This complexity again highlights how little we know of this 'Cromerian Complex' in northern England.

Conclusion

The evidence for the Quaternary development of northern England between the Late Pliocene and Cromerian warm phase is fragmentary. In the warm temperate stages speleothem growth took place in the high-level cave systems in Derbyshire and the Yorkshire Dales. During the colder phases there is certainly circumstantial evidence for ice being present in the uplands of northern England, Wales and Scotland, although all the evidence is indirect. The scale and size of such ice masses and the effects that they undoubtedly had on the landscape can only be conjectural given the current evidence. The relationship of most of these stages to the marine oxygen isotope record also is debatable.

The Middle Quaternary

This period includes the traditional Anglian cold stage, Hoxnian temperate stage, Wolstonian cold stage and the last interglacial Ipswichian temperate stage and covers the oxygen isotope stages 12 through to 5e. The major difficulty is corre lating the cold phases, their deposits and landforms and deciding on the status of the various postulated cold stages.

Oxygen Isotope Stage 12: Anglian cold stage

This cold stage has been reviewed by Jones and Keen (1993). Most of the evidence has been obtained in East Anglia and successions in other parts of the country traditionally have been thought to contain little or no representation of this stage. The record of glacial sediments in East Anglia that had been attributed to two time-independent glacials (Mitchell *et al.,* 1973) became simplified by suggesting that most of the pre-Devensian sediments were part of the Anglian cold stage (Bristow and Cox, 1973) and dated to Oxygen Isotope Stage 12 (OIS 12) of the marine sequence. A by-product of this has been the questionable status of the Wolstonian glaciation formally designated as later in time (Mitchell *et al.,* 1973), and Bowen (1978) has suggested that the type locality at Wolston was unrelated to any interglacial marker horizon, the fundamental basis of the 1973 classification. Since then a variety of evidence has been advanced to show that the Wolstonian type site proposed as the post-Hoxnian, pre-Ipswichian glaciation is pre-Hoxnian and is correlated with the Anglian Stage of East Anglia (Perrin *et al.,* 1979; Sumbler, 1983a, b; Maddy *et al.,* 1991). The discovery of organic deposits correlated with the Hoxnian on the surface of the Wolstonian deposits at Froghall appears to have settled this controversy (Keen *et al.,* 1997; Maddy, 1997). At present the only lithostratigraphical evidence adduced to support a post-Hoxnian but pre-Ipswichian glaciation of East Anglia comes from the Nar valley in Norfolk, where gravels interpreted as outwash overlie the marine clays of the Nar Valley Formation, but no contemporaneous till has been identified (Gibbard *et al.,* 1991, 1992). Increasingly all the glacial sediments in Britain are being attributed to the Devensian or the Anglian. Hence the precise position of some of the older glacial deposits in northern England that are stratigraphically below interglacial deposits earlier than Holocene can be seen as either Anglian or Wolstonian in age.

How did this position develop? As the primary mapping of the Quaternary drifts proceeded during the nineteenth century, the Newer Drift, associated with the Devensian glacial, and the Older Drift, which was associated with more than one earlier glacial, were distinguished. The division was based partly on geomorphological criteria, as the Newer Drift retained fresh, depositional landforms, such as eskers, kames and drumlins whereas the Older Drift typically did not, the constructional relief having been smoothed by erosion and hill-slope processes because of the longer time period since formation. The Older Drift was also generally found on plateaux, dissected by later erosion, with later drift-free valleys cut into the original drift cover. In contrast, the Newer Drift was found most often in valleys and the drainage network had not had time to become integrated and rivers flowed around the depositional landforms. However, a major problem is that an advancing ice sheet erodes and incorporates older stratigraphical evidence as it moves forward. This means that the Anglian ice sheets completely covered any earlier advances, leaving only chance evidence of their occurrence that is difficult to interpret. It can be assumed too that the records of any later glacial advances in OIS 10, 8, 6 and 4 of the marine record were reworked, or hidden by, the Devensian (OIS 2) advance. Over western and central Europe, three separate glaciations have been recognized, with a possible fourth. For example, in The Netherlands three glacials are readily recognized because the successive Elster (OIS 12), Saale (OIS 10) and Weichselian (OIS 2) ice advances were each slightly smaller in extent, leaving a marginal zone of sediments, together with intervening interglacial beds. The extent of the Scandinavian ice sheet was about 98%, 100% and 85% by relative area in these three major glacials, and hence the Saalian ice overran the Elsterian ice along most of the southern limit of glaciation. There seems no doubt that the Anglian and Devensian in Britain are correlated with the Elsterian and Weichselian phases, which means that the traditional British Wolstonian must coincide with the most extensive glaciation in continental Europe, the Saale. At one stage the uppermost chalky till of East Anglia was correlated with the Saalian glacial, but a reconsideration of the East Anglian stratigraphy has led to the almost universal adoption of a monoglacial chronology, with the North Sea (Cromer Till) Formation and Anglian Till (Chalky Boulder Clay) attributed to two sequential Anglian advances from different directions. Farther north in eastern England, remnants of possible Anglian glacial deposits have been noted on the summit areas of the Yorkshire Wolds, although they could be Baventian in age as noted earlier (Catt, 1982), on the North Yorkshire Moors (Call, 1987a), in the southern part of the Vale of York in the Selby and Doncaster areas (Gaunt, 1981) and on the Pennine slopes east of Leeds, Wakefield, Sheffield and Chesterfield. In the latter area patches of grey till and gravel that contain erratics of Carboniferous sandstone, limestone, chert, coal, vein quartz, Permian limestone and occasional Lake District rocks were mapped by the [British] Geological Survey, and it was realized for over a century (Green *et al.,* 1878) that the entire region had been covered by ice containing Lake District and Pennine erratics. This ice was earlier than the last glacial because the erratics extend well outside the Devensian limit (Gaunt, 1981) and usually are at greater heights than the Devensian till in the Vale of York, reaching over 100 m OD near Leeds, over 200 m OD near Sheffield and over 300 m near Chesterfield. However, there is no evidence that the ice surmounted the 400 m cuesta around the northern and eastern flanks of the Peak District. If these uplands were ice free, glacial lakes may have existed and laminated clay is intimately associated with glacial deposits near Barnsley (Green *et al.*,1878), near Rothwell (Gilligan, 1918), at Balby and on top of Brayton Barff (Catt, 1991b). Gaunt (1981), on the basis of till-fabric analyses and erratic provenance (Figure 4.3) suggested the initial ice movement was via Stainmore and the Vale of York, as favoured by Carter (1905) and Harmer (1928).

In the southern Vale of York area, however, Catt (1991b) suggested that the various tills beyond the Devensian ice limit were Wolstonian in age. These tills lie rather higher than the adjacent Devensian tills and include occurrences at Bawtry (Gaunt *et al.,* 1972), at Holme upon Spalding Moor and perhaps the large erratic (over 100 m long and 4 m thick) of Cave Oolite, which overlies chalky gravel with far-travelled erratics at 50 m OD near South Cave (Stather, 1922). Deep, narrow-sided valleys near Doncaster are partly filled with over-consolidated clays, often covered with grey till (Gaunt, 1981) and are interpreted as subglacial tunnel valleys eroded beneath the pre-Devensian Vale of York glacier. So there seems the possibility here that these deposits south of the Devensian limits could be either Wolstonian or Anglian. Catt (1991b) is adamant, however, that the erratics and heavy minerals in deposits high on the Yorkshire Wolds must be pre-Wolstonian and therefore likely to be Anglian.

Scattered till deposits have been recorded in the Peak District (Stevenson and Gaunt, 1971). Those that are deeply weathered and at higher altitudes were deposited probably during the Anglian (Briggs and Burek, 1985; Burek, 1991). These highly weathered, complex till deposits, scattered over the Brassington Formation sand pits at heights of 330–360 m OD, lie unconformably over limestone collapse structures and are laterally limited. Limited fabric analyses indicate a possible eastern derivation for these cherty tills (Burek, 1991). At the Bees Nest pit a silty, roughly stratified, cherry deposit with scattered pebbles overlying the Mio-Pliocene sands and clays was interpreted as a soliflucted till because of the presence of rare, far-travelled erratics (Ford, 1972). Scattered erratics up to 396.5 m OD (Dale, 1900) also have been suggested as being deposited from an Anglian ice source (Burek, 1991). In the limestone areas these may be explained by intense post-depositional decalcification of an originally thicker till and the transport of the finer-grained sediments into the cave systems. In the Dark Peak, however, the evidence for weathering is less convincing and the suggestion is that the tills here were never thick or continuous. Briggs and Burek (1985) suggest that the Peak District was affected by relatively clean, cold-based ice which introduced little extraneous debris and carried out limited erosion. There is, however, a clear difference between the upper and lower tills in X-ray diffraction analyses (Burek, 1978; Briggs and Burek, 1985).

The tills at lower altitudes show decalcification in their upper layers, comprise a fine-grained, brown-grey clay matrix, which supports dominantly local clasts such as limestone, dolerite, basalt and sandstone, but with smaller quantities of far-travelled rocks, including granites from the Lake District and Scotland. The till distribution is impersistent and restricted, with the majority of the deposits covering bench-like, dissected surfaces. Striations on the bedrock, fabric analyses and stone counts all indicate ice movement from the NNW and the implication is that ice advanced into the Peak District across the Dove Holes col at 310 m OD (Briggs and Burek, 1985). The stratotype for this Bakewell Formation is the Shining Bank Quarry (Thomas, 1999).

The continental sequence of Saalian age includes three tills, which are often attributed to three separate ice advances: the Warthe, Drenthe and Fuhne. The Warthe, the youngest, tends to be found low in the landscape, whereas the earlier two phases deposited sediments that have been dissected, like the Elster, and generally occupy plateau locations. Thus it is feasible that two or more morphologically separable Wolstonian sequences could occur in Britain. One could be difficult to separate from the Devensian, such as the Vale of York glacial tills and buried channels, whereas the other could easily be confused with the Anglian, such as the type Wolstonian of the East Midlands. However, credible evidence for the missing Wolstonian Stage has yet to be found (Ehlers *et al.,* 1991), although it seems likely that some of the deposits in northern England, in Durham, Derbyshire, Yorkshire and north Lincolnshire, are from this stage.

It has been demonstrated that the deposits of the type site Wolstonian in the Midlands are of Anglian and pre-Anglian age (Rose, 1987, 1991), although there is a some evidence that a post-Anglian, pre-Devensian glaciation did indeed affect the Midlands (Maddy *et al.,* 1991). This suggests that pre-Holocene lake basins, resting on till and yielding pollen sequences may well be of different ages. At the same time, it seems possible that two episodes, each with a 'Hoxnian-type' pollen signature are recorded from the Middle Pleistocene (Roe, 1995; Keen *et al.,* 1997). Thomas (2001) reviews the evidence for interglacial deposits in the Midlands that occur in lithostratigraphical contexts comparable with Hoxnian sites in East Anglia. She concludes that the palynology of lake sequences in the Midlands shows strong similarities to comparable records from East Anglia, suggesting that all represent lakes formed after the same Anglian glacial and therefore record sediments of the same Hoxnian interglacial. Despite these complexities, which are still not fully resolved, it is assumed in this book that there is evidence for a Wolstonian age glacial in northern England, although demonstrating that age is difficult.

Oxygen Isotope Stage 9: the Hoxnian temperate stage

This interglacial has been defined by West (1956) based on the type site at Hoxne (Suffolk), where lacustrine sediments overlie Lowestoft Till (Anglian). It is now correlated with OIS 9 about 338 000–302 000 years Before Present (BP), although there have been a number of correlation and dating problems (Jones and Keen, 1993). A number of other occurrences of Hoxnian deposits have been described from localities in East Anglia, the Thames Valley and the Midlands, and several locations from northern England appear to show development stages during this interglacial. At Kirmington close to the eastern foot of the Lincolnshire Wolds, Watts (1959) described peat associated with estuarine sediments at 27 m OD from this interglacial. Shingle above the silts was probably deposited as a beach during the highest stand of the sea in the later part of the interglacial (Catt, 1977b). At Speeton, south of Filey on the Yorkshire coast, estuarine silt and sand exposed at about 30 m OD has a temperate fauna and is overlain by till of probable Wolstonian age. Catt and Penny (1966) and Penny and Catt (1972) have suggested that the altitude and stratigraphical relationships of these estuarine deposits are consistent with a Hoxnian age, although palynological data reported by West (1969) are more indicative of Ipswichian vegetation. Wilson (1991) has identified a comparable pollen assemblage to that obtained by West, but amino-acid ratios of *Macoma balthica* shells from the deposit suggest that it accumulated during OIS 7. This site is discussed more fully in the site report for Speeton (this chapter). There may also be palaeosol sites partly related to this interglacial in the North Yorkshire Moors (Bullock *et al.,* 1973) and in the north-eastern Lake District (Boardman, 1985c), as soil may be polycyclic and contain evidence of more than one climatic episode. These problems are discussed further in the Harwood Dale Moor and Thornsgill site reports (this chapter). In the Peak District, the warm, moist conditions of this interglacial cemented screes, tufas formed and speleothem development was active in the high caves at Castleton (Burek, 1991). The Hathersage river terrace was formed during the extensive in-situ weathering and soil formation of this stage, when the rivers Derwent and Wye were incised to this level. Ford (1985) has also provided evidence for substantial cave development during and before the Hoxnian through isotopic dating of the Castleton speleothems.

Oxygen Isotope Stages 6–8: the Wolstonian cold stage

Mitchell *et al.* (1973) assigned the period between the Hoxnian and the Ipswichian interglacials to the Wolstonian cold stage, but there has been much discussion as to its status in Britain, as noted earlier. There is also evidence available for another interglacial between those of the Hoxnian and Ipswichian, and for an associated cold stage, either from a reappraisal of known sites, such as Trafalgar Square, Ilford, Aveley, Portland, Minchin Hole, or new sites, such as Stanton Harcourt and Marsworth (Jones and Keen, 1993). In northern England, sites with supposed Wolstonian sediments are usually problematic and the sediments could be assigned to this cold stage or an earlier one. So, for example, the Oakwood Till at Chelford (Worsley, 1978), if not Early Devensian (Worsley *et al.* 1983), could be Wolstonian or Anglian (see the site report for Chelford, Chapter 5, for further discussion). The same applies to the thin till deposit at the base of the Burland borehole, Cheshire (Bonny *et al.,* 1986). There has already been a discussion on the age of the Lincolnshire tills and in eastern Yorkshire the Basement Till observed at several localities between Filey Brigg to Spurn Point, and which occurs below an Ipswichian raised beach at Sewerby and above the Speeton Shell Bed in Filey Bay has been referred to the Wolstonian. Isolated patches of deeply weathered glacial material on the Yorkshire Wolds and North Yorkshire Moors may have been deposited during the Wolstonian, and the landforms and sediments in the southern Vale of York may be from this cold phase. Some of the glacial deposits in the area around East Retford, Worksop and Gainsborough (Smith, E.G. *et al.,* 1973) and in the Sheffield (Eden *et al.,* 1957) and Chesterfield areas (Smith *et al.,* 1967) could date from this time. They have been referred to the Balby Formation by Thomas (1999) and described as decalcified till containing local rock types and Lake District erratics. Tills in the Wye, Derwent and Manifold valleys of the Peak District seem to be Wolstonian (see earlier) and the Derbyshire Derwent underwent a glacial diversion (Straw, 1968b). The till below presumed Ipswichian deposits at Scandal Beck in the north-eastern Howgill Fells (Carter *et al.,* 1978) is presumed to be Wolstonian (see the site report for Scandal Beck, this chapter, for further detail). In the north-east Lake District, pre-Devensian glacial sediments are underlain by palaeosol features likely to have been developed in three temperate episodes (Boardman, 1985c). The older fill could be Anglian or Wolstonian in age (see further discussion in the site report for Thornsgill and Mosedale, this chapter). The basal till in the Low Furness region may also belong to this stage (Huddart *et al.,* 1977; Tooley, 1977) as does the Warren House Till of the Durham coast (Trechmann, 1915; Francis, 1970). Around the fringes of the Lake District the oldest known glacial deposits are the scattered till units deposited from the 'First' or 'Early Scottish' glaciation (Trotter and Hollingworth, 1932; Huddart, 1970, 1971a). These have been recognized at Willowford in the Irthing valley (Trotter, 1929), in the Wiza Beck valley (Eastwood *et al.,* 1968), Gillcambon Beck on the fringes of Greystoke Forest, along with a lower till below a drumlin-ized till and disturbed silts and clays seen in M6 motorway sections at St. Brelades in the Petteril valley (Huddart, 1970) and the lower till in the Derwent valley. Nirex (1997b) and Akhurst *et al.* (1997) describe sporadic deposits of weathered brown, sandy diamicton of the Drigg Till Formation in boreholes in the Drigg area and other pockets of weathered, basal diamicton in a river cliff of the River Calder. In Edenside a small percentage of Scottish granite erratics have been noted in the Main Glaciation (Devensian) drift by Trotter (1929), Huddart (1971b) and Letzer (1981), and as it is considered that the ice movement was from the south to north in Edenside at this time, these Scottish erratics must have been derived from an earlier Scottish ice advance. It was considered that these scattered examples of early glacial activity could relate either to Saalian (Wolstonian) ice, or to ice advance at the beginning of the last glacial period, when presumably an ice sheet in Scotland would form earlier than in the Lake District (Huddart, 1971b). However, see the discussion of the possibility of an Early Devensian glacial in Chapter 5. As with so many of these types of 'lower' tills the exact chronology is speculative. This too is the case in the western Pennines, where there is little evidence for pre-Devensian till except for some weathered till, 25 m thick, preserved in a col at Pilkenzane, Longdendale (Johnson and Walthall, 1979).

The central North Sea adjacent to northern England has produced evidence for Wolstonian activity (Cameron *et al.,* 1987). Valleys cut during the Anglian continued to be infilled, mainly with glaciomarine sediments. In the late Wolst-onian there was a major erosional episode, with a new valley system running mainly north–south, probably incised by glacial meltwater. The offshore sequence has suggested to Cameron *et al.* (1987) and Long, D.C. *et al.* (1988) that terrestrial ice did not move far out into the North Sea and that it was not in contact with Scandinavian ice.

In-situ flowstone obtained from within sand and silts at Robin Hood's Cave, Cresswell, southeast Derbyshire has been dated to about 165 ka by uranium-series dating (Rowe and Atkinson, 1985). The palynology of the sequence (Coles *et al.,* 1985) suggests a vegetation that changed from grassland to open deciduous woodland, subsequently reverting to steppe and tundra. It was considered that it was a temperate equivalent to that identified at Marsworth, with the date for the latter being obtained from a tufa (Green *et al.,* 1984). There have been many archaeological and palaeontological finds from Robin Hood's Cave, but the initial excavations in the western chamber reported by Mello (1875, 1877) and Dawkins (1876) seem to have been haphazard and marred by considerable confusion over the nature of some of the finds. However, an archaeological sequence of a lower assemblage of Middle Palaeolithic artefacts and an upper assemblage of Upper Palaeolithic artefacts was revealed. There was an extensive assemblage of vertebrate remains reported, including hyaena, bison, woolly rhinoceros, horse, dirk-toothed cat and reindeer. Knowledge of the remains from the rear of this cave (Laing, 1889) is limited but tantalizing, and includes finds of hippopotamus. Other parts of the cave have yielded human remains and Acheulian artefacts, but all these finds have been lost.

Conclusion

The probable geological succession in East Anglia for the Hoxnian to the Ipswichian is given in (Table 4.2). This revised sequence now incorporates two temperate episodes (Wolstonian 1–2 and Ilfordian) separated by three colder intervals (Wolstonian 1, 2 and 3), with the glacial in Wolstonian 2 and intense periglaciation in Wolstonian 3. Uranium-series dates defining phases of speleothem growth in the Craven District cave systems (Gascoyne *et al.,* 1983) have assisted in refining this chronology. Mineral precipitation was profuse during the periods 90–135 ka and 170–350 ka but ceased during the period 140–160 ka and was reduced about 260 ka. The temperate conditions required for speleothem growth from 170–350 ka have been equated with OIS 7 and 9. The period of zero growth has been assigned to OIS 6 (Wolstonian cold stage) and that of diminished accumulation probably equates to OIS 8.

This period again shows a complicated picture of climatic change and there are major difficulties in correlating the limited successions that are available. There have been major problems associated with the status of the Wolstonian glacial and the orthodox Pleistocene succession in Britain (Mitchell *et ed.,* 1973) has required change, with many more climate events present than at first thought (Bowen, 1999).

The Upper Quaternary

Oxygen Isotope Stage 5e: the Ipswichian temperate stage

This interglacial is dated between 135 and 115 ka, when the interglacial climate was thought to be at its warmest, and it is correlated with marine OIS 5e. From 115 ka onwards the climate began to deteriorate towards the next glacial. There are sites from most parts of the country, although most are in the Midlands and East Anglia, outside the limits of the last glacial, in river valley locations where there was marked river alluviation in this period. Nevertheless, there are some sites ascribed to this interglacial in northern England, although no well-defined, geochronologically constrained unit is known (Thomas, 1999). However, there are mammal bones in limestone fissures, organic muds and palaeosols, cave deposits, river terrace deposits and estuarine sediments and peats incorporated in till from this region that are suggested as Ipswichian. As usual there are problems of correlation because the records are fragmentary and no site extends throughout all the interglacial's sub-stages. There have also been issues as to whether some of the deposits should be assigned to this interglacial, or to an earlier post-Hoxnian temperate stage.

At the Devensian stratotype locality at Four Ashes (see site report, Chapter 5), near Wolverhampton, basal organic sediment in a bedrock hollow has yielded *Taxus, Vex* and *Alnus* macrofossils (Morgan, A.V., 1973) and a pollen assemblage in which *Alnus* and *Quercus* dominate. The postulated Ipswichian age has been confirmed on palynological criteria by Andrew and West (1977), who have suggested reference to Zone llb of this interglacial. Although a sparse insect fauna occurs in these deposits, it is not diagnostic of the climatic environment (Morgan, A., 1973). The Arclid Member, which is a complex organic-rich sand succession proved in a borehole, originally was thought to be part of the Farm Wood Member peat (Worsley, 1991b) and a probable early Devensian interstadial deposit, but pollen analysis on organic detritus associated with a molar of *Mammathus* has suggested an Ipswichian age (Worsley, 1992).

At Austerfield, in southern Yorkshire, sand and gravel deposited by an ancestral River Idle contains an organic silt bed (Gaunt *et al.,* 1972). Palaeobotanical investigation has demonstrated a single biozone representing mixed-deciduous forest, including *Acer, Alnus, Pinus* and *Carpinus,* which is probably of late-temperate Ipswichian age. Insect, pollen and macrofossils showed that in Zone 111 times a marshbound lake was surrounded by the woodland in a climate at least as warm as at present. The insect fauna includes *Bembidion elongatum, Bothrideres contractus, Brachytemnus submuricatus* and *Scolytus carpini* (which exists largely on *Carpinus),* all of which are now extinct in Britain and possess ranges in southern and central Europe. The presence of a lake at about 4 m OD on a contemporaneous floodplain implies that the drainage base level, in effect sea level, was close to OD (Gaunt, 1981). At Langham, near Goole, Ipswichian Zone 11b deposits occur as low as –12 m OD (Gaunt *et al.,* 1974) and show that, early in the interglacial, rivers had incised courses to considerable depths in response to a sea level still eustatically depressed from the preceding glaciation. Pollen, macrofossils and dinoflagellate cysts in clays, sands and gravels between –12 m and –6 m OD show that, as sea level rose in Ipswichian 11b times, estuarine sediments were forming in an area containing pine and oak woodland. At Westfield Farm, Amthorpe a thin clay contains pollen, plant debris and dinoflagellate cysts which show that at the junction with Zones 111 and IV, estuarine sediments were forming with sea level at, or slightly above OD in an area containing a pine-rich woodland. The dinoflagellate cysts at Langham and Westfield Farm are dominated by *Spiniferites* species, whereas at Langham, *Lingulodinium machaerophorum,* tolerant of weakly saline conditions, has been recorded. The assemblage indicates an estuarine environment in a cool-temperate climate, not dissimilar to that of the sea around Britain today. West (1969) has suggested that a mixed-oak forest pollen assemblage obtained from the Speeton Shell Bed in Filey Bay is analogous to that characteristic of Zone 11f of the Ipswichian (see site report for Speeton, this chapter, for further discussion.)

At Bielsbeck, near Market Weighton, a Pleistocene faunal assemblage that contains *Palaeoloxodon antiquus, Stephanorhinus hemitoechus* and *Equus* but lacks hippopotamus (Stather, 1910; de Boer *et al.,* 1958) has been reevaluated recently by Schreve (1997, 1999) and Schreve and Bridgland (in press). It is now considered to be most consistent with the later part of the OIS 7 interglacial, possibly Sub-stage 7a. The mammalian fauna also includes wolf, brown bear, lion, woolly mammoth, red and roe deer, aurochs, bison and an indeterminate elephant. This fauna indicates both open grassland and woodland habitats. The molluscan list includes several thermophiles that suggest fully temperate conditions. The mammalian fauna is very similar to that from the upper part of the sequence at Aveley (Essex), the Uphall Pit at Ilford and Brundon, all of which have been correlated with OIS 7 (Bowen *et al.,* 1989; Bridgland, 1994; Schreve, 1997). The key factor is the co-occurrence of *P. antiquus* with *Mammathus primigenius,* a combination unknown from any other interglacial. Schreve (2001) correlates the Bielsbeck assemblage and similar assemblages at Hindlow Cave, Derbyshire (Schreve, 1997) and Pontnewydd Cave, Clwyd (Green, 1984) with the Sandy Lane Mammalian Assemblage Zone of the OIS Stage 7 interglacial and separate from the Ipswichian Hippopotamus faunas of Sub-stage 5e.

Sites close to Bielsbeck at North Cliffe and Mott's Field (South Cliffe) have yielded mammalian fauna comparable to the original site and led Schreve and Bridgland (in press) and Schreve (1999) to suggest that the sediments are probably lateral equivalents. However, remains of *M. primigenius* found in two adjacent pits on Galley Moor, 3.2 km north-west of Bielsbeck and some associated organic material have yielded ^{14}C dates of 47 000 and 46 000 ± 2300 years BP respectively (Halkon, 1999), so whether they are related to the Bielsbeck assemblage is debatable.

In the Peak District, travertine from Elder Bush Cave in the Manifold valley contains leaf impressions of *Acer monspessulanum* (Montpelier maple) and *Corylus avellana* (hazel). These were in association with a fauna that included lion, hyaena, wolf, giant deer, hare, large bison and hippopotamus. This evidence suggests fairly dry, temperate to warm conditions (Bramwell, 1964). A similar Ipswichian fauna has been reported from Hoe Grange Quarry Cave, Longcliffe (Bemrose and Newton, 1905), although this is now completely quarried away. Other possible Ipswichian cave sites remain unpublished, such as that at Etches Cave, East Sterndale (Coles, 1985) and further north in the Pennines in a limestone fissure at Raygill Delf, a mammalian fauna (Miall, 1880) has been identified as Ipswichian by Earp *et al.* (1961).

At the Boulton Moor GCR site, the stratotype of the Alvaston Formation (Thomas, 1999), gravels of the Beeston Terrace of the River Derwent contain a mammalian fauna correlated with the Ipswichian (Jones and Stanley, 1974) (see GCR site report in Allen *et al.,* in press). There are probably equivalent deposits at Allenton (Godwin, 1975) and at Leeds, which contain hippopotamus (Edwards *et al.,* 1950). At the latter location a large hippopotamus bone assemblage and teeth had been discovered in a clay pit at Wortley (Denny, 1854a, b). The problems of dating the museum specimens were discussed subsequently by Harkness *et al.* (1977), but an indefinite date of over 40 000 radiocarbon years from a large molar suggested an Ipswichian age for the bones and teeth. However, although three other bones gave dates of about 31 000 radiocarbon years and are thought to be contaminated, the deposits in which these bones were found are considered to be glaciofluvial and of Devensian age.

Kirkdale Cave, north of Kirkbymoorside (North Yorkshire), first investigated by Buckland (1822) and reported on by Boylan (1972, 1977a), has produced a typical Ipswichian climatic optimum fauna. So has the Lower Cave Earth from Victoria Cave, Settle (Boylan, 1977b), but the exact provenance of a hand-axe from this deposit in relation to dated flowstone (uranium-series dates ranging from 135 to 114 ka) there is unknown. From this cave too, flowstones covering a characteristic Ipswichian mammal fauna have been dated to 120 ± 6 ka and the animal remains correlated to OIS 5e (Gascoyne *et al.,* 1981). Other flowstone dates from the Craven District (Gascoyne *et al.,* 1983) indicate a period of abundant speleothem growth between 90–135 ka and the Ipswichian stage is defined as occurring between 135 and 115 ka.

Interglacial marine deposits at Sewerby show a typical Ipswichian faunal assemblage (see site report for Sewerby, this chapter) with the marine beach and an associated buried cliff associated with the Ipswichian sea level traced along the western side of Holderness and the Lincolnshire Marsh (Can, 1977a, 1987a). This has been correlated with temperate marine faunas at Shippersea Bay, Easington (see site report for Shippersea Bay, this chapter) from the raised beach at over 30 m above modern sea level, but this height is difficult to reconcile with Sewerby. It has been claimed by Bowen *et al.* (1991) that the Easington beach dates from OIS 7 based on amino-acid analysis of the molluscs. In fact two populations of shells were identified based on amino acid ratio data, an older one with a mean D/L ratio of 0.228 ± 0.12 and a younger one with a ratio of 0.174 ± 0.01. The older population was interpreted as reworked from deposits dating from a previous high sea-level phase, which they attributed to OIS 9. The younger population indigenous to the Easington beach was indicative of OIS 7.

A similar problem occurs around Morecambe Bay where wave-cut notches and caves in Carboniferous Limestone at locations such as Edgar's Arch and Kirkhead Cave at heights of about 4.9–6.4 m OD might demonstrate Ipswichian marine erosion (Tooley, 1977), but it also has been suggested that they are Hoxnian or older (Tooley, 1982, 1985). At Whitbarrow there are notches at +30 m OD and below the cavern on Kirkhead Hill and on Warton Crag there are notches at +15 m and +30 m OD (Ashmead, 1974; Tooley, 1985). It seems possible that we could have a sequence of OIS 9 and 7 wave erosion features around the margins of Morecambe Bay. However, it also has been suggested that the so-called 'sea caves' are phreatic and unrelated to any contemporary sea level, that their heights are not as reported by Ashmead (1974) and that the features often reported as marine-cut notches are the result of glacial plucking of weak bedding planes in the limestone (Gale, 1981).

Farther to the north in Furness, Rose and Dunham (1977) described unconfirmed reports of peat beneath till from a borehole at North Scale (Walney) and at Lindal-in-Furness, where, from a series of shafts at Lindal Cotes and Crossgates, a peaty deposit, up to 8 m thick, containing insects, leaves and fruit receptacles of beech, and diatoms, and overlain by up to 30 m of till was described by Bolton (1862) and Hodgson (1862). However, the latter author doubted whether the material was interglacial and believed it to be a recent infilling of a subterranean drainage course. Later Kendall (1881) described an extensive organic deposit, southwest of Lindal, from numerous boreholes, which proved a peaty deposit up to 7 m thick that was overlain by up to 30 m of till, sand and clay. An attempt to relocate this deposit by an IGS borehole proved negative (Anon.,1972). These Furness peats have been suggested as being Ipswichian in age by Huddart *et al.* (1977) and Thomas (1999). Hodgson (1862) also described a griked limestone surface near Ulverston, capped by up to 3.5 m of till, but with the grikes filled with a stone-free tenacious yellow clay, which could be a weathering horizon. No Ipswichian deposits have been reported from the recent Nirex (1997a, b) investigations, but it is assumed that the presumed marine deposits from Wigton are Ipswichian in age. Here a borehole proved lenses of drab clay containing *Turritella comminus* Risso, foraminifera and ostracods, beneath gravel and till (Eastwood *et al.,* 1968). However, there were gaps in the cores, both above the clay and between the clay and the underlying Stanwix Shales, and it is possible that the clay was not *in situ* and was an erratic within the till. It also is possible that the unit could be evidence for a mid-Devensian marine sequence as reported from the Drigg area (Eaton and Curtis, 1995; Huddart, 1997).

Probable Ipswichian interglacial weathering profiles have been recognized in plateau areas not glaciated during the Devensian, such as parts of the North Yorkshire Moors (see site report for Harwood Dale Moor, this chapter) and the Pennines and it is suggested that at least part of the weathering that contributed to the Troutbeck Palaeosol in the Lake District (see site report for Thornsgill and Mosedale, this chap ter) took place in this interglacial. There are two other undoubted Ipswichian peat deposits in northern England, a raft within Devensian till at Hutton Henry in County Durham (Beaumont *et al.,* 1969) and a glaciotectonized peat succession at Scandal Beck (Carter *et al.,* 1978; Letzer, 1978, 1981; see site report for Scandal Beck, this chapter).

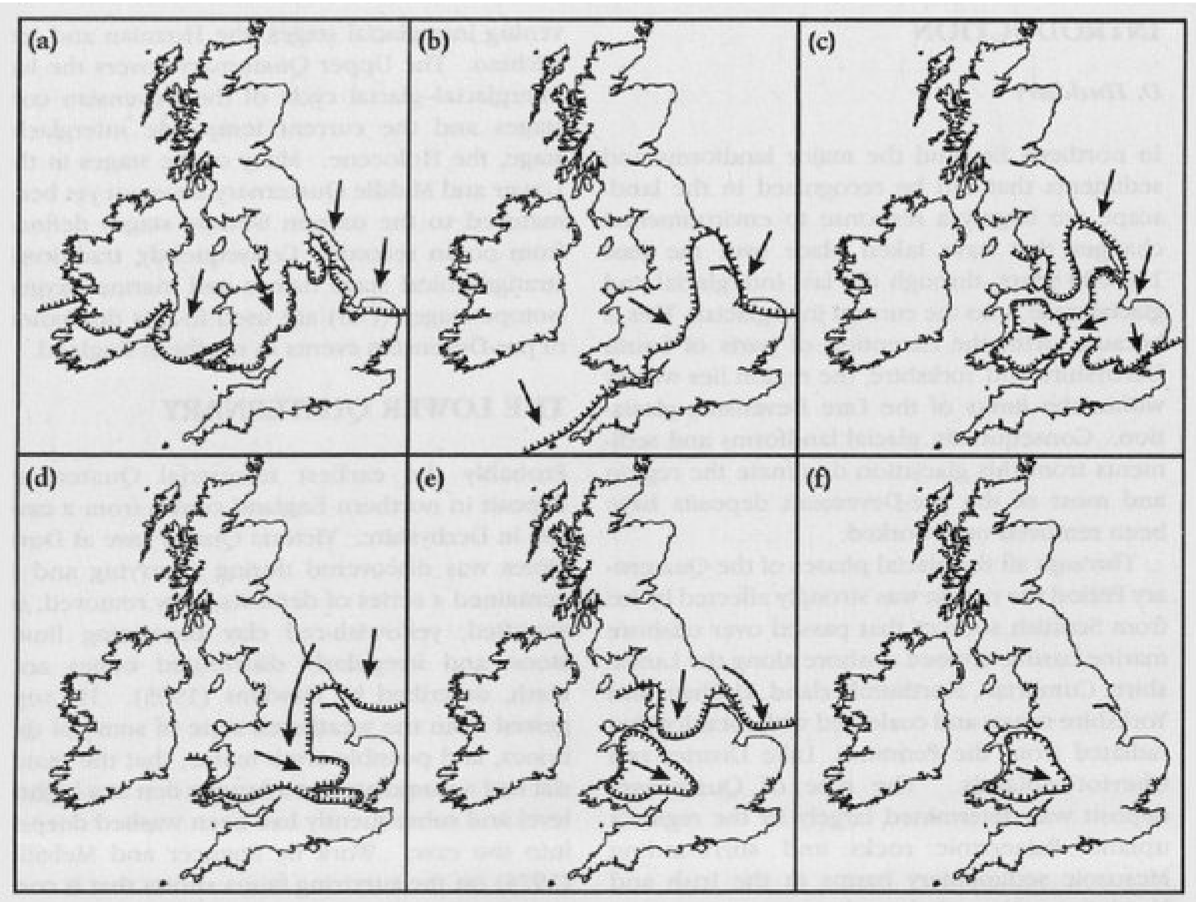
Conclusion

Thus in northern England the Ipswichian Stage record is fragmentary with historical records of sites that cannot be, or recently have not been relocated, and with sites that are likely to have been incorporated into Devensian till. The best preserved records appear to be in caves. There is controversy over the age of some suggested Ipswichian deposits, with correlation to both OIS 5e and OIS 7.

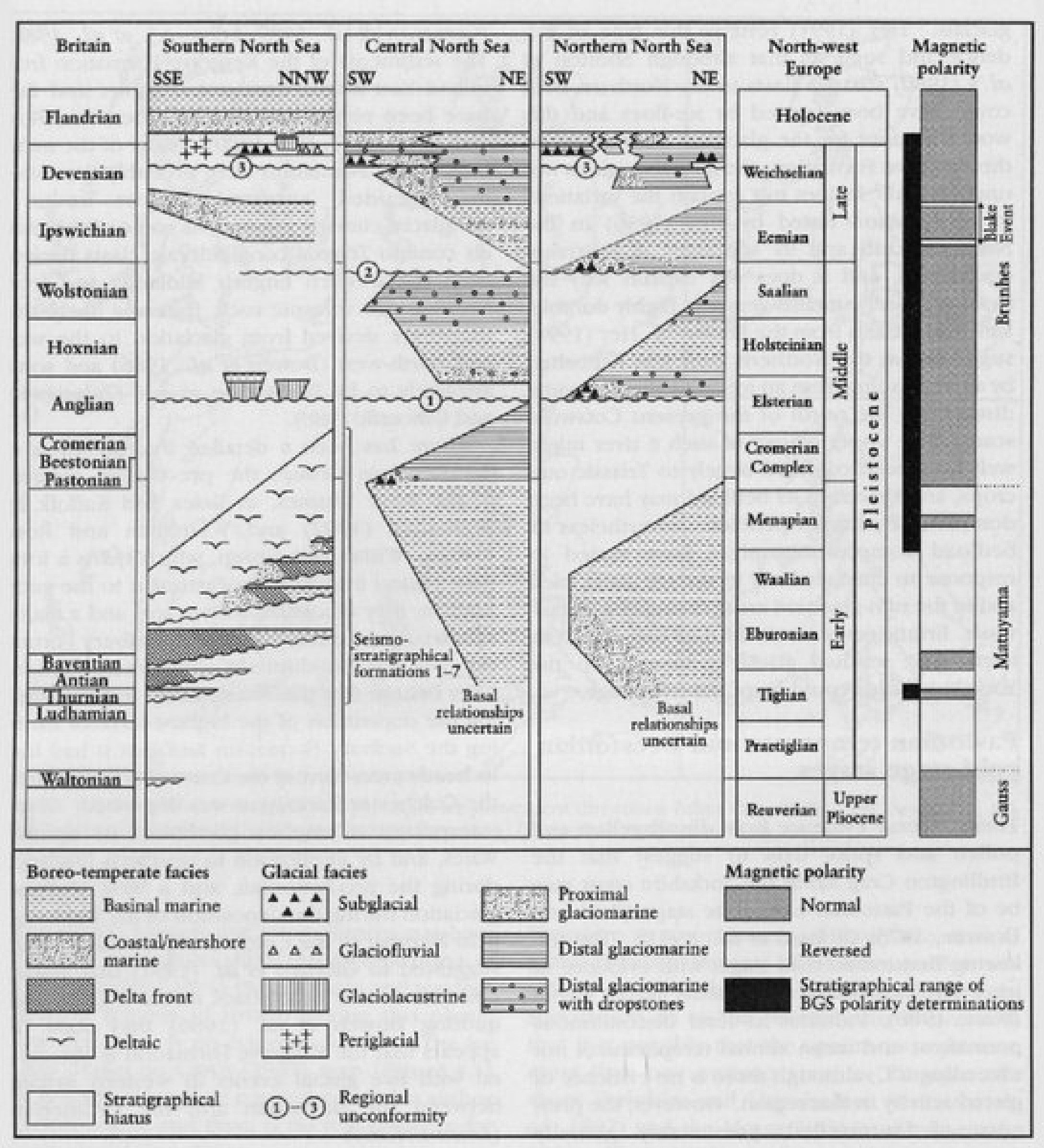
References

Stage	Stratotype	Notes
Flandrian		Begins 10 ka (^{14}C); base at bottom of pollen zone IV
Devensian	Four Ashes, Staffordshire (SJ 914 082)	Late: 26–10 ka (^{14}C) Middle: 50–26 ka (^{14}C): includes Upton Warren interstadial complex Early: preceding 50 ka (^{14}C): includes Chelford interstadial ~60 ka (^{14}C)
Ipswichian	Bobbitshole, Ipswich (TM 148 414)	Base at beginning of pollen zone II
Wolstonian	Wolston, Warwickshire (SP 411 748)	Includes Baginton–Lillington gravels, Baginton sand, Wolston series, Dunsmore gravels; base at bottom of Baginton–Lillington gravels
Hoxnian	Hoxne, Suffolk (TM 543 977)	Base at beginning of pollen zone HI
Anglian	Corton Cliff, Suffolk (TM 543 977)	Lowestoft Till, Corton Sands, Norwich Brickearth/Cromer Till; base at bottom of lower till
Cromerian	West Runton, Norfolk (TG 188 432)	Upper Freshwater Bed; base at bottom of pollen zone C1
Beestonian	Beeston, Norfolk (TG 169 433)	Arctic Freshwater Bed; base at bottom of pollen zone PI
Pastonian	Paston, Norfolk (TG 341 352)	Gravels, sands and silts; base at bottom of pollen zone BeI
Baventian	Easton Bavents, Suffolk (TM 518 787)	Marine silt; base at bottom of pollen zone L4
Antian Thurnian Ludhamian	Ludham, Norfolk (borehole at TG 385 199)	Marine shelly sand; base at bottom of pollen zone L3 (forams: Lv) Marine silt: base at bottom of pollen zone L2 (forams: Lm) Shelly sand: base at bottom of pollen zone L1 (forams: Ll)
Waltonian	Walton-on-the-Naze, Essex (TM 267 237)	Older Red Crag; base at bottom of Crag at Walton

(Table 2.3) Proposed climato-stratigraphical stages in Britain (after Mitchell et al., 1973).



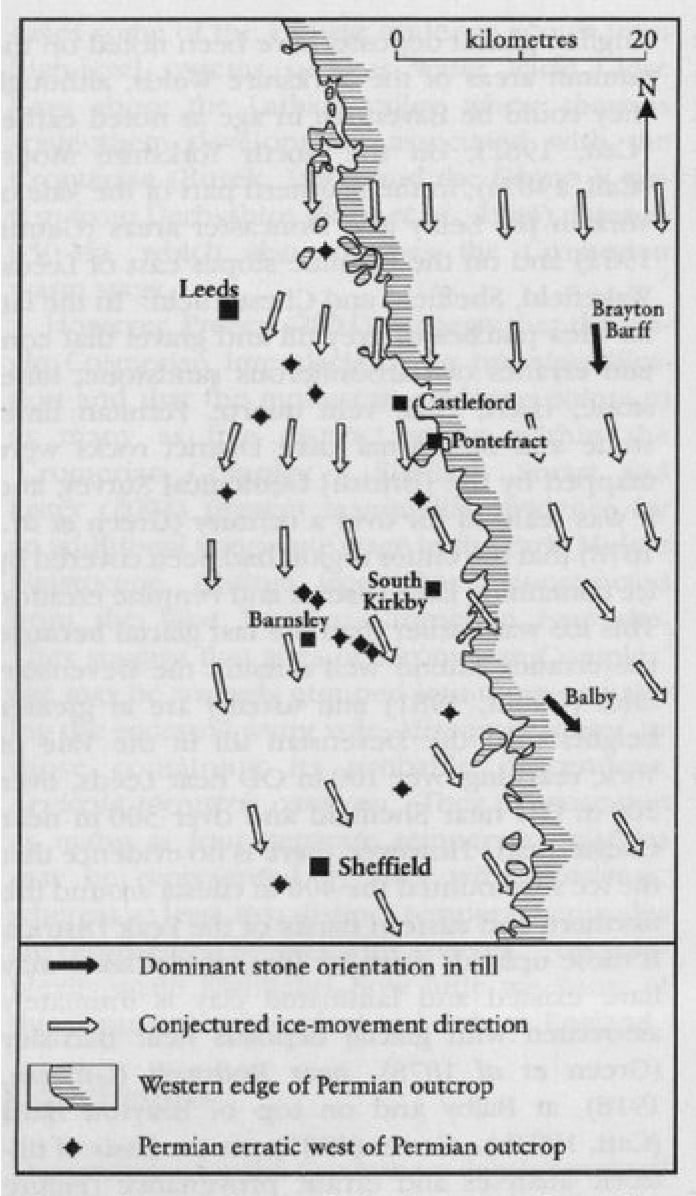
(Figure 4.1) Possible ice margins and principal ice movement directions (after Catt, 1981): (a) Devensian; (b) Wolstonian; (c) Anglian; (d) Beestonian; (e) Baventian; (f) another early Quaternary stage.



(Figure 4.2) Summary of the probable Pleistocene chronostratigraphical ranges of the sedimentary facies represented in the UK sector of the North Sea (after Cameron et al., 1987; Long, A.J. et al., 1988).

$\delta^{18}O$	Isle of Man	Lancashire	Cumbria	Yorkshire and Derbyshire	Northumbria	Cheshire and Staffordshire	Shropshire Lowlands
1	Point of Ayre Formation (Ayre, Cranstal and Ballaquark Farm members); Bungalow Formation; Curragh Formation	Lytham Formation; Swettenham Formation	Solway Formation; Grange Formation; Blelham Formation	Ringinglow Formation	Thornsby Formation	Elmore Member; Fenns Whixall Member	
2	Ballaugh Formation (Ballacregga, Ballyre, Ballaleigh, Sulby, Ballaugh, Carwyn and Ramsey members); Snaefell Formation (Druidale, Ballure and Mooar members); Jurby Formation; Glen Ballyre Bed; Jurby Head Bed; Ballateare, Ballaquark, Cranstal, Nappin, Phurt and Trunk members; Orrisdale Formation (Orrisdale Head, Bishop's Court, Ballavarkish, Ballacottier, Kionlough and Dog Mills members); Shellag Formation (Bride, Crosby, Cronk Ny Lau, Wyllin and Kirk Michael members)	Seacombe Formation; Shirdley Hill Formation; Kirkham Formation	Windermere Formation; St Bees Head Bed; Wolf Crags Formation; Morecambe Formation; Threlkeld Formation (Threlkeld, Lobbs and Mosedale members); Black Combe Formation (Annaside, Gutterby and St Bees members); Carlisle Formation (Rose Hill, Holme St Cuthbert and Brunstock members); Penrith Formation (Baronwood and Eden members); Irthing Formation (Lanercost, Brampton and Great Easby members); Selker Formation	Sutton Formation; Bingley Bog Formation; Escrick Formation; Filey Formation; Pickering Formation; Hemingbrough Formation	Bamburgh Formation; Bradford Kames Formation; Ebchester Formation; Linhope Spout Formation; Acklington Formation; Sunderland Formation (Pelaw, Swaddles Hole, Ryhope, Herrington and Seaham Harbour members); Wear Formation (Framwellgate, Butterby, Durham and Winch Gill members); East Durham Formation (Horden, Peterlee and Blackhall members); Rockcliffe Formation	Stockport Formation	Shrewsbury Formation
3				Harrle Dale Bed; Oxbow Bed		Chelford Formation; Berland Member; Farm Wood Member; Ardil Member	Four Ashes Formation
4			Luce Bay Formation	Stump Cross Bed			
5			Scandal Beck Bed				
5e		Raygill Delf Formation	Wigton Formation; Lindal Cote Bed; Troutbeck Palaeosol	Alvaston Formation; Elder Bush, Austerfield, Kirkdale and Victoria beds; Raincliff Formation	Hutton Henry Bed		
6/8	Kiondroughad Formation	Pilkenzane Formation	Thornsgill Formation	Bakewell Formation; Balby Formation	Warren House Formation	Oakwood Formation; Lapwing Bed	
7/9	Ayre Formation				Easington Formation		
Pre-9	Isle of Man Formation			Dove Hole Formation	Blackhall Colliery Formation		
9						Trysull Member	
10							
11							
12						Seisdon Formation	
13–16							

(Table 4.1) Correlations betweennorthern England and the marine oxygen isotope stratigraphy (after Thomas, 1999)



(Figure 4.3) Evidence of the direction of initial ice advance in the 'Older' glacial stage in part of Yorkshire after Gaunt (1981) (Wolstonian or Anglian? — see text).

Stage	Years (BP)	Sea level
	75 000	
Ipswichian		High 6–8 metres OD
	128 000	
Wolstonian 3		Low
	195 000	
Ilfordian		High 15 metres OD
	240 000	
Wolstonian 2		Low
	297 000	
Wolstonian 1/2		
	330 000	
Wolstonian 1		
	367 000	
Hoxnian		High 20 metres OD
	400 000	

(Table 4.2) Summary of the probable Quaternary sequence in East Anglia from the Hoxnian to the Ipswichian (after Wymer, 1985).