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Early Middle Pleistocene drainage in southern central England

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Abstract

The fluvial sequences of the Milton and the Letchworth formations in the south Midlands of England and neighbouring regions represent at least two pre-existing rivers, the Milton and Brigstock streams, underlying Middle Pleistocene glacial sediments. The Milton Formation includes sand sourced from the Midlands bedrock. This implies that both streams were aligned in a northwest to southeast direction. This direction parallels the contemporaneous courses of the rivers Thames and Trent, the former turning towards the east and northeast to enter the North Sea. Their alignments indicate that the Milton and Letchworth streams formed left-bank tributaries of the Thames, joining the river in Hertfordshire and Essex, as illustrated in the article. This reconstruction has important implications for the interpretation of the proto-Soar river of the south Midlands, represented by the Baginton Formation. Although originally thought to represent a late Middle Pleistocene line, this southwest to northeast aligned system was reinterpreted as the headwaters of a pre-Anglian 'Bytham river', a1ligned towards East Anglia. However, recent work has shown that this river could not have existed in the pre-Anglian since there is no link between the Midlands and East Anglian spreads. Recent re-recognition that the Baginton Formation deposits do represent a later, post-Anglian drainage line is reinforced by the identification of the Milton and Letchworth streams, whose catchments occupied the area later drained by the proto-Soar. Overall, the main drainage alignment in southern England during the pre-Anglian period was dominated by northwest–southeast-draining consequent rivers adjusted to the regional geological dip. After widespread drainage disruption caused by the Anglian glaciation, northeast–southwest-orientated subsequent streams eroded frost-susceptible clay bedrock under periglacial and permafrost conditions, and beheaded the courses of some of the older consequent streams.

Keywords: Pre-Anglian, fluvial, gravels and sands, palaeogeography, glaciation

Introduction

Research over the last century has demonstrated that the drainage system of lowland Britain is the product of repeated glaciation through the Middle and Late Pleistocene. Remodelling of the landscape by the damming, diversion, creation and destruction of major drainage lines has occurred repeatedly during and immediately following each glaciation. These drainage realignments have had important palaeogeographical implications for the landmass as well as for the colonisation of the land by plants and animals. The alignment of the main drainage lines before the region was glaciated has become better understood in recent years. In particular, it has been established that, in the absence of external forces, the major drainage alignment in southern England during the pre-Anglian period was broadly northwest to southeast, parallel to the regional tilt of the landmass (Gibbard, 1988; Gibbard & Allen, 1994; Gibbard & Lewin, 2003).

One such major drainage line is that represented in the English Midlands (Fig. 1). Here the late Middle Pleistocene Wolston Formation glacial sediments (and equivalents) of the region overlie deposits of a pre-existing river system, represented by the Baginton–Lillington gravel and sand (members) and its equivalents (Shotton, 1953, 1968, 1976, 1983a,b, 1989; Bishop, 1958; Rice, 1968, 1981, 1991; Rice & Douglas, 1991; Bridge et al., 1998). The fluvial deposits mainly comprise predominantly quartz-rich sediment derived from underlying Triassic bedrock. Shotton (1953, 1983a,b; 1989) concluded that the proto-Soar river, which deposited these sediments, formed after the Hoxnian (= Holsteinian) Stage and was overridden by the Wolstonian (= Saalian Stage) ice, and therefore it could only have existed for a relatively limited period, i.e. a maximum of c. 200 ka. This was based on the relationship of the glacial sediments to Hoxnian-age interglacial sediments in the Birmingham area and on the mammalian fossils recovered from the proto-Soar Baginton–Lillington gravels and sands. However, the suggestion by Rose (1987, 1989a,b, 1994) that the Wolston Formation sediments should be reassigned to the Anglian (=Elsterian) Stage led to reinterpretation of the underlying Baginton–Lillington Member sediments as representing the headwaters of a pre-Anglian 'Bytham river'. This river, aligned towards East Anglia across the Fenland (Figs 1 and 2), was interpreted as linking to a spread of quartz-bearing fluvial sediments identified in central to eastern East Anglia, termed the Ingham Formation (Hey, 1976, 1980; Clarke & Auton, 1984; Hey & Auton, 1988), where they for the most part underlie Anglian-age diamictons.

Fig. 1. Location map of the area discussed showing the sites mentioned in the text. The red symbol and outline indicates the position of the borehole A43 road cross-section shown in Fig. 5.

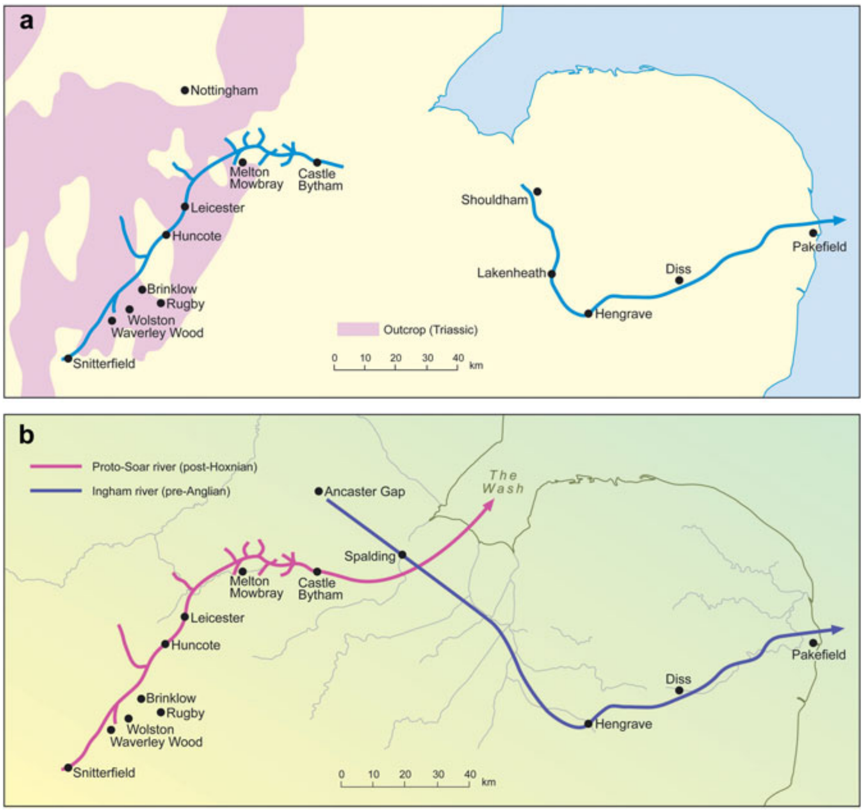

Fig. 2. Contrasting drainage-line reconstructions for the proto-Soar/'Bytham river' courses. a. The presumed pre-Anglian (= Elsterian) Bytham river according to Rose (1987, 1994) and Lee et al. (2004a); also shown is the outcrop of Triassic bedrock. b. The pre-Anglian Ingham Formation (Trent) river of Clarke & Auton (1984), Hey & Auton (1988) and Gibbard et al. (2013), and the post-Hoxnian proto-Soar of Shotton (1953, 1968, 1976, 1983a,b, 1989); Bishop (1958); Rice (1968, 1981, 1991); Rice & Douglas (1991) and Bridge et al. (1998), after Gibbard et al. (2013). See text for details. These plots should be compared with Fig. 7.

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This interpretation was favoured for some years (Lewis, 1989, 1991; Lewis et al., 1999; Lee et al., 2004a). In addition, the discovery of Palaeolithic artefact assemblages from sediments at Brooksby, Leicestershire (Rice, 1991; Stephens et al., 2008) and those equated to the Ingham Formation system in East Anglia have given them a greater significance in recent years (e.g. Rose & Wymer, 1994, Lee et al., 2008).

As reconstructed by Rose and colleagues (e.g. Rose, 1987, 1994; Lee et al., 2004a), this 'Bytham river' system would thus have extended from near Stratford-upon-Avon, in Warwickshire, to, and presumably beyond, the present coast between Great Yarmouth and Ipswich at its maximum development (Figs 1 and 2a), until its destruction by glaciation during the Anglian Stage (Rose, 1987, 1994).

However, recent investigations in East Anglia, in particular on the eastern margin of the Fenland (Gibbard et al., 1992, 2009, 2012a,b; Gibbard & Clark, 2011) and the Norfolk–Suffolk eastern borderlands (e.g. Gibbard & van der Vegt, 2012) have led to questioning of the 'Bytham river' concept. Indeed it has been demonstrated that the river could not have existed in the form proposed by Rose (1987, 1994, 2009) and Lee et al. (2004a,b), among others. Gibbard et al. (2009, 2012a,b) have demonstrated that there are almost certainly no pre-Anglian-age fluvial sediments preserved on the eastern Fenland margin (Fig. 1) where the deposits, classified as 'Bytham river' equivalents, are in fact of glacial origin. Instead, there was probably a quartz and quartzite gravel capping to higher ground across the modern central Fenland basin (a conclusion also reached by Belshaw, unpublished), the implication being that the Fenland basin did not exist at this time. Today the pre-Anglian sequences are confined to central to east East Anglia, where they are grouped as the Ingham Formation (Clarke & Auton, 1984; Hey & Auton, 1988; Gibbard et al., 2013). The stream responsible for this spread was almost certainly a precursor of the East Midlands-derived Trent, as earlier authors concluded (Shotton 1953, 1968, 1976, 1983a,b, 1989; Bishop, 1958; Rice, 1968, 1981, 1991; Rice & Douglas, 1991). This river can be traced upstream northwestwards across the Fenland into southern Lincolnshire, where it may have passed through the Ancaster Gap from the Trent catchment (Fig. 1). The river represented a left-bank tributary of the Thames up to and including the early Middle Pleistocene, before it was overridden and destroyed by the Anglian Lowestoft Formation glaciation (Fig. 2b).

Following from their investigations of glacial sequences on the eastern Fenland region, Gibbard et al. (2012b, 2013) have shown that the Baginton-Lillington Member sediments were deposited by a markedly younger, post-Hoxnian Stage river, as Shotton concluded. It was aligned northeastwards across the Midlands region at least into the Wreake Valley, Leicestershire, from where, instead of continuing northeastwards towards the eastern coast Humber estuary, it probably passed through the South Witham gap into south Lincolnshire (Figs 1 and 2b). From here, rather than turning southeastwards to cross the Fenland, it flowed into the Wash, then northeastwards into the Silver Pit, on the floor of the North Sea (during a lowstand phase). This proto-Soar/'Bytham river' continued to exist only until glaciation late in the Wolstonian Stage (early in Marine Isotope Stage (MIS) 6) entered the catchment, buried the deposits and dammed the river in the east and north to initiate the proglacial Lake Harrison. The latter drained into the Upper Thames catchment, as Bishop (1958) showed. Glacial overriding and drainage of the lake led to the establishment of the modern drainage system in the region following the glacial retreat late in the Wolstonian Stage. Whilst this evidence for changes to the main drainage lines has now been established, there remain several places where tantalising information on pre-Anglian river courses is available but its significance has yet to be assessed in the light of the latest discoveries.

Our aims are to evaluate the drainage significance of two critical pre-Anglian river systems of the south Midlands: the Milton Formation of Northamptonshire and the Letchworth (Gravel) Formation of Hertfordshire (Fig. 1). This enables us to rationalise the interpretation of the early Middle Pleistocene drainage development of south central England.

Milton Formation

Substantial spreads of gravel and sands, underlying Anglian-age glacial deposits, have been described from the Northamptonshire district, most recently by Belshaw (Belshaw, 1989, 2007, unpublished; Belshaw et al., 2004, 2005, 2006; Barron et al., 2006; Figs 1 and 3) and previously by Castleden (1980), Clarke & Moczarski (1982), Davey (1991) and Smith (1999). Their significance has not been fully considered in regional pre-glacial drainage reconstructions, as Belshaw (unpublished) stressed. The details presented herein incorporate his views, supplemented by his unpublished notes.

The pebbly sands of Northamptonshire occur in a series of spreads that extend from the Watford Gap southeastwards to south of Northampton. They have been typically exposed in the village of Milton Malsor (National Grid Reference (NGR): SP 7355), and were investigated and described from workings at Hill Farm (NGR: SP703577: Fig. 3) by Belshaw and colleagues (2004, 2005), where they were up to 10 m thick, although they generally reach 5–7 m (Belshaw, 1989). They continue to the south of Bedford, where they are mapped near Cardington (Barron et al., 2010). This spread has been traced a distance of over 30 km. A second spread from beneath Rockingham Forest is also well-known (Judd, 1875) and has been described in detail by the same authors. It was worked at Brigstock (NGR: SP558850) and appear to fill a buried network of drainage channels reported by Hollingworth and Taylor (1951) and Kellaway and Taylor (1952).

The similarity of these pebbly sands (the clasts comprising local Jurassic lithologies, but the sands attributed to a Triassic source) has resulted in them being grouped together as the

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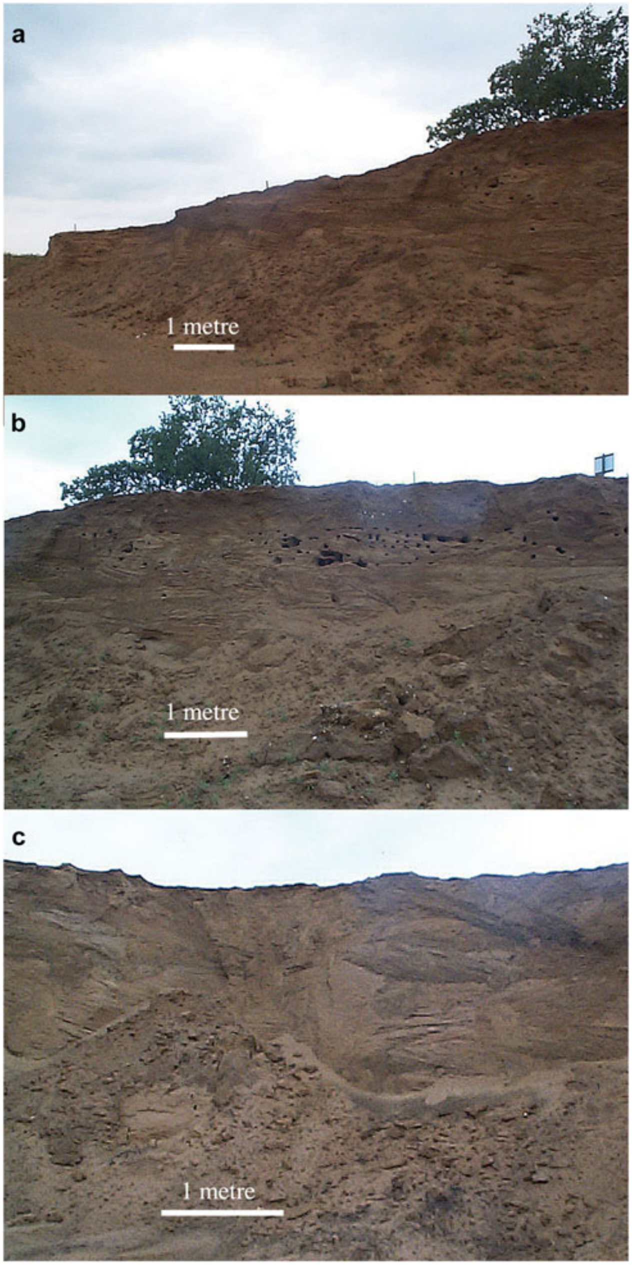

Fig. 3. Milton Formation sands and gravels at Hill Farm Quarry (for location see Fig. 1): a. looking towards the northeast; b. adjacent view towards the east; c. adjacent view towards the southeast–south (photographs by R.K. Belshaw, private collection).

Milton Formation (Sinclair & Smith, in Maddy, 1999). Their sedimentary structures indicate that they were laid down by braided streams flowing in a southeasterly direction predominantly in cold climates.

Exposures in the Milton Formation deposits are scarce, therefore a new cross-section along the A43 road south of the junction with the M1 motorway (Fig. 1; reconstructed from boreholes assembled from the BGS website: *http://mapapps.bgs.ac.uk/GeoRecords/GeoRecords.html*) provided a rare opportunity to examine the form of the sediment body. This section (Fig. 4) shows Milton Formation sands and gravel resting on Lower Jurassic (Lias) clay and underlying glacial diamicton (Lowestoft and possibly potentially the Wolston Formation), confirming previous authors' observations. Here the Milton Formation (Milton Malsor river) sequence fills a channel wider than 1 km, clearly trending in a southeastwards direction. The deposits are locally incised by a small stream, alluvial deposits filling a small cross-cutting valley.

The Milton Formation deposits of the Milton Malsor and Brigstock streams consistently indicate two sub-parallel drainage lines, aligned from WNW to ESE across Northamptonshire from close to the M1 motorway towards the southeast (Belshaw et al., 2004, 2005, 2006; Belshaw, 2007, unpublished). The local lithology of the gravel-sized clasts contrasts with the long-distance origin of the sand fraction. Belshaw (2007, unpublished) was convinced that the lack of quartz and quartzite pebbles was significant in indicating the provenance of these deposits. However, the absence of these clasts could reflect that the rivers were reworking the sand facies of the Sherwood Sandstone Formation (Triassic) since this represents the closest source of the quartz-bearing sands. This observation, together with their altitudinal distribution, convinced Belshaw et al. (2004, 2005, 2006) and Belshaw (2007, unpublished) that this indicates that the rivers must predate the initiation of the perpendicularly aligned proto-Soar/'Bytham river' in the Midlands region. Subsequently, the Milton Formation deposits were eroded during emplacement of overlying Lowestoft Formation (and potentially Wolston Formation) glacial deposits (Barron et al., 2010).

In general there are limited indications of the age of these spreads, apart from them being sandwiched between the Jurassic bedrock beneath and the Lowestoft Formation till (Anglian Stage) above, implying that they are of pre-Anglian age. The only vertebrate fossils recovered include a few fragments of horse bone, a tooth and 'three rotted tusks' from Hill Farm; 'none . . . allow an age determination' (Belshaw, 1989, p. 43), but the occurrence of horse, a steppe animal, supports the view that the river gravels and sands were laid down, as elsewhere in southern Britain, under cool-climate conditions.

In the 1990s, however, an exposure at Courteenhall Grange Farm, near Collingtree (NGR: SP7555: Figs 1 and 5), revealed fossiliferous fine-grained sediments up to 12 m thick filling a channel within the pebbly sands. Although this Courteenhall Member is thought to represent a separate Brigstock stream, its general setting and lithological similarity mean that it has been grouped with the Milton Formation. The fossil assemblages recovered include plant macrofossils of fruits, seeds and wood, and ostracods (Smith, 1999; Smith et al., 2000), which together indicate a fluvial interglacial floodplain channel–fill complex, accumulated under a temperate climate. Based on the fossil assemblages, Smith (1999) and Smith et al. (2000) correlated the interglacial deposits with the Cromerian Stage *s.l.* (i.e. early Middle Pleistocene). Assuming this age is correct, it confirms

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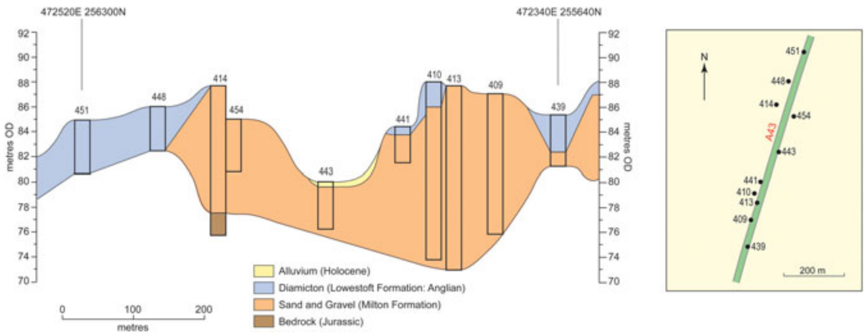

Fig. 4. Cross-section along the A43 trunk road, south of the junction with the M1 motorway (Fig. 1), reconstructed from borehole records (source: http://mapapps.bgs.ac.uk/GeoRecords/GeoRecords.html), showing the channel-like distribution of the Milton Formation and its relation to the bedrock and overlying deposits.

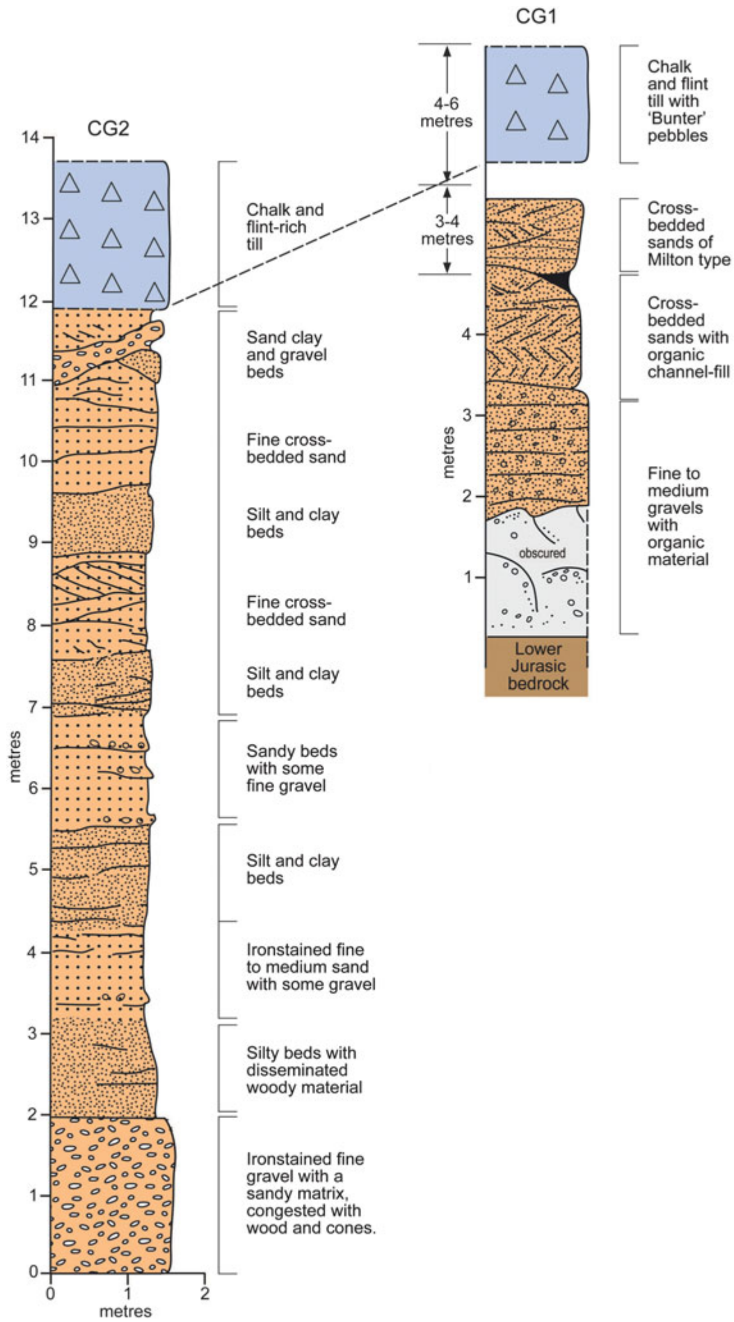

Fig. 5. Sediment sequences exposed at Courteenhall Grange Farm, near Collingtree, Northamptonshire (for location see Fig. 1), modified from Smith et al. (2000), showing the Milton Formation fluvial gravel and sands (including intercalated finer-grained Cromerian-age interglacial fluvial channel-fill units), unconformably overlain by Lowestoft Formation glacial diamicton (till).

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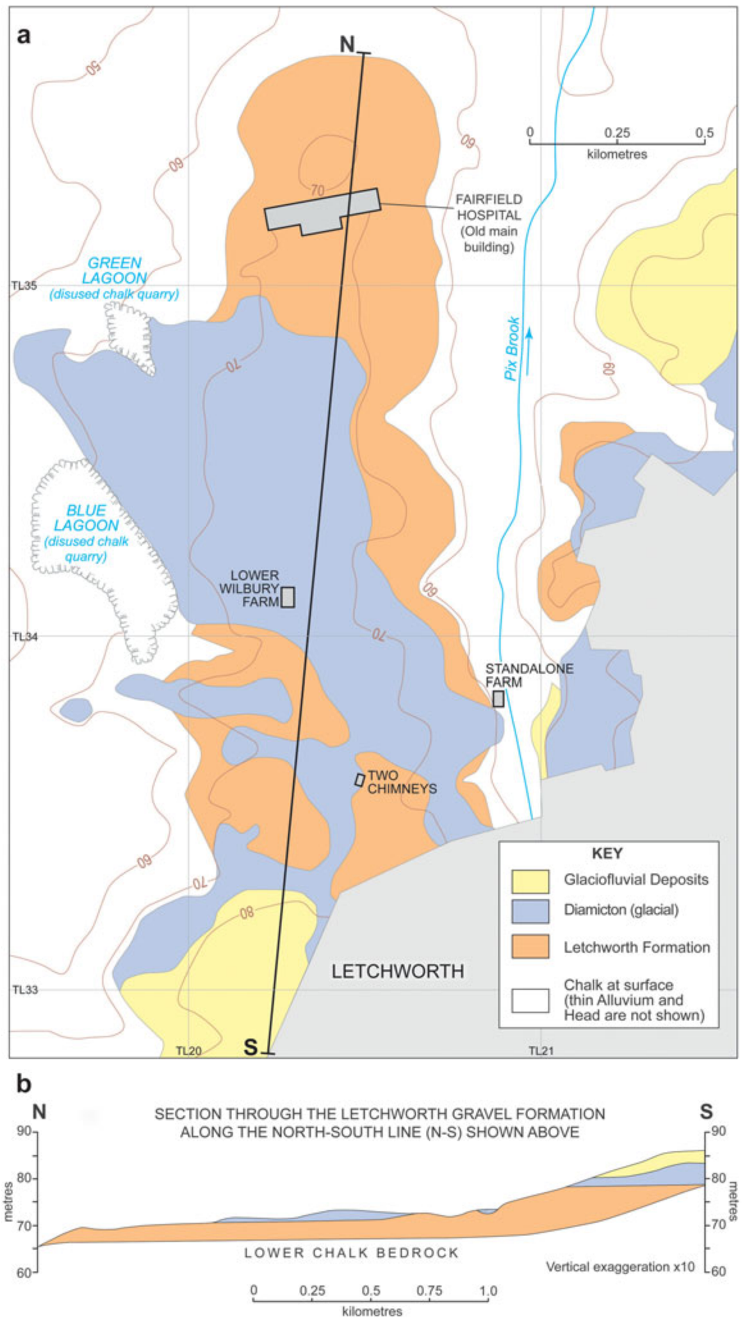

Fig. 6. Letchworth Formation: A. distribution map; B. cross-section along the north–south line shown in a, modified from Smith & Rose (1997).

that the stream was flowing before the Anglian-Stage glaciation.

Complex discussion of local details led Belshaw (207) to conclude that the Milton and Brigstock rivers originated during the early Pleistocene but continued into the early Middle Pleistocene based on drainage line relationships in the region, a view restated by Barron et al. (2006, 2010). The principal reason for suggesting this age was the presence of the proto-Soar 'Bytham river' in the immediate pre-Anglian, as suggested by Rose and colleagues (Rose, 1987, 1994, 2009; Lee et al., 2004a,b; cf. above, Fig. 2). However, since it is now known that the latter cannot have existed until after the Anglian-Stage glaciation, based principally on the litho- and biostratigraphy in the Midlands and East Anglia, the history of the drainage alignments in the region is greatly simplified. It appears that the immediately pre-Anglian period, i.e. the local pre-glacial Pleistocene, was characterised by a drainage system that is aligned WNW to ESE, the rivers of the south Midlands flowing southeastwards potentially to join the Thames as left-bank tributaries, as discussed below. Upstream the Milton course appears to be aligned towards the Watford Gap, northwest of Northampton (Barron et al., 2006; Fig. 1).

Letchworth Formation

A minor find of critical importance is the Letchworth Gravel (Figs 1 and 6). A small spread of sandy gravels (facies Gms) and pebbly sands was discovered capping a hill beneath

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Fairfield Hospital (now a residential development) immediately northwest of Letchworth in Hertfordshire (NGR: TL 205353) at c. 70–77 m OD during geological mapping by Hopson et al. (1996). The gravels here are 3.5 m thick, but reach as much as 9 m thick further south. Their pebble assemblage includes abundant quartz and quartzite pebbles, together with some sandstone and local flint. This isolated outcrop rests on chalk bedrock and is overlain by the local Anglian-age Lowestoft Formation diamicton. It is therefore interpreted to represent an immediately pre-Anglian or possible early Anglian Thames left-bank tributary stream derived from the Midlands (the Midlands Triassic rocks being the source of the quartz and quartzites exotic to the Hertfordshire region; Hopson et al., 1996; Smith & Rose, 1997; Fig. 2). Not unreasonably, the stream was assumed to be a Thames Kesgrave Formation equivalent (Hopson et al., 1996; Smith & Rose 1997), derived from the area west of Leicester, judging from the broadly northwest to southeast sub-parallel alignment of regional pre-glacial drainage in southern Britain (Gibbard, 1988). Whilst it is possible that it would broadly be aligned with the Milton Formation Brigstock course, it is more likely that it is the downstream equivalent of the Milton Malsor course (Fig. 7). Although this explanation is certainly reasonable given the lithologies and the unit's setting, Belshaw et al. (2005) state emphatically that no upstream equivalent is known in Northamptonshire, so this spread partially remains enigmatic.

However, to have sourced the quartz and quartzite-bearing Triassic bedrock (Fig. 2), this stream would almost certainly have crossed, or at least come very close to, the proto-Soar/ 'Bytham river' valley had the two rivers existed at the same time. Moreover, although the gradient of the Letchworth stream cannot be reliably determined, it would have crossed the proto-Soar valley at a level higher than that at which the Baginton Formation deposits occur in the Leicester area (c. 60 m OD: Rice, 1968). The inevitable conclusion is that the Baginton Formation river could not have coexisted with the Letchworth stream, and therefore the former, since it is the larger river and potentially occurs at a lower level, must be younger – a conclusion also reached by Smith and Rose (1997). These authors attempt to explain this apparent conflict of evidence by invoking later beheading of the Letchworth Formation stream by a younger 'Bytham river' aligned from the southwest. Whilst this is possible, there is no evidence to support this assertion (since the latter has no long history in the Midlands area; Gibbard et al., 2012b; Belshaw, unpublished) and therefore it cannot be tested. In summary, this single Letchworth spread reinforces the view that the Midlands 'Bytham river' cannot have existed before the Anglian-Stage

Fig. 7. Reconstructed drainage alignments in southern central England during the pre-Anglian Middle Pleistocene, based on the interpretations presented in the text.

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glaciation and indicates that the drainage in the Midlands region was aligned perpendicular to the later proto-Soar course.

The Letchworth Formation spread occurs immediately east of the Hitchin–Stevenage tunnel valley, a major landform that originated as an Anglian-age glacial meltwater conduit (Woodland, 1970; Gibbard, 1974, 1977; Hopson et al., 1996: Fig. 1). Such substantial valleys are generally regarded as having been superimposed on the landscape without necessarily requiring pre-existing valley alignments. However, the occurrence of the Letchworth deposits implies that a depression through the Chiltern Hills (Fig. 1) must have occurred along the broad NNW–SSE alignment to have allowed the river to continue towards its confluence with the River Thames in Hertfordshire (cf. Smith & Rose, 1997). Indeed these authors concluded that altitudinal correlation of the Letchworth sediments with the youngest member (Westmill Lower Gravel) of the Thames Kesgrave Formation via this route to Ware implied that the unit was deposited just prior to the Anglian-Stage glaciation.

Palaeogeographical implications

In a recent compilation of the Cenozoic drainage history of the region, Gibbard and Lewin (2003) concluded that the major river systems have remained broadly consistent in their alignments over much of the era. This interpretation, based on fluvial sedimentation and provenance, unequivocally demonstrated that the major elements (the Thames, Solent, Irish Sea river and possibly the early Trent river) existed throughout much of the Tertiary, i.e. for at least 55 Ma, and continued to flow throughout the pre-glacial Pleistocene (Gibbard, 1988). This evidence indicates that the precursors of the major drainage lines of southern England were initiated on a southeast to eastwards-sloping land surface resulting from uplift in the west and northwest that began at the end of the Cretaceous and has continued intermittently throughout the Cenozoic (e.g. Cope, 1994, 1995). This gave rise to a predominant northwest to southeast alignment of major streams, i.e. parallel to the regional dip of the Mesozoic and Tertiary strata (Gibbard & Allen, 1994; Boreham & Langford, 2006). In the light of this observation, it is striking that the 'Bytham river' (proto-Soar), as originally proposed, was aligned southwest to northeastwards across the Midlands, i.e. perpendicular to the regional dip, or parallel to the strike of the Mesozoic strata. The alignment of the 'Bytham river' perpendicular to the regional topographic slope is problematic for capture of the Thames headwaters, as Rose (1987, 1989a, 1994) has advocated. Indeed, the establishment of the proto-Soar following beheading and redirecting of the Thames waters (cf. Maddy, 1999) as a consequence of substantial glaciation of the region is a more credible explanation.

The proto-Soar/'Bytham river' is much younger than the Anglian glaciation and this explains the apparent conflict of evidence for a pre-existing (i.e. pre-Anglian) drainage alignment of both major and minor streams, such as those represented by the Milton and Letchworth formation deposits. Judging from their projected courses, these streams were aligned broadly northwest to southeast from the south central Midlands to join the Thames as left-bank tributaries in Hertfordshire and Essex. Their courses would therefore have been aligned sub-parallel to the Ingham stream (Trent) in the east and the Thames' own headwaters in the west (Fig. 7).

The alignment of the Milton and Letchworth formation streams implies that their courses towards the Thames were adjusted to the regional geological dip on the Chalkland Chiltern Hills, their courses appearing to have been exploited by the later Anglian-age Hitchin–Stevenage and Cam–Stort tunnel valleys.

Additional evidence of a drainage pattern that evolved from 'consequent' streams to 'subsequent' streams is provided by the six other major valleys that cross the Chiltern cuesta in the extra-glacial area to the southwest of the Hitchin–Stevenage valley, at Luton, Dunstable, Dagnall, Tring, Wendover and Princes Risborough. Five of these 'gaps' are dry ('wind gaps'), whereas the sixth, the easternmost one, is occupied by the River Lea, southeast of Luton (Fig. 1). The floors of the gaps decline in elevation southeast towards the Vale of St Albans and the London Basin lowlands (Jones, 1981, pp. 34–35) and gravels occur within some of them, for example the Princes Risborough Sand and Gravel (Horton et al., 1995). These authors attributed such gravels to deposition by rivers that flowed southeastwards through the Chalk cuesta. According to Sumbler (1995), these former 'consequent' rivers flowed down the Chalk dipslope towards the Thames; their valleys, now truncated by the Chiltern scarp, are higher than, and therefore predate, the drainage system of the River Thame, a 'subsequent' river which extends into the Vale of Aylesbury. This realignment, resulting from lowering of river base levels throughout the Thames' system catchment, could have occurred in response to river diversion following the opening of the Dover Strait. This evolution closely parallels the coeval response reported in the upper Scheldt basin in Flanders by Vandenberghe and De Smedt (1979).

As Belshaw et al. (2004) noted, it is clear from the lithological composition of the Milton gravels (which lack exotic lithologies especially the quartz and quartzite assemblages that typify rivers that drained the Midlands' Triassic rocks) that the stream extended through the Watford Gap, potentially to the Rugby area. The stream must therefore have been reworking predominantly sand. Judging from the same criteria, however, the occurrence of frequent quartz pebbles in the Letchworth deposits, in contrast to the Milton Formation units, could reflect the fact that the stream was exploiting Triassic pebble-bed lithologies that had been unroofed in the Rugby area later than the spreads present in the Northampton district. If this is accepted, this implies that the Letchworth deposits are younger that those further to the north-west. The interglacial deposits

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identified at Courteenhall Farm indicate that the Brigstock stream was certainly flowing in the early Middle Pleistocene.

The implication of these conclusions therefore is that the main drainage alignment in southern England was dominated by northwest to southeast-aligned consequent streams until the Middle Pleistocene Anglian glaciation. This pattern continued that already established during the preceding late Tertiary (cf. Gibbard, 1988; Gibbard & Allen, 1994; Gibbard & Lewin, 2003), i.e. parallel to the regional tilting of the British landmass, as later concluded by Belshaw et al. (2005).

This river system was effectively destroyed by regional (Anglian) glaciation in the Middle Pleistocene, a new system being established on the deglaciated terrains. The alignments of this new system were dictated, in part, by the glacial topography, as noted by Rose et al. (1985) in East Anglia. Subsequent topographic evolution has been controlled across the region by weathering, mass movement and fluvial erosion principally under periglacial and permafrost conditions. Under these conditions strike-orientated rivers, aligned along the vales of the region underlain by frost-susceptible Mesozoic clays, such as the recent Soar and Ouse, came to dominate the landscape following deglaciation (Belshaw, 2007, unpublished; Murton & Belshaw, 2011; Boreham & Langford, 2006). As elsewhere in lowland eastern England this must have begun forming in the latest, postglacial Wolstonian (i.e. = Warthe Stadial) times (e.g. Gibbard et al., 2012a), judging from the topographic situation in which the last interglacial (Ipswichian/Eemian Stage) fluvial deposits occur and assuming that the Wolstonian glaciation is the equivalent of that during the Drenthe Stadial on the near Continent, as these authors demonstrate. The development continued throughout the cold phases of the Devensian (= Weichselian) Stage.

Conclusions

1. Recent interpretations, based on fluvial sedimentation and provenance, indicate that the precursors of the major drainage lines of southern England were initiated on a southeast to eastwards-sloping land surface resulting from uplift in the west and northwest that began at the end of the Cretaceous and has continued intermittently throughout the Cenozoic. This predominant northwest to southeast alignment gave rise to major consequent streams (Fig. 7).
2. Pre-existing (i.e. pre-Anglian) major and minor streams, such as those represented by the Milton and Letchworth formation deposits, were aligned sub-parallel from the south central Midlands to join the Thames as left-bank tributaries in Hertfordshire and Essex (Fig. 7).
3. The lithological composition, exposure and borehole evidence of the Milton Formation gravels demonstrate that the streams represent significant drainage lines, the catchment of the Milton Malsor river extending through the Watford Gap to include the Rugby district. Likewise, the Letchworth river must be the downstream equivalent of the Milton Malsor stream, but its quartz pebble assemblage suggests that it might represent a younger depositional unit (based on the lack of coarse quartz clasts in the Milton exposures). The lack of equivalent deposits preserved in the Northamptonshire region must reflect later, potentially significant glacial erosion. The Brigstock stream grades upstream towards the east of Leicester. The streams flowed both under cool (steppe) and temperate climate conditions.
4. The Milton and Letchworth formation drainage courses indicate that the pre-Anglian drainage in the Midlands' region was aligned perpendicular to the later Baginton Formation proto-Soar course. This reinforces the view that the Midlands 'Bytham river' (proto-Soar) cannot have existed before the Anglian-Stage glaciation.
5. Glaciation of the south central Midlands during the Anglian Stage destroyed the network of consequent streams there.
6. After the Anglian Stage the proto-Soar river began to flow from southwest to northeast and deposited the sediments of the Baginton Formation.
7. Renewed glaciation of the south central Midlands during the Wolston Formation time in the late Middle Pleistocene (Wolstonian Stage) destroyed the course of the proto-Soar river.
8. Following this second glaciation, a new drainage system developed on the deglaciated terrain. Subsequent topographic evolution occurred largely under periglacial and permafrost conditions. Strike-orientated rivers, aligned along the clay vales of the region, such as the Soar and Ouse, came to dominate the landscape from the latest Wolstonian (i.e. = Warthe Stadial) to the present.

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