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Early-Middle Pleistocene Beheading of the River Thames
La capture de la Tamise au Pléistocène inférieur et moyen
Die Ablenkung der Themse im mittleren Pleistozän

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Résumé de l'article

Cet article marque le centenaire du premier de trois articles consacrés par W.M. Davis à la capture de la Tamise qui commençait par une déclaration de son hypothèse de capture en 1895 et concluait par des tentatives d'explication du réseau inadapté, en 1899 et 1909. L'article discute de la thèse classique de Davis de capture suivant une évolution lente, à long terme, du paysage, et son apparente réticence à accepter le fait des changements climatiques rapides survenus au Quaternaire. Par opposition, les travaux récents, fondés sur la lithostratigraphie, la biostratigraphie et la morphostratigraphie, soulignent l'importance de la période quaternaire et son influence sur les captures. Les mécanismes pouvant être responsables de la capture de la Tamise, notamment la tectonique, l'érosion glaciaire, la capture fluviale classique selon Davis, ainsi que la chronologie des événements, sont discutés. En conclusion, cet article résume les faits connus et les éléments méconnus du problème de la capture de la Tamise et discute des limites de l'influence de Davis sur les études postérieures sur la Tamise.

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EARLY - MIDDLE PLEISTOCENE BEHEADING OF THE RIVER THAMES

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ABSTRACT This paper marks the centenary of the first of three articles by W.M. Davis on the beheading of the Thames, beginning with a statement of his capture hypothesis in 1895 and concluding with attempts to explain anomalous misfit streams in 1899 and 1909. It discusses Davis's classic thesis of river capture by slow, long-term landscape evolution and his apparent reluctance to accept the fact of rapid Quaternary climate change. In contrast, recent work based on lithostratigraphy, biostratigraphy and morphostratigraphy emphasises the dynamism of the Quaternary Period and its influence on river capture. Possible mechanisms for the beheading of the Thames, tectonism, glacial erosion and conventional Davisian river capture, and the timing of the event, are discussed. In conclusion, the paper summarises known and unknown components of the problem of the beheading of the Thames, and discusses the extent of Davis's influence on later Thames studies.

RÉSUMÉ *La capture de la Tamise au Pléistocène inférieur et moyen.* Cet article marque le centenaire du premier de trois articles consacrés par W. M. Davis à la capture de la Tamise qui commençait par une déclaration de son hypothèse de capture en 1895 et concluait par des tentatives d'explication du réseau inadapté, en 1899 et 1909. L'article discute de la thèse classique de Davis de capture suivant une évolution lente, à long terme, du paysage, et son apparente réticence à accepter le fait des changements climatiques rapides survenus au Quaternaire. Par opposition, les travaux récents, fondés sur la lithostratigraphie, la biostratigraphie et la morphostratigraphie, soulignent l'importance de la période quaternaire et son influence sur les captures. Les mécanismes pouvant être responsables de la capture de la Tamise, notamment la tectonique, l'érosion glaciaire, la capture fluviale classique selon Davis, ainsi que la chronologie des événements, sont discutés. En conclusion, cet article résume les faits connus et les éléments méconnus du problème de la capture de la Tamise et discute des limites de l'influence de Davis sur les études postérieures sur la Tamise.

ZUSAMMENFASSUNG *Die Ablenkung der Themse im mittleren Pleistozän.* Dieser Artikel hebt den hundertsten Jahrestag des Erscheinens des ersten von drei Artikeln von W.M. Davis über die Ablenkung der Themse hervor. Dieser begann 1895 mit der Darlegung seiner Ablenkungs-Hypothese und schloss 1899 und 1909 mit Erklärungsversuchen anomaler unter- oder überfähiger Strömungen. Der Artikel setzt sich mit Davis' klassischer These der Flussablenkung durch langsame langzeitige Landschaftsentwicklung auseinander sowei seinem Widerstreben, die Tatsache einer schnellen Klimaveränderung im Quartär zu akzeptieren. Im Gegensatz dazu betonen neuere Arbeiten ausgehend von Lithostratigraphie, Biostratigraphie und Morphostratigraphie die Dynamik der Quartär-Zeit und ihren Einfluss auf die Flussablenkung. Mögliche Mechanismen bei der Ablenkung der Themse wie Tektonik, glaziale Erosion und die konventionelle Flussablenkung nach Davis, sowie der zeitliche Ablauf dieses Geschehens werden diskutiert. Abschliessend fasst der Artikel bekannte und unbekannte Elemente des Problems der Ablenkung der Themse zusammen und erörtert, inwieweit Davis spätere Themse-Studien beeinflusst hat.

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INTRODUCTION

"Of all the river contests in England, that by which the Thames system has been shorn of its original importance is the most interesting." These words of William Morris Davis (1895, p. 144), without doubt one of the leading geomorphologists of this century, were published 100 years ago following his visit to Britain to study English river networks. Davis made three excursions (1894, 1898 and 1908) to the region of Central England known as The Cotswolds (Cotteswolds), or Cotswold Hills, where the River Thames and many of its upper tributaries now have their source. He was already familiar, from cartographic studies carried out in America, with the distribution of rivers in this region (Fig. 1), an area of gently dipping Jurassic strata which, with the Cretaceous Chalk strata, he referred to as the "Mesozoic coastal plain" (Davis, 1899, p. 87).

His first field visit confirmed *for Davis* the correctness of his general deductive scheme of river development. In retrospect, however, it is clear that Davis' methodology was fundamentally flawed. Not only was it based on a concept of slow, long-term landscape evolution, thereby minimising the potential effects of rapid climate change during the Quaternary, but it ignored important lithological and sedimentological evidence which invalidated the reliance on cartography. It is only during the last three decades with the detailed study of sediments, in conjunction with terrace morphology, that significant progress has been made towards resolving the question of the contraction of the Thames catchment. Even so, the precise timing of this event, and the mechanism by which it was achieved, remain subjects of considerable interest for British Quaternary palaeogeographers some 100 years later. The aims of this paper are fourfold: to review the Davisian contribution to studies of the River Thames, to summarise the present state of knowledge about the beheading of the Thames, to discuss these views in the context of Davis' thesis, and to suggest lines of further productive study.

THE DAVISIAN CONTRIBUTION TO THAMES STUDIES

Davis wrote three papers with specific references to the beheading of the River Thames. They reveal an interesting progression from an initial confident statement of his theory through a series of attempts to account for obvious anomalies. Following his first visit, Davis (1895) presented his well-known theoretical arguments for river capture and river network development, together with a brief description of his interpretation of the evolution of English rivers, including the Thames (Fig. 1). His theory was based largely on the concepts of widespread periodic uplift and geological structural control. Only at the end of his presentation did Davis (1895, p. 141) refer to possible effects of "other [local] movements, as well as of glacial episodes", and suggest that they should be "carefully examined when the subject is minutely studied, instead of broadly sketched".

In his second paper, on the drainage of cuestas, Davis (1899) acknowledged two earlier contributions to the Thames story, those of Ellis (1882) and White (1897). In particular, White (1897) had inferred the beheading of the Thames from sedimentary evidence on the Cotswolds dipslope. These sediments contain Triassic rocks from northwest of the Cotswolds, and, at least in part, take the form of linear spreads of gravel, a feature which White interpreted as indicative of fluvial rather than marine or glacial processes. White (1897. p. 168) was effusive in his praise of Davis' (1895) "work - distinguished for its acumen, its suggestiveness, and for the valuable comprehensive technical terms it introduce[d]". For

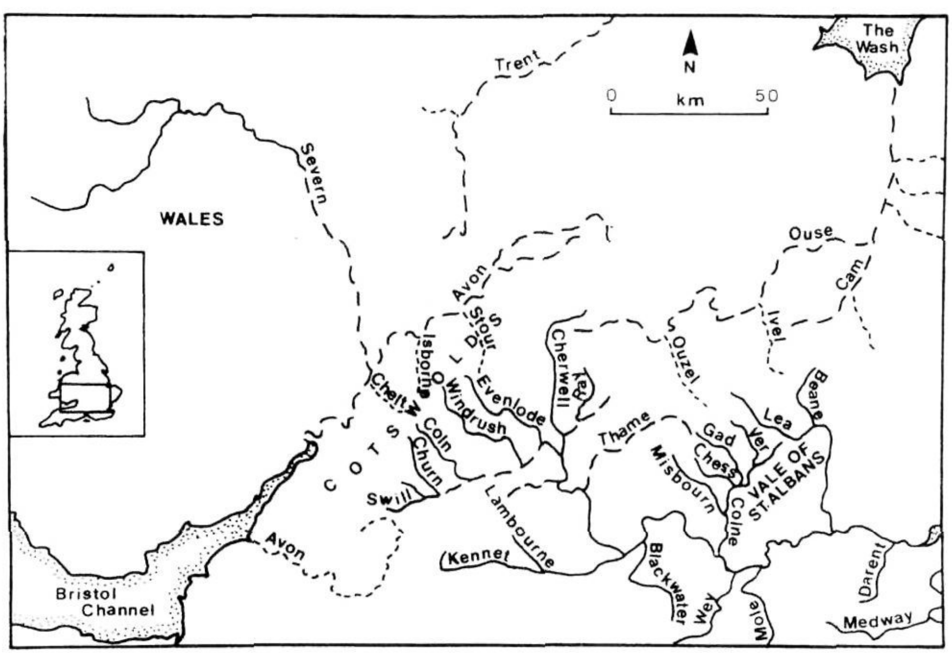

FIGURE 1. Consequent (solid lines), subsequent (long dashes) and obsequent (short dashes) rivers, according to Davis (1895).

Cours d'eau conséquents (lignes pleines), subséquents (tirets longs) et obséquents (tirets courts), selon Davis (1895).

White, Davis provided the critical theoretical support for his sedimentological evidence of the beheading. Davis (1899) also drew particular attention to another of White's (1897) conclusions; that both river discharge and channel width, in addition to debris supply, would be reduced following the reduction in catchment size. These parameters are important elements in Davis' (1899) discussion of 'misfit' streams in tributary valleys of the Upper Thames. Davis (1899, p. 92) argued that if capture is the sole cause of the reduction in discharge inferred by the 'misfit' streams, then "the branches of the [River] Severn system [which he assumed had effected the capture] ought to be as robust as those of the Thames system are feeble". To test this, Davis visited the Stour River and found "to his surprise.. [that].. that stream [is] also a misfit in a meandering valley" (p. 92). Map evidence indicated to Davis that the River Avon, likewise northwest of the Cotswold escarpment, is another 'misfit'. Reference to other areas caused Davis (1899, p. 93) to suggest that "a similar complication of the problem" was found in the case of the Meuse and Moselle, and the Aisne and Aire rivers in France. Davis (1899, p. 93) was obliged to concede a "*general* decrease of stream volume" and suggested that the cause might be either "increased evaporation following the destruction of ancient forests and the cultivation of the ground" or "some climatic change of *external* or *obscure* origin" (author's italics). The italicised words reveal Davis' reluctance to accept climate change as a cause of fluvial network change (Chorley *et al.*, 1973), and he actually concluded his second Thames paper with a firm expression of confidence in "the correctness of the general scheme" (Davis, 1899, p. 93). Nevertheless, the complication introduced by the unexpectedly 'underfit' nature of the streams responsible for the capture clearly gave Davis cause for concern because he addressed the problem again in a short paper (Davis, 1909) following his third visit to the Cotswolds in 1908.

Davis (1909) began his explanation for the ubiquitous 'misfits' from the premise that glacial drift exists on the Cotswolds dipslope. For this he acknowledged Professor Sollas of Oxford University, though J. Geikie (1877) had already made the suggestion. Davis (1909, p. 151) argued that "Cotswold ice-water [glaciofluvial] streams" would have been competent to produce the large valley meanders which contain the present underfit stream of the River Evenlode (the present day successor of the former River Thames) on the Cotswolds dipslope. As the ice sheet retreated to the northwest of the Cotswolds escarpment, tributaries of the River Severn in this area would have been similarly swollen with meltwater producing large valley meanders, while the discharge of the River Evenlode (Thames) would have been reduced. On further retreat of ice from the area the Severn and Avon rivers also would have reverted to their preglacial size, becoming 'underfit' streams rather than the 'overfit' streams implied by Davis' model. Although this argument provided Davis with a neat explanation of the local 'complication', it obviously cannot be applied to the many extra-glacial regions where Davisian-style capture has been proposed.

The scattered drift deposits on the Cotswolds dipslope have often been interpreted as glacial (Geikie, 1877; Pocock, 1908; Sandford, 1926; Tomlinson, 1929; Arkell, 1947; Shotton *et al.*, 1980), especially that at Bruern Abbey (Hey, 1986; Whiteman and Rose, 1992), and yet convincing sedimentological evidence for glaciation in this area has never been presented. The only generally accepted glacial deposit within the Cotswolds area is the Moreton Drift (Tomlinson, 1929) of Anglian age (Rose, 1987) extending from the West Midlands into the Moreton Gap, the col in the Cotswolds escarpment between the Rivers Evenlode and Stour (Fig. 2b). As these glacial deposits fill the 'post-diversion' valleys we believe that this Anglian glaciation post-dates the beheading of the Thames (Whiteman and Rose, 1992).

MODERN THAMES STUDIES

Recent work has re-focused the spotlight on the question of the beheading of the Thames, concentrating on local studies and detailed lithostratigraphic analysis. In addition, evidence of a Quaternary river flowing in the opposite direction to the present River Avon (Shotton, 1953; Fig. 2b), with headwaters presumably in the area crossed by the former route of the Thames northwest of the Cotswolds, has been considerably expanded within the last decade (Rose, 1987, 1989). Detailed lithological and morphological evidence shows that this former river (the Bytham River of Rose, 1994) breached the Jurassic escarpment in eastern England and flowed across East Anglia ultimately to a confluence with the lower reaches of the Early and Middle Pleistocene Thames or Rhine in the area of the present North Sea. The headward expansion of this large river system may have been responsible for capturing the River Thames in central England (Rose, 1987, 1989, 1994), though the apparent absence of unequivocal samples of distinctive Welsh volcanic rock in the sediments of this river does not support this, as they are a conspicuous component of gravels deposited by the captured Thames.

Another analysis, concerned with the Thames system itself, approached the catchment problem by paying more attention to the geomorphological elements of catchment palaeodrainage parameters. It was shown (Whiteman, 1992) that Thames terraces in the lower part of the system possess significantly lower gradients (*ca.* 0.5 m/km) than had often been inferred in earlier correlations of the terraces (*ca.* 1 m/km) (Hey, 1980; Green *et al.*, 1982; Gibbard, 1983; Allen, 1984; Bridgland, 1988). If the steeper gradients, postulated by earlier studies, were projected upstream the resulting elevations of Thames terraces would far exceed the altitude of actual terrace remnants in the present Upper Thames area and their projected equivalents to the northwest. In contrast, the less steep gradients are far more appropriate, geomorphologically, to a large Thames catchment extending over much of the West Midlands and Wales. Correlations of Thames terrace members, based on these lesser gradients (Whiteman and Rose, 1992; Fig. 3), demonstrate a clear difference between a group of lower, younger members (comprising the Colchester Formation of Whiteman, 1992) which, from the evidence of their gradient, are confined within the present catchment and do not cross the escarpment, and a group of higher, older members (comprising the Sudbury Formation of Whiteman, 1992) which can all be projected to

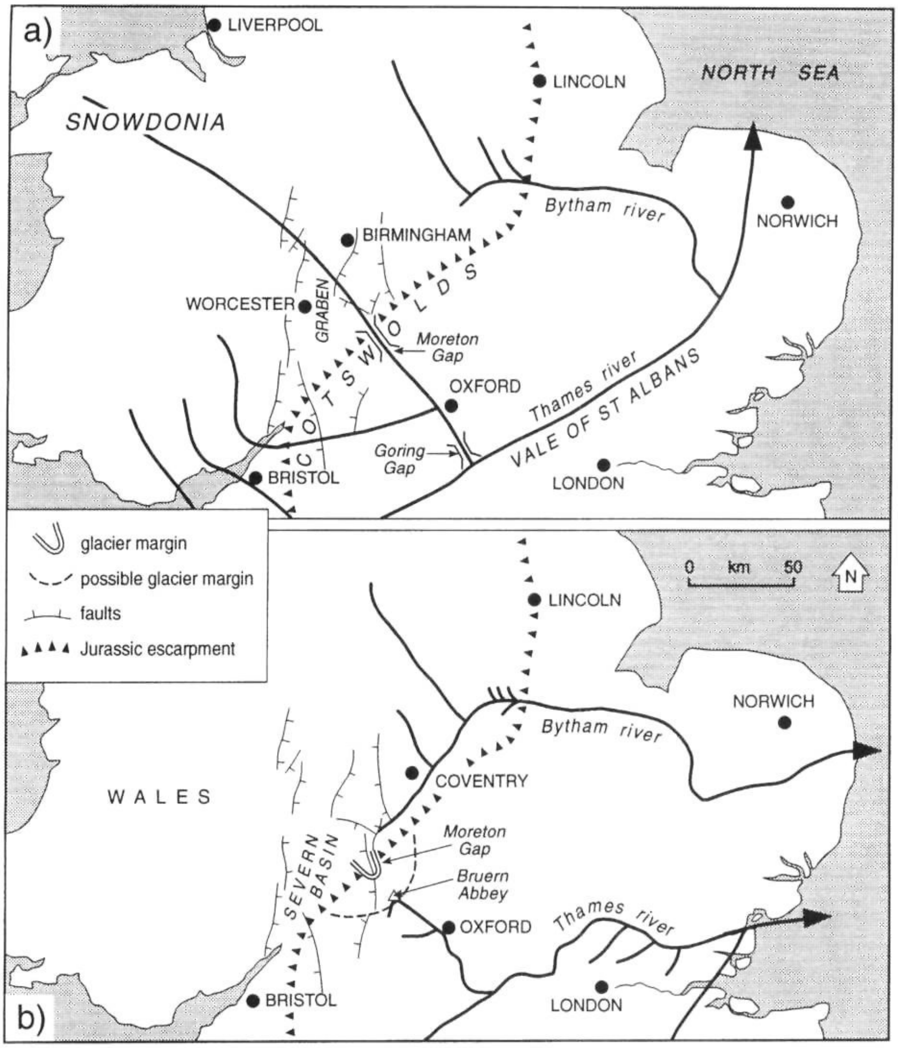

FIGURE 2. The Thames and Bytham river systems before (a) and after (b) the capture event, according to Rose (1989). Figure a also shows the major faults associated with the Worcester Graben. Figure b also shows the position of a possible pre-Anglian ice margin near Bruern Abbey and the Anglian Stage ice margin in the Moreton Gap.

Les réseaux hydrographiques de la Tamise et de la Bytham avant (a) et après (b) la capture, selon Rose. En a apparaissent également les principales failles associées au graben de Worcester. En b apparaissent aussi la position d'une hypothétique marge glaciaire pré-anglienne près de Bruern Abbey et la marge glaciaire à l'Anglien dans le Moreton Gap.

the northwest through and beyond the Moreton Gap in the Cotswolds escarpment (Fig. 4).

This idea of a larger Thames catchment is, as we have already seen, not a new one (Ellis, 1882; Davis, 1899; White, 1897). What had not been demonstrated until recently is the geomorphological link between this extended catchment and the whole of the rest of the Thames terrace system (Whiteman and Rose, 1992). Within the even larger context of southern British Quaternary river systems in general (Rose, 1994), the cause and the timing of the beheading of the River Thames assume considerable importance. Before these crucial questions are addressed, evidence for the contraction of the Thames catchment will be briefly summarised.

EVIDENCE FOR CONTRACTION OF THE THAMES CATCHMENT

Evidence for the existence of a larger, former Thames catchment (Fig. 2a) comes primarily from two sources: the presence in the Thames deposits of substantial amounts of quartz and quartzite (up to 50%) that can only have come from the West Midlands, together with small but significant quantities of acid volcanic rocks from the Snowdonia area of North Wales; and the morphology of terraces and their associated sediments.

Several types of lithological and morphological evidence for the contraction of the Thames river catchment have been recognised (Whiteman, 1990; Rose, 1994); (i) mean ratios of flint to quartz plus quartzite in 58 comparable clast analyses from southern East Anglia (Hey, 1965, 1980; Allen, 1984; Bridgland, 1988; Whiteman, 1990) show a conspicuous difference of lithology between the Sudbury and Colchester Formations reflecting a change in the source of sediment; (ii) both a decrease in floodplain width and an increase in floodplain sinuosity are revealed by the reconstruction of terrace surfaces from borehole evidence in the Vale of St. Albans and western Essex (Whiteman, 1990) which is likely to reflect the smaller discharge of the river which deposited the Colchester Formation; (iii) the steeper surface gradients of the terraces that form the members of the Colchester Formation compared to those of the Sudbury Formation reflects the smaller discharge of the later river and the new relative position of these younger terraces near the head of a shortened catchment; (iv) it seems possible to explain the position of flu-

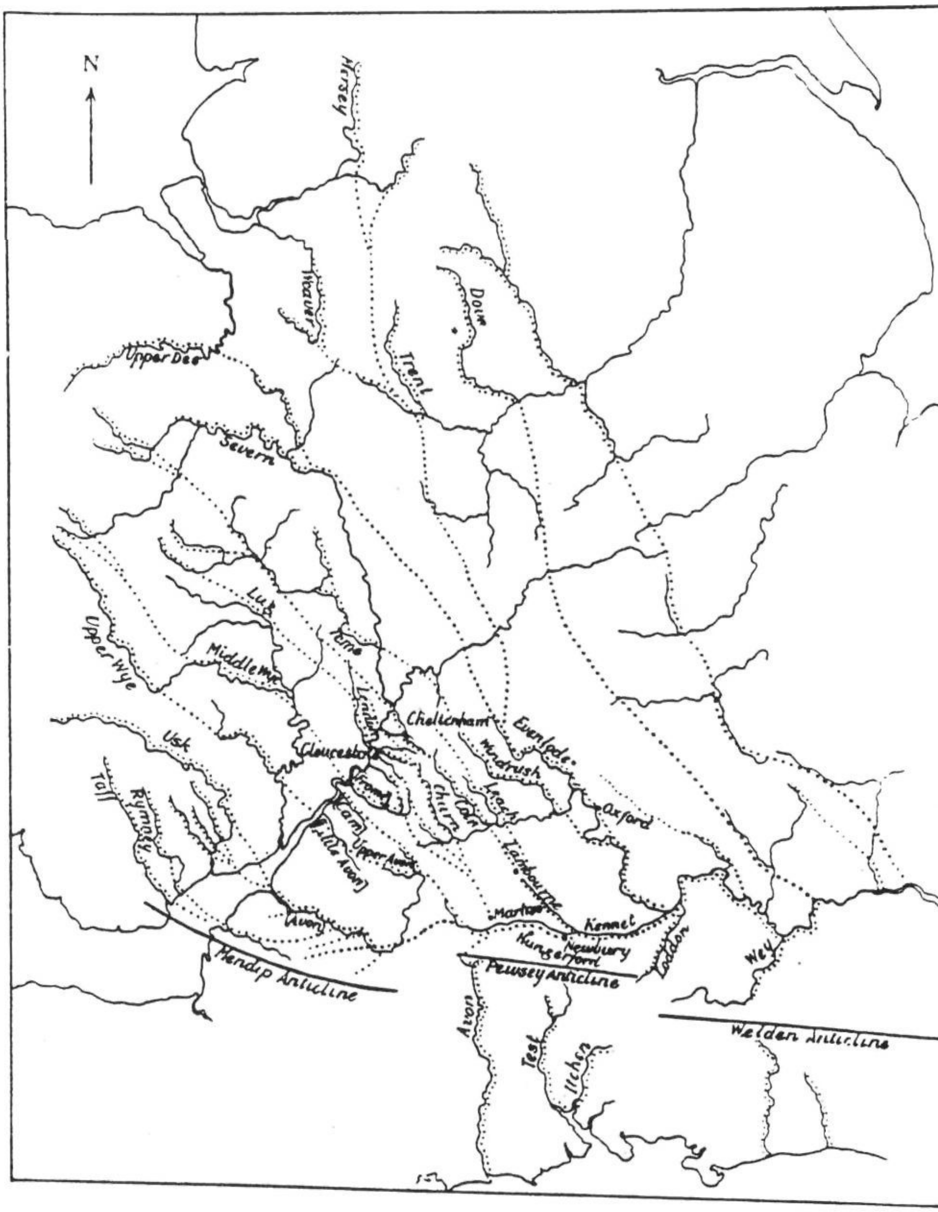

FIGURE 3. Davisian-type reconstruction of consequent rivers (from Buckman, 1900, Fig. 12, p. 181).

Reconstitution davisienne d'un réseau de cours d'eau conséquents (de Buckman, 1900, fig. 12, p. 181).

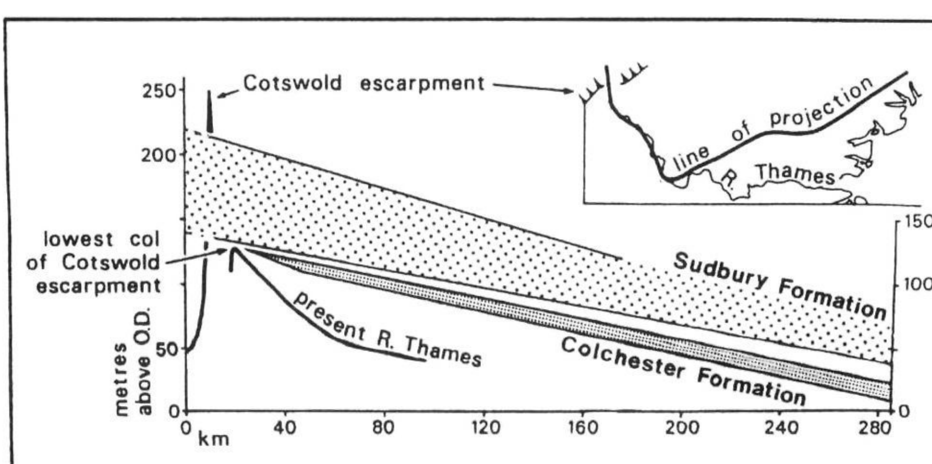

FIGURE 4. Diagrammatic representation of long profiles of the Thames showing the Sudbury and Colchester Formations and their relationship to the lowest col through the Cotswold escarpment.

Diagramme des profils en long de la Tamise montrant les formations de Sudbury et de Colchester et leur relation avec le col le plus bas de l'escarpement de Cotswold.

vial gravel remnants within gaps in the Cotswold escarpment only by reference to a former river system flowing from an area to the northwest of that escarpment.

CAUSES OF CONTRACTION OF THE THAMES CATCHMENT

There is obviously no problem in demonstrating that the beheading is a real phenomenon. It is proving more difficult to explain how the beheading was achieved. One reason for this difficulty is the lack of sediment attributable to deposition by the Thames in the supposed truncated part of the catchment to the northwest of the Cotswold escarpment. Here only erosional evidence, which is difficult to interpret, apparently survives. Nevertheless, we will consider three possible mechanisms which could have caused the beheading; i) river capture due to tectonism, ii) glacial erosion and iii) conventional Davisian river capture.

RIVER CAPTURE DUE TO TECTONISM

The diversion or capture of rivers resulting from tectonism has been widely reported from tectonically active areas (*e.g.* Thomas and Shaw, 1988) and there can be little doubt that this is a feasible explanation for the beheading of the Thames. Two large structural depressions, the Severn Basin and the Worcester Graben, and other major faults are located in appropriate areas of the West Midlands (Fig. 2b) northwest of the Cotswolds escarpment (Hains and Horton, 1969; Anderton *et al.*, 1979). Although vertical movement associated with these structures amounts to hundreds of metres, these structures formed long before the Quaternary and unequivocal evidence of a major fault initiation during the Quaternary is lacking (Hains and Horton, 1969). Shotton (1965) suggested that structural deformation affecting Quaternary sediments in the Midlands may reflect reactivation of basement faults following deglaciation, but Hains and Horton (1969) argued that glacial unloading is more likely to have resulted in many small adjustments rather than large displacements along existing deep faults. It seems unlikely, therefore, and there is no clear evidence that the loss of a substantial part of the Thames catchment is attributable to major tectonic movements.

GLACIAL EROSION

The second mechanism which may possibly account for the contraction of the Thames catchment is glacial erosion. We have already alluded to the presence of glacial sediments in the Cotswolds area. Those which extend from the northwest into the gap near Moreton-in-Marsh are unequivocally glacial and attributable to the Anglian (Elsterian) Stage of the British Quaternary (Rose, 1987). As they also occur in the lowlands to the northwest of the Cotswolds escarpment, and overly the most northwesterly extension of sediments of the Colchester Formation, the ice sheet which deposited them cannot be implicated in the beheading of the Thames.

Less substantial evidence supporting glaciation in the area southeast of the Cotswolds escarpment includes a striated clast from a gap in the Chalk escarpment west of the Goring Gap (Whittow, 1976; Fig. 2) and others further north in the Evenlode Valley (Sandford, 1926); and glacially etched sand grains in gravels of the Middle Thames (Hey *et al.*, 1971). However, the sand grains were probably introduced into the area by glacier meltwater and therefore cannot be used to imply presence of ice at any specific location with certainty. A glacial process may have been responsible for depositing the 'striated' rocks in the Evenlode Valley as their striations are described as showing 'slight abrasion and smoothing' (Sandford, 1926, p. 107). The single striated clast from the Chalk escarpment is an isolated find which is difficult, if not impossible, to link positively with a particular glacial episode or deposit. None of these lines of evidence can be used with confidence.

More extensive evidence supporting glaciation on the Cotswolds is the generally reddish sandy clay containing quartzose erratics derived from the area northwest of the Cotswolds escarpment, which is scattered over a larger area of the dipslope at a range of altitudes. This material is commonly referred to as 'Northern Drift' (Buckland, 1823) and has been interpreted by many as glacial (Geikie, 1877; Pocock, 1908; Sandford, 1926; Tomlinson, 1929; Arkell, 1947; Shotton *et al.*, 1980). A patch of Northern Drift which has been most frequently accepted as a till, though never analysed in detail, is the clay-rich diamicton which extends across an irregular land surface near Bruern Abbey in the Evenlode Valley (Arkell, 1947; Hey, 1986; Fig. 2b). Quartzite clasts at least 27 cm in diameter are said to be present in this area (Hey, 1986). The location of this deposit in relation to the rest of the Northern Drift suggests that it could be the remnant of glacial deposits formed near the limit of pre-Anglian glaciers in southern Britain (see below). Given this glacial interpretation the 'beheading' of the upper part of the Thames catchment could have been caused by the glacial erosion of 'soft rocks' in the Severn lowlands between the Cotswolds and the Welsh borderland. However, a glacial cause for the beheading remains unproven due to the lack of exposure and detailed analysis, and possibly destruction of evidence by subsequent sub-aerial erosion in a region of highly erodable 'soft rocks'.

RIVER CAPTURE

The third mechanism, river capture due to differential exploitation of rock structure by subsequent rivers, is the one favoured by Davis (1895); but which river effected the capture?

The current drainage of the beheaded area comprises the Severn and Avon river systems draining towards the southwest into the Bristol Channel (Fig. 1). It is this modern configuration of rivers which Davis (1895) assumed, on the evidence of cartography and geological structure, was responsible for the beheading of the Thames. However, sedimentological and lithological evidence (Shotton, 1953; Rose, 1987) shows that a pre-Anglian river flowed in the opposite direction along the route of the present Avon and continued towards the northeast. The present pattern of rivers as they appear on a map came into being only as a consequence of glaciation during the Anglian Stage, whereas biostratigraphical and geomorphological evidence (discussed above) indicates that the beheading had already taken place.

TIMING OF THE CONTRACTION OF THE THAMES CATCHMENT

A traditional view of river development in southern England and Wales (Ramsey, 1872; Linton, 1951), recently reiterated by Cope (1994, 1995), is that some major English rivers, including the Thames, originated as consequent streams on a gently dipping Cretaceous Chalk cover extending westwards across all but the highest parts of Wales, if not the whole country. Following Davis' hypothesis it could be argued that gradual removal of the Chalk cover would have led to the exposure of underlying rocks of variable erodability and the development of subsequent streams, one of which, the River Severn, ultimately beheaded the Thames. However, according to George (1974) this scenario underestimates the influence of tectonic and isostatic events during the Tertiary and he has argued strongly, on the basis of sedimentary sequences in Cardigan Bay to the west of Wales, that the Chalk cover was removed from Wales soon after deposition. In his view the current fluvial landscape of Wales has more to do with a younger (Late Neogene) pattern of consequent rivers superimposed following later marine submergence, than one controlled by the Chalk cover. This pattern is closely related to present stream networks rather than large 'consequent' catchments. It nevertheless suggests that the present pattern of drainage, including the beheaded Thames, evolved before the Quaternary Period began.

Unfortunately, the sands and gravels of most of the Thames and Bytham rivers, do not lend themselves easily to absolute dating by existing geochronometric methods, and relative dating only has been achieved by a tentative correlation with the Dutch Quaternary sequence constrained by the palaeomagnetic record (Whiteman and Rose, 1992). Preliminary attempts to date Thames sediments using palaeomagnetic techniques have proved inconclusive due probably to post-depositional modification of the sediment (Barbara Maher, pers. comm.). For the time being, therefore, we must rely on bio- and lithostratigraphical evidence in Britain in order to provide at least an earliest and a latest date for the event.

Thames deposits are represented by four geological formations, the Nettlebed (Gibbard, 1985), Sudbury, Colchester (Whiteman, 1992) and Maidenhead (Gibbard, 1989) Formations. Recent correlations of Thames terraces, based largely on lithostratigraphic and morphostratigraphic evidence (Whiteman, 1992; Whiteman and Rose, 1992), suggest that the beheading took place during the time interval between the Sudbury and Colchester Formations (Fig. 4). The timing of this change can be positioned more accurately by reference to lithostragraphy and biostratigraphy. On this basis, marine sediments in East Anglia, correlated with the fluvial facies of the Nettlebed Formation, are equivalent to the Praetiglian to Tiglian C4b of the Netherlands (Gibbard *et al.*, 1991), rare temperate organic deposits in the Sudbury Formation have been equated with the British Pre-Pastonian (West, 1980) and correlated with the Tiglian C4c of the Netherlands (Gibbard *et al.*, 1991), and organic sediments in the Colchester Formation provide biostratigraphic evidence of both temperate and cold conditions that is considered equivalent to the 'Cromerian Complex' of the Netherlands. Therefore, deposition of the Sudbury Formation probably occurred during the period of Tiglian C4c-6, Eburonian, Waalian, Menapian and the 'Bavel Complex' (Whiteman and Rose, 1992). If these biostratigraphic correlations between the Thames region and the Netherlands are correct, they suggest that the beheading took place between the 'Bavel' and 'Cromerian Complexes' about 780,000 years BP. Assuming that the beheading was effected by the Bytham River, and/or glacial erosion of the Severn lowlands, it would be useful to have supporting evidence for dating the event from the area of the beheading.

Organic deposits have been recovered from several sites exposing the younger member of the Bytham river sediments (locally known as the Baginton/Lillington Sands and Gravels in the region of the beheading (Sumbler, 1983) in the present Avon Valley. Although they cannot be assigned to a specific stage, it is most likely that they are equivalent to part of the 'Cromerian Complex' (Shotton *et al.*, 1980; Rose, 1994). This supports dating evidence provided by amino acid ratios from Waverley Wood near Coventry, which appear to show that deposition of an early part of the unit occurred in Oxygen Isotope Stage 15 (Bowen *et al.*, 1989). The fact that the Bytham River occupied a site some 40 m below the level of the Moreton Gap indicates that the beheading must have preceded OI Stage 15. The oxygen isotope signal (Shackleton and Opdyke, 1973) shows that the largest expansion of glaciers prior to the Anglian Stage (OI 12) occurred during OI Stage 16. If ice reached the Cotswolds at this time it may have excavated the softer rocks of the lower Severn Valley, and the upper Bristol Channel where glacial deposits of this age, also dated by amino acid geochronology (Bowen *et al.*, 1989), have been found. It seems possible, therefore, that the Thames was deprived of a substantial part of its catchment by the process of river capture initiated by glacial erosion.

DISCUSSION

In this paper we have sought to commemorate and evaluate the contribution of a celebrated geomorphologist to a problem which continues, a century later, to stimulate the imagination and tax the analytical skills of fluvial palaeogeographers. It is not entirely clear whether the nature of the beheading of the Thames remains a problem due to lack of evidence, our inability to recognise the evidence, a general satisfaction with Davis' hypothesis, or a combination of all or some of these reasons. However, now that so much more has been revealed about the river network of East Anglia and the Midlands (Rose, 1994) the resolution of this problem assumes even greater importance in terms of the Early Pleistocene history of the region.

Some elements of the problem are no longer in serious dispute, including the provenance of the Thames gravels (Hey and Brenchley, 1977; Green *et al.*, 1980; Bridgland, 1986; Whiteman, 1990), their fluvial origin, and the former existence of a larger Thames catchment, the latter strongly implied by both gravel lithology and the spatial distribution and gradients of the surfaces of the gravel members of the Sudbury

Formation (Whiteman, 1992; Whiteman and Rose, 1992; Bridgland, 1994). What is not known for certain is the exact size and shape of the former catchment and the nature of the mechanism which led to its truncation.

The presence of Snowdonian volcanic rocks in the Thames gravels of the Vale of St Albans and East Anglia implies that Snowdonia, in northwest Wales, was once part of the Thames catchment. The question is whether the Thames itself had headwaters in Snowdonia or whether sediments were transported from that region into the Thames catchment by glaciers. However, details of the pre-beheading drainage pattern of the region are difficult to reconstruct due to more recent glacial erosion on high relief slopes. It is certainly not something that Davisian methodology could resolve.

With regard to the possible methods of capture which we have considered, present knowledge of the distribution, scale and timing of tectonic deformation in the Midlands does not allow firm conclusions to be drawn either in favour of or against this mechanism. It is a subject which still requires further study as Davis (1895, p. 141) advocated. Similarly the glacial hypothesis, which we favour, remains unproven due both to lack of exposure and detailed analysis of sediments in the area of the Cotswolds, and to the apparent destruction of sedimentary evidence in the area to the northwest of the Cotswolds. Again Davis (1895, p. 141) should be acknowledged for suggesting that "glacial episodes must be carefully examined when the subject is minutely studied". Finally, the river capture mechanism, advocated by Davis (1895), appears seductively simple. It should be easily testable by lithological analysis because the supply of distinctive rock types, such as the Snowdonian volcanic tuffs and lavas formerly carried to the lower reaches of the Thames catchment, should have been transferred to either the lower Severn or the Bytham river following capture. However, to date these lithologies have not been recorded in gravels attributable to either of these rivers. The fact that *both* of these capture possibilities need to be considered draws attention to a fundamental flaw in Davis' methodology; reliance on visible, modern river configurations to the exclusion of litho- and geochronological evidence. Given Davis' methods it was inevitable that he remained ignorant of the possibility that more than one choice existed.

Clayton (1980, p. 6) has suggested that "Davis' interpretation of south-east England was rapid and in many ways superficial; ..[but].. demonstrated the power of his ideas, and the ease with which quite an elementary range of evidence could be used to construct the model [of landscape evolution]". Herein lies a possible cause of the lack of progress towards resolving the problem of the truncation of the Thames catchment. Buckman (1900), who accompanied Davis on at least one of his excursions, was immediately converted and produced an elaborate cartographic reconstruction of consequent river patterns in the region between eastern Wales and the Thames Basin based on Davisian ideas (Fig. 3). White (1897) enthusiastically endorsed Davis' deductions as support for his own view that Triassic debris on the Cotswolds dipslope was of fluvial rather than glacial origin. Some decades later Wooldridge (1938), the dominant personality in Thames studies for forty years, invoked Davis' Cotswold paper and his concept of river capture to support his views on another Thames problem: whether or not that river always flowed through the Vale of St. Albans until its deflection by an ice sheet (Fig. 2a). Wooldridge (Wooldridge and Cornwall, 1964), undoubtedly favoured the morphological methodology: he used clast lithology, heavy mineralogy and micromorphology but not systematically. Wooldridge (1955, p. 90) remained "heavily in debt to Davis" and resented the criticism levelled at him. But, in both his Thames work and in his wider analysis of landscape development in southeast England (Wooldridge and Linton, 1939, 1955) Wooldridge has been shown to be in error by later workers (*e.g.* Hey, 1965; Hodgson *et al*, 1974; Catt and Hodgson, 1976; Gibbard, 1977; Green and McGregor, 1978; Rose, 1983; Allen *et al*., 1991), who addressed the problems largely from a sedimentological and lithological standpoint.

Unfortunately, although exclusive or dominant reliance on morphology has been shown to be an inadequate methodology for correlating river terrace systems such as the Thames, the over-reliance on lithology can also be shown to be less than satisfactory for this purpose. The clast lithology of individual gravel aggradations in the Thames system is not sufficiently distinctive to allow unequivocal correlation of the different members along the catchment and it was not until the palaeodrainage parameters relating to river long profiles, as discussed earlier, were introduced into the argument (Whiteman, 1992) that a realistic correlation scheme for the whole of the Early/Middle Pleistocene Thames trunk stream became a feasible proposition. Analysis of a dense network of boreholes, tightly constrained by pedological, lithological, sedimentological and stratigraphical criteria (Whiteman, 1992), demonstrated that gradients on the surfaces of members of the Sudbury Formation in southern East Anglia are only half of what had earlier been proposed and are consistent with a large catchment extending into Wales. These recent results demonstrate that the best solutions are obtained when the widest range of evidence is included in the analysis.

CONCLUSIONS

Analysis of the publications resulting from Davis' three brief excursions to view the River Thames in the Cotswolds shows him struggling to overcome 'complications' for his general river capture scheme introduced by the ubiquity of 'underfit' streams. His eventual explanation for the beheading of the Thames is ingenious but apparently he failed to appreciate the full ramifications of his argument because he did not fully accept the significance of climate change to river development and the great importance played by other processes than cool-temperate river activity such as glaciation and periglaciation. Whether later workers were convinced by Davis' views into thinking that the problem of the beheading of the Thames had been solved, or they found it too difficult or too trivial to contemplate, is immaterial now. What is clear is that almost a century passed before emergence of a range of new evidence and reinterpretation of existing evidence again made the subject an important and viable object of investigation by palaeogeographers. Our considered view is that the beheading of the Thames was effected by glacier erosion in a region of erodable bedrock, roughly about the time of the Early/Middle Pleistocene boundary, but conclusive evidence has yet to be found. It will be ironic if Davis' interpretation of the mechanism of the beheading of the Thames proves to be correct even though his methodology is flawed.

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REFERENCES

Allen, P., 1984. Field Guide to the Gipping and Waveney Valleys. Quaternary Research Association, Cambridge, 116 p.

Allen, P., Cheshire, D.A. and Whiteman, C.A. 1991. The Tills of Southern East Anglia. p. 255-278, *In* J. Ehlers, P.L. Gibbard and J. Rose. eds, Glacial Deposits of Great Britain and Ireland. Balkema, Rotterdam, 580 p.

Anderton, R., Bridges, P.H., Leeder, M.R. and Sellwood, B.W., 1979. A Dynamic Stratigraphy of the British Isles. Allen and Unwin, London. 310 p.

Arkell, W.J., 1947. The geology of the Evenlode Gorge, Oxfordshire. Proceedings of the Geologists' Association, 48: 87-113.

Bowen, D.Q., Hughes, S.A., Sykes, G.A. and Miller, G.H., 1989. Land-sea correlations in the Pleistocene based on isoleucine epimerization in non-marine molluscs. Nature, 340: 49-51.

Bridgland, D.R., 1986. The rudaceous components of the East Essex Gravels: Their characteristics and provenance. Quaternary Studies, 2: 34-44.

——1988. The Pleistocene fluvial stratigraphy and palaeogeography of Essex. Proceedings of the Geologists' Association, 99: 291-314.

——1994. The Quaternary of the Thames. Chapman and Hall, London, 441 p.

Buckland, W., 1823. Reliqiae Diluvianae: or Observation on the Organic Remains Contained in Caves, Fissures and Diluvial Gravel and on Other Geological Phenomena, Attesting the Action of a Universal Deluge. John Murray, London, 303 p.

Buckman, S.S., 1900. Excursion notes: Chiefly on river features. Proceedings of the Cotteswold Field Club, 13: 175-185.

Catt, J.A. and Hodgson, J.M., 1976. Soils and geomorphology of the Chalk in South-east England. Earth Surface Processes, 1: 181-193.

Chorley, R.J., Dunn, A.J. and Beckinsale, R.P., 1973. The History of the Study of Landforms: Vol. 2. The Life and Work of William Morris Davis. Methuen, London, 839 p.

Clayton, K., 1980. The historical context of 'Structure, Surface and Drainage in South-east England, p. 1-12. *In* D.K.C. Jones, ed., The Shaping of Southern England. Institute of British Geographers Special Publication 11, Academic Press, London.

Cope, J.C.W., 1994. A latest Cretaceous hotspot and the southeasterly tilt of Britain. Journal of the Geological Society, 51: 905-908.

——1995. Reply to Thomson, K., Discussion on a Cretaceous hotspot and the southeasterly tilt of Britain. Journal of the Geological Society, 152: 729-731.

Davis, W.M., 1895. The development of certain English rivers. Geographical Journal. 5: 127-146.

——1899. The drainage of cuestas. Proceedings of the Geologists' Association, 16: 87-93.

——1909. The valleys of the Cotswold Hills. Proceedings of the Geologists' Association, 21: 150-152.

Ellis, T.S., 1882. On some features in the formation of the Severn Valley as seen near Gloucester. Transactions of the School of Science Philosophical Society, Gloucester [for 1882], p. 3-15.

Geikie, J., 1877. The Great Ice Age (2nd ed.). Stanford, London.

George, T.N., 1974. The Cenozoic evolution of Wales. *In* T.R. Owen, ed., The Upper Palaeozoic and Post-Palaeozoic Rocks of Wales. University of Wales Press, Cardiff.

Gibbard, P.L., 1977. Pleistocene history of the Vale of St. Albans. Philosophical Transactions of the Royal Society of London, B280: 445-483.

——1983. The diversion of the Thames: A review, p. 8-23, *In* J. Rose, ed., Diversion of the Thames: Field Guide. Quaternary Research Association. Cambridge.

——1985. The Pleistocene History of the Middle Thames Valley. Cambridge University Press, 155 p.

——1989. The geomorphology of a part of the middle Thames forty years on: A reappraisal of the work of F. Kenneth Hare. Proceedings of the Geologists' Association, 100: 481-503.

Gibbard, P.L., West, R.G., Zagwijn, W.H., Balson, P.S., Burger, A.W., Funnell, B.M., Jeffery, D.H., de Jong, J., van Kolfschoten, T., Lister, A.M., Meijer, T., Norton, P.E.P., Preece, R.C., Rose, J., Stuart, A.J., Whiteman, C.A. and Zalaziewicz, J.A., 1991. Early and early Middle Pleistocene correlations in the southern North Sea Basin. Quaternary Science Reviews, 10: 23-52.

Green, C.P. and McGregor, D.F.M., 1978. Pleistocene gravel trains of the River Thames. Proceedings of the Geologists' Association, 89: 143-156.

Green, C.P., Hey, R.W. and McGregor, D.F.M., 1980. Volcanic pebbles in Pleistocene gravels of the Thames in Buckinghamshire and Hertfordshire. Geological Magazine, 117: 59-64.

Green, C.P., McGregor, D.F.M. and Evans, A., 1982. Development of the Thames drainage system in Early and Middle Pleistocene times. Geological Magazine, 119: 281-290.

Hains, B.A. and Horton, A., 1969. British Regional Geology: Central England. HMSO, London.

Hey, R.W., 1965. Highly quartzose pebble gravels in the London Basin. Proceedings of the Geologists' Association, 76: 403-420.

——1980. Equivalents of the Westland Green Gravels in Essex and East Anglia. Proceedings of the Geologists' Association, 91: 279-290.

——1986. A re-examination of the Northern Drift of Oxfordshire. Proceedings of the Geologists' Association, 97: 291-301.

Hey, R.W. and Brenchley, P.J., 1977. Volcanic pebbles from Pleistocene gravels in Norfolk and Essex. Geological Magazine, 114: 219-225.

Hey, R.W., Krinsley, D.H. and Hyde, P.J.W., 1971. Surface textures of sand grains from the Hertfordshire pebble gravels. Geological Magazine, 108: 377-382.

Hodgson, J.M., Rayner, J.H. and Catt, J.A. 1974. The geomorphological significance of the Clay-with-Flints on the South Downs. Transactions of British Geographers, 61: 119-129.

Linton, D.L., 1951. Midland drainage: Some considerations bearing on its origin. Advancement of Science, 7: 449-456.

Pocock, T.I., 1908. The geology of the country around Oxford. Memoir of the Geological Survey of Great Britain.

Ramsey, A.C., 1872. On the river courses of England and Wales. Quarterly Journal of the Geological Society of London, 28: 148-160.

Rose, J. (ed.), 1983. Diversion of the Thames: Field Guide. Quaternary Research Association, London.

——1987. The status of the Wolstonian Glaciation in the British Quaternary. Quaternary Newsletter, 53: 1-9.

——1989. Tracing the Baginton-Lillington Sands and Gravels from the West Midlands to East Anglia, p. 102-110. *In* D.H. Keen, ed., The Pleistocene of the West Midlands Field Guide. Quaternary Research Association, Cambridge.

——1994. Major river systems of central and southern Britain during the Early and Middle Pleistocene. Terra Nova, 6: 435-443.

Sandford, K.S., 1926. Pleistocene deposits, p. 104-172. *In* J. Pringle, ed., The Geology of the Country around Oxford. Memoir of the Geological Survey of Great Britain.

Shackleton, N.J. and Opdyke, N.D., 1973. Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V23-238: Oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale. Quaternary Research, 3: 39-55.

Shotton, F.W., 1953. The Pleistocene deposits of the area between Coventry, Rugby and Leamington and their bearing upon the topographic development of the Midlands. Philosophical Transactions of the Royal Society of London, B237: 209-260.

——1965. Normal faulting in British Pleistocene deposits. Quarterly Journal of the Geological Society, London, 121: 419-434.

Shotton, F.W., Goudie, A.S., Briggs, D.J. and Osmaston, H.A., 1980. Cromerian interglacial deposits at Sugworth near Oxford, England, and their relation to the Plateau Drifts of the Cotswolds and the terrace sequence of the Upper and Middle Thames. Philosophical Transactions of the Royal Society of London, B289: 55-86.

Sumbler, M.G., 1983. A new look at the type Wolstonian glacial deposits of central England. Proceedings of the Geologists' Association, 94: 23-31.

Thomas, D.S.G. and Shaw, P.A., 1988. Late Cainozoic drainage evolution in the Zambezi Basin: Geomorphological evidence from the Kalahari rim. Journal of African Earth Sciences, 7: 611-618.

Tomlinson, M.E., 1929. The drifts of the Stour-Evenlode watershed and their extension into the valleys of the Warwickshire Stour and upper Evemlode. Proceedings of the Birmngham Natural History and Philosophical Society, 15: 157-196.

West, R.G., 1980. The Pre-glacial Pleistocene of the Norfolk and Suffolk Coasts, Cambridge University Press, 203 p.

White, H.J.O., 1897. On the origin of the high-level gravel with Triassic debris adjoining the valley of the Upper Thames. Proceedings of the Geologists' Association, 15: 157-174.

Whiteman, C.A., 1990. Early and Middle Pleistocene stratigraphy in central Essex, England. Ph.D. thesis, University of London, 772 p.

——1992. The palaeogeography and correlation of pre-Anglian Glaciation terraces of the River Thames in Essex and the London Basin. Proceedings of the Geologists' Association, 103: 37-56.

Whiteman, C.A. and Rose, J., 1992. Thames river sediments of the British Early and Middle Pleistocene. Quaternary Science Reviews, 11: 363-375.

Whittow, J.B., 1976. The Cold Harbour glaciogenic deposit, p. 45, *In* D. Roe, ed., Field Guide to the Oxford Region. Quaternary Research Association, Cambridge.

Wooldridge, S.W., 1938. The glaciation of the London Basin, and the evolution of the Lower Thames drainage system. Quarterly Journal of the Geological Society, London, 94: 627-624.

——1955. 'Geographical Essays' by W.M. Davis, Geographical Journal, 121: 89-90.

Wooldridge, S.W. and Cornwall, I.W. 1964. A contribution to the new datum for the pre-history of the Thames valley, Bulletin of the Institute of Archaeology, University of London, 4: 223-232.

Wooldridge, S.W. and Linton, D.L. 1939. Structure, Surface and Drainage in South-east England. Institute of British Geographers Publication No. 10.

——1955. Structure, Surface and Drainage in South-east England, George Philip, London.