WAS THERE A GLACIAL LAKE HARRISON IN THE SOUTH MIDLANDS OF ENGLAND?

by

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Summary

Glacial Lake Harrison has long been accepted as an example of a pro-glacial lake for which "detailed evidence" is available. Recent work by the British Geological Survey has introduced a refreshing air of controversy into the theory. This paper is a review of current ideas and evidence. It is concluded that, although the geomorphological aspects of the theory seem increasingly problematic, the sedimentary evidence continues to support some form of lake hypothesis. However, there is uncertainty as to whether there was a single extensive lake covering the whole area or a series of smaller, transient lakes on top of, within and in front of an advancing ice sheet. The status of the Lake Harrison sediments (i.e. the Wolstonian) as a separate episode in the British glacial chronology, is also disputed.

Introduction

The period from the late 1950's to the early 1970's witnessed a sustained critique of the use of the model of a pro-glacial lake and its overflow channels as an explanation of drainage anomalies and related landforms (Sissons, 1958; Price, 1973). In particular the process of locating former pro-glacial lakes solely on the basis of the supposed position of meltwater overflow channels is now regarded as totally inadequate. The absence of additional confirmatory evidence in the form of lacustrine deposits and shoreline features has undermined previously 'classic' applications of the theory, such as the Cleveland Hills 'system' (Gregory, 1965; Edwards, 1981) and Lake Lapworth (Shaw 1972). Nevertheless, until recently, Shotton's 1953 theory of glacial Lake Harrison, which explains glacial deposits and landform assemblages of the South Midlands, has remained unquestioned. Indeed, Embleton and King (1968), in their review of the field, included Lake Harrison as an example for which 'detailed evidence' is available.

In his 1953 paper Shotton argued for the existence of a 'Lake Harrison' stretching from Leicester and Birmingham to Moreton-in-Marsh during the Wolstonian or Saale-Riss glaciation (Fig. 1). This water was impounded in the Avon basin between the Jurassic escarpment to the south-east and three ice lobes (western Severn Valley or Welsh Ice, northern ice and north-eastern Chalky Boulder—Clay Ice). Three gaps in the Jurassic escarpment were interpreted as former overflow channels (the Watford or Daventry gap, the Fenny Compton Gap and the Dasset Gap).

The 'detailed evidence' for these ideas has been derived from three major sources:

(*a*) a close examination of the Quaternary sediments
  (i) in the area around Wolston in Warwickshire (Shotton, 1953);
  (ii) along the proposed lake shoreline in South Warwickshire (Bishop, 1958);
  (iii) further north in Leicestershire (Shotton, 1976; Rice, 1968, 1981; Douglas, 1980).

(*b*) the discovery of a 400′ bench, which was interpreted as a wave-cut platform, along the southern margins of the region (Dury, 1951).

(*c*) evidence from boreholes suggested the possible existence of a major valley (the Proto-Soar) beneath the Quaternary deposits, stretching north-east from Moreton-in-Marsh to Leicester. Shotton argued, that the earlier melting of the Welsh ice and the resultant drainage of Lake Harrison to the south-west, led to the development of a south-westerly flowing drainage system, which was the precursor of the present River Avon and thus reversed the drainage of much of the area.

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The persuasiveness of this theory and its accompanying evidence have convinced most geomorphologists of the validity of the Lake Harrison idea. It is usually quoted without question in accounts of the geomorphology of the English Midlands (Straw and Clayton, 1979; Open University, 1980). However, recent work derived from the BGS mapping of the Warwick sheet has introduced a refreshing air of controversy into the topic (Ambrose and Brewster, 1982; Sumbler, 1983a). The time seems right for a reappraisal of the original ideas and evidence. The purpose of this paper is to offer a review of the current arguments. The debate will be dealt with under the following headings: (*a*) depositional evidence, (*b*) the 400' wave-cut bench, (*c*) overflow channels, (*d*) the impounding of Lake Harrison and (*e*) drainage reversal.

Depositional Evidence

In his original 1953 paper, Shotton interpreted the Wolstonian sequence of Quaternary deposits in the South Midlands mainly in terms of alternating lacustrine (i.e. laminated, varved and stoneless clays) and shoreline (i.e. deltaic) conditions. Lake conditions were correlated with periods of ice damming, due to glacial advance, whilst the deltaic environment was associated with phases of ice melting and retreat (Table 1).

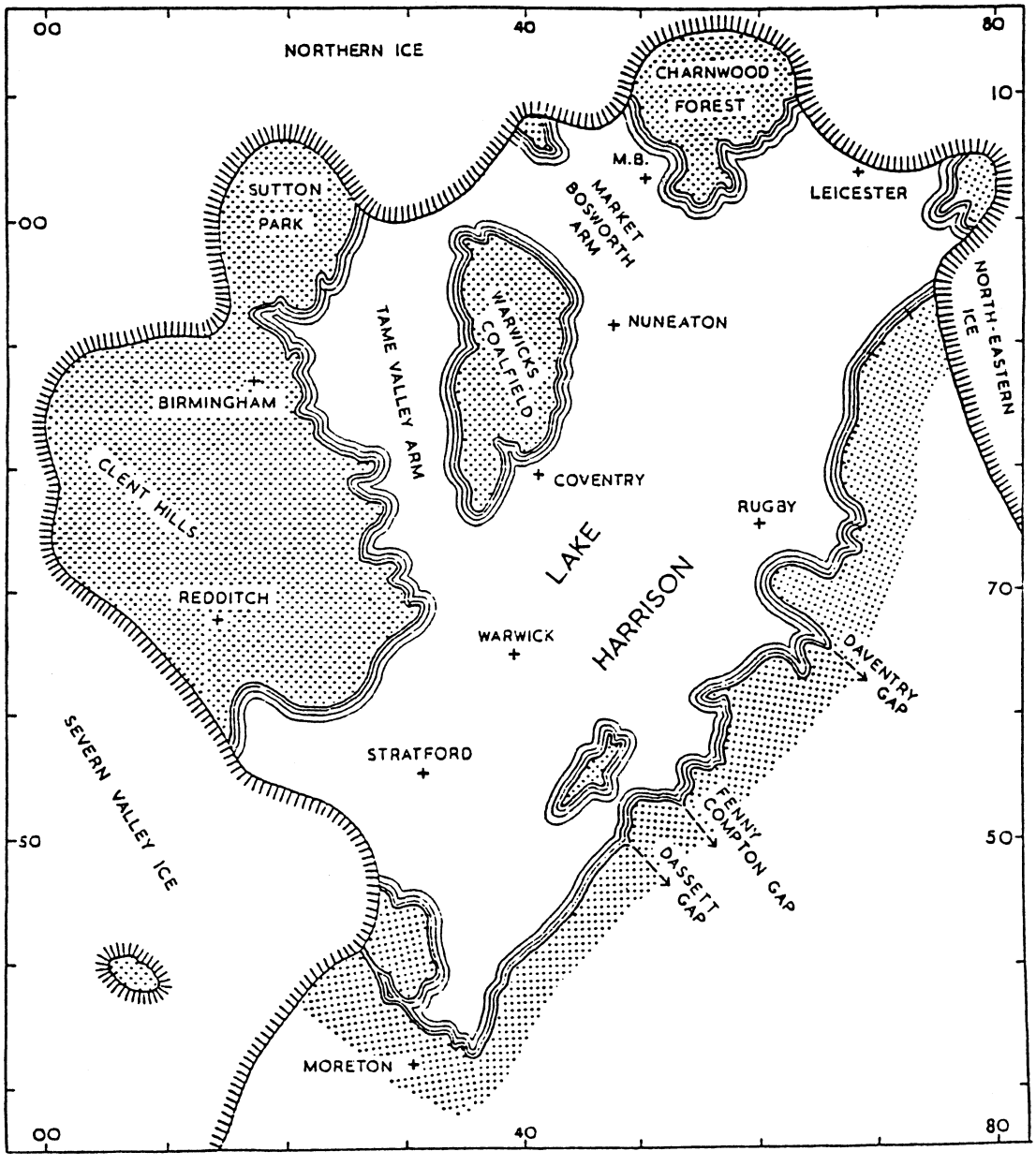

Fig. 1. Possible appearance of Lake Harrison near to its maximum extent, from Shotton, (1953), p. 251.

Research during the last 30 years has gradually eroded confidence in some of Shotton's original ideas, so that a significantly smaller proportion of the Wolstonian sequence is now regarded as lacustrine or deltaic in origin (Table 2). eg.

1. Whereas, in 1953, Shotton argued that the beginnings of lacustrine conditions were already evident in the Baginton-Lillington sands and gravels, there now seems to be general agreement that the series were entirely "cold climate riverine" in origin (Sumbler 1983a, p.24; Shotton 1984, p.262).

2. In 1953 Shotton regarded both the Lower and Upper Wolston Clays as deposits of ponded water. Today his original Lower Wolston Clays have been subdivided into two sections (Table 2). It is now generally agreed that the lower series is not lacustrine but is instead a till derived from Triassic bedrock (Thrussington Till), deposited directly by an overlying ice sheet (Shotton, 1976; Rice, 1981; Sumbler, 1983a). Shotton (1976) has argued for the onset of lake conditions at this time in the south of the region, but has based this judgment upon Tomlinson's (1935) evidence of laminated clays from only one locality, namely Snitterfield. Rose (in preparation) has recently confirmed this interpretation as follows: "At Snitterfield, the top of the Baginton Sands interdigitates with the base of the Lower Wolston Clay (which were formed in a pro-glacial lake), confirming the continuity of sedimentation initially suggested by Shotton 1953, (p.6)". However, recent B.G.S. reports indicate little additional support for this idea of an early Lake Harrison to the south of Leamington Spa. No mention is made of any form of lacustrine deposit in the geological survey of the area around Stratford-upon-Avon (Williams and Whittaker, 1974). In detailed notes on parts of sheets 183 (Redditch) and 184 (Warwick), only brief mention is given to 'bedded clays and sands' and these are described mainly as "pockets within boulder clay" rather than as lacustrine deposits (Ambrose and Strange, 1982). In their memoir of the 'Geology of the Country around Redditch', Old *et al.* (in preparation) describe how the glacial lake deposits of the area "are commonly interbedded with thicker accumulations of sand and gravel and boulder clay". Such depositional assemblages might be better explained as the product of small, localised lake conditions in close proximity to ice, or even sometimes as the remnants of kettle holes, rather than the product of a single lake.

3. The main area of Wolston Sands is now generally interpreted as an outwash plain or sandur stretching as far south west as Wolston rather than as a delta. For example, "the sedimentary structures consistently indicate deposition by moving water rather than into ponded water" (Douglas, 1980, p. 283). Shotton (1983, 1984), concedes this point, although, on the basis of his 1953 observation, he still prefers the lacustrine interpretation for the sands in the south, around Wolston itself.

4. The Upper Wolston Clays are now seen mainly as a till, belonging to the Chalky Boulder Clay series (Oadby Till), with only occasional lacustrine inclusions (Shotton, 1976, 1984; Rice, 1981; Sumbler, 1983a and b). This, rather than as a major Lake Harrison deposit, which was Shotton's preferred interpretation in 1953.

5. There has been long standing general agreement that the Dunsmore Gravels represent the remnants of a former outwash plain marking the final retreat of the Wolstonian ice sheet (Shotton, 1953; Sumbler, 1983a).

6. This leaves only the upper section of the original Lower Wolston Clays as truly lacustrine[1]. Recent research has in fact strengthened the evidence for lake conditions during this phase, especially in the area around Market Bosworth. Here, there has been the discovery of significant thicknesses of fine-grained laminated Quaternary deposits, which can be differentiated from the main till sequences in the area by particle-size analysis. Although "at first sight massive and structureless", (this clay) "is generally finely-laminated" indicating "deposition in standing water" (Old *et al*, 1987, p.53). These sediments now constitute the best available evidence in support of the Lake Harrison theory (Douglas, 1980; Shotton, 1976, 1983, 1984; Sumbler, 1983a; Old *et al*, 1987) and it has been suggested that they indicate the presence of a pro-glacial lake across the area, lasting for some 10,000 years (Shotton, 1976, p.248).

However, there are still some grounds for scepticism. According to Old *et al.* (1987), the Wolston Clay in Warwickshire is rarely entirely free of stones, which again suggests that the lake conditions might have been in close proximity to ice. Evidence from contemporary glaciers suggests that such ponded water could have developed either within a glacier or on top of the ice, as well as in a pro-glacial situation (Embleton and King, 1975; Drewry, 1986). Also there are often beds of sand and gravel within the clay/silt series, which suggest the close proximity of either englacial or proglacial fluvial conditions although small-scale turbidites have been suggested as an alternative explanation by Douglas (1980, p.282). Here, Shotton's use of the idea of alternating glacial advances and retreats is no longer sufficient to explain such clay/sand and gravel sequences (Boulton, 1970, 1972). Despite these reservations, there is general consensus that a lacustrine environment does offer the best explanation for the Lower Wolston Clay.

How far does the current state of understanding of the Quaternary deposits in the South Midlands vindicate Shotton's (1953) theory? At present there are two main views. Sumbler (1983a, p.25) has suggested that instead of "a single, semi-permanent body of water", there may have been "a succession of transient ice-marginal lakes ponded against the higher ground in front of the Oadby Till ice-sheet, as it advanced up the Proto-Soar Valley". It is interesting that Shotton used a similar interpretation to explain otherwise anomalous lacustrine material in 1953 (p.247). Sumbler has elaborated further upon this idea in

correspondence with the author, arguing "tentatively" that there was a "soggy and wet ice sheet advancing with pauses over its own deposits so that the whole sequence was laid down in one". This view and its evidence has been summarised in the 'Warwick' memoir, as follows: "The close association between the Wolston Clay and the overlying and underlying tills, coupled with the widespread occurrence of till in the Wolston Clay, suggest the close proximity of ice. Possibly the clays accumulated in transient glacial lakes and ponds formed in front of, upon and even within ice-sheets advancing, intermittently from the north and east" (Old *et al*, 1987, p.53).

Shotton meanwhile continues to prefer the single lake hypothesis, arguing that the evidence of the Bosworth Clays and Silts in the north-east suggest a more extensive lake (Shotton, 1984, p.264). Judging from recent publications Old *et al*, (1987 and in preparation) it seems difficult to resolve the Sumbler-Shotton disagreement on the basis of present Quaternary deposits, except to say that supporting evidence for the single lake hypothesis is very rare outside the Leicestershire survey areas. Sumbler, in correspondence with the author, has suggested that neither theory is either provable or amenable to disproof on the basis of present evidence.

There is one further area of controversy, which could be important to the evaluation of Lake Harrison theory. Until recently, the glacial deposits of the Coventry, Leamington, Rugby area have been used as the type for the Wolstonian Stage, which covers the sediments laid down during the glaciation between Hoxnian and Ipswichian interglacials. Sumbler (1983a) has disputed this interpretation, arguing that, as yet, no Hoxnian or Ipswichian deposits have been found in sequence with the Wolstonian glacial material. Instead, he puts forward the case for interpreting the drifts as Anglian in origin, on the admittedly 'tenuous' grounds that "the Oadby Till is chalk-bearing and the only chalk-bearing tills yet dated with certainty in eastern England are Anglian in age" (Old *et al*, 1987, p.48-9). This view has recently received further support from evidence that "the lower members of the Wolstonian sediments, the Baginton/Lillington Gravels and the Baginton Sands ... can be traced into East Anglia where they underlie Lowestoft Till" (Bowen *et al*, 1986, p.307). Rose (in preparation) therefore recommends that, "the use of the term 'Wolstonian' is misleading" and "should be abandoned". If this alternative chronology is accepted, then an even longer period of time becomes available for post-lacustrine developments. This has important implications for the chances of survival of the geomorphological features associated with the theory. It is to this evidence at and beyond the lake margins that we now turn.

400′ Wave-Cut Bench

At the same time as Shotton was investigating the Quaternary deposits of the Leamington-Rugby area, a 400′ bench was identified by slope profile analysis along the southern margins of the Midlands lowland basin (Dury, 1951). Its close correlation with the uppermost levels of lacustrine deposits known at that time, persuaded Shotton to suggest that the feature was a wave-cut platform marking the upper limit of the former lake shoreline (Shotton, 1953). Since 1953, this interpretation has had to survive a number of empirical difficulties. Bishop (1958), in trying to replicate Dury's work, found that "some of the benches were not located" and some were too high to conform with the original lake-height theory. There were also problems in trying to relate the 400′ bench to local glacial deposits (Bishop, 1958, p.276)[3]. In addition, Bishop (1958) reported discoveries of lake deposits above the presumed lake height of 400′. One might think that this conflicting evidence should have cast serious doubts upon both the validity and significance of any relationship between Dury's bench and the former shoreline of Lake Harrison. Instead, Bishop postulated an elaborate 2-stage theory of glacial advance and retreat, in order to accommodate a Lake Harrison at two different levels (435′ and 410′). Of course, this could be the correct explanation. However, recent work by the B.G.S. has cast fresh light on the controversy in finding a correlation between the bench and an outcrop of the '70-marker' member, a hard bed in the Lower Lias, thus arguing that the feature could have a structural rather than a wave-cut, shoreline origin (Ambrose and Brewster, 1982). In response Shotton (1983) has maintained that this structural bench could still have coincided with a former lake-level. Such a coincidence, although obviously a possibility, would, however, have been remarkable and Ambrose and Brewster (1982) have found no evidence of shoreline deposits along the main Middle Lias escarpment at or around 400′, to support this view. Moreover, if the above suggestion of an 'Anglian' origin for Lake Harrison is accepted, the long period of time available for subsequent weathering and erosion would make the survival of a wave-cut bench highly unlikely (Sumbler, 1983b).

Table 1. The sequence of Pleistocene deposits around Coventry, Rugby and Leamington, including a description of environmental changes during the Wolstonian (based upon Shotton, 1953).

			ENVIRONMENTAL CONDITIONS
NEWER DRIFT	DEVENSIAN	AVON TERRACES	
	IPSWICHIAN INTERGLACIAL		
OLDER DRIFT	WOLSTONIAN i.e. LAKE HARRISON PHASE	DUNSMORE GRAVEL	Outwash zone left by the final retreat of the ice.
		UPPER WOLSTON CLAY	Readvance of the mainly eastern ice causes Lake Harrison to reoccupy the area. Ice eventually advances across the lake as far as Moreton-in-Marsh.
		WOLSTON SAND	Meltwater streams from retreating ice cause delta to be formed across the lake deposits.
		LOWER WOLSTON CLAY	Ice blocks all outlets. Lake Harrison covers the area.
		BAGINTON SAND	Continued ice advance leads to the beginnings of ponding.
		BAGINTON/ LILLINGTON GRAVEL	Outwash zone due to the advance of northern ice.
	HOXNIAN INTERGLACIAL		
	ANGLIAN	BUBBENHALL CLAY	

Table 2. The sequence of the type Wolstonian glacial drift deposits and a description of environmental changes (based upon Shotton, 1976; Rice, 1981; Sumbler, 1983 and Old et al., 1987).

Shotton (1976) Rice (1981)	Sumbler (1983) Old et al. (1987)	Environmental Conditions	Shotton (1953) Equivalents
Dunsmore Gravel	Dunsmore Gravel	Outwash sandur left by final retreat of the ice.	Dunsmore Gravel
Upper Oadby Till Lower Oadby Till	Upper Wolston Clay and Oadby Till	Ice readvances across the whole region from the north-east leaving mainly a Chalky Till with occasional lacustrine beds.	Upper Wolston Clay
Wolston Sand and Gravel	Wolston Sand and Gravel	Outwash sandur from retreating ice.	Wolston Sand
Bosworth Clays and Silts	Lower Wolston Clay	Ice-front retreats to a position in North Leicestershire. EITHER Lake Harrison (Shotton, 1983) OR a series of separate pro-glacial lakes (SUMBLER, 1983), occupy the region.	Lower Wolston Clay
Thrussington Till	Thrussington Till	Ice covers the region (at least as far SW as Leamington). A pro-glacial lake may have occupied the zone between the ice and the Jurassic escarpment.	
Baginton Sand Baginton-Lillington Gravel	Baginton Sand and Gravel	Fluviatile outwash material associated with the advance of northern ice.	Baginton Sand Baginton-Lillington Gravel

We have seen that three overflow channels were originally postulated for Lake Harrison. How far does this aspect of the theory stand up to critical scrutiny? Firstly, it is important to go back to the original roots of the idea. The precise locations of Lake Harrison's overflow channels were initially based upon Shotton's assumption of a lake height at approximately 410', eg.

> "The possible outflows of Lake Harrison are several, for there are at least three cols across the Jurassic scarp on the south-east side of the Lake, which have a level at least within a few feet of 410' .... They are the Daventry, Fenny Compton and Dassett gaps" (Shotton, 1953, p.251).

This lake height of 410' was based upon the coalescence of two lines of evidence:

(a) 'the highest levels of lake clays known at that time'

eg.
"Moreton-in-the-Marsh 404', Thurlaston 370', Lutterworth 389', Sibson 390', Hinckley 398' .... (Therefore) .... it seems justifiable to assume a level of just over 400' for the lake and I shall henceforth use a figure of 410' without further argument" (Shotton, 1953, p.237).

(b) Dury's 400' bench.

Certain empirical weaknesses have since come to light. The original evidence was based upon a small sample of lake bottom rather than shoreline deposits, of which only one (Moreton-in-Marsh) was located at the assumed lake margin. It has already been noted that lake clays were subsequently found at heights above 410' and necessitated a two-stage lake theory (Bishop, 1958). More recent discoveries of lacustrine deposits have, however, been consistent with the 410' shoreline in the eastern parts of the region (Douglas, 1980; Old *et al.* in preparation), but examples well above the level continue to be found in the west (Old *et al*, in preparation). These height anomalies inevitably create uncertainty about the single lake hypothesis and alongside the doubts already expressed about Dury's 400' wave-cut platform, the identification of cols suitable as overflow channels begins to look increasingly arbitrary. Research has so far failed to provide supporting evidence of the fluvial deposits which might be expected at the three gaps, nor is there any morphological evidence that would distinguish the features as having an overflow origin.

Shotton (1983) has attempted to use morphological and sedimentary evidence from the Cherwell valley to justify the overflow channel hypothesis, eg.

> "Bishop (1958) demonstrated that Lake Harrison water had escaped through the Fenny Compton gap into the Cherwell .... He traced the morphological flat, which developed at the head of the Cherwell, down river until it carried sediment upon itself, and finally into the Wolvercote Terrace. (p. 34)

Although fashionable during the pre-1960 'Denudation Chronology' phase, this process of extrapolating 'flats' over great distances in order to correlate terrace formations is viewed with scepticism today. It assumes smooth curves of river profiles, which never seem to exist in reality. Bishop (1958, p.283) acknowledged these difficulties and was originally much more tentative in his conclusions than is apparent from Shotton's above statement, eg.

> "The tracing of this level downstream is difficult, but a line approximately parallel to the river is suggested, approaching gradually upstream towards the flood plain. It *appears* to link with the top of the Wolvercote terrace".

On the other hand, the idea of a movement of glacial drift material southwards by meltwater is strongly supported by the evidence of the river terrace material. Tomlinson (1929), Sandford (1932) and Bishop (1958) have all shown that erratics from the Oadby Till were carried across the present drainage divide into the Evenlode and Cherwell valleys, to produce a distinctive change in the terrace lithology with the formation of the Wolvercote Terrace. Also, it is argued that the morphological flats can be closely correlated with this critical sedimentary evidence over quite short distances (Rose, personal correspondence). This all seems to support some form of glacial meltwater process, associated with the Fenny Compton and Moreton cols. However, it is less clear that these meltwaters have to be the product of lake overspill. Direct meltwater from a decaying ice-front situated against the Liassic Scarp face is perhaps the more likely explanation.

Finally, although Sumbler (1983a, p.25) acknowledges that his "marginal lakes" .... "may have found outlets through some of the cols", it would appear from the above discussion that the overflow channels do not represent strong primary evidence for the existence of Lake Harrison as a single extensive sheet of water.

Impounding of Lake Harrison

In order to explain and justify the location of Lake Harrison, Shotton (1953) had to invoke the presence of glacial obstructions at a number of points around its margins:

> "Clearly this lake could not have held water .... if the col below 300' between Bredon Hill and Church Lench remained open .... it is necessary to invoke the presence of the Second Welsh Glacier in the Severn and Worcestershire Stour Valleys, forming a wall from the Clents to the Cotswold Scarp. The simultaneous existence of the dams at both ends of the ancient valley is essential if it is to hold water."

> "To retain water up to the level of 410', certain other outlets must be blocked. Ice must have covered the low ground around Kibworth Harcourt (6897), while, on the other side of the valley pre-glacial cols at Snarestone (3508) and Caldecote (3596) cannot have functioned as overflows" (p.250).

As recently as 1980, Douglas has identified yet another potential outlet/overflow channel, at Saddington, which would have required glacial blockage in the context of a single lake hypothesis (p.283).

The problem is that observations of contemporary glaciers have revealed that they do not necessarily form impermeable barriers to meltwater drainage. Nor do they always support extensive long-term lake development, especially in the ice-melt zone of temperate glaciers (Embleton and King, 1975, p.532-5). Moreover, in the case of Lake Harrison, although there is evidence that the blockage areas were glaciated, it is difficult to demonstrate the simultaneous existence of ice at each of the postulated outlet points. Of course, this does not disprove the existence of Lake Harrison. It is equally true that pro-glacial lakes do form and survive for long periods, providing that the topographic position is appropriate or as a result of crustal depression due to ice loading (eg. L. Agassiz). Nevertheless, the full supporting sedimentary evidence for the simultaneous impounding of Lake Harrison at each of its outlet points is not yet available. In its absence, we have to rely upon circular arguments and in the end, it can seem just too convenient for the model that every altitude anomaly should be explained away so easily. In Popperian terms, it constitutes 'weak' theory, in not being sufficiently amenable to tests for falsification.

Drainage Reversal

In the introduction, it was noted that evidence had been found suggesting the existence of a sub-drift valley (Proto-Soar) stretching from Moreton-in-Marsh to Leicester. The line of this valley from south west to north east was also followed by the Baginton Sands and Gravels at the base of the Wolstonian (Shotton, 1953). Rose (in preparation) has used the distribution of Baginton Sands and Gravels to trace this buried Proto-Soar valley into South Lincolnshire and East Anglia, "towards Bury St. Edmunds, Diss and the region of the North Sea". As yet, nobody has disputed either this evidence or the idea of the shift of the Soar-Avon watershed from Moreton-in-Marsh into Leicestershire as a result of the eventual drainage of Lake Harrison towards the end of the Wolstonian. However, in their recent account of 'the Geology of the Country around Warwick', Old, *et al.* (1987) do begin to show some reservations. They argue that "not only are data meagre, but the rock-head contours are the integration of several distinct episodes of subaerial, glacial and possibly sub-glacial drainage, and so are most unlikely to represent the surface topography at any given time" (p.49). However, even if the sub-drift evidence does prove to be valid, it does not follow that the existence of Lake Harrison was an essential pre-requisite for the reversal of drainage in the Soar-Avon. The overriding of the region by ice from the north and north-east would inevitably have disturbed any previously north-east flowing drainage system. The eventual melting and retreat of these glaciers would have encouraged the establishment of a predominantly south-westerly drainage, even if Lake Harrison had not existed.

Conclusion

Shotton's theory of Lake Harrison is an elaborate and imaginative synthesis of the glacial evidence in the South Midlands, which has clearly had a dominant influence upon all subsequent research into the Quaternary history and geomorphology of the region. None of the geomorphological ramifications of the theory seem to offer strong support for Lake Harrison. However, the evidence of lacustrine deposits especially in the north and east of the region (Shotton, 1976; Douglas, 1980; Rice, 1968, 1981) and around Snitterfield, near Stratford- upon-Avon (Rose, personal communication) does suggest some form of lake hypothesis. Nevertheless, the exact nature and extent of this lake environment is still controversial. For some recent writers, a single large Lake Harrison remains the best model available for understanding the glaciation of the area. (Shotton 1983, 1984; Old *et al.*, in preparation; Bowen *et al.*, 1986; Rose, in preparation). Others argue that the presence of lacustrine clays in a number of localities does not prove that they were all deposited simultaneously in the same lake. For them, a transient series of glacial lakes or ponds 'in front of, upon and even within' the ice sheets advancing from the north and east seems a preferable explanation (Sumbler, 1983a; Old *et al.*, 1987). This dispute is not yet resolved and readers will find the dichotomy still reflected in the different approaches to the lacustrine deposits adopted in the forthcoming Warwick and Redditch memoirs.

Acknowledgments

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Notes

1. These Lower Wolston Clays were renamed the Bosworth Clays and Silts by Shotton (1976), but the recent Warwick Memoir (Old *et al.*, 1987) has reverted to the old name (Lower Wolston Clay).
2. Old, *et al.* (in preparation), attempt to reconstruct an elaborate system of ice-front lakes and overflow channels to explain these lacustrine deposits, but appear not to try to accommodate the different height anomolies explicitly.
3. According to Bishop (1958), the 400′ bench truncates drift ranging from lower to upper Wolstonian in age. Bishop therefore placed the formation of the bench as Late Wolstonian. Otherwise, the bench would have been overrun by the final advance of the Oadby Till ice sheet without being destroyed or obscured. However this Late Wolstonian age for the lake does not correlate with the main phase of lacustrine sedimentation, which, we have seen, was Lower Wolstonian.

References

Ambrose, K. and Brewster, J., 1982. A re-interpretation of parts of the 400 foot bench of South-East Warwickshire, *Quaternary Newsletter*, No.36, 21–24.

Ambrose, K. and Strange, P.J., 1982. *Geological notes and local details for 1:10,000 sheets SP26 NW, NE, SW, SE and parts of SP25 NW and NE Warwick and Hatton*, Inst. Geol. Sci., Keyworth.

Bishop, W.W., 1958. The Pleistocene geology and geomorphology of three gaps in the Midland Jurassic escarpment, *Phil. Trans. Royal Soc. London*, B 241, 255–306.

Boulton, G.S., 1970. On the deposition of subglacial and melt-out tills at the margins of certain Svalbard glaciers, *J. Glaciology*, 9, 231–246.

Boulton, G.S., 1972. Modern Arctic glaciers as depositional models for former ice-sheets, *J. Geol. Soc. London, 182, 361–393.*

Bowen, D.Q., Rose, J., McCabe, A.M., Sutherland, D.G., 1986. Correlation of Quaternary Glaciations in England, Ireland, Scotland and Wales, *Quaternary Sci. Rev.*, vol.4, 299–340.

Douglas, T.D., 1980. The Quaternary deposits of Western Leicestershire. *Phil. Trans. Royal Soc. London*, B 288, 259–286.

Drewry, D., 1986. *Glacial Geologic Processes*, (Arnold), London.

Dury, G.H., 1951. A 400 foot bench in South-Eastern Warwickshire, *Pro. Geol. Assoc. London*, 62, 167–173.

Edwards, A., 1981. Lake Pickering—the lake that never was?, *Geology Teaching*, 6, No.1, 20–24.

Embleton, C. and King, C.A.M., 1968. *Glacial and periglacial geomorphology*, (Arnold).

Embleton, C. and King, C.A.M., 1975. *Glacial Geomorphology*, (Arnold).

Gregory, K.J., 1965. Proglacial Lake Eskdale after sixty years, *Trans. Inst. Br. Geog.*, 36, 140–162.

Old, R.A., Ambrose, K. and Sumbler, M.G., 1987. *Geology of the Country around Warwick*, Mem. B.G.S., Sheet 184.

Old, R.A., Hamblin, R.J.V. and Ambrose, K., in preparation, *Geology of the Country around Redditch*, Explanation 1:50,000 sheet, B.G.S., Sheet 183, England and Wales.

Open University, 1980. *Surface and sedimentary processes: palaeoclimatology case study*, (S335PA, The Open University Press).

Price, R.J., 1973. *Glacial and fluvioglacial landforms*, (Edinburgh, Oliver and Boyd).

Rice, R.J., 1968. The Quaternary deposits of central Leicestershire, *Phil Trans. Royal Soc. London*, B262, 459–509.

Rice, R.J., 1981. The Pleistocene deposits of the area around Croft in South Leicestershire, *Phil. Trans. Royal Soc. London*, B293, 385–418.

Rose, J., in preparation, Status of the Wolstonian Glaciation in the British Quaternary.

Sandford, K.S., 1932. Some recent contributions to the Pleistocene succession in England, *Geol. Mag.*, 69, 1–18.

Shaw, J., 1972. The Irish Sea glaciation of North Shropshire - some environmental reconstructions, *Field Studies*, 3, No.4, 603–631.

Shotton, F.W., 1929. The geology of the country around Kenilworth, Warwickshire, *Q. J. Geol. Soc. London*, 85, 167–222.

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, *Phil. Trans. Royal Soc. London*, B237, 209–260.

Shotton, F.W., 1968. The Pleistocene succession around Brandon, Warwickshire. *Phil. Trans. Royal Soc. London*, B254, 387–400.

Shotton, F.W., 1976. Amplifications of the Wolstonian stage of the British Pleistocene, *Geol. Mag.*, 113, 241–250.

Shotton, F.W., 1983. Observations on the type Wolstonian glacial sequence, *Quaternary Research Association Newsletter*, 40, 28–36.

Shotton, F.W., 1984. The Wolstonian stage of the British Pleistocene in and around its type area of the English Midlands, *Quaternary Sci. Rev*, 2, 261–280.

Sissons, J.B., 1958. Supposed ice-dammed lakes in Britain with particular reference to the Eddleston Valley in Southern Scotland, *Geografiska Annaler*, 40, 159–187.

Straw, A. and Clayton, K.M., 1979. *The geomorphology of the British Isles; Eastern and Central England*, Methuen, London.

Sumbler, M.G., 1983. A new look at the type Wolstonian glacial deposits of Central England, *Proc. Geol. Assoc. London*, 94 (1) 23–31.

Sumbler, M.G., 1983b. The type Wolstonian sequence—some further comments, *Quaternary Research Assoc. Newsletter*, 40, 36–39.

Tomlinson, M.E., 1929. The drifts of the Stow-Evenlode Watershed and their extension into the valleys of the Warwickshire Stour and Upper Evenlode, *Proc. Birm. Nat. Hist. Soc.*, 15, 157.

Tomlinson, M.E., 1935. The superficial deposits of the country north of Stratford-on-Avon, *Q. J. Geol. Soc. London*, 91, 423–460.

Williams, B.J. and Whittaker, A., 1974. *Geology of the country around Stratford-upon-Avon and Evesham*, Inst. Geol. Sci., London, H.M.S.O.

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