Biostratigraphical correlation between the late Quaternary sequence of the Thames and key fluvial localities in central Germany

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BRIDGLAND, D. R., SCHREVE, D. C., KEEN, D. H., MEYRICK, R. & WESTAWAY, R. 2004. Biostratigraphical correlation between the late Quaternary sequence of the Thames and key fluvial localities in central Germany. *Proceedings of the Geologists' Association*, **115**, 125–140. The shared characteristics of limestone bedrock geology and resultant calcareous groundwater have allowed excellent preservation of mammalian and molluscan faunas within the terrace sequences of the Lower Thames and the rivers of the Muschelkalk region of Thuringia, central Germany. The mammalian and molluscan assemblages from the Lower Thames have underpinned the dating of one of the most important late Middle Pleistocene sequences in Britain and probably also Europe; one that is the repository of a highly significant Lower and Middle Palaeolithic archive. The most complete terrace records in Thuringia are those from the River Wipper, in the region of Bilzingsleben, and the Ilm, around Weimar. Both here and in the Lower Thames, interglacial deposits representing the four major post-Elsterian temperate-climate complexes (=oxygen isotope stages (OIS) 11, 9, 7 and 5 of the oceanic record) have been identified. In the Thames the interglacials are represented by fluvially deposited sediments, whereas in Thuringia they are frequently represented by travertines that formed around calcareous springs, often containing exquisitely preserved fossils.

Evidence from Lower Thames interglacial deposits within four different terrace formations (Boyn Hill/Orsett Heath, Lynch Hill/Corbets Tey, Taplow/Mucking and Kempton Park/East Tilbury Marshes) is reviewed, in addition to which new evidence from a site at Hackney Downs, East London, is summarized. The deposits at the last-mentioned site are part of the Lynch Hill/Corbets Tey Formation and include interglacial sediments attributed to OIS 9. As well as the record of travertine complexes from each terrace level within the Bilzingsleben staircase, the celebrated travertine sequence at Weimar-Ehringsdorf, on Terrace 4 of the Ilm, is described. The biostratigraphical and palaeoenvironmental evidence from the Ehringsdorf travertines compares closely with that from interglacial deposits at Aveley, in the Mucking Formation of Lower Thames; both are attributed to OIS 7, with comparison possible at the oxygen isotope substage level.

Key words: fluvial deposits, Quaternary, Pleistocene, Germany, Thames

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1. INTRODUCTION

An important objective of IGCP project No. 449 is the comparison and correlation of fluvial records both within regions and across significant distances, culminating in comparison across and between continents. This paper attempts comparison between the important late Middle Pleistocene fluvial sequence in the Lower Thames (UK), in which four post-Anglian (post-Elsterian) climatic cycles have been identified, and records from key sites in central Germany. It subsumes presentations at the Prague conference on individual sites at Hackney Downs, London (Keen *et al.* 2001) and Thuringia, Germany (cf. Meyrick & Maul, 2002), as well as more general contributions comparing British and German records (Schreve, 2001a) and exploring the relation between the Thames terrace record and cyclic (Milankovich) climatic fluctuation (Bridgland & Schreve, 2001a).

The Lower Thames fluvial record is one of the most complete late Middle Pleistocene archives, with excellent preservation of interglacial faunal remains and a wealth of rich and sometimes primary-context Palaeolithic assemblages (Bridgland, 1994, 2000; Bridgland &

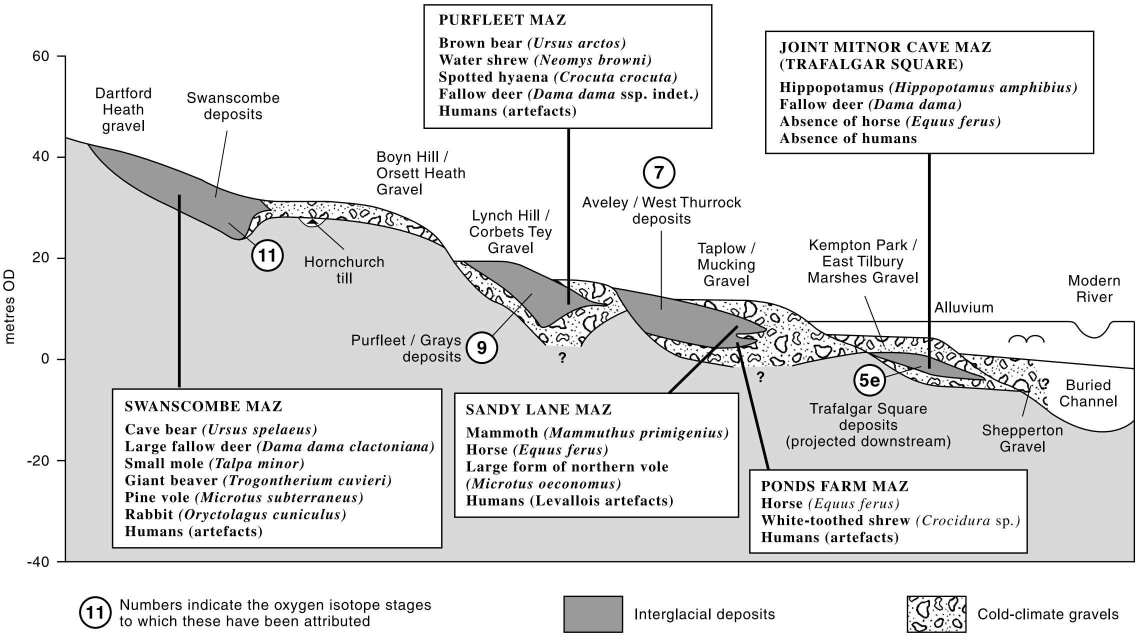

Fig. 1. Idealized transverse section (staircase diagram) through the Lower Thames terrace sequence. Selected details of mammalian assemblage zones, key to dating of the terrace sequence, are indicated (modified from Bridgland & Schreve, 2001b)

Schreve, 2001b). Comparison with other fluvial records of the last 500 ka from NW Europe shows that few have the potential to equal the richness of that from the Thames. Worthy of note are the terraces of the Somme and Seine in northern France, which have yielded important Palaeolithic assemblages, although, in contrast to the Thames sequence, much of the fluvial record of these French rivers has been obscured by later colluvial and loessic deposition. The individual terraces, therefore, do not preserve comparably rich, biostratigraphically diagnostic vertebrate and invertebrate assemblages, although the presence of fossil soils within the overburden above the fluvial deposits provides an important additional dating control (Antoine, 1990, 1994).

An analogous sequence to that of the Thames, with at least four interglacials represented within a terrace staircase, is recorded in central Germany, in the valley of the River Wipper at Bilzingsleben (Mania, 1995), where the interglacials are represented by travertine deposits from calcareous springs. The Triassic (Muschelkalk) limestone bedrock in this part of Germany has led to other instances of travertine deposition, such as within the terrace sequence of the River Ilm in the vicinity of Weimar (e.g. Soergel, 1924; Kahlke *et al.*, 2002; Maul, 2002), in the valley of the River Ilm, and at Burgtonna in the valley of the River Unstrut (Meyrick & Maul, 2002). Such travertines are frequently rich sources of mammalian and molluscan fossils, two animal groups that have been demonstrated to be particularly useful for Quaternary biostratigraphy (Sutcliffe, 1964; Kerney, 1971; Keen, 1990, 2001; Preece, 1999; Bridgland & Schreve, 2001b; Schreve, 2001b). In addition, they are rich sources of plant fossils (see below), of considerable value as sources of palaeoenvironmental evidence.

2. SUMMARY OF THE LOWER THAMES RECORD

Numerous publications describing the Lower Thames sequence have appeared in recent years (Bridgland & Harding, 1993; Bridgland, 1994, 1995; Gibbard, 1994, 1995; Schreve *et al.*, 2002), so it is necessary to provide only a summary here. Bridgland (1994, 1995, 2000) and Bridgland & Harding (1993) have promoted an interpretation in which temperate-climate sediments within the four separate Lower Thames terraces are attributed to the last four interglacials, as identified in the oceanic record (Fig. 1), i.e. oxygen isotope stages (OIS) 11, 9, 7 and 5 (Substage 5e). Although this has not been universally accepted (cf. Gibbard, 1994, 1995), it has received support from amino acid geochronology (Bowen *et al.*, 1995), from the interpretation of archaeological evidence (Bridgland, 1998; White, 1998), from molluscan biostratigraphy (Keen, 1990, 2001; Preece, 1995, 1999) and from mammalian biostratigraphy (Schreve, 1997, 2001b, c).

Each Lower Thames terrace will now be described in turn, with a brief summary of the nature of the evidence and mention of the most important localities (see also Table 1).

Table 1. Presence/absence data of selected biostratigraphically important mammals and molluscs from British and German late Middle Pleistocene interglacial deposits and proposed correlation with the marine isotopic record. Sources for German faunas are Mania (1995), Kahlke (2002) and Maul (2002).

Suggested correlation with oxygen isotope record	11		9	early 7		late 7	
Site	Boyn Hill/ Orsett Heath[a]	Bilzingsleben II	Lynch Hill/ Corbets Tey[b, c, d]	Taplow/ Mucking[d]	Ehringsdorf Lower Travertine	Taplow/ Mucking[d]	Ehringsdorf Upper Travertine
Mammalia							
Talpa minor	x						
Trogontherium cuvieri	x	x					
Ursus spelaeus	lab	x			x		x
Dama dama clactoniana	lab	x					
Oryctolagus cuniculus	lab						
Microtus (*Terricola*) *subterraneus*	lab	x			x		
Macaca sylvanus	x	x	lab				
Stephanorhinus kirchbergensis	fab	x	x	x	x		
Equus spp.	x	x	x	x	x	x	x
Homo sp.	x	x	x	x	x	x	x
Stephanorhinus hemitoechus	fab	x	x			x	x
Ursus arctos			fab		x	x	x
Dama dama dama			fab		x		
Crocuta crocuta			x		x	x	
Mammuthus primigenius (Ilford type)						x	x
Coelodonta antiquitatis						x	x
Mollusca							
Theodoxus serratiliniformis	x	x					
Unio crassus	x		lab				
Corbicula fluminalis	x		x	x		lab	
Pisidium clessini	x		x	x		lab	

x, confirmed presence; fab, first appearance in Britain; lab, last appearance in Britain.

[a] Additional data can be obtained from Schreve (1996).

[b] Additional data can be obtained from Schreve (2002).

[c] Additional data can be obtained from Schreve *et al.* (2002).

[d] Additional data can be obtained from Schreve (2001b).

Boyn Hill/Orsett Heath Formation

This is the highest and oldest terrace and the first to be formed within the Lower Thames valley, which was newly occupied by the river following glacial diversion during the Anglian/Elsterian (Gibbard, 1977, 1979; Bridgland, 1988; Bridgland & Gibbard, 1997). It is well represented on the northern flank of the valley east of London and then switches to the southern side in the Dartford–Northfleet area (Fig. 2), a distribution that reflects course changes since Boyn Hill times rather than differential preservation. Suggestions that the older Black Park Terrace is represented at Dartford Heath (Gibbard, 1979, 1994) can be rejected on the grounds that the Dartford Heath deposits are of interglacial origin and lateral equivalents of the sediments at Swanscombe (White, 1998; Wenban-Smith & Bridgland, 2001). Both can be attributed to OIS 11 (Bridgland, 1994, 1995; Bridgland & Schreve, 2001b; Wenban-Smith & Bridgland, 2001; Fig. 1; cf Conway *et al.*, 1996).

The sites at Barnfield Pit, Swanscombe and the nearby Dierden's Pit (Ingress Vale), Greenhithe, have provided the vast majority of the palaeontological and Palaeolithic evidence from this terrace. Key features of mammalian assemblages of this age are the presence of extinct archaic forms, including *Talpa minor* (small mole), *Trogontherium cuvieri* (giant beaver), *Ursus spelaeus* (cave bear) and a large subspecies of fallow deer *Dama dama clactoniana*, the presence of the extant European pine vole (*Microtus subterraneus*) and the first occurrences in Britain of *Megaloceros giganteus* (giant deer), *Stephanorhinus kirchbergensis* (Merck's rhinoceros), *Stephanorhinus hemitoechus* (narrow-nosed rhinoceros) and *Bos primigenius* (aurochs). *Crocuta crocuta* (spotted hyaena) is notably absent from this mammalian suite. Also important is the appearance of an exotic, central and southern

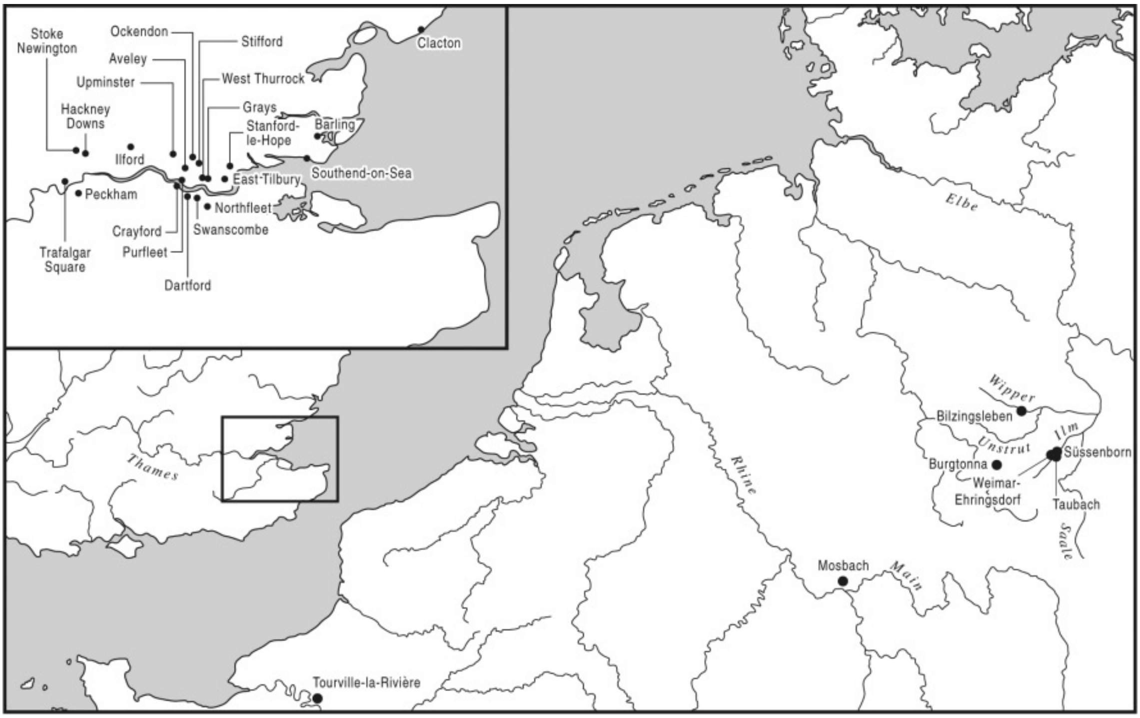

Fig. 2. Location of the German and Thames (inset) sites discussed in the text.

European suite of Mollusca (typified by such species as *Theodoxus serratiliniformis* (=*danubialis*), *Corbicula fluminalis*, *Belgrandia marginata* and *Unio crassus*) part-way through the interglacial, believed to indicate a connection with the Rhine (Kennard, 1938; Kerney, 1971). In addition, there is a distinctive archaeological sequence, with the occurrence of Clactonian artefacts in the early part of the interglacial and hand-axe making represented only later, after the immigration of the 'Rhenish' molluscs. White & Schreve (2000) have suggested that the changes in the archaeological record may be directly related to the changing palaeogeography, perhaps reflecting separate pulses of early human immigration before and after the reconnection of Britain to mainland Europe. The apparent complexity of the Swanscombe sequence, in which at least two discrete phases of temperate climatic conditions are represented within a single interglacial, separated by evidence of periglacial activity, led Schreve (2001c) to propose that climatic variability at the oxygen isotope substage level may be recorded there.

Lynch Hill/Corbets Tey Formation

This terrace is represented by a belt of deposits to the south of the Boyn Hill/Orsett Heath outcrop east of London, then follows a reverse S-shaped course through Ockendon, Stifford and Purfleet, from which point it has been largely obliterated by the erosion of the modern valley (Bridgland, 1988, 1994; Schreve *et al*., 2002). Downstream from Purfleet a small but important remnant survives around Grays, beyond which the terrace is represented by outcrops at East Tilbury and Stanford-le-Hope (Fig. 2). Fossiliferous interglacial sites attributable to this terrace have been recorded at Ilford (Cauliflower/High Road pits), Upminster (Ward, 1984), Purfleet (Hollin, 1977; Bridgland, 1994; Schreve *et al*., 2002) and Grays (Hinton & Kennard, 1900). The interglacial is believed to be that identified in the oceanic record as OIS 9 (Bridgland, 1994; Schreve, 2001b; Schreve *et al*., 2002). In terms of the mammalian record, it appears that *T. minor*, *T. cuvieri*, *U. spelaeus*, *D. d. clactoniana* and *M. subterraneus* did not recolonize Britain after OIS 11. Their absence from assemblages in the Lynch Hill/Corbets Tey terrace is consequently considered to be an important diagnostic character and one that cannot be explained by taphonomic, environmental or sampling biases. The OIS 9 interglacial also marks the first re-immigration into Britain of *C. crocuta* since the Cromerian Complex and the first appearance of *Ursus arctos* (brown bear) and a smaller-bodied fallow deer, *Dama dama* ssp. indet. In addition, the presence of a more derived morphotype of *Arvicola terrestris cantiana* (water vole) serves to differentiate assemblages of this age from those of the older Boyn Hill/Orsett Heath terrace (Schreve, 2001b; Schreve *et al*., 2002). Although some of the characteristic

'Rhenish' molluscs, such as *T. serratiliniformis*, do not reappear in the Corbets Tey/Lynch Hill terrace, it is significant that others, such as *C. fluminalis*, were again present in Britain from the very beginning of this interglacial.

Further downstream, an equivalent interglacial site has recently been reported at Barling, near Southend-on-Sea (Bridgland *et al.*, 2001; Fig. 2), while the complex of sites originally described in the nineteenth century around Stoke Newington and Hackney (Smith, 1883, 1894) in NE London was correlated with the OIS 9 interglacial by Bridgland (1994). New evidence from part of this complex, at Hackney Downs, is presented below.

A unique archaeological sequence occurs within the sediments forming this terrace, as exemplified at Purfleet (Wymer, 1985; Schreve *et al.*, 2002), where three separate Palaeolithic industries occur in stratigraphical superposition; a Clactonian assemblage in the earliest deposits, followed by an Acheulean (hand-axe) industry and then the important first appearance in Britain of Levallois artefacts in the uppermost Corbets Tey deposits (Bridgland, 1994, 1998; Schreve *et al.*, 2002).

Taplow/Mucking Formation

This terrace is the first to be well represented throughout the modern course of the Lower Thames, appearing on pre-1990s Geological Survey maps as 'Floodplain Gravel'. Fossiliferous interglacial sediments have been recorded at numerous sites (Figs 1, 2): Ilford (Uphall Pit), Aveley (Blezard, 1966), West Thurrock (Bridgland & Harding, 1994, 1995), Crayford (Kennard, 1944) and, in the tributary Ebbsfleet valley, the Baker's Hole–Northfleet complex of sites (Bridgland, 1994; Wenban-Smith, 1995). Invariably, the interglacial component of these deposits was attributed to the Ipswichian (Eemian; Last Interglacial), largely on pollen biostratigraphical grounds (cf. West, 1969; Hollin, 1977; Holyoak, 1983; Gibbard, 1994, 1995), prior to the widespread adoption of the expanded sequence indicated by the oceanic record. Doubts, based on mammalian biostratigraphy, about the age of these interglacial sites were expressed, however, by Sutcliffe (1975) and Sutcliffe & Kowalski (1976). Shotton (1983) first established that the interglacial represented was probably OIS 7, a view that has received considerable support more recently (Bridgland, 1994, 1995; Schreve, 1997, 2001b, c; Preece, 1999).

The vertebrate evidence is complex and indicates the presence of at least two distinctive mammalian assemblage-zones (Schreve, 2001b, c); key elements that mitigate against an Ipswichian age for these faunas include *Mammuthus primigenius* (woolly mammoth), *Equus ferus* (horse), *S. kirchbergensis* and early hominids, none of which occur in the Last Interglacial in Britain. In addition, significant elements of the Ipswichian mammal fauna, such as *Hippopotamus amphibius* (hippopotamus) and *Dama dama* (fallow deer) are completely absent from sites within the Taplow/Mucking terrace, despite suitable climatic and environmental conditions and the recovery of many thousands of specimens of other taxa (Sutcliffe, 1975, 1976, 1995; Bridgland & Schreve, 2001b). There is a characteristic suite of Mollusca, also found in OIS 7 contexts outside the Thames basin, dominated by *Corbicula fluminalis*, but also with the last appearance of *Pisidium clessini* (Keen, 1990, 2001; Preece, 1999).

The lowermost sediments within this terrace contain the last evidence for Lower/Middle Palaeolithic human occupation of Britain prior to a lengthy absence of hominids during OIS 6 and the Last Interglacial; subsequent occupation by Middle and Upper Palaeolithic groups followed sea-level lowering in the last glacial cycle. Important archaeological assemblages, characterized by well-developed Levallois technology, occur in these lowermost Taplow/Mucking deposits at West Thurrock, Crayford and Northfleet (Wymer, 1968, 1999; Bridgland & Harding, 1994, 1995), where they represent occupation during late OIS 8 and early OIS 7.

Kempton Park/East Tilbury Marshes Formation

This is the terrace formation that, according to Bridgland (1994), incorporates the celebrated last interglacial (Ipswichian/Eemian) deposits at Trafalgar Square, although it is buried beneath Holocene alluvium in the Lower Thames (Fig. 1). Gibbard (1985, 1994), however, classifies the Trafalgar Square Silts and Sands and the overlying Kempton Park Gravel as separate members. Preece (1999) has noted that the Spring Gardens Gravel, which underlies the silts and sands and had been regarded as a separate pre-interglacial member, contains molluscan remains that indicate it to be part of the Ipswichian sequence. In the molluscan record, *C. fluminalis* is conspicuous by its absence from this terrace, whereas the mammalian fauna is characterized by the unique occurrence of *H. amphibius* in Britain.

Upstream from London this formation gives rise to the 'Floodplain Terrace' (Bromehead, 1912) – later 'Upper Floodplain Terrace' (Dewey & Bromehead, 1921) – but downstream from the city centre it has fallen to a level below the Holocene alluvium. The Lower Thames name 'East Tilbury Marshes Gravel' arises from the one site where it has been studied, in a part-flooded quarry in the floodplain (Bridgland, 1983, 1988). The furthest downstream that the interglacial member has been identified is Peckham, SE London, where Gibbard (1994) recorded shelly and organic sediments sandwiched beneath gravels, the upper one identified as the Kempton Park/East Tilbury Marshes Gravel. It is possible that further lenses of last interglacial deposits survive beneath the Holocene alluvium and estuarine sediments and will be discovered by future borehole investigations or civil engineering projects. All of the temperate-climate sediments exposed thus far in quarries downstream from London are believed by the present authors to be of pre-Ipswichian (Middle Pleistocene) age.

3. NEW EVIDENCE FROM HACKNEY DOWNS

Organic river terrace sediments have been known in North London, at the boundary between the Middle and Lower Thames, since the middle of the nineteenth century (Prestwich, 1855; Tylor, 1868; Whitaker, 1889), although the highly built-up nature of the area has meant that they have seldom been examined since (see, however, Harding & Gibbard, 1984; Gibbard, 1994). Redevelopment of part of this area in 1999–2000 allowed modern field and laboratory methods to be applied in a new study of the deposits, a full account of which will appear elsewhere (Green *et al.*, in press).

The sequence at Hackney Downs investigated in 1999–2000 consists of a lower gravel (the Leytonstone Gravel of Gibbard, 1994), intermediate sands and silts (Highbury Silts and Sands) and an upper gravel (Hackney Downs Gravel) underlying a terrace surface at 19 m OD. The nature of the sub-Pleistocene surface led Gibbard (1994) to suggest that the sediments were deposited by the River Lea *c.* 5 km from its confluence with the Thames. Pollen from the Highbury Silts and Sands was considered by Gibbard to be indicative of an age in the Ipswichian Interglacial. In the radically different scheme for the Thames terraces proposed by Bridgland (1994), the terrace flat in the Hackney Downs area was ascribed to the Lynch Hill/Corbets Tey terrace of the Thames and the interglacial sediments to OIS 9.

Although the sequence at Hackney Downs has produced extensive plant and invertebrate remains (Green *et al.*, in press), most are of little value for biostratigraphy, either because they are not distinctive to particular temperate phases (pollen) or because there are few potentially correlative Middle Pleistocene assemblages with which to compare (Coleoptera, herpetofauna, ostracods). However, the Hackney Downs deposits are rich in Mollusca, including a number of species that Keen (1990, 2001) and Preece (1999) have recognized as biostratigraphically significant. The assemblage is dominated by *Corbicula fluminalis* and *Belgrandia marginata* and also contains specimens of *Unio crassus* and *Pisidium clessini*. An assemblage of this type must, therefore, be pre-Ipswichian in age, since *P. clessini* became extinct at the end of OIS 7 and *C. fluminalis* has not been known in Europe since that date (Preece, 1999; Meijer & Preece, 2000). Equivalence with OIS 7 is also unlikely, given that *U. crassus* is only known in Western Europe prior to OIS 8 (Preece, 1999; Keen, 2001). Although some members of the ‘Rhenish’ fauna recognized at Swanscombe are present, such as *C. fluminalis*, other highly characteristic forms, such as. *T. serratiliniformis*, are absent. This strongly differentiates the Hackney Downs molluscan assemblage from that known from OIS 11 deposits in the Thames system (Kerney, 1971; Preece, 1995; Roe, 2001). Thus, by a process of elimination, an age within OIS 9 can be inferred for the Hackney Downs site on the basis of the molluscan evidence.

4. THE RIVER WIPPER SEQUENCE AT BILZINGSLEBEN

The Wipper is a tributary stream of the Saale–Elbe system, draining the Muschelkalk limestone region of Thuringia (Fig. 2). At Bilzingsleben, in a single meander core of the Wipper, a remarkable terrace staircase is preserved in which successive interglacials are represented by subaerially precipitated travertine deposits (Mania, 1995, 1998; Fig. 3). These deposits contain superbly preserved animal and plant fossils. In a lower facet within what has been interpreted as the highest terrace complex (Fig. 3), hominid fossils and archaeological remains have also been recovered from extensive excavations at the Bilzingsleben II level (Mania *et al.*, 1980; Mai *et al.*, 1983; Mania & Weber, 1986; Fischer *et al.*, 1991).

The travertines of the lower terraces in the sequence have been exposed only in temporary excavations and no mammalian faunas are yet known from them (D. Mania, pers. comm., 2000). The entire terrace sequence in the Bilzingsleben meander can be demonstrated to post-date the Elsterian glaciation, based upon the superposition of glacial deposits above the gravels of the 45 m terrace in another part of the valley nearby (Mania, 1995; Fig. 3). The glaciation associated with the 45 m terrace is the first of two Elsterian advances in central Germany, the Elster I glaciation, which some authors have correlated with OIS 14 (e.g. Šibrava, 1986). The earliest (Bilzingsleben I) Wipper interglacial deposits, also known only from small-scale excavations, contain a molluscan assemblage that includes *T. serratiliniformis*, one of the species that appears as part of the ‘Rhenish fauna’ part way through the interglacial sequence attributed to OIS 11 at Swanscombe, in the Lower Thames (see above). The stratigraphical range of this species on the continent is not firmly established (Preece, in Schreve & Bridgland, 2002a, b), but it has been regarded as indicative of a Holsteinian age, for example at Herzeele in NW France and Lo in SW Belgium (Meijer, 1988). The occurrence of *S. kirchbergensis* in the Bilzingsleben I deposits has been claimed as support for a post-Elsterian, Holsteinian interpretation (Schreve & Bridgland, 2002a, b), but the occurrence of this animal at Mosbach, near Stuttgart, in sediments attributed to OIS 13 (van der Made, 2000) raises the possibility that it was present in the late Cromerian Complex and that Bilzingsleben I might, thus, be as old as OIS 13, a possibility that requires further investigation.

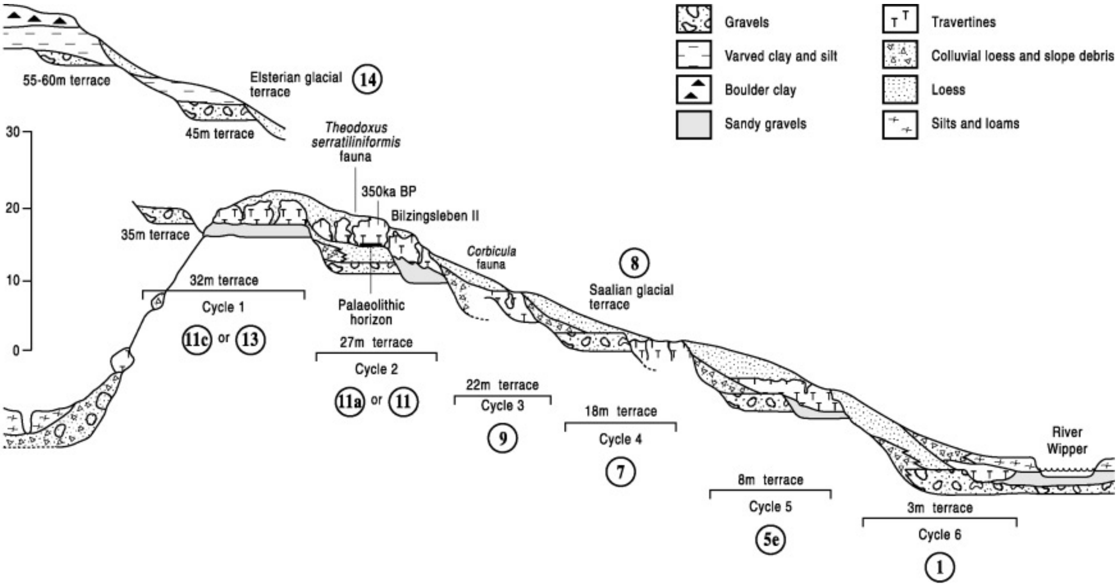

Fig. 3. Transverse section through the terrace sequence of the River Wipper in a single meander core at Bilzingsleben, Thuringia (the uppermost two terraces are projected from a nearby area). Correlations with marine oxygen isotope stages are suggested and the positions of the deposits correlated with the Elsterian (Elster I) and Saalian glaciations are indicated. Modified from Schreve & Bridgland (2002b).

The mammalian assemblage from Bilzingsleben II (Fischer *et al.*, 1991), the main archaeological horizon and the level that has received most attention, closely resembles British Hoxnian (=OIS 11; Schreve, 2001b) faunas such as those from Swanscombe and Clacton. Key features are the occurrence of *U. spelaeus*, *D. d. clactoniana*, *S. kirchbergensis*, *S. hemitoechus*, *A. t. cantiana*, *T. cuvieri* and *M. sylvanus* (Table 1). Also consistent with an OIS 11 interpretation for Bilzingsleben II is uranium series and electron spin resonance (ESR) dating, which have given, respectively, a minimum age estimate of *c.* 350 ka and an age (with a large error margin) of *c.* 400 ka (Schwarcz *et al.*, 1988). The transverse section through the Bilzingsleben sequence (Fig. 3) suggests that levels I and II are part of a single terrace complex, possibly separated by minor incision, so the attribution of both to OIS 11, notwithstanding the above discussion of a possible OIS 13 age for Bilzingsleben I, is not unreasonable. Schreve & Bridgland (2002a, b) suggested that climatic variability within OIS 11 might be represented here at the oxygen isotope substage level, as at Swanscombe (Schreve, 2001c). As with the Thames, it is clear that formation of the Wipper terraces has been climatically driven, although enabled by regional uplift. It is notable that the rate of incision is similar in these two widely separated systems (both *c.* 0.07 $\mathrm{m\,ka^{-1}}$, perhaps implying comparable uplift histories (cf. Maddy, 1997; Westaway *et al.* 2002).

The transverse section through the Wipper terraces (Mania (1995; Fig. 3) is strikingly similar to the Lower Thames staircase diagram (Fig. 1), although the latter is, of course, idealized. The interpretation of the Wipper sequence promoted here is fully corroborative of that by Mania (1995), although he did not make correlations with the marine isotopic record. An interesting implication of this interpretation is that the Saalian glacial input into the Wipper occurs at a level indicative of an OIS 8 age (cf. Kukla, 1975, 1977; Šibrava, 1986; Mania, 1995; Bridgland *et al.*, 1997), rather than the OIS 6 age for that glaciation that is generally favoured (cf. de Jong, 1988). Although the multiple Saalian advances into the Netherlands may have taken place wholly within OIS 6 (Turner, 2000), the possibility exists that, further east, earlier glaciations have been conflated with that of OIS 6 (cf. Litt & Turner, 1993).

5. EVIDENCE FROM THE RIVER ILM

The River Ilm is another tributary of the Saale–Elbe system, to the south of the Wipper (Fig. 2). As with the Wipper at Bilzingsleben, the Ilm terrace deposits include fossiliferous travertines, amongst which those at Ehringsdorf remain visible in a quarry, now partly conserved, on the southern outskirts of Weimar. The definitive description of the Ilm terraces remains that by Soergel (1924, 1926). He recognized a staircase of ten aggradational terraces, which he summarized in a correlation table and in an early example of an idealized staircase diagram (Soergel, 1924, fig. 6). A translated and updated version of the latter, showing the stratigraphical positions of the key localities of

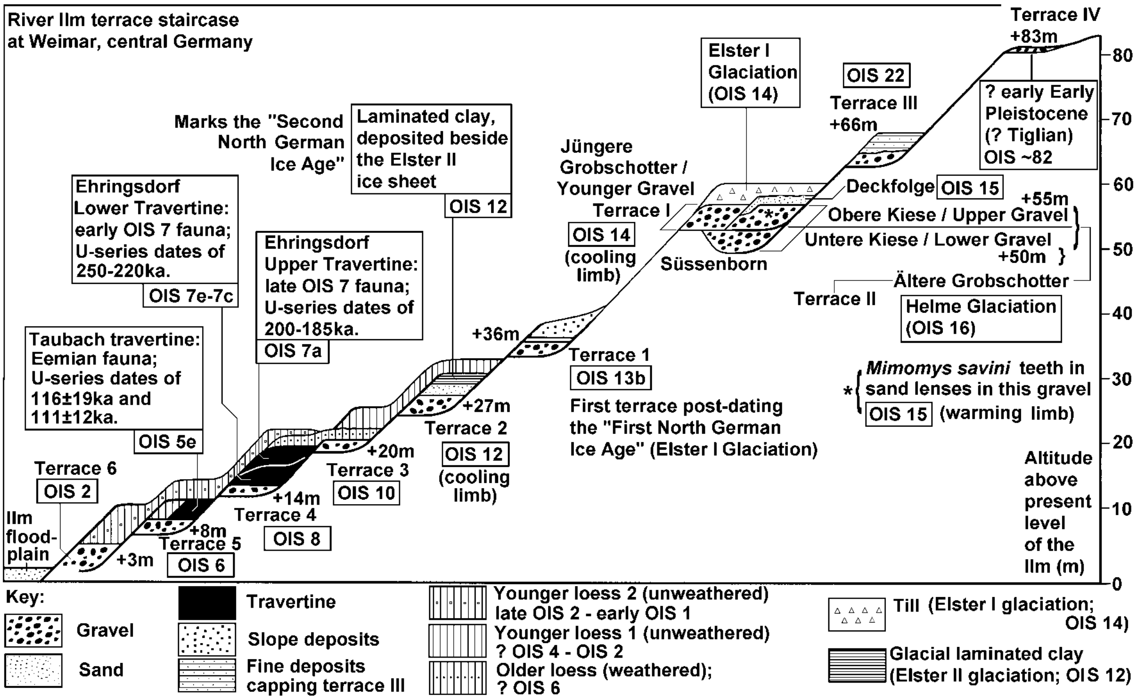

Fig. 4. Updated idealized transverse profile of the Ilm terraces, using the notation of Soergel (1924) and showing evidence from the key localities of Süssenborn, Ehringsdorf and Taubach (see text). Information is incorporated from the publications by Soergel (1926, 1939), Kahlke (1961, 1969b), Steinmüller (1969), Zeissler (1969), Fejfar (1969), Brunnacker *et al.* (1983), Unger & Kahlke (1995), Bratlund (1999), Mallik *et al.* (2000), Maul (2002), Kahlke *et al.* (2002) and Schreve (2002).

Taubach, Ehringsdorf and Süssenborn, is provided here as Figure 4.

Soergel placed the Ehringsdorf interglacial between the deposition of the Ilm Terrace 4 and Terrace 5 gravels (Fig. 4). Particularly important are the positions at which he placed the two pre-Weichselian North German glaciations known to him, which, it would appear, are those now classified (cf. Šibrava 1986) as Elster I (OIS 14?) and Elster II (OIS 12). The Saalian glaciation (OIS 8/6) did not reach the Weimar area (Unger & Kahlke, 1995).

It has not been possible to reinvestigate the Taubach locality in recent years; as Bratlund (1999) noted, most of its travertine was quarried decades ago and the site has now been built over. However, geological description by Bratlund (1999) suggests that this travertine caps Soergel's Terrace 5 (Fig. 4). Uranium-series dating (Brunnacker *et al.*, 1983; Fig. 4) has confirmed an Eemian age for the Taubach travertine.

Soergel (1924) also reported that the gravel of his Terrace 2 (Fig. 4) is capped by laminated clay that he thought was deposited at the margin of the ice sheet dating from what he called the 'Second North German Ice Age'. In modern terminology, this was the Elster II glaciation, at the peak of OIS 12 (cf. Sibrava, 1986), indicating that Terrace 2 aggraded during the preceding interglacial–glacial transition. In the quarry at Süssenborn, three distinct Ilm gravel units have been exposed, disposed as shown schematically in Figure 4. The superimposed Lower and Upper Gravels (collectively known as the Ältere Grobschotter; Soergel's (1924) Terrace II, *c.* 15 m thick overall), are capped by fine-grained fossiliferous temperate-climate deposits (the Deckfolge) then inset by the Younger Gravel or Jüngere Grobschotter, Soergel's (1924) Terrace I. These gravels are covered by till and other glacial deposits assigned to what Soergel (1924) called the 'First North German Ice Age'. In modern terminology, this is the Elster I glaciation, assigned by many to the OIS 14 climatic minimum (cf. Sibrava, 1986), indicating that Terrace I aggraded during the preceding climatic cooling. Furthermore, at Süssenborn, the tops of both Terraces I and II are at about the same level, *c.* 55 m above the Ilm (Fig. 4). According to Soergel (1924), Terrace II maintains a roughly constant relative level, whereas further upstream Terrace I is lower, only *c.* 47 m above the river. Similar variations have been observed for other river terraces adjacent to the margins of ice sheets, such as the lower Thames in SE England during OIS 12 (Maddy & Bridgland, 2001; Westaway *et al.*, 2002) and the Elbe in the Czech–German border region during OIS 14 and 12 (e.g. Tyráček *et al.*, 2004). In the Thames and Elbe they have been explained as a result of aggradation while the adjacent crust was loaded by ice, followed by subsequent isostatic rebound after this ice-load was removed. It is, thus, possible that Ilm Terrace I at Süssenborn shows a similar isostatic effect; it perhaps aggraded immediately before this area was overridden by the Elster I ice sheet. This phase of glaciation (evidently the most important in this part of central Germany) caused major changes to the drainage, as shown on palaeogeographical maps for instance by Steinmüller (1969, fig. 1) and Unger & Kahlke (1995, fig. 1).

Sandy deposits interbedded with the Süssenborn Lower and Upper Gravels and the overlying temperate-climate fine-grained Deckfolge (Fig. 4) have yielded an abundant mammalian and molluscan fauna (e.g. Zeissler, 1969; Kahlke, 1969a; Meyrick, 2002; Kahlke, 2002; Maul, 2002). Most importantly, rooted teeth of the water vole *Mimomys savini* have been found in deposits interbedded with the Upper Gravel (e.g. Fejfar, 1969). This species was superseded by its descendant *Arvicola terrestris cantiana*, with continuously growing teeth, during the latter part of the Cromerian Complex (cf. Westaway *et al*., 2002). It is, thus, unlikely that the fossiliferous sediments at Süssenborn are significantly younger than OIS 16, which correlates in central-northern Germany with the Helme Glacial (e.g. Unger & Kahlke, 1995), although it is evident that any Scandinavian ice sheet that developed at this time did not reach as far south as the Ilm catchment.

The faunal records from Ehringsdorf

The molluscan and mammalian records from Ehringsdorf arguably provide the most detailed palaeoecological and biostratigraphical information on the site (Kahlke *et al*., 2002) but the Ehringsdorf deposits also preserve, often in fabulous detail, plant remains (both pollen and incrustations of leaves and fruits), fungi, insects, ostracods, herpetofauna, birds (including feathers, eggshells and nests), endocranial casts and hominids (including bones, artefacts and other evidence of human activity) (Kahlke, 1974, 1975a).

At the base of the sequence are 11 m of fluvial gravels (Terrace 4; Fig. 4) overlain by up to 2 m of ‘floodloam’. The gravels are characterized by a cold-stage tundra-steppe molluscan assemblage (Mania, 1993) and by the occurrence of *M. primigenius* and *Coelodonta antiquitatis* (woolly rhinoceros). The overlying floodloams were deposited under less extreme climatic conditions, the molluscs (such as *Pupilla sterri* and *P. triplicata*) indicating an open, exposed steppe environment (Zeissler, 1975).

The Lower Travertine, which is up to 15 m thick, contains abundant plant macrofossils that indicate deciduous mixed oak forest (Vent, 1974) and warmer conditions than during the later deposition of the Upper Travertines (see Stebich & Schneider, 2002). Molluscan evidence shows that warm and forested conditions already prevailed by the time of deposition of the lowermost Lower Travertine but that the site was relatively open during the deposition of the upper part of the Lower Travertine (Zeissler, 1975). Although *P. antiquus* (straight-tusked elephant) and *S. kirchbergensis* both occur in the lower horizons of the Lower Travertine, they are lacking from the mid-Lower Travertine upwards, the latter taxon being replaced by *S. hemitoechus*, suggesting increasingly drier biotopes (Kahlke, 1975b). The Lower Travertine contains a number of ‘cultural horizons’ that preserve both Neanderthal fossils and evidence of human occupation, particularly in the form of hearths (Vlček, 1993).

Fissure infills within the upper part of the Lower Travertine contain the remains of amphibians, reptiles and small mammals, the last predominantly indicative of open landscapes, such as *Spermophilus citelloides* (ground squirrel) and *Cricetus cricetus* (hamster) but with woodland species, such as *Clethrionomys glareolus* (bank vole), and temperate indicators, such as *Crocidura* sp. (white-toothed shrew), also represented (Heinrich, 1981).

The Lower Travertine is separated from the Upper Travertines by the more porous, loess-rich ‘Pariser’ horizon (up to 2 m thick), the upper part of which consists of a palaeosol. The Pariser, which appears to represent an interruption in travertine deposition, contains a large mammal assemblage, including *Megaloceros giganteus* (giant deer), *S. hemitoechus* and *M. primigenius*, that is suggestive of cool-temperate and open conditions (Kahlke *et al*., 2002). In concurrence, pollen analysis indicates that a predominantly open and species-rich vegetation prevailed at this time (Frenzel, 1974), whilst the molluscan fauna primarily consists of open-ground taxa, with the relatively high abundance of *Pupilla sterri* suggesting a more steppe-like environment than earlier (Zeissler, 1975). The subsequent Pariser palaeosol witnesses the re-immigration of trees, including *Larix* (larch), *Picea* (spruce) and various *Pinus* (pine) species (Frenzel, 1974) and an associated return of optimum forest land snails, such as *Platyla polita*, *Helicigona lapicida* and *Helicodonta obvoluta* (Zeissler, 1975). It also preserves the remains of a fully interglacial herpetofauna, including *Salamandra salamandra* (European or fire salamander) and *Elaphe longissima* (Aesculapian snake) (Böhme & Heinrich, 1994). The small mammal fauna from the palaeosol is the richest known from the entire Ehringsdorf sequence, with high frequencies of *Apodemus sylvaticus* (wood mouse), *Clethrionomys glareolus* (bank vole), *Glis glis* (edible dormouse) and *Microtus subterraneus* (European pine vole), providing further evidence of climatic optimum conditions (Böhme & Heinrich, 1994).

The Upper Travertines (up to 10 m thick) are less coherent than the Lower Travertine and are subdivided into four layers (A–D) by three ‘Pseudopariser’ horizons (I–III). The vegetation of the travertines is

Table 2. Key stratigraphical units at Ehringsdorf and their palaeoclimatic interpretations.

Sedimentary unit	Prevailing palaeoclimate
Overburden	Cold
Fissure infill (colluvial soil)	Continental
Upper Travertines	Temperate (but cooler than the Lower Travertine)
Pariser soil	Climatic amelioration
Upper part of the Lower Travertine and Pariser	Transition to cooler, more continental conditions
Lower part of Lower Travertine	Climatic optimum
Upper floodloams	Climatic amelioration
Basal gravels and lower floodloams	Cold

predominantly that of mixed oak woodland, with the occurrence of *Vitis* (common grape vine) indicating temperatures warmer than those of the Ilm Valley today. The molluscan fauna of the Upper Travertines is primarily that of a Central European woodland (Mania, 1993) but optimum forest elements are rare and steppe taxa are important components of the land snail assemblage (Zeissler, 1975; Mania, 1993). Significant differences are also apparent in the mammalian assemblages of the Upper Travertines. *P. antiquus* and *S. kirchbergensis* are now completely absent, having been replaced by *M. primigenius* (Guenther, 1975) and *S. hemitoechus*, with the later addition of *C. antiquitatis* (Kahlke, 1975c). This implies a change to more open conditions (Kahlke *et al.*, 2002), an interpretation that is echoed in the small mammal fauna with the appearance of *Spermophilus* ex gr. *citellus* (extinct ground squirrel) and *C. cricetus*. A '*Chondrula tridens* fauna' typical of the Chernozem Steppe was obtained from the 'Pseudopariser' horizons, suggesting that these sediments were deposited during intervals characterized by cool, dry, temperate climates with warm summers (Mania, 1993). Palaeolithic artefacts and charred horizons are also known from the Upper Travertines (Steiner & Steiner, 1975; Kahlke, 1985).

Fissures within the Upper Travertines, which extend as deep as the Pariser horizon, are filled with a dark chernozem colluvium rich in microvertebrates (Böhme & Heinrich, 1994), with both the amphibian and small mammal assemblages made up entirely of open-ground elements. Conversely, the molluscan fauna is one of a warm and relatively moist woodland and includes two truly exotic taxa, *Pagodulina pagodulina*, which has a Central and Southeast European modern distribution, and *Discus perspectivus*, which is today restricted to the eastern Alps, the Carpathians and the Balkans (Mania, 1993).

Palaeoclimatic conditions prevailing during the deposition of each of the sedimentary units at Ehringsdorf, which include a loessic/colluvial capping, are summarized in Table 2.

Age of the Ehringsdorf deposits

Soergel (1926) made clear his interpretation that the Ehringsdorf travertines cap Ilm Terrace 4 (Fig. 4). In his 1926 paper he presented an interpretation that was remarkable for its day in that it matched the climate fluctuations evident in this sedimentary record to variations, calculated by Milankovitch, in astronomical forcing through the Last Interglacial–Glacial transition. Like many others, he thus thought that this travertine was Eemian and matched the climatic variations to the Milankovitch substages that are now termed OIS 5e–5a.

However, the age of the Ehringsdorf travertine complex has become a subject of much contention. The consensus of a Colloquium in 1968 (in Weimar) devoted to the site was that the Lower Travertine was Eemian (OIS stage 5e) in age and the covering sediments represented the beginning the Weichselian (Kahlke, 1974, 1975a). Subsequent arguments have been put forward, however, for a pre-Eemian age for at least part of the sequence (however, cf. Weber *et al.*, 1996). Morphometric analysis of *Arvicola* (water vole) and *Castor* (beaver) remains from the Lower Travertine indicated that they represent less-derived (older) morphologies than those from the Eemian sites of Taubach, Schönfeld and Stuttgart–Bad Cannstadt (Heinrich, 1987, 1989), although both taxa are unfortunately absent from the Upper Travertines. Similarly, morphological examination of *S. kirchbergensis* molars from Bilzingsleben, Ehringsdorf and Taubach led Made (2000) to conclude that the lower and middle parts of the Ehringsdorf Lower Travertine pre-date the Eemian. This is supported by uranium-series (Schwarcz, 1980; Schwarcz *et al.*, 1988; Schüler, 1994) and ESR (Schüler, 1994) age estimates from the Lower Travertine. The presence of *Apodemus maastrichtiensis* (a wood mouse) in the Pariser palaeosol is also significant, since it is only known from pre-Eemian deposits (Heinrich, 1994).

It has also been suggested that the Upper Travertines pre-date the Eemian (e.g. Mania, 1993; Schreve, 2002; Schreve & Bridgland, 2002a). Mania (1993) correlated both the Lower and Upper Travertines with an intra-Saalian interglacial corresponding with OIS 7, a view reiterated by Schreve (2002) and Schreve & Bridgland (2002a, b). Comparison with evidence from the Lower Thames has indicated that both the Lower and Upper Travertines might be included within OIS 7 (Schreve & Bridgland, 2002b; Fig. 5). Patterns of faunal turnover within the

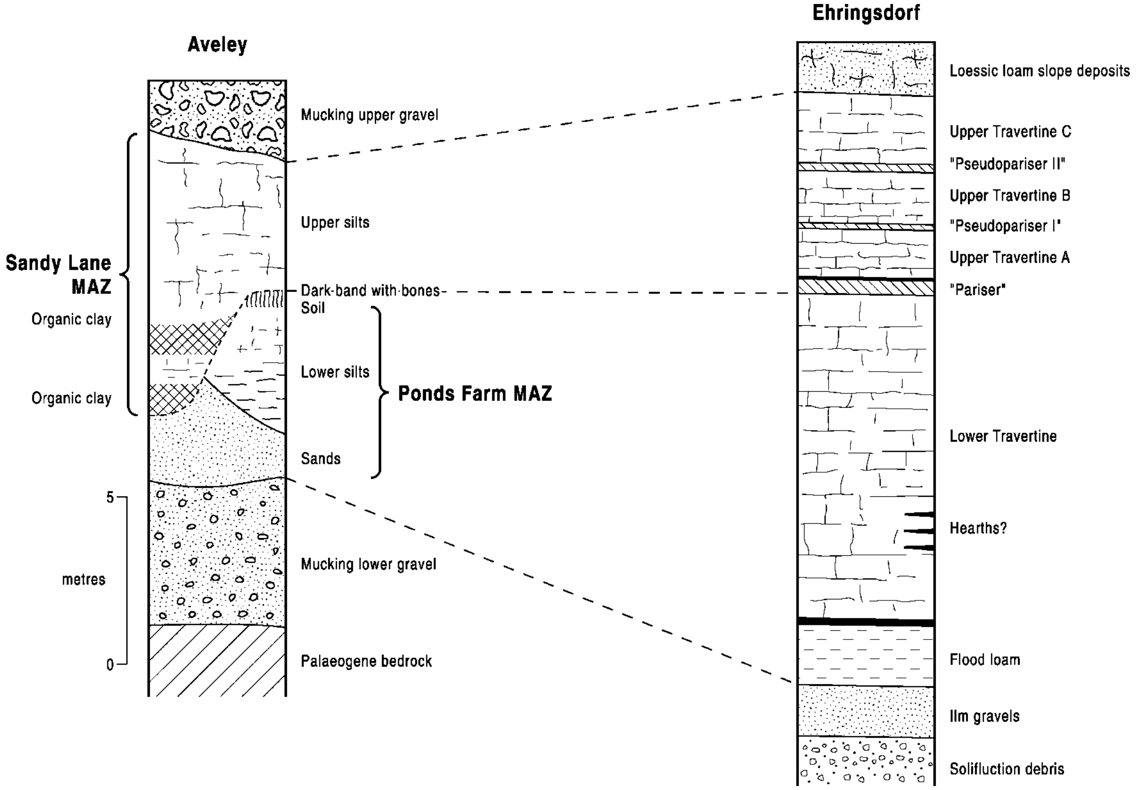

Fig. 5. Comparison of the Quaternary sequences at Ehringsdorf, in the River Ilm valley, Thuringia, and Aveley in the Lower Thames (after Schreve & Bridgland, 2002b). The Ponds Farm MAZ and the Sandy Lane MAZ are mammal assemblage zones defined by Schreve (2001b), corresponding to the early 7 and late 7 faunas (respectively) in Table 1.

sequence, the presence of indicator species such as *A. maastrichtiensis* and the degree of morphological evolution in other taxa, such as *Arvicola* and *Mammuthus*, combine to suggest that only a single, pre-Eemian interglacial is represented at the site. Furthermore, no lithological or palaeontological evidence exists for the intervening period of severe cold that would represent the OIS 6 glaciation. More recent U-series dating by Mallik *et al.* (2000) places the Lower Travertine at 250–220 ka and the Upper Travertine at 200–185 ka (Fig. 4), seemingly supporting the above view.

6. DISCUSSION AND CONCLUSIONS

Remarkable similarities have been observed between the Middle Pleistocene fluvial sequences in Thuringia and the Lower Thames. In particular, the terrace staircase of the River Wipper at Bilzingsleben (Fig. 3) closely resembles that of the Lower Thames (Fig. 1), despite significant differences in the scale of the two river systems, as well as the fact that the Wipper is located within the heart of the European continent, whereas the Lower Thames lies within the estuarine reach during interglacials. Evidence from mammalian and molluscan biostratigraphy has shown that this resemblance results from equivalence of age at the level of interglacial–glacial cycles. Both these staircases are unusually complete and can be used as templates for regional comparison with records elsewhere (fluvial and otherwise) in which fewer individual climatic episodes are represented. An attempt has been made here to develop, along these lines, a terrace stratigraphy for the nearby River Ilm, essentially an update of the work of Soergel (1924, 1926). This has involved pooling biostratigraphical data from the well-known sites at Süssenborn, Ehringsdorf and Taubach (Fig. 4). The biostratigraphy from all three systems has been corroborated by the available geochronological data, such as uranium series dates from Bilzingsleben, Ehringsdorf and Taubach (see above) and amino acid analyses of shells from the Lower Thames (Bowen *et al.*, 1995).

This comparative study has highlighted the value both of fluvial sequences as repositories of key Quaternary records and of biostratigraphy as a means for correlation, if not continent-wide, then at least across distances of several hundred kilometres. Comparisons can be made using common fossils from the same fluvial habitats and sedimentary facies in these different sequences, utilizing the fluvial terrace lithostratigraphy as a framework. The presence (and sometimes the absence) of key species can be shown to be a meaningful guide to age. An example of an extremely uniform fauna that can be traced from the UK through France (e.g. Tourville la Rivière, Carpentier & Lautridou, 1982) and into eastern and southern Germany is the mammoth-horse fauna that characterizes the later part of the OIS 7 interglacial (Shotton, 1983; de Rouffignac *et al.*, 1995; Buckingham *et al.*, 1996; Schreve 1997, 2001b, c). The distinctive 'Rhenish fauna' that occurs in OIS 11 sites in Britain includes elements that are recognizable in Thuringia, well to the east of the Rhine. Other constraints include the restriction, in the late Middle Pleistocene, of *Corbicula fluminalis* to pre-Eemian assemblages and *Hippopotamus* to the Eemian/Ipswichian (OIS 5e).

Quaternary biostratigraphy differs significantly from that in earlier geological systems, not least because the time-scales involved are much shorter. This means the use, primarily, of assemblage zones (e.g. Schreve, 2001b). Nevertheless, patterns of evolutionary change and extinctions are valuable, particularly in mammals, where detailed measurements of commonly fossilized parts, such as teeth, can allow assemblages to be placed chronologically within a changing series of morphotypes. Many of the key mammalian species and one or two of the molluscs used to recognize the late Middle Pleistocene interglacials identified in this study are globally extinct; others, especially the molluscs, have much-reduced ranges in the Holocene.

It should also be emphasized that complementary strands of biostratigraphy need to be applied in Quaternary studies, rather than expecting a single fossil group to supply all the answers. The mammalian and molluscan signals can, indeed, be used in combination to indicate relative age and, in the UK, have largely replaced pollen as a means for identifying interglacials (Keen, 2001; Schreve, 2001b).

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