

WEST MIDLANDS

Field Guide

Edited by

D.H. KEEN

Quaternary Research Association



1989

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A giant erratic of Old Red Sandstone, Chelmarsh Pit

Photo by G.R. Coope

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THE PLEISTOCENE OF THE WEST MIDLANDS: FIELD GUIDE

Edited by D.H. Keen.

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INTRODUCTION

Twenty five years ago the first Easter Field Meeting of the Quaternary Field Studies Group (now Q.R.A.) was held in Birmingham. A quarter of a century later we return to many of the localities visited on that first excursion seeing many familiar features and deposits through new, although perhaps not necessarily better, eyes.

The mapping of the extent of the "Older Drifts" by Shotton in the years prior to that earlier meeting has been largely vindicated by the extensive gravel workings which have continued in the area between Coventry and Leamington, and exposed the Wolston type series to intimate scrutiny. The age of these deposits has, however, been reinterpreted and there is now dispute whether the Wolston Series is of the age originally proposed or part of the Anglian. The present meeting will address this problem by examining the old ground, by studying the newly discovered fossiliferous channels below the type Wolstonian, and by examining the possible continuation of the Wolston succession to the north and east of the type area.

The Hoxnian interglacial deposits, high on their hill-top at Quinton, have glacial deposits above and below them and pose a further complication as to which glaciation is of Anglian and which of Wolstonian age? The great incision that followed these events cuts down through a vast thickness of tough Carboniferous strata before reaching the level at which the Ipswichian Hippopotamus bearing gravels of Stourbridge were deposited.

This incision seems to represent a long period of time without a sedimentary record west of Birmingham, but in the valleys of the two major rivers of the area, the Severn and Avon, the river terraces have yielded a range of excitements both old and new. These terraces continue to provide fossils of a variety of types from large mammals to insects and Mollusca. In the Avon this evidence gives strong hints of additional interglacials before the Ipswichian, but which are not the Hoxnian, and this may fill some of the gap in the great incision noted above. In the Severn the huge erratics and till at Chelmarsh occur well beyond the conventional Devensian limit and suggest that a reorganisation of ideas on the extent of glaciation in this area is necessary.

If, with luck the Q.R.A. celebrates its 50th anniversary (in 2014), the West Midlands should also be the venue, to look back to the two previous meetings in the area and to see how many of the ideas of 1964 or 1989 are still standing.

G.R. Coope
D.H. Keen

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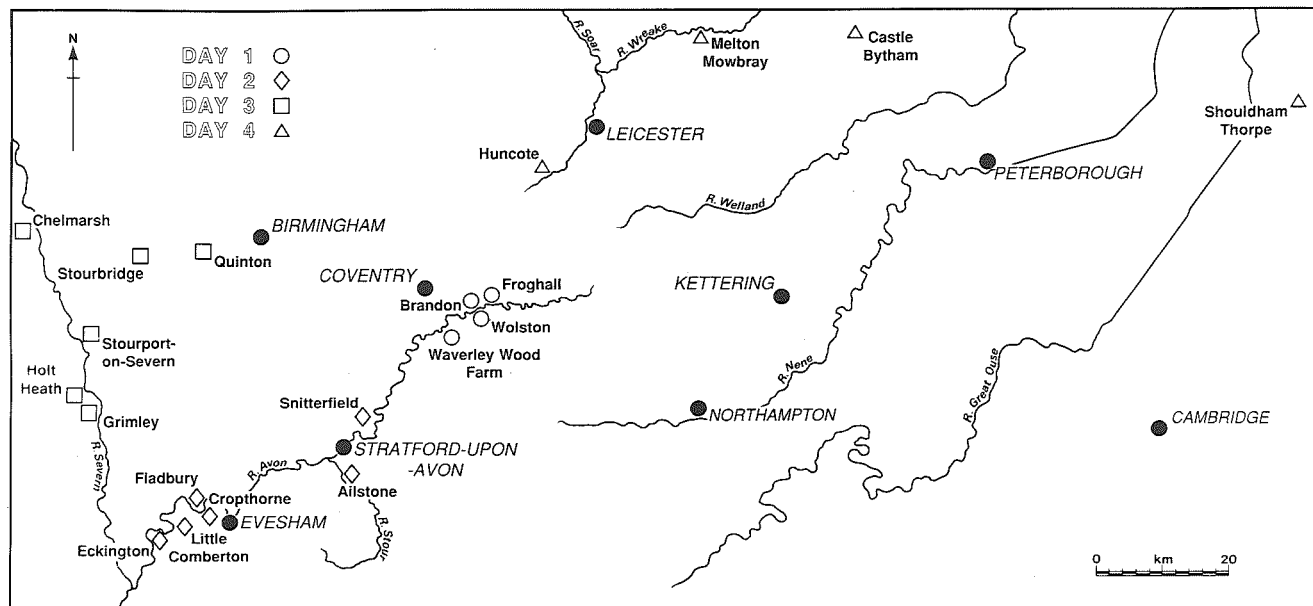


Fig. 1. Location of sites to be visited.

THE WOLSTON SEQUENCE AND ITS POSITION WITHIN THE PLEISTOCENE

Any discussion of the Quaternary sequence of the English Midlands should start with the Wolston Series. I have not used the term Wolstonian, since that has stratigraphical implications that are in dispute at the moment. The Wolston Series was first mapped by Shotton (1953) and amplified in later papers (Shotton 1976; Rice 1968, 1981; Douglas 1980). An acceptable sequence of strata was stated and named by Shotton as follows (in descending order).

Dunsmore Gravel outwash gravel, with "Bunter" pebbles and flint predominant, retreating outwash from the Oadby Till.

Oadby Till divided into an upper member, predominantly with Cretaceous Chalk and flint and Jurassic rocks and Carboniferous Limestone as erratics, and a lower member which includes a recognizable Jurassic content, together with a content of red Mercia Mudstones.

Bosworth Clays and Silts. A glaciallacustrine series.

Thrussington Till. A true till, derived by incorporation of Mercia Mudstones, together with erratics from the local Bromsgrove Sandstone and local Carboniferous/Permian, mega-erratics of igneous rocks from NW Leicestershire and from the Nuneaton Ridge.

Baginton Sand. Separable from the underlying gravel but with thin inclusions of it at the junction.

Baginton-Lillington Gravel. Coarse pebble beds, dominantly of "Bunter" quartzites, but at its southernmost extent including also a Jurassic and Carboniferous content.

These formations are exposed in the valleys of the Rivers Severn and Warwickshire Avon. They can be mapped continuously as a virtually horizontal succession over many square miles. The base of the Quaternary can be contoured and delineates a valley running down to the NNE from a level of c.88 m above OD (near Bredon Hill) to a level of c.58 m OD in the centre of the valley near Leicester. This valley was named by Shotton the Proto-Soar.

The Wolston Series therefore is a record of what happened to this old river flowing to the north. Its sediments comprise coarse gravels and finer sands terminated by a glacial advance which deposited the Thrussington Till. This only advanced to just south of Snitterfield. It terminated at this position and the water drainage from the south was ponded by the southward advancing ice of the Thrussington Till glacier, to give the lacustrine deposits of "Lake Harrison". That is why Lake Harrison sediments south of Snitterfield rest directly on the Baginton Sands without the intervention of till. The glaciallacustrine deposits of Lake Harrison continue to the region of Leicester, where they are terminated by another complex glacial advance. The Oadby Tills are the physical reflection of these glacial forward movements still pushing up the Proto-Soar southward. In front of themselves the Oadby Glaciers had difficulty in ponding water because Lake Harrison at its upper end was sufficiently shallow to be flowing across into the Upper Thames drainage (Bishop 1958) at Moreton-in-Marsh. From the north end a large sandur built up, coarse in the north (Wigston Gravel) and fine to the south (Wolston Sand) (Douglas 1980). Eventually this sandur was over-run by the Oadby Till Glacier, to leave the Dunsmore Gravel as its retreating outwash.

At this time a major ice body must have filled the ancestral Severn Valley, otherwise Lake Harrison, could not have existed. On the melting away of this ice blockage, the ponded water of the Proto-Soar was free to escape to the south and thus was initiated the cutting back of the Avon drainage and its diversion into the Bristol Channel.

The river terraces of the Avon testify to the cutting back of the Avon and its newly forming tributaries. No. 5 (Tomlinson 1925) is the highest and is little lower than the deposits into which it cuts which remain as relics. Nos. 3 and 4 cut deeper and further back (Tomlinson 1935) and there is still room for contention about the relative age of these two terraces. What is certain however, is that the Last (Ipswichian) Interglacial is represented by No. 3 Terrace, with its fauna of Hippopotamus, and Belgrandia, and Nos. 2 and 1 indicate the Last (Devensian) Glaciation with Mammoth and Woolly Rhinoceros, reindeer and musk ox and other arctic mammals, accompanied by an arctic flora and giving radiocarbon dates of between 47 K+ and 10 K years. This was the latest phase of the last major Glaciation of the Quaternary are leading via a short-lived cold period between 11 K and 10 K years ago, to the Interglacial which we are now enjoying.

The Hoxnian Period

This period is critical. It is named from Hoxne in Suffolk where a deep hollow cut into the Chalky Boulder Clay (Lowestoft Till) is filled with interglacial deposits. The succession was originally worked out by West (1956) who demonstrated that although the succession was incomplete, it included unquestioned deposits representing a warm climate, an interglacial. At its close, there were indications that another cold period was approaching. Thus there is no doubt that at Hoxne there is an interglacial later than the Chalky Boulder Clay (which is Anglian). At other places in East Anglia such as Marks Tey, a similar relation can be established of an interglacial being entrenched into the Anglian Chalky Boulder Clay. The Birmingham evidence is critical. At Nechells, borings for the foundations of a number of flats revealed a series of interglacial deposits in the form of muds covered by and underlain by gravels. The lower gravels were deeply entrenched by the muds, the base of the upper gravels was horizontal. Actually this line of horizontality was so predictable that when the drill reached to it, it was possible to insert a device for 100% core recovery which picked up unbroken sequences through the whole mud succession. Kelly (1964) concluded that this had all the characteristics of the Hoxnian Interglacial deposits, but only went about two thirds of the way upwards before giving place to the overlying gravels. The horizontal contact between the Hoxnian Interglacial deposits and the overlying gravels was an unconformity. Subsequently excavation of the muds revealed this unconformity and enabled collection of samples for complete palaeontological determination (Shotton and Osborne 1965).

The upper gravels were too coarse to yield fossils, but Kelly was able to connect these to records elsewhere locally which had three interstratified tills. Subsequently Horton (1974) maintained that only two tills were present in the upper gravels but the original interpretation was not fundamentally changed.

At Quinton, about 10.5 kilometres WSW of Nechells, a very important sequence was revealed by boreholes and in part by excavations. Boreholes proved that there were two thick tills present (upper till = Quinton Till, lower till = Nurseries Till) separated by interglacial sediments. The latter were worked upon by Dr Bell and then by Dr Margaret Herbert-Smith. Dr Herbert-Smith's results are embodied in a Birmingham University PhD

thesis (see Horton - this volume). There could be no doubt that at Quinton two thick tills were separated by an interglacial deposit which occupied a valley cut into the lower till. The situation resembled that at Hoxne. Palynologically the interglacial deposits were correlated with the stratotype at Hoxne.

At Quinton neither of the two boulder clays was of chalky boulder clay type but this was predictable from their relation to the non-Cretaceous Midlands. What is clear is that two glacial periods separated by an interglacial must both be earlier than the Devensian, for that is developed geographically and topographically in the Wolverhampton area, clearly both altitudinally below and to the north of Quinton. (Morgan, Anne 1973, Morgan, A.V. 1973). The present conflict of opinion springs from the work of Perrin et al (1973, 1979) who put forward the case that the Hoxnian is later than the Anglian Lowestoft Till into which it is cut and therefore the Anglian is contemporary with the Wolstonian. On this view, there is no room for the two pre-Devensian tills of West Birmingham. Perrin et al have gone further and assuming that the Anglian till entered the British Isles from the North Sea via the Wash, postulate that it spread from here in all directions north, west and south. The north-spreading stream, having crossed the Lincolnshire Wolds, turned south and so incorporated Chalk and pre-Chalk erratics from the strata west of the Wolds.

This has all been done on the basis of statistics, mostly on third order statistics. Straw has assailed these statistics as being terribly weighted in favour of the Chalky Boulder Clay of eastern England and almost entirely neglecting that which lies east of the Pennines and west of the Wolds. Straw maintains that there was a post-Hoxnian later course for glaciation running roughly north to south close to the Pennines (Welton Till) having crossed over the Chalk on the Lincolnshire Wolds and then incorporating erratics from the Lower Cretaceous, the Lincolnshire Limestone, the Lower Jurassic, the Trias and the Carboniferous Limestone. I observed all of these, some as mega-erratics, in Kilsby Pit which I visited a short time ago. This was interpreted from its altitude as being Oadby Till and equivalent to the Welton Till.

Rose (1987) is now the principal exponent of an Anglian age for the Wolstonian Series, carrying a London school with him. In that paper he claims to reconstruct the course of the Proto-Soar valley to the sea, where the Ingham Beds are credited with being the equivalent of the Baginton-Lillington Gravel. One can criticize this reconstruction on several grounds. The first is that the seaward course of the plotted levels of gravels which mark the course of the alleged river, lack consistency. One cannot expect exposures to occur at the exact levels at which one wants them to fit an hypothesis, but Rose's reconstruction departs by 40-70 metres from where it should be to carry conviction. Another point which should surely be made, is what is the case, palaeontological or mineralogical for the equation of the Ingham Beds with the Baginton-Lillington Gravel? Most inconclusive of all is the reconstruction of an alleged profile for the base of the Wolston Series for over 50 kms where the Flandrian deposits of the Wash completely conceal the older deposits of which Rose reconstructs the course. In reality the case for abolishing the Wolstonian as a Pleistocene stage in its own right depends upon the conviction that there can only be one Chalky Boulder Clay. On the other hand there certainly seems to be a Hoxnian and it is difficult to place the Quinton Till except in a cold period which follows the Hoxnian and precedes the Ipswichian and the Devensian. Rose in his 1987 paper concedes that this is the case in the

Netherlands and West Germany and that this time coincides with the maximum extent of glaciation in Europe. So it could have been in Britain and there is no case for abolishing the Wolstonian as a stage in the Middle Pleistocene. Search should continue for gravels as a continuation of the Proto-Soar leading to the sea in the direction of the River Wreake.

F.W. Shotton

MAMMALIAN FAUNAS AND THE WOLSTONIAN DEBATE

In the current debate over the age of the type Wolstonian sequence of the Midlands, workers on both sides of the discussion have invoked the mammalian faunas of the deposits, and have suggested that restudy of the fossils in question was desirable (Sumbler 1983a & b; Shotton 1983a & b; Rose 1988). As a contribution to this issue, I have examined relevant mammalian fossils preserved at Birmingham University Geology Department, Warwick Museum and Leamington Museum, and here present my findings for discussion.

The sites

The following mammaliferous sites have at various times been cited in the context of this debate:

King's Newnham or Lawford Pit, Warwickshire (SP 464 774)

Shotton (1953) showed that the mammalian fossils labelled "Lawford" almost certainly came from this disused pit, and has argued (Shotton 1953, 1983a) that they were found in outcrops of sand broadly equivalent to the Baginton Sand and Baginton-Lillington Gravels. According to Sumbler (1983b), however, the bulk of Pleistocene deposits in the area of the pit pertain to the Devensian Avon No. 2 Terrace, with a much smaller proportion correlatable to the type Wolstonian. In view of the fact that many of the fossils were collected as early as 1815 (Buckland 1823), so that their precise provenance cannot now be reconstructed with certainty, it seems wisest to omit them from a discussion of the type Wolstonian mammalian fauna, as accepted by Shotton (1983b). In any case, as stated by Shotton (1983a&b), and as confirmed in the present study (see later), there is only one species (Crocota crocuta) from Lawford Pit which is not found at other sites of the type Wolstonian sequence. This species would not have contributed significantly to the debate as it is elsewhere known from deposits both pre- and post-dating the Hoxnian.

Baginton and Lillington, Warwickshire

Several pits in this area have yielded mammalian fossils from the Baginton Sand and Baginton-Lillington Gravels. The most important are Pratt's Pit, Lillington (SP 327 675), active in the 1920's and later (Shotton 1929, 1953) and Manor Pit, Lillington (SP 335 671), active in the 1940's (Shotton 1983a). Shotton states that the majority of the finds came from the gravels, and where their provenance is known more precisely, from the lower part of the gravels. This corresponds to the labels on several specimens in museum collections. Other specimens (chiefly in Warwick Museum) are simply labelled "Lillington". Shotton (1929, p.209; 1983b, Fig. 2) points out that the position of Lillington village in relation to outcrops of the Baginton-Lillington sequence on the one hand, and terrace deposits of the Leam and Avon on the other, makes it most likely that specimens labelled "Lillington" came from the former. However, there are also specimens labelled "Lillington, No. 2 Terrace, Devensian", and while this may be in error, it casts some doubt in general on the age of material from "Lillington" where the precise locality is not given. In this study, therefore, I place emphasis only on material definitely from Pratt's Pit and Manor Pit, whose position within the Baginton-Lillington outcrops is clear (Shotton 1983b). The only species made uncertain by this decision is Rangifer tarandus which, as will be shown below, is not of great biostratigraphic significance in the current debate.

Ditchford Hill, Gloucestershire

Faunal remains from the Paxford Gravel at this locality are mentioned by Richardson and Sandford (1961) and Shotton (1983a). The Paxford Gravel underlies the chalky tills and clays of the Moreton Drift, which has been correlated with the Wolston Formation (Bosworth Clay and Oadby Till) (Tomlinson 1929; Shotton 1953, 1973). The gravel itself, comprising cemented angular fragments of oolitic limestone, is interpreted as a cold climate deposit (Shotton 1973).

Stretton-on-Fosse, Warwickshire

The Stretton Sand, a deposit of coarse sand with thin sporadic beds of gravel, underlies the Paxford Gravel at pits around Stretton-on-Fosse, and was formerly exposed at Ditchford Hill (Shotton 1973). It has been regarded either as of fluvioglacial origin, and pertaining to the early part of the cold stage represented by the type Wolstonian (Tomlinson 1929; Shotton 1973); or on the basis of the mammalian fauna, to a temperate phase, presumably the preceding interglacial (Shotton 1973).

Snitterfield, Warwickshire

Lloyd (1870) described a section at Hutchin's Brick Pit, Snitterfield. At least 4 m of gravels were overlain by 7-8 m of finer sediments. The pit was located at SP 235 579, and yielded an elephant tooth from the gravel (Tomlinson 1935). Recently, further faunal remains have come from the base of sands and gravels at the same site (Lister, Keen & Crossling, in prep.; see this volume, pp. 34-35). The deposits at Snitterfield are now interpreted as Baginton-Lillington Gravels and Baginton Sand, overlain by Wolston Clay, with evidence of continuity of deposition between the latter two units (Shotton 1983a; Rose 1987).

Waverley Wood Farm, Warwickshire

Faunal remains recently recovered at Waverley Wood Farm come from the base of the Baginton-Lillington Gravels (Currant, pers. comm.).

It is significant for the interpretation of the mammalian remains from these sites that in all cases they are from deposits beneath till, i.e. pre-dating an episode of glaciation in the Midlands. Both Shotton (1953) and Rose (1987) thus regard them as dating from the early part of the cold stage, whether that cold stage be Anglian or "Wolstonian" (*sensu* Gibbard & Turner 1988).

The mammalian species

Palaeoloxodon antiquus (straight-tusked elephant)

A partial skull and other remains of this species were recently found in situ in the basal levels of the Baginton-Lillington Gravels at Snitterfield (Lister, Keen & Crossling, in prep.; see this volume, pp. 34-35). In addition, the identity as P. antiquus of the tooth from Pratt's Pit recorded by Shotton (1953, p.219) is confirmed. It is an upper third molar, and according to its label came from the base of the Lillington gravels. Similarly, the tooth (a lower M2 or M3) from Stretton-on-Fosse (Shotton 1973) is unquestionably P. antiquus.

In terms of climate and vegetation, the distribution of this species in the European Quaternary suggests that while it was clearly at home in temperate forested interglacial conditions, and did not occur in phases of

fully stadial steppe-tundra, yet it probably also lived in semi-open "parkland" conditions. It is quite possible that it could have occurred in Britain during certain interstadial phases of the Anglian and "Wolstonian" Stages, whose faunas are in any case extremely poorly known. The species cannot be said necessarily to contribute to a full interglacial designation of the Stretton Sands (cf. Shotton 1973).

At present, the earliest known entry of P. antiquus into northern and central Europe was in the late Cromerian or early Anglian. This is attested in Britain by two teeth in the Green collection from Ostend, Norfolk, found below Anglian till in association with Arvicola cantiana (Stuart & West 1976; specimens listed by them as Mammuthus trogontherii). In central Europe, P. antiquus occurs in small numbers (relative to the dominant Mammuthus trogontherii) in late Cromerian/early Elsterian A. cantiana faunas from Mosbach and Mauer, FRG. Thus far there are no finds from mid-Cromerian or earlier faunas in these regions: thus the species is absent from the Mimomys savini faunas at West Runton, Norfolk (although elephant remains there are rare in general), Voigstedt, FRG (Dietrich 1965; Stuart 1981) and Süssenborn, FRG (Adam 1961). Recently, however, the species has been recorded, in association with Mimomys savini, below the Brunhes/Matuyama boundary at Isernia la Pineta, Italy (Peretto 1988). It is not certain whether this is a geographical difference or indicates earlier occurrence of P. antiquus in Europe as a whole. In sum, the presence of straight-tusked elephant in the Baginton-Lillington sequence is consistent with either an early Anglian or an early "Wolstonian" age. If, however, the base of this sequence is regarded as even earlier than Anglian, as implied by Rose (1987, Fig. 2), and in the case of Stretton-on-Fosse earlier still, then the records of straight-tusked elephant from these deposits would have to be accepted as the earliest in northern and central Europe.

Finally, the detailed morphology of the P. antiquus teeth here considered does not, at our present state of knowledge, provide clues to their age. It was previously believed that P. antiquus shared with Mammuthus primigenius a common ancestry in the Lower Pleistocene Archidiskodon meridionalis, so that the earliest representatives of both species would converge to a similar, primitive morphology. Students of elephant evolution now accept, however, that while Mammuthus may be descended from an A. meridionalis stock, Palaeoloxodon is a separate lineage which probably arose in Africa (Maglio 1973). Nor has anyone convincingly demonstrated a chronological morphocline in European Palaeoloxodon antiquus which could be used as a biostratigraphic indicator. Thus the statements of Sandford (in Tomlinson 1935, p.436) that a tooth from Snitterfield "strongly suggests the form of the archaic Elephas antiquus ... from the Hanborough Terrace and bears some similarity to the Elephas antiquus trogontherii mutation ...", and of Shotton (1973, p.475) that the Stretton-on-Fosse tooth "is so normal that it is unlikely to belong to the Cromerian Interglacial" cannot be upheld.

Mammuthus primigenius (mammoth)

Evidence of this species is provided by specimens at Leamington Museum from Pratt's Pit, Lillington, mentioned by Shotton (1929, 1953). These comprise an associated pair of upper first molars and a partial upper third molar, of typical M. primigenius form. A fragmentary portion of an elephant molar from "Lillington gravel base, Pratt's Pit" conserved at Birmingham University also has lamellar pattern referable to M. primigenius, although the portion of tusk from the same site mentioned by Shotton (1953) cannot with certainty be identified to species. Richardson and Sandford (1961) recorded a mammoth molar from the Paxford

Gravel at Ditchford Hill, and although this specimen could not be traced during the present study, two lamellae of a small tooth (probably fourth premolar) from the same locality, mentioned by Shotton (1983a) and conserved at Birmingham, are referable to M. primigenius. Despite their fragmentary condition, the shape of the lamellae and their thin enamel are characteristic of this species. The molar from Snitterfield mentioned by Tomlinson (1935) and Shotton (1983a) as Palaeoloxodon antiquus may instead be referable to M. primigenius (Lister, Keen & Crossling in prep.). Finally, Shotton (1953, Table 2) listed M. primigenius from Manor Pit and "Lillington in general", but no material definitely attributable to mammoth from these sites was seen during the present study.

The evolution of the mammoth has long been regarded as an example of gradualistic evolution which could be used as a valuable biostratigraphic marker. Briefly, the transition from Mammuthus trogontherii (early Middle Pleistocene) to M. primigenius (Upper Pleistocene), involving dental changes such as a thinning of enamel and increase in lamellar frequency, has been assumed to occur in a gradualistic fashion, specimens of intermediate morphology being assigned an intermediate age even in the absence of independent dating (e.g. Adam 1961). Work in progress is beginning to challenge this view (Lister, in prep.). M. primigenius of typical, "late" form, with thin enamel and high lamellar frequency, is found in several deposits pertaining to the penultimate, "Wolstonian"/Saalian Cold Stage in both Britain and continental Europe. There is even evidence of its occurrence at the time of the Anglian glaciation, based on material from Homersfield, Norfolk, in gravels interdigitating with the Anglian till (Coxon 1979; Stuart 1982; Lister, in prep.).

The classic samples of M. trogontherii are from Süssenborn, Mosbach and Mauern, Germany, in deposits correlated to the Cromerian or early Anglian/Elsterian stages. In this context it is not surprising that Shotton (1983a) cites the presence of advanced M. primigenius (described, following Sandford (1924), as the "Siberian" form) as evidence against an early Anglian age for the Baginton-Lillington Gravels. With current research suggesting a transition from M. trogontherii to M. primigenius some time during the Anglian Stage, the occurrence of M. primigenius may not be inconsistent with a "Wolstonian" or even an Anglian age for the Baginton-Lillington Gravels. However, a dating as early as Mosbach or Süssenborn, i.e. earliest Anglian or even older, as implied by Rose's (1987, Fig. 2) designation "Pre-Anglian", is highly unlikely on the basis of the mammoths.

Coelodonta antiquitatis (woolly rhinoceros)

If the Coelodonta remains from King's Newham and "Lillington" (without specified locality) are disregarded, there still remains the specimen from Manor Pit, Lillington listed by Shotton (1953). This left second metacarpal has been correctly identified as C. antiquitatis (Shotton 1983b). Sumbler (1983b) queried its provenance, but Shotton (1983b) affirmed its source as "unimpeachably from the Manor Pit".

C. antiquitatis, which arose in Asia, has generally been regarded as having entered Europe in the penultimate cold stage. Thus Guérin (1980) in a review of European records, lists it for the "Riss"/Saalian but not for the "Mindel"/Elsterian. Kahlke (1969) asserts that its appearance in Europe at least post-dates the early Elsterian. On the other hand, it must be stated that our knowledge of mammalian faunas of the main body of the Anglian/Elsterian Stage is very poor. C. antiquitatis has recently been identified from the Homersfield Gravels, Norfolk, (Stuart 1982),

which implies an occurrence contemporary with the Lowestoft Stadial, and this would be the earliest known record. At present, negative evidence suggests that the rhinoceros bone from Manor Pit is unlikely to be early Anglian in age.

Equus caballus (horse)

Horse is the most abundantly represented species in the sites here considered. In the Matley collection are a quantity of limb bones and teeth labelled "base gravel, Manor Pit, Lillington". In addition, eight associated teeth of E. caballus were found by Shotton (1953, 1983b) at Baginton, although the precise locality is not given.

The presence of E. caballus does not in itself provide significant biostratigraphic information, since the species is known since at least as early as the Cromerian. The evolutionary history of the species is complex, and the morphology of the material at hand might yield stratigraphic clues to a future specialist study.

Bos and/or Bison sp. (aurochs or bison)

There are two bones of large bovid from the Stretton Sand, as listed by Shotton (1973). In addition, Shotton (1929) mentions a bovid tooth found in gravel in an old pit near Lillington village and within the area of the Baginton-Lillington sequence. This specimen, and also the bovid material listed by Shotton (1953) from the Manor Pit, were not seen during the present study. Specialist examination of this material would probably allow its identification as Bos or Bison, but its stratigraphic value is likely to be limited.

Rangifer tarandus (reindeer)

The antler fragment mentioned by Shotton (1953, 1983b) can be confirmed as R. tarandus. However, since its provenance is not known more precisely than "Pleistocene Gravel, Lillington", it may be safest to omit it from the argument (see above). In any case, reindeer is known in Europe from the earliest Anglian/Elsterian (Kahlke 1969; Stuart 1982), so that its presence in the Baginton-Lillington sequence would not affect the current debate.

Megaloceros giganteus (giant deer)

Shotton (1973) described some antler fragments and a partial metacarpal from the Stretton Sand as Megaceros sp. One of the specimens, the base of a left antler with pedicle attached, is referable on close examination to Megaloceros giganteus. This is based on the large size of the specimen and the oblique angle of the antler beam relative to the skull (feature of Megaloceros in general), and the presence, although broken, of a broad tine at the very base of the beam (characteristic of M. giganteus). Other species of Megaloceros, M. verticornis, M. dawkinsi and M. savini, have lower tines of quite different form and position (Lister 1987).

This identification has considerable stratigraphic significance. M. giganteus is generally unknown in Europe in deposits pre-dating the Hoxnian or Holsteinian temperate Stage. Recently, remains of the species have been identified from the Homersfield Gravels, Norfolk, believed to be contemporary with the Anglian glaciation (Stuart 1982; Lister 1986; see above). In the Cromerian and probably early Anglian, however, the species is unknown, being replaced by M. verticornis, M. dawkinsi and M. savini.

(Lister 1986), as at West Runton, Voigtstedt, Süßenborn, Mosbach, and most recently Little Oakley, Essex (Lister 1986, Lister et al. submitted).

Thus it is unlikely that the Stretton Sand is of early Anglian age, and even less likely that it is earlier still. Given that the Stretton Sand underlies the Paxford Gravel which in turn underlies till, an Anglian age for the Stretton Sand Megaloceros could be maintained only if both the Stretton Sand and the Paxford Gravel fitted into a phase after the extinction of the earlier Megaloceros species but before this particular glaciation in the Midlands. If this glaciation were contemporary with that of East Anglia, the Stretton Sand M. giganteus would be the earliest known in Europe. If, however, the Midlands glaciation postdated that of East Anglia, the Stretton Sand could be roughly contemporaneous with or younger than the Homersfield Gravels, and the Stretton Sand giant deer not uniquely old. Precise contemporaneity of these deposits is, however, unlikely because of the presence of several species in the former (Palaeoloxodon antiquus, Cervus elaphus and Megaloceros giganteus) which avoided stadial conditions.

Alternatively, the record of Megaloceros giganteus is quite consistent with a Hoxnian, "Wolstonian" or indeed later age for the Stretton Sand. Since the species is known from both temperate stages and interstadials, its presence does not distinguish between interglacial and cold stage conditions at the time of deposition of the Stretton Sand.

Cervus elaphus (red deer)

The basal part of an antler listed by Shotton (1973) from the Stretton Sand is confirmed as red deer. In view of the fact that this species is common in Europe from at least as early as the Cromerian until the present day, and encompasses both temperate and cold stages in Britain (Lister 1986), its presence in the Stretton Sand does not hold particular biostratigraphic or palaeoclimatic weight. Red deer antlers from the Cromerian and early Anglian differ from those of later date in the morphology of their distal part (Lister 1986), but this part is not preserved in the present specimen.

Lepus sp. (hare)

A skull of Lepus sp. was listed by Shotton (1973) from the Stretton Sand. This specimen requires specialist study and has not been examined in the present work. All pre-Holocene British Quaternary hares identified to date have been referred to L. timidus (varying hare) rather than L. capensis (brown hare), and the species is known from the Cromerian of West Runton onwards, including records from Westbury-sub-Mendip (early Anglian) and the Tornewton Cave Glutton Stratum ("Wolstonian") (Mayhew 1975).

Summary and conclusions

A chart showing the occurrence of species by site is given in Table 1. In sum, the large mammal fauna from deposits which have been correlated to the type Wolstonian and locally correlated deposits comprises Equus caballus, Palaeoloxodon antiquus, Bos or Bison, Mammuthus primigenius, and Coelodonta antiquitatis. This assemblage is most consistent with an interstadial phase providing grassland as well as some wooded areas. The somewhat older Stretton Sand expands the list with the addition of Megaloceros giganteus and Cervus elaphus. The Stretton Sand fauna is also consistent with interstadial conditions, or alternatively with an interglacial event.

Species of particular biostratigraphic interest in this list are mammoth Mammuthus primigenius, giant deer Megaloceros giganteus, and woolly Rhinoceros Coelodonta antiquitatis. Drawing together the stratigraphic comments given under the individual species headings, it can be stated with confidence that the deposits which yielded these three species cannot be of earliest Anglian age or older. They must post-date the well-known European early Middle Pleistocene fauna exemplified at such sites as Mosbach and Süssenborn, which are correlated to the Cromerian or early Anglian, and which find their approximate equivalents in Britain at Westbury and Boxgrove.

If the dating of the Homersfield Gravels, Norfolk is correct (Coxon 1979; Stuart 1982) then the occurrence of M. primigenius, C. antiquitatis and M. giganteus in Britain as early as the Lowestoft Stadial finds some precedent. Otherwise, these species are not known before the Hoxnian/Holsteinian Stage. In the Midlands, the Baginton-Lillington sequence, Stretton Sand, etc underly till, so that their faunas would fit into the Anglian only if these units date to a phase after the extinction of the classic early Middle Pleistocene fauna but before the glaciation in question. If glaciation was synchronous between the Midlands and East Anglia, then the records of these three species in the Baginton-Lillington sequence would pre-date those from Homersfield and be the earliest known in Europe. Less appeal to uniqueness would be required if the till in the Midlands were younger than the Lowestoft till of East Anglia, so that the Baginton-Lillington Gravels and Homersfield Gravels were roughly contemporaneous. Alternatively, however, the whole of the fauna listed thus far is perfectly conformable with a "Wolstonian" age (*sensu* Gibbard & Turner 1988). It would also be consistent with a Devensian age, except for the presence of P. antiquus which became extinct in North West Europe in the Ipswichian or at the latest the earliest Devensian. Assuming P. antiquus and the other species in Table 1 to be contemporaneous, a pre-Devensian age is likely on purely faunal grounds.

Also to be considered, however, is the fauna from Waverley Wood Farm, Warwickshire, where Arvicola cantiana and Sorex savini have been found in deposits at the base of the Baginton-Lillington Gravels (Currant, pers. comm.). A. cantiana indicates that the deposits post-date the middle Cromerian, while S. savini is not known later than the late Cromerian/early Anglian. In European Pleistocene deposits, S. savini does not occur in association with M. primigenius, C. antiquitatis and M. giganteus. The presence of S. savini at Waverley Wood Farm is therefore difficult to square with the fauna of the other Baginton-Lillington sites discussed above. It is conceivable that there could have been a period of coexistence between the latest S. savini on the one hand, and the earliest M. primigenius, C. antiquitatis and M. giganteus on the other, but at present this is speculative. It is more reasonable at out present state of knowledge to suppose that the Waverley Wood fauna is older than that of the other sites. The finding of more extensive large-mammal fauna at Waverley Wood would be of extreme interest, as would any other new mammalian fossils from the type of Wolstonian area.

A.M. Lister

	Pratt's Pit	"Lillington Pit"	Manor Pit	Baginton	Ditchford Hill	Stretton-on- Fosse	Snitterfield
<u>Palaeoloxodon antiquus</u>	X					X	X
<u>Mammuthus primigenius</u>	X		(X)		X		?
<u>Coelodonta antiquitatis</u>			X				
<u>Equus caballus</u>	X		X	X			
<u>Bos or Bison</u>		(X)	(X)			X	
<u>Megaloceros giganteus</u>						X	
<u>Cervus elaphus</u>						X	
<u>Lepus</u> sp.						(X)	

Table 1. Mammalian faunas from sites of the type Wolstonian and locally correlated deposits (excepting Waverley Wood Farm).

X = material seen in the present study.

(X) = material not seen in the present study but description and provenance appear reliable.

? = material seen in the present study but identification uncertain.

Tuesday 4 April

1. Pools Farm Pit, Brandon SP 388 762
2. Wolston Pit, Wolston SP 410 747
3. Froghall Pit, Stretton SP 415 735
4. Waverley Wood Farm Pit, Bubbenhall SP 364 715
5. Snitterfield Pit SP 234 595

POOLS FARM PIT, BRANDON

Brandon lies within the type area for the Wolstonian glacial stage (Wolston being less than 2 km from Brandon) and is therefore fundamental to the stratigraphy proposed by Shotton (1953; 1986). Essentially two elements of the stratigraphy at Brandon are important. Firstly, the recorded organic deposits from within the Baginton-Lillington Gravels and secondly, the nature of the gravels underlying the River Avon Terrace No. 4.

Previous Research

Shotton (1968) described the location and nature of a silt filled channel from within the Baginton-Lillington Gravels (Fig. 2, Loc. 5). These silts were found to be organic, containing both floral (Kelly, 1968) and faunal (Osborne and Shotton, 1968) remains. The flora, which was generally of cold aspect, contained a small but significant thermophilous component and was interpreted as being of interstadial nature.

The fauna described from the channel consisted of Coleoptera, Insecta and fish.

Shotton's description of the river terrace units included a section cut through Terrace No. 4 deposits (Fig. 3). Shotton recognised two gravel facies underlying Terrace No. 4, the lower "purple clayey gravels" were low in flint content (2%), while the upper gravels, which were laterally more extensive, in contrast were high in flint content (19%).

The lower unit was equated with the organic deposits reported from the base of Avon Terrace No. 4 at Ailstone in the Lower Avon valley (Tomlinson, 1925), and, following Tomlinson, was assigned by Shotton to the Eemian (last) Interglacial based upon its supposed relationship to Hippopotamus bearing gravels underlying Avon Terrace No. 3 (see discussion on Cropthorne and Ailstone pp. 51-67). The upper gravels were clearly younger and displayed periglacial disturbance and thus were believed to have been deposited during the early part of the last glacial stage (Würm). Thus the stratigraphic relationship of Avon Terrace No. 3 to Terrace No. 4 recognised by Tomlinson (1925) for the Lower Avon was apparently reinforced by the evidence as interpreted by Shotton (1968) from Brandon.

Pools Farm Pit, Brandon

By far the most extensive exposures in the Brandon area at present lie within the recently opened Pools Farm Pit excavation (for location see Fig. 2). The Pleistocene sediments in the area of the pit are mapped as Baginton-Lillington gravels by Shotton (1953; 1986). The new exposures reveal previously unrecorded fine grained fossiliferous channel deposits and suggest a more complex stratigraphy for the area than was previously postulated.

Site Description and Interpretation

The stratigraphic units described below are shown in the generalized fence diagram of the pit faces exposed during the extraction (Fig. 4).

Unit 1 is generally poorly exposed but where observed consists of a clast supported gravel (facies Gm) with much coarse interstitial sand and is seen in places to rest directly on the Mercia Mudstone bedrock. The exact

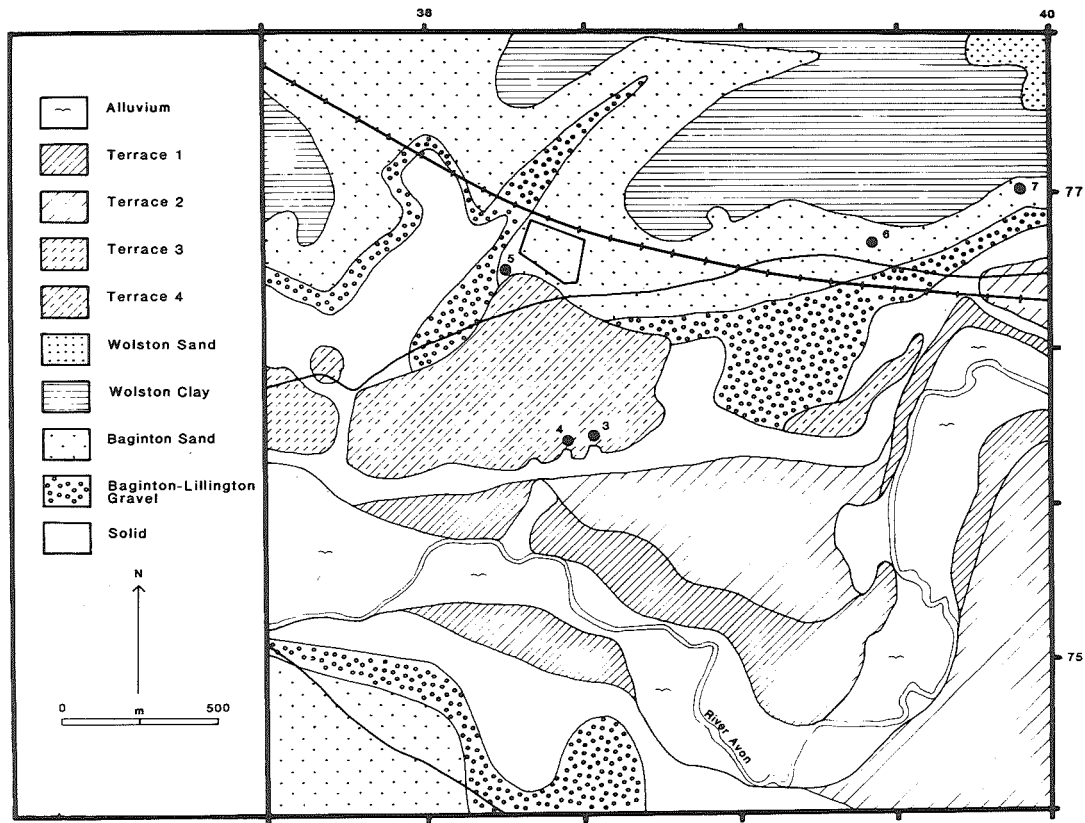


Fig. 2. The Pleistocene deposits around Brandon, Warwickshire (after Shotton, 1968).

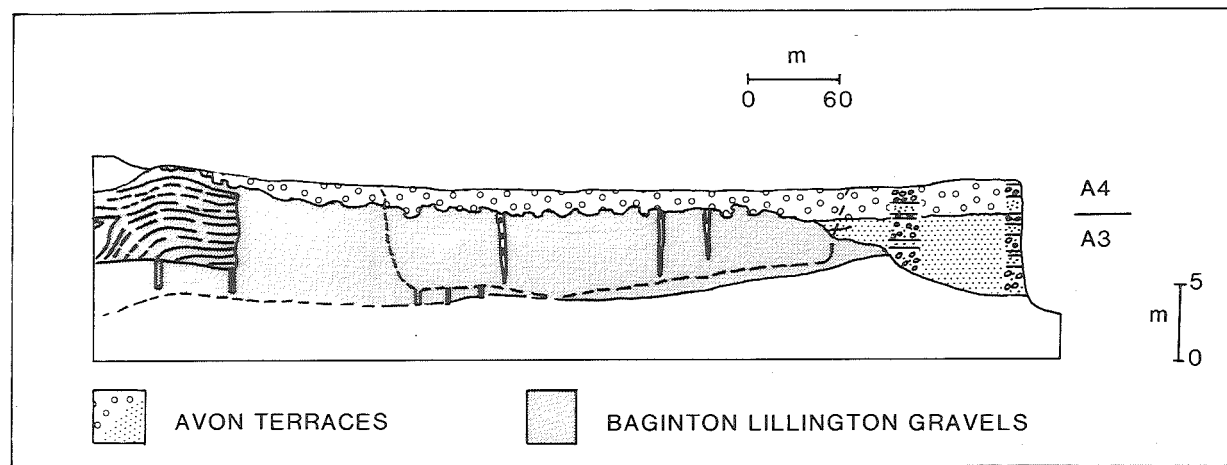


Fig. 3. Generalised section through the Avon Terrace deposits and Baginton-Lillington gravels at Brandon (after Shotton, 1968).

nature of the lower bounding surface is unknown, due to only limited exposure. A maximum thickness of 1.2 m is estimated, although typically thinner deposits are preserved. The gravels are generally of medium to coarse grade and display only rudimentary bedding.

The sequence is interpreted as reflecting aggradation by the superimposition of successive bar core sediments, although sheet gravel deposition cannot be ruled out. The apparent lack of avalanche face development suggests deposition on longitudinal bars (Miall, 1977). However, the exact pattern of deposition in unit 1 is indeterminate, but the grade of sediment would suggest high energy conditions.

Unit 2 lies upon an erosional lower bounding surface, the "feather edge" of which is observed at location 1 (L1) to be lying upon unit 1. In the east this unit may cut directly into bedrock. A basal, clast supported gravel (unit 2a [facies Gm]), occurs at the base of this unit. The gravel appears to be concordant with the lower bounding surface. Unit 2b lies conformably upon unit 2a and consists of fine to medium sands at location 1 (facies Sm) and fine laminated sands and silts at location 3 (facies Fl). Present within these sediments are abundant plant macrofossils (spruce and pine cones, along with large wood fragments) and pollen (described below). The organic deposits appear to thicken towards the east, being 0.39 m thick at location 1, with a maximum recorded thickness of 2.1 m being augered at location 3.

These sediments clearly represent a major decline in available river energy, sedimentation being essentially fine grained. The erosional base is perhaps the result of an initial increase in energy available for erosion due to a decrease in sediment supply. This condition could be expected where colonisation by vegetation (suggested by the faunal and floral content of the channel fill [see below] pp. 23-28) leads to increased bank stabilisation by vegetation. The basal gravel (unit 2a) perhaps represents a channel lag deposit. As colonisation progressed sedimentation was restricted, in the main, to finer grained sediments (facies Fl) which appear to coarsen towards the banks (facies Sm at L1). The occurrence of massive gravel lenses within this unit at location 5, suggests at least periodic higher flood flows capable of gravel entrainment.

Unit 3 rests upon unit 2 with an erosional planar contact and consists of a medium grade, clast supported gravel with coarse interstitial sand (facies Gm). As with unit 1 only rudimentary horizontal bedding is recognised. Generally unit 3 is thin, with an estimated thickness of around 0.5 m. Unit 3 represents a return to deposition over a wider area and is interpreted as representing conditions similar to those described above for unit 1. Where unit 2 is not developed it is not possible to distinguish between units 1 and 3.

Unit 4 is the thickest unit present within the exposed sequence, with maximum recorded thicknesses of ca.6.5 m. The majority of the exposure (unit 4a) consists of a fine to medium grade sand, dominated by planar cross sets and co-sets (facies Sp), along with subsidiary trough cross sets (facies St). Palaeocurrent data from unit 4a show a vector mean flow direction of 52.24° with a magnitude of 63.81%.

Unit 4b consists of a series of clast supported gravels (facies Gm) with much interstitial sand and massive sand beds (facies Sm) [see S3]. The gravels frequently lie upon concave-up lower bounding surfaces, the gravel fills being concordant with the lower bounding surfaces. This unit is both underlain and overlain by unit 4a.

The contact of unit 4 with the underlying units is erosional, cutting across units 1 and 3, and where observed overlying unit 1 (3?), is planar, although survey data of the heights of the bounding surface show lateral variability. Towards the top of unit 4, a distinct change in colouration of the matrix occurs. A reddening and general mottling of the sand is noticeable.

Unit 4 displays evidence of post depositional extensional (normal) faulting along with minor water release fissures. Additionally involution structures are present at the top of the unit, obscuring the nature of the upper bounding surface with the overlying unit 6.

Clearly Unit 4 represents a major facies change. Unit 4a is interpreted as representing sedimentation on the slip faces of numerous linguoid or transverse bars (facies Sp) and on in-channel dunes (facies St) (Miall, 1977). It is suggested that unit 4b represents multiple channel fill sequences, indicating either the simultaneous existence of multiple channels or frequent channel migration and/or avulsion.

The occurrence of unit 4b as a distinct separate horizon suggests either deposition during one major runoff event or a short lived increase in available energy.

Unit 5 is a fine grained organic deposit, lying upon a lower erosional, concave-up bounding surface. Unit 5 is both overlain and underlain by unit 4 and thus appears intimately related. The fine grained infill sediments overlie a basal, thin, concordant gravel lag. The overlying fine grained silts and clays are laminated at the base (facies Fl) passing vertically upwards into more massive fines (facies Fm). At its recorded maximum the channel deposits are 1.8 m thick.

The channel form is clearly preserved and crosses the present exposures at an oblique angle. These deposits contain abundant pollen and spores described below (pp. 23-26).

Unit 5, as with unit 2, represents a decline in flow energy in this area. As unit 5 is seen to interdigitate with unit 4a a close association in deposition is inferred. It is suggested that the organic sediments represent a cut-off channel infill, the active channel zone perhaps having migrated away from this area of the valley floor. The presence of vertical stones suggests contemporary periglacial activity. The position of unit 5 makes it likely that this deposit represents the lateral equivalent of the organic deposit recorded by Kelly (1968).

Unit 6 consists of a series of fining upwards, horizontally bedded, clast supported gravels (facies Gm) and massive sands (facies Sm). This unit lies with an erosional, planar contact across units 4 and 5 and reaches a maximum recorded thickness of 1.55 m. Large scale involution structures occur at the boundary with the underlying unit 4 and unit 6 also contains a small intraformational frozen ground pseudomorph. The altitude of the lower bounding surface slopes down towards the south.

Unit 6 represents, once again, a return to higher energy flow conditions with deposition of gravels across the whole area, overstepping units 4a and 5. The erosional nature of the contact perhaps removing unit 4a from above unit 5 in places and also accounting for the reddened matrix (derived from the top of unit 4) and fines contact (derived from unit 5). Conditions are again similar to those described above for units 1 and 3, although the preservation of interbedded coarse to medium sands suggests preservation of lower stage or flood waning deposits. The fall in

altitude of the lower bounding surface towards the south may suggest a derivation from the north for this deposit.

Unit 7 caps the sequence and is a complex unit consisting of a matrix-supported, poorly sorted gravel (facies Gms) observed only towards the south of the recorded exposures. The matrix consists of coarse to medium grade reddened sands, with a low but significant fines content. This unit is readily distinguishable on lithological grounds (see below). Sand inclusions from unit 4, are present in places within the deposit, along with areas of apparent sediment sorting (graded areas). Difficulty, however, is experienced in defining the position and nature of the lower bounding surface. Sections where units 6 and 7 are present are too high to be logged accurately, however, examination, as far as is possible, suggests a conformable bounding surface.

Unit 7 (facies Gms) is interpreted as a sediment gravity flow. The poorly sorted nature of the deposit, together with the matrix-support and perhaps a concordant lower bounding surface suggests an origin other than by fluvial deposition. The lithological nature of the deposit (see below) perhaps suggests flow from the higher ground to the north-east.

Lithological analysis

Six gravel samples in all were collected from the exposures and subjected to clast lithological analysis of the 11.2-16.00 mm size fraction. Samples were obtained from units 1 (G104), 3 (G105), 4 (G106), 6 (G117, G126) and 7 (G107). The results of this analysis are shown in Table 2.

In all samples the predominant lithologies are quartzite and quartz. Lithologically units 1, 3 and 4 appear almost identical, although a gradual increase in chert and a decrease in the incorporation of the underlying Mercia Mudstone bedrock is suggested up through the profile. Unit 6 shows an increase in hard sandstone content, the highest value being recorded from sample G126. This content appears to fall to the south in sample G117. Similarly chert content appears high in G126 but falls away again to the south in G117. Unit 7 (G107) is distinguished from the other units by its relatively high flint content (3.08%), also appearing high in chert and igneous lithologies.

Interpretation

Units 1, 3 and 4 display compositions typical of the Baginton-Lillington gravels, being dominated by quartzites and quartz with additional schorls from the Kidderminster Formation of the West Midlands. Additionally Warwickshire coalfield (Carboniferous) cherts and sandstones along with Triassic sandstones make up the minor components.

Unit 6 is again dominated by these lithologies and shows a relative increase in hard sandstones and cherts, suggesting a proportionately greater arrival of more local materials. Both Carboniferous and Triassic sandstones crop out to the north and west of the site, but the relative decline in content towards the south leads to a northerly origin being preferred.

Unit 7 shows the distinctive new input of material derived from eastern glacial deposits. The percentage of flint present is too low to have been deposited either directly as outwash or directly from the River Avon where percentages are usually greater than 10%. Low percentages of flint (3% or less) have been recorded from the lower gravels beneath Avon Terrace No. 4 from the drainage section (Shotton, 1968 [see above]) and attributed to

Table 1

Summary Lithological Count Data, Pools Farm Pit
(11.2-16.0 mm size fraction)

Sample No.	104	105	106	107	117	126
	Unit 1	Unit 4	Unit 4	Unit 7	Unit 6	Unit 6
Quartz	36.77	33.33	32.42	36.13	33.89	37.68
Quartzite	55.16	57.61	58.66	52.66	59.63	50.74
Hard Sandstone	01.79	02.31	01.91	00.56	03.52	05.15
Chert	01.79	02.12	03.39	04.20	00.93	03.31
Flint	00.00	00.00	00.00	03.08	01.66	03.12
Other	04.49	04.63	04.23	03.37	01.66	03.12
n	669	519	472	357	540	544

Avon valley drainage. However, it is suggested above that this deposit is the result of a gravity flow and as with unit 6 probably derived from the north. The source of flint, therefore, is more likely to be the result of this southwards transport tapping an input from the eastern glacial materials preserved to the north and east of this site. The earlier unit 6 however, although derived from the same direction, clearly did not tap this source area.

Discussion

The present findings have important implications for the previous interpretation of Shotton (1968).

Firstly, the Baginton-Lillington Sands and Gravels are interpreted as representing a complex aggradational episode which spans at least one cycle of cold-warm-cold climate oscillation. The transition from the gravels of Unit 3 to more sandy sediments of Unit 4 remains enigmatic but clearly represents a major change in basin dynamics.

Secondly, the interpretation of the terrace sequence requires modification. The lithological composition of the upper gravels (Units 6 and 7) from the Pools Farm Pit bear a strong resemblance to those recorded from terrace gravels to the south recorded by Shotton, 1968, p. 392. Indeed if one assumes that the unit 6 of the Pools Farm exposure is of fluvial, and unit 7 of slope origin, and that their lower bounding surface represents a former ground surface, then the gradient of this lower bounding surface (approximately 1.5°) would allow correlation of these units with the deposits of low flint content at the base of the drainage ditch section of Shotton, 1968 p. 391. Thus, the low flint content gravels at the base of Terrace No. 4 are of local origin derived mainly from the north and not from the upper reaches of the River Avon to the east. There is no justification for assigning these deposits to Avon Terrace No. 3 and thus to the last interglacial.

The change to higher flint content within the gravels further up the sequence may merely reflect the migration of the main Avon channel into the area previously occupied by the northerly derived tributary deposit.

D. Maddy

PALYNOLOGY OF THE FOSSILIFEROUS DEPOSITS AT BRANDON, WARWICKSHIRE

Palynological investigations were carried out on two sample profiles at points A and C, within the Baginton-Lillington Gravel Member of the Wolston Formation at the Brandon Quarry.

The sequence obtained from the two profiles differ considerably in fossil content and are described in stratigraphical order.

Brandon A

All the spectra from this 20 cm thick sequence fall into a single Pinus-Picea pollen assemblage biozone (p.a.b.) (Fig. 5).

This assemblage is dominated by coniferous tree pollen. Although Pinus is the most abundant, the high frequencies of Picea (up to 20%) indicate that a high concentration of spruce trees was growing in the immediate vicinity. Indeed the occurrence of both conifers adjacent to the site is confirmed by abundant finds of cones and needles in the sediments (particularly of Picea). Of other trees recorded, the only significant pollen records are low numbers of Alnus and Betula both of which were probably growing in the local area.

The pollen of plants of a variety of herb communities are represented. Of particular note is pollen of damp ground tall herbs. However, a drier ground herb-rich grassland community is also well represented. Aquatic plant pollen is rare throughout the sequence. To judge by the frequencies of reworked and unidentified palynomorphs, reworking was not important, a fact that suggests that local erosion was minimal.

In summary the vegetation indicated by the spectra from profile A comprised regional boreal forest. The local river floodplain supported a range of herb-rich grassland communities on both drier and wetter areas. No change in the composition of the assemblage is recorded in these determinations.

Brandon C

The spectra from this profile also fall into a single Gramineae-Cyperaceae-Artemisia p.a.b. (Fig. 6).

In contrast to the previous sequence these pollen spectra are dominated by that of Gramineae and Cyperaceae, with significant records of Artemisia at all levels. A variety of other herb pollen taxa are also present and overall indicate a range of herb-dominated vegetation representing a complex of environments from disturbed ground to wet channel side communities. Of the tree and shrub pollen present, low percentages of both Pinus and Betula occur, but are not present in sufficient quantity to suggest local growth of these taxa. However, at least some of the Betula pollen could represent that of the dwarf birch B. nana. All other trees were absent, but Juniperus and Salix may have occurred locally.

Reworking was very important throughout the period represented, as recorded by the abundance of pre-Pleistocene palynomorphs.

No compositional change of the pollen assemblage is indicated by the spectra, the herb-dominated vegetation being that typically found during cold stages of the Middle and Upper Pleistocene in the lowland Britain

BRANDON A

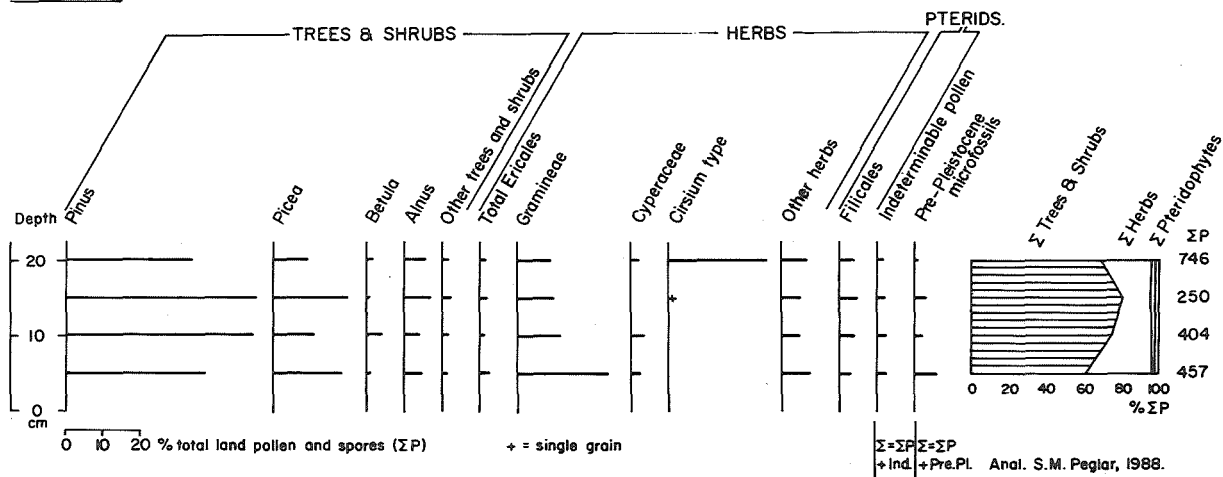


Fig. 5. Summary pollen diagram for Brandon A profile (Unit 2).

BRANDON C

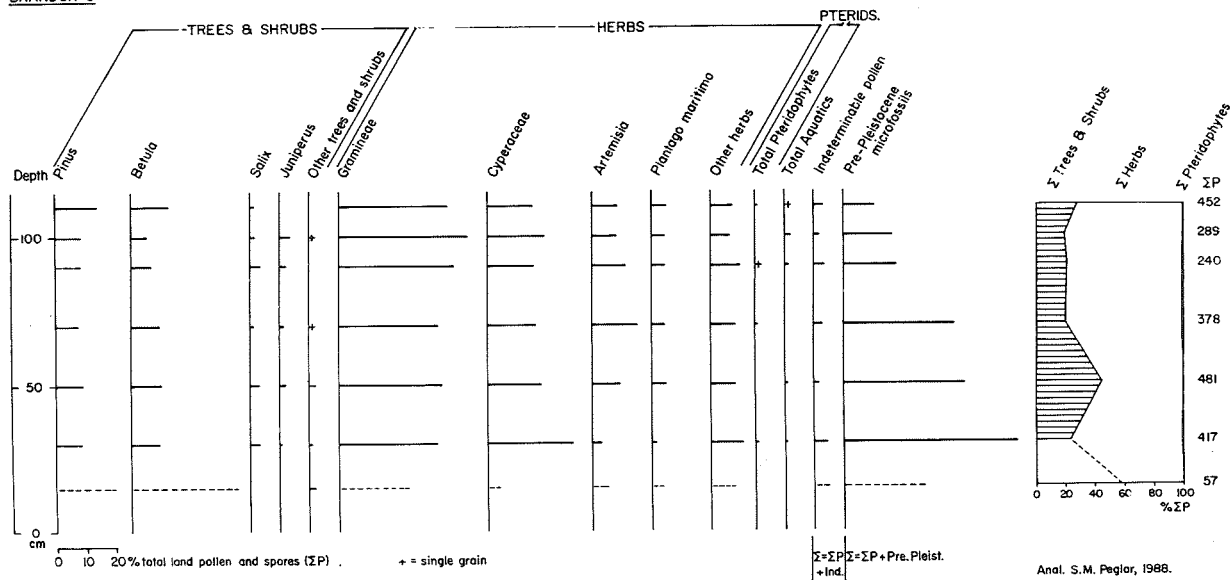


Fig. 6. Summary pollen diagram for Brandon C profile (Unit 5).

(cf. West, 1988). The communities identified are those that would be expected to colonise a gravel and sand river braidplain and its immediate surroundings.

Comparison of the pollen sequence obtained from profile C with that recorded by Kelly (1968) from very similar sediments found interdigitating with the Baginton-Lillington Gravels close to this locality shows a close correspondence between the two assemblages.

Stratigraphical significance of the sequences

The occurrence at this site of two sequences deposited under contrasting climatic regimes demonstrates that a climatic change from boreal to cold climate took place during deposition. Precisely how the two sequences relate in time is unclear however, since although profile A underlies profile C, they are separated by a thickness of gravel and sand. They may therefore be of very different age, since the length of time represented by the erosional hiatus above profile A could, although need not be, considerable.

Having said this, neither sequence contains evidence from the palaeobotany that is of stratigraphical significance. Boreal forest such as that found in profile A occurs frequently in the Middle and Upper Pleistocene. It occurs at both the beginning and the end of temperate stages as the pre-temperate and post-temperate substages (West, 1980). Boreal forest is also recorded from forested interstadial events, such as that represented at Chelford (Simpson and West, 1958).

It is perhaps worth noting, however, the similarity between the sequence from profile A and that from nearby Waverley Wood Farm (Shotton, pp.30-33) where a thicker channel fill deposit underlying the Baginton-Lillington Gravel yielded a comparable boreal forest floral assemblage (Aalto, Peglar and Gibbard, submitted).

Cold stage floras similar to that present in profile C occurred throughout much of the cold stages of the Middle and Upper Pleistocene and therefore cannot be used for correlation.

P.L. Gibbard
S.M. Peglar

COLEOPTERA FROM THE LOWER CHANNEL, BRANDON, WARWICKSHIRE

A bulk sample of about 20 kg was taken from the Lower Channel (Unit 2) and wet sieved for insect remains. 52 taxa were recovered of which 36 have been determined to the species level. A complete report on this fauna will be published separately, but a brief summary of its environmental and stratigraphical implications will be given here.

Local environment

Individuals of species indicative of running water outnumber all other taxa put together by three to one (341:111). These species are characteristic of energetic, well aerated water moving over a stony bottom. A few species are present that require still water and these may represent small pools on the floodplain of the river. Marshy ground beside the river supported sedges and grasses grading gradually into light woodland made up of both deciduous and coniferous trees.

Climatic implications

Taken as a whole, this assemblage of beetles indicates a temperate climate, warm enough for ash trees to grow - the food plant of the bark beetle Lepericinus varius. Eremotes strangulatus is a wood boring weevil that attacks various species of pine. Its geographic range today reaches as far north as central France but it was present in central England in the Flandrian (pollen zone VIIb). These relatively southern species are associated with others of more northern aspect. The water beetle Potamonectes griseostriatus and the weevil Notaris aethiops are dominantly boreo-alpine species, but reach as far south as northern Germany. The riffle beetle Dupophilus brevis does not reach as far north as Britain or Fennoscandia but it lives in cold streams in central European mountains.

The climatic regime that may be inferred from this fauna must have been about as warm as that of the Midlands at the present day but the stream itself was rather cold. Thus if we use climatic criteria to recognise interglacials, the period when this deposit was laid down should qualify for interglacial status.

Stratigraphical implications of the fauna

Several species of beetle are present in this fauna that may be of stratigraphical importance. Micropeplus hoogendorni has so far not been found anywhere as a living species. It was described by John Matthews from Alaska where it occurred in deposits capped by a lava flow dated at about 5.7 million years ago. It has also been recovered from Upper Tertiary (Miocene or possibly Pliocene) deposits in the high arctic of the Northwest Territories of Canada. Its presence at Brandon in what must be undoubted Middle Pleistocene deposits is made doubly significant by its presence also in the channel deposits at Waverley Wood Farm Pit.

A second species of Micropeplus is also interesting. This is named provisionally as Micropeplus sp A. and though highly distinctive it has so far not been matched with any living species. This species was found by Peter Osborne in a previously exposed channel deposit at Brandon that appeared to be interstratified within the Baginton-Lillington gravels. This species has also been found in the channel deposits at Waverley Wood Farm Pit. Neither of these species of Micropeplus have up to now been found anywhere else in Europe.

A distinctive species of Aphodius is also shared by the Lower Channel at Brandon and the channel deposits at Waverley Wood Farm Pit. This species has not yet been identified, and so far it has not been found elsewhere.

This assemblage of beetles has not been found in any other deposit in Britain and faunas from all the well established (and some less well established) interglacial periods have now been sampled. It is an intriguing possibility that at Brandon we have a hitherto unrecorded interglacial episode.

G.R. Coope

Wolston Pit SSSI (SP 411 747)

The former sections at this locality described in detail by Shotton (1953), are now completely obscured by tipped material and weathered talus. It is hoped that a cleaned section will be available to be examined during the meeting, close to the stratotype section. The last section seen at the pit was during the INQUA meeting of 1977 and at that time the section exposed consisted of 4 m of Baginton Sand, overlain by ca. 3 m of Thrussington Till, ca. 1 m of lacustrine deposits including varves (base of Bosworth Clay) and a surface solifluxion layer; but the Baginton-Lillington Gravel, 3-5 m thick, lies beneath the end of the pit and on the hillside above, the whole of the remainder of the sequence to the Dunsmore Gravel has been proved by boring (Shotton 1953, Fig. 10 page 250).

F.W. Shotton

Froghall Pit

It is hoped to visit this newly opened (February 1989) pit working Dunsmore Gravel. This is one of the few sites in the area where Dunsmore Gravel has been seen in section, but the faces of the pit are too new to allow any guide book description.

D.H. Keen

The Exposures at Waverley Wood Farm (SP 3262 7135) north of Leamington Spa

These exist now and have continuously existed for several years, for the exploitation of the Baginton-Lillington Gravel and the Baginton Sand. The Pleistocene usually rests on Mercia Mudstones and vast quantities have been removed in the past. The area thus quarried is contracted to the Warwickshire County Council for the reception of domestic rubbish and many hectares have already been obliterated by fill and the process is continuing.

The site is in Bubbenhall parish but I have been reluctant to use this name because of the possible confusion with the Bubbenhall Clay, a name which I coined for a formation which I believed existed beneath the Wolston Series. What I encountered then in a borehole could have been part of the oldest Pleistocene deposits, beneath the Baginton-Lillington gravel, to be described shortly, but to perpetuate the name Bubbenhall could lead to confusion. Instead I name them after Waverley Wood FARM, which is in the middle of the quarried area. Waverley Wood itself is an unquarried wood belonging to the Forestry Commission, lying south of that which I am now describing and separated from it by Weston Lane.

Over the area, extraction of the gravel and sand has continued until the overburden of Thrusington Till becomes thick enough to render extraction unprofitable (usually 3 to 4 metres). When I first described the Wolston Series, I divided the basal deposits into two parts, Baginton Sand above and Baginton-Lillington Gravel below. Although the Geological Survey in their recent map of the Warwick Sheet (184) has united these under one name, the Baginton Sand and Gravel, I prefer to keep the two terms separate since at Waverley Wood Farm they map as two clearly defined strata.

In September 1984 the quarry company had a trench made in the floor of the quarry, to drain it, for it had become very wet. I saw this cutting a day after it was done. It was very obvious that part of it showed an assortment of sediments, gravel, sand, silt and clay, filling a clearly defined channel beneath the Baginton-Lillington Gravel. The section was surveyed immediately after it was cut, before its vertical sides had deteriorated, and then subsequent trenches were cut and measured for purely exploratory purposes, thanks to the co-operation of Mr Derek Pope, the quarry manager.

The removal of gravel has been complicated by the existence of an oil pipe line which ran across the site in an E-W direction. As this originally had to be preserved, a second quarry had to be opened south of the pipeline, hence my possible references to north and south quarries (Fig. 7). In the south quarry both sides of the old channel were proved, continuing the run of it as found in the north quarry. As I have to write this several months before it is read, I understand that permission to resite the pipeline and exploit the ground so freed has been granted. Even now work is being done and I would estimate that by the time these notes are read, the north and south quarries will be one.

I asked various authorities to report on the palaeontology. They were Dr M. Aalto, macro plants; Ms S. Peglar and Dr P. Gibbard, pollen; Dr D.H. Keen, molluscs; Dr E. Robinson, ostracods; Dr G.R. Coope and his student Mrs L. Holdridge, insects; Dr Andrew Currant, vertebrates. Mr J. Wymer reported on the Palaeolithic artefacts which were found. All but two of these authorities have fully reported and I know something from these two to add some conclusions.

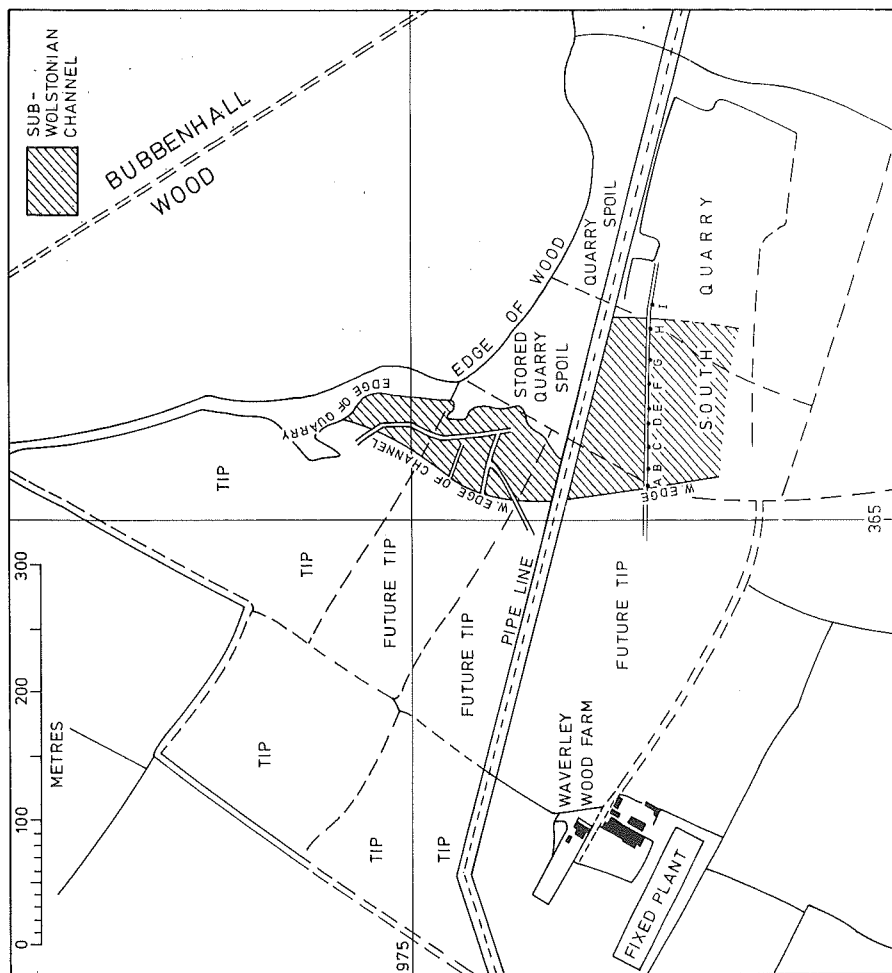


Fig. 7. Location map of the exposures at Waverley Wood Farm Pit showing the position of the sub-Baginton-Lillington Gravel Channel.

The older channel is clearly overlain unconformably by the Baginton-Lillington Gravel. This channel is about 150 m wide (one drainage trench shows it as 130 m), runs north and south for about 400 m and disappears under higher Wolston deposits beneath Bubbenthal Wood.

There were many fossils in the older channel, but few that were diagnostic of age. The clays were most productive, but although the beetles indicated one episode of cool climate and the molluscs one of somewhat milder conditions than the present day, in no case was till encountered. There was one instance which might have been interpreted as cryoturbation, but the consensus of opinion favoured loading. Large vertebrate remains from the channel were few. From a clay within it came an elephant tusk, not strongly curved and at its widest, about 15 cm in diameter. This was not recognised by the digger before it had been broken into many pieces, and it was ultimately dispersed amongst souvenir hunters. When the first drainage trench was being followed, by Shotton and Coope, an incisor of Equus was picked out from gravel in the face of the cutting.

Of much greater importance were the remains of small mammals washed out from clay in the channel during the sampling for molluscs by Dr Keen. Though I have not received a full list of identifications from Dr Currant, I understand that it includes Sorex savini which is Lower Pleistocene or at the base of the Middle Pleistocene. The freshwater Mollusca also have a lower Middle Pleistocene aspect with Unio crassus present.

The basal gravel of the overlying Wolston Series is coarse with boulders up to 20 cm or more in size. They are very well rounded if they are not frost-split, because most of them are of quartzite originally from the "Bunter Pebble Beds". They are recognizable by anyone familiar with the Kidderminster Conglomerate of the Midlands, but no assumption can be made that they have not been recycled several times before their final resting place.

There must be a considerable unconformity at the base of the Baginton-Lillington Gravel. It yields remains of large mammals, notably elephant teeth all of which are worn and broken. As far as I know, they are all of Palaeoloxodon antiquus and come from very large animals. More than a dozen must have come from the gravel, but now the fashion of using the species of elephants for dating has largely gone out of favour. Amongst other fossils from the basal gravel are an enormously large phalanx from an unknown species of Equus and horn cores of ?Bison. Fragments of limb bones of elephants abound and there are two examples of a very large femur ball joint. Also from this horizon have come four artefacts, two of andesitic tuff and two of "Bunter Quartzite" which Wymer relates to anywhere between Cromerian and Hoxnian.

The unconformity below the Baginton-Lillington Gravel betokens a considerable break during which a big lapse of time must have passed. The channel which is certainly old is but a small fragment of a pre-existing landscape which was thoroughly scoured. The section which used to be visible along the south side of the North Pit had much more than 650 m of Baginton-Lillington Gravel overstepping only 130 m of earlier channel sediments. In the large area south of Coventry where the Wolston Series has been dug for its sand and gravel, and where I would certainly have known of any "strange" channel occurring, there have been 130 hectares where the Pleistocene rested directly on Mercia Mudstones without any earlier Pleistocene intervening. There must have been wholesale erosion when the Baginton-Lillington deposition occurred.

It is surely of significance that after this there were two other periods of ice advance, the Thrussington and Oadby Tills, into the Lake Harrison area; and finally the two tills at Quinton are separated by an interglacial event that looks to be the Hoxnian.

It is in the nature of unconformities that what they rest upon does not determine their date, which is sometime after. If the Baginton-Lillington Gravel does reach the sea in Norfolk that does not make it necessarily Anglian. Much more work, particularly on the fauna, needs to be done before the case of Professor Rose is proved and in particular the alternative of escape via the Wreake still needs examination.

In terms of the Continental sequence, certain fossils from the type area of Lillington are significant. A piece of reindeer antler at Warwick Museum almost certainly comes from a once-existent pit near the village. The teeth and a tusk of Mammuthus primigenius which were seen by me when they were found together as far back as 1928, came from Pratt's Pit below Lillington Church. They were donated then to Leamington Museum, where they were confirmed in turn by myself and several officers of the British Museum. There can be no question of these fossils being derived. In a different state of preservation, suggesting derivation, was the molar of Palaeoloxodon antiquus from the same pit by Lillington Church. More recently a cranium of P. antiquus has been found near the site of Hutchin's brick yard, Snitterfield, and it will go to Warwick Museum. Despite its having 4 upper molars and remains of tusk sockets it has been badly distorted, but not greatly derived (Keen and Lister, this volume pp. 34-5).

During the 1939-45 War the Manor Pit was opened, without question in the Wolston Series in Lillington itself and Dr Matley watched it for fossils. Subsequently his collection came to Birmingham University Geology Department. It includes a toe bone which Dr Currant has identified as a left-second metacarpal of Coelodonta antiquitatus. According to Guérin, this species does not appear in Europe until the Saale Glaciation. So in reality, the contention that the Baginton-Lillington Gravel can be followed to the coast in Norfolk where it is related to the Anglian, does not prove anything about its age. Over most of its extent it lies upon Trias, but that does not make it Triassic in age. There can be no doubt that the unconformity beneath the Wolston Series is an extensive one, and its termination can only hope to be approximately judged by determining the age of its newest member, the Dunsmore Gravel. From what I have seen of exposures in this formation, which hitherto were restricted to a small quarry which was soon filled with obnoxious tip, and fleeting temporary sections in road cuttings, the chances of finding diagnostic fossils are very small. However, hope springs eternal in excursions of the QRA.

F.W. Shotton

SNITTERFIELD PIT AND FAUNAL REMAINS

This pit, at circa SP 235 597, was open during 1985-7 but is now closed, partly infilled and with most available faces degraded. It was not thought suitable for a visit during the meeting, but because of the importance of the find of the skull of a straight-tusked elephant (Palaeoloxodon antiquus) in the pit in 1986 the site is briefly described here. A fuller report (Lister, Keen and Crossling in prep.) has been submitted to the Proceedings of the Geologists' Association.

The pit is close to the site of a former quarry, Hutchin's Brickyard, which was worked in the nineteenth century and also yielded elephant material (Lloyd, 1870; Lucy, 1872; Lister this volume pp. 5-12). The stratigraphy consists of up to 8 m of Pleistocene sediments composed largely of fluvial gravel at the base, which Lister et al consider to be part of the Baginton-Lillington Gravel. Above the gravel are fine-grained lacustrine sediments and till. These three units are similar to the lower units of the Wolston Series of Shotton (1953) and may be equated with them.

The elephant skull was found in the basal layers of the gravel. Despite being somewhat crushed and fragmentary it is the most complete skull of P. antiquus species known from the British Isles. The skull was lifted from the quarry and painstakingly conserved by C. Collins of Leicester Museum and is now in Warwick Museum.

The specimen measured approximately 90 cm long by 70 cm across and comprised most of the lower part of the skull, from the occipital condyles at the back to the tusk sockets at the front. The top of the skull is missing, rather as though it had been sliced off, perhaps by later erosion as it lay in the gravel. The form of the upper dentition leaves no doubt whatever of the identity of the specimen as P. antiquus. It also explains the relatively small size of the skull, as with only the first molars in wear, the animal was not yet fully grown. A section of tusk was present in one of the sockets, and other tusk fragments found nearby may also be from the same animal.

P. antiquus was previously recorded from an earlier pit at Snitterfield (Tomlinson, 1953), but the specimen in question, preserved at Warwick Museum, is a very worn molar which on re-examination cannot with certainty be assigned to this species and may instead represent Mammuthus primigenius (Lister, pp. 5-12; Lister et al, in prep.).

Accompanying the elephant remains was a sparse molluscan fauna, also recovered from the basal layers of the succession. A total of seventeen taxa were recovered consisting mostly of aquatic species of moving water such as Valvata piscinalis, Ancylus fluviatilis and Pisidium henslowianum. Also present were two complete, but abraded valves of Unio sp. The land elements of the fauna included species from marsh habitats (Oxyloma pfeifferi), grassland (Pupilla muscorum bigranata and Vallonia costata) and perhaps woodland (Clausilia sp.).

These Mollusca and the occurrence of P. antiquus suggest temperate conditions for the deposition of the base of the Baginton-Lillington Gravels. Whether the conditions were of a fully forested mid-interglacial character, of more open end-interglacial type, or from a "parkland" type habitat which might occur in a warm interstadial is not certain.

The limited fauna from Snitterfield can also only give a hint of an age for the deposits at the site. P. antiquus is known in Europe from at least as early as the late Cromerian, so it cannot serve to distinguish an "Anglian" from a "Wolstonian" age for the deposits sensu Gibbard and Turner, 1988 (see also Lister, pp. 5-12 this volume). None of the Mollusca are diagnostic as to age, but the presence of P. muscorum bigranata, which also occurs in the upper level of the Waverley Wood Farm channel (Keen in Shotton in Prep.), and in the highest terrace of the Severn at Bushley Green, Hereford and Worcester (Bridgland, Keen and Maddy, 1986) may also serve to link these deposits and associate them with an age matching that of the earlier parts of the succession in the West Midlands. The common P. muscorum is usually the form present in the terraces of the Avon and other deposits younger than the Baginton-Lillington Gravels.

A.M. Lister
D.H. Keen

Wednesday 5 April

1. Ailstone SP 211 512
2. Crophorne SO 997 443
3. Eckington SO 919 418
4. Little Comberton SO 967 428

THE DEVELOPMENT AND SEQUENCE OF DEPOSITION OF THE AVON VALLEY RIVER-TERRACES

Introduction

Recent years have seen a welcome resurgence in interest in the river-terraces of the Avon valley. Previous documentary knowledge of their Quaternary history and relationships rests almost entirely on the work of the late Dr. Mabel Tomlinson (1925) and Professor F.W. Shotton (1953, 1968, 1977).

Knowledge to date

Tomlinson (1925) allowed for 5 terrace-levels above alluvium, of increasing age upwards. It is indeed a tribute to Tomlinson that this physical framework and many of her views on it still gain the support of Quaternary science.

Shotton (1968) effectively underwrote Tomlinson's observations and applied the following time-periods to the aggradations beneath the terraces viz.

- No. 5 -
- No. 4 early Devensian
- No. 3 Ipswichian
- No. 2 mid-Devensian
- No. 1 -

Since 1970 fieldwork by the writer has provided much additional information relating to the development and biota of the terraces, some of which is referred to later.

Current difficulties

At some levels (e.g. No. 2) the terraces form extensive, uniform morphological features correlating altimetrically above the thalweg. It is a mistake to assume that the events under the terraces are themselves uniform. Work on the complex lower terraces of the Thames valley, or on the lower terraces of the Severn valley demonstrates the truth of this. In the latter case, what previously there was of the Main Terrace was scoured away by the ingress of glacial meltwater through the Ironbridge gorge, the Main terrace as it now stands postdating that event.

A further difficulty is provided by recognition that events under a terrace represented by the vertical separation of only a few centimetres of sediment (Four Ashes, Tattershall for instance) may themselves represent totally distinct biozones. This calls for the sort of controlled methodical sampling that in 1925 would not have been appreciated.

In the Avon valley it is now evident that the terrace content reflects both more, and more subtle vacillations of climate than previous knowledge would permit. If the field worker is to understand these he requires extensive sections with diagnostic lithologies coupled with the occurrence of zone-fossil-containing assemblages securely tied to them - a rare ideal! The absence of this ideal will however, greatly limit any attempts at correlation.

I now wish to look briefly at specific relationships between some of the terraces and their locations, where future work may profitably provide fresh knowledge.

The relationship of No. 1 and No. 2 Terrace, and their alluviation

There have been a number of instances where gravels earlier than No. 1 Terrace have been recognised in sections through alluvium. These include Eckington (SO 919 400), Evesham (SP 037 433) (Whitehead 1979) where they pass beneath the modern river and contain a fauna dated 8460 bp (Birm-655), Bidford-on-Avon (Shotton 1972, Whitehead 1979), and Aldington (SP 049 448) where they contain remains of Cervus elaphus (see appendix). I have referred previously to the vicissitudes of sedimentation under the terraces. One can cite the situation at Pershore as a clear instance of this. Here, a major river channel (up to 200 m in width and 7 m in depth) has been incised in to No. 2 Terrace (Vince & Whitehead 1979) which on the evidence of dated wood 5.1 m deep (3950 bp Birm-965) began to fill during the Neolithic. At some point following this the channel was abandoned by the river and it was used as a Roman tip. The bulk of the fill bringing the channel surface almost to that of No. 2 Terrace took place rapidly in the 13th century A.D., which almost certainly means that Pershore Abbey was built effectively on an island. The relationship of the existing river south of Pershore to its earlier course through this channel is an unresolved matter of some interest.

That there is a geometrically-defined No. 1 Terrace there is no doubt; what is far from clear is the geological relationship between the sediments under No. 1 and No. 2 Terrace. I have seen this relationship at only 2 sites in the lower Avon valley. At Eckington (SO 9140) gravels descended without a break from No. 2 to No. 1 Terrace level where they eventually passed under alluvium. At Bredon's Hardwick, the situation is somewhat more complex. Here the 'modern' floodplain is itself a composite feature. An upper Roman artefact-bearing clay extends significantly back over No. 2 terrace. This is distinguished from a lower alluvial plain by the small bluff at the back of it; this lower member contains later prehistoric (pre-Roman) artefacts and it appears, therefore, that in this area it is a post-Roman erosional feature. Roman-bearing alluvium also extends (just) onto No. 2 Terrace in the Carrant Brook at Aston Mill.

The crucial point at Bredon's Hardwick is this. Gravels descend continuously from No. 2 to No. 1 Terrace-level where they pass under a modern upper, but not a modern lower flood plain (recent floods having inundated No. 2 Terrace). No. 1 Terrace appears therefore to be an erosional feature. The situation is somewhat similar at Lower Moor, near Fladbury, where the surface of No. 1 Terrace is buried under alluvium, some of it extending back into the Flandrian by about 5000 years (Shotton, pers. comm.). It is particularly desirable to locate organic sediments near the base of No. 1 Terrace, but these have not yet been found.

No. 2 Terrace at Twynig, Gloucestershire (SO 8936)

This site demonstrates a number of interesting features. Extensive sections were required to determine fully the relationships and extent of the beds. At the back of No. 2 Terrace a generalised section through the formation from the top down was as follows:

- a) loam becoming gravelly
- b) solifluction (gravel) from No. 4 Terrace, Acheulian (Whitehead 1988)
- c) Jurassic-rich gravel, Acheulian artefacts
- d) orange-pink Triassic-derived sand
- e) Lower Lias Clay bedrock

The Jurassic-rich gravel revealed lenses of peat basally which were dated at 36600 bp (Birm-599). It contained remains of Mammuthus primigenius, Coelodonta antiquitatis, Megaloceros giganteus, Equus sp., and Bison.

The Triassic-derived quartzose sand must have been introduced into the Avon by the Severn, and demonstrates strikingly the influence of that river prior to 36600 bp. These sands contained no organic lenses or beds, but they did provide a distinctive suite of vertebrates, Canis lupus, Microtus agrestis, Rangifer tarandus, and Bison priscus.

These sands only occur under No. 2 Terrace near its confluence with the Severn, and a fieldworker upstream would be working in total ignorance of them. In one comparatively small area at Twynning where the sands were in contact with the Lias Clay of the valley side, they had been forced up from beneath, their bedding planes clearly revealing that they had in fact virtually been overturned.

The relationship of No. 3 and No. 4 Terrace (see also Bridgland, Keen and Maddy pp. 39-67)

A major difficulty surrounding these two terraces has been the need to allow sediments of No. 3 Terrace to underlie those of No. 4 Terrace. (Tomlinson 1925, Shotton 1968). There is no proof of this anywhere in the Avon valley, and it is further credit to Tomlinson that she actually suggests (1925, p.160) that the reverse may indeed be true i.e. that No. 4 Terrace sediments are the older. Little value can be placed on the nineteenth century vertebrate faunas; I have established that almost all of the remains ascribed to Bos primigenius at that time are actually from Bison. With the possible exception of a mandibular ramus from No. 3 Terrace at Cropthorne (now in Evesham Museum) Bos primigenius may not have occurred at all in the Pleistocene of the Avon valley, which is a pity because it is a better indicator of climate than Bison.

Sections at Eckington in 1974 revealed that a) sediments of No. 3 Terrace, a lithologically distinct formation, passed underneath No. 2 Terrace sediments and more importantly b) that they were themselves underlain by sediments descending from the height of No. 4 Terrace. At Eckington therefore No. 3 and No. 4 Terraces can be shown to be distinct, as therefore must be their faunas in support of Evans (1971 p.318), and, more recently Shotton (1985).

At Twynning, No. 4 Terrace was composed of two lithologically distinct members (Whitehead 1988) the one overlying the other, with a 'full-glacial' biota (Mammuthus primigenius, Coelodonta antiquitatis, Equus cf spelaeus, Rangifer tarandus, Bison, Pisidium vincentianum, 'polar' vegetation) in the basal member. The upper member composed of Triassic-rich sands and gravels revealed ice-wedge pseudomorphs originating within it, and a fresh valve of Corbicula fluminalis in situ.

The development of No. 4 Terrace at Twynning is therefore:

- a) erosion to bedrock
- b) aggradation of Jurassic-rich gravels in 'full-glacial' climate
- c) erosion of b) locally almost entirely
- d) aggradation to modern terrace flat

time-breaks occur at all intervals in the sequence.

It is necessary to reconcile the existence at d) of *C. fluminalis* and (higher up) of ice-wedge pseudomorphs. Possibly the aggradation marks a climatic transition.

The fauna at Ailstone (*C. fluminalis*, *Potomida littoralis*) under No. 4 Terrace of the Stour can only be interglacial (see below pp. 51-67).

If the development of No. 4 Terrace were to extend over a long period of time, it may be that some of the evidence in the tributaries for it has been removed from the Avon itself.

Mention must be made of the difficult last-century site at Bengeworth near Evesham (SP 050 435) (Winnington-Ingram 1879). Here the fauna, at No. 3 level, was held to include *Hippopotamus* and *Rangifer tarandus*. Wherever *Hippopotamus* is known in the Avon valley the sediments are Ipswichian, and the inexplicable presence of Reindeer (the specimen cannot be traced) should not be permitted to interfere with this fact.

No. 5 Terrace at Pershore, Worcestershire (SO 038 464)

A section opened up for road-widening in April 1975 (Fig. 8) at the height of No. 5 Terrace revealed a deeply incised channel in the Lower Lias Clay. The sand and gravel fill of this channel outcrops on the modern land surface and the assumption is that at 39 m above alluvium they represent No. 5 Terrace sediments. (There is a minor note of caution, lest these sediments represent something buried under No. 5 Terrace, itself now totally removed).

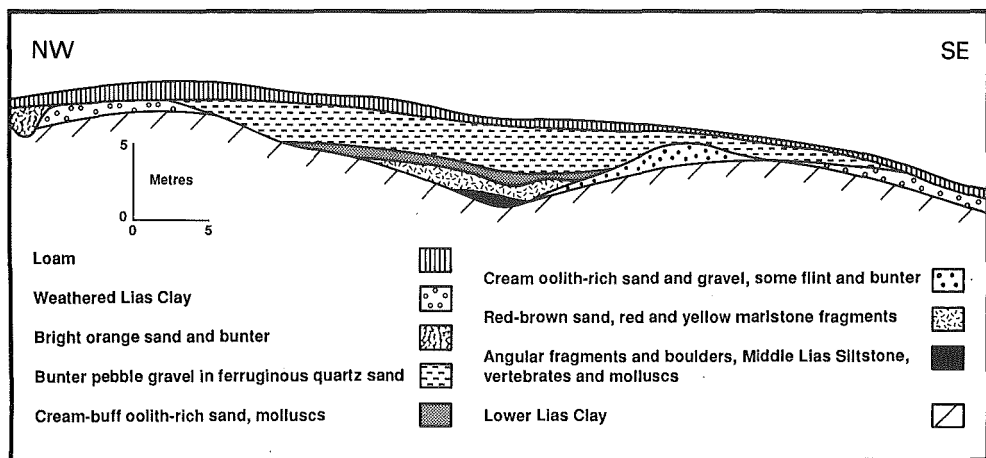


Fig. 8. Section in No. 5 Terrace of the Avon, Pershore, Worcestershire.

It has been possible to establish that this channel was at least 7.2 m deep and from organic samples that it contained eventually clear, gently flowing water with such deep-water hydrophytes as Groenlandia densa and Potamogeton paelongus. The ostracod Limnocythere sanctipatricii (det. J.E. Robinson) prefers deeper sluggish water bodies. The existence of the bivalve mollusc Pisidium moitessierianum and Red Deer (Cervus elaphus) bones coupled with the evidence from the flora indicates a somewhat temperate climate (possibly not dissimilar to that of present-day Pershore). That No. 5 Terrace and the Bushley Green Terrace of the Severn correlate is a possibility, but for the moment, however, this must remain conjecture.

Revised Sequence of Terrace Formation in Avon valley

I propose that the sequence of terrace formation in the Avon valley is as follows:

Sequence	Sediments	Notes
Alluvium	Flandrian	Rich Bronze Age biota pre-dating 'canalised' course of existing river.
Post No. 1 gravels	Flandrian	8460 bp (Birm-655) at Evesham
No. 1	Flandrian- Devensian	Sole biota - Reindeer at Lower Moor. Subject to Flandrian alluviation.
No. 2	Mid-Devensian	At Aston Mill (Carrant) terrace-flat post dates 26000 bp. (Birm-382)
No. 3	Ipswichian	Pollen at Wick = open steppe ?Ip IV.
No. 4	Pre-Ipswichian	Full-glacial at Twynning; interglacial at Ailstone. Middle Palaeolithic disc-core <u>in situ</u> at Twynning.
No. 5	Pre-Ipswichian	Temperate at Pershore.

Conclusion

Climatic vacillations following the establishment of the River Avon are more complex, and the evidence more subtle, than previous knowledge has assumed. The sequence of terrace formation proposed here simplifies the relationship of No. 3 and No. 4. The post-No. 5 excavation that lowered the valley by about 80 ft (Tomlinson 1925) is no longer supported; an excavation of about 30 ft. in depth at that time is all that is necessary to support the new sequence.

P.F. Whitehead

THE QUATERNARY MALACOFAUNA OF THE WARWICKSHIRE-WORCESTERSHIRE AVON

Introduction

All of the Avon valley river terraces which have a history of study extending back 150 years, have now yielded biotic information. The recent appreciation by Quaternary scientists that the record is a more sensitive expression of changing environments than hitherto believed, places the Avon valley in the forefront of British Quaternary studies.

Elsewhere in this guide I refer to difficulties surrounding the understanding of the sequential succession of these river terraces. My intention here is to enable the guide-user to gain quick access to the essential character of the mollusc fauna of the terrace-sediments.

All of my own numerous records are covered by this review, but much background information must of necessity be omitted. A major source of these records are from well-studied sections at:

Twynning, Gloucs. SO 8936 (No. 2, 2.1975; No. 4, 11.1973)
Bredon Station, Worcs. SO 927 367 (No. 4, 1973)
Eckington, Worcs. (long transect from river to height of No. 4, 1974)
Pershore, Worcs. SO 938 464 (No. 5 level, 1975)
Little Comberton-Wick, Worcs. SO 9744 (No. 3, 4.1974)
Cropton, Worcs. SP 0044 (No. 3, 12.1977)
Lower Moor, Worcs. SO 9846 (No. 1 level with F.W. Shotton, 12.1979)

PFW has also examined personally 60 organic samples from the Carrant Main Terrace (Aston Mill, Beckford = No. 2 terrace), on which little has previously been published.

The significant publications to date are those of Strickland (1858), Kennard & Woodward (1925), Briggs et al. (1975) and Keen and Bridgland (1986). Molluscs from the Bengeworth fauna (Maddy et al. 1987) are excluded from the following list as they have not been dated conclusively.

This account closes with a synopsis of radiometrically dated mollusc faunas in the Avon valley. In isolation its value is somewhat limited; deductions should be made only in the broadest and most general terms. Viewed in relation to other dated faunas however, its value is considerably enhanced.

Although work has been published on the older mollusc faunas of other English river terrace sequence (Briggs and Gilbertson 1973, Bridgland et al. 1986) there are too many variables to even consider correlation between them.

It is well known that in general terms, terrestrial and freshwater molluscs are good ecological indicators, but, many being eurythermic they are limited in their ability to indicate climate. Amongst these are those which can be observed, from the list, to occur under most of terraces, the climate of their periods of sediment aggradation ranging broadly from 'full-glacial' (No. 2) to interglacial (No. 3).

Then there are the species, gastropods or bivalves, which are more sensitive to environmental parameters. Some of these are climatically

Taxon	Terrace & Tributary Correlatives				
	1	2	3	4	5
<u>V. cristata</u> Müll.			+		
<u>Valvata piscinalis</u> (Müll.)		+	+	+	+
<u>Belgrandia marginata</u> (Mich.)			+		
<u>Bithynia tentaculata</u> (L.)		+	+	+	+
<u>B. leachii</u> (Sheppard)	?				
<u>Carychium minimum</u> Müll.		+			
<u>Lymnaea truncatula</u> (Müll.)	+	+	+	+	
<u>L. truncatula</u> form X		+			
<u>L. palustris</u> (Müll.)		+	+		
<u>L. auricularia</u> (L.)			+		
<u>L. peregra</u> (Müll.)	+	+	+	+	+
<u>Planorbis planorbis</u> (L.)			+		
<u>Anisus leucostoma</u> (Müll.)	+	+	+	+	
<u>A. vortex</u> (L.)			+		
<u>Bathyomphalus contortus</u> (L.)			+		
<u>Gyraulus laevis</u> (Alder)		+	+	+	
<u>G. albus</u> (Müll.)			+		
<u>Armiger crista</u> (L.)	+	+	+	+	
<u>Ancylus fluviatilis</u> Müll.			+	+	
<u>Acroloxus lacustris</u> (L.)			+		
SUCCINEIDAE gen. indet.					+
<u>Succinea oblonga</u> Drap.				+	
<u>S. o. forma elongata</u> Sandberger		+			
<u>S. putris</u> (L.)		+			
<u>Oxyloma pfeifferi</u> (Rossm.)		+	+		
<u>Cochlicopa lubrica</u> (Müll.)		+	+		
<u>C. lubricella</u> (Porro)		+			
<u>Columella columella</u> (Martens)		+			
<u>Vertigo pygmaea</u> (Drap.)		+	+		
<u>V. genesii</u> (Gredler)		+			
<u>V. angustior</u> Jeff.			+		
<u>Pupilla muscorum</u> (L.)	+	+	+	+	+
<u>Vallonia costata</u> (Müll.)		+	+		
<u>V. pulchella</u> (Müll.)	+	+	+		
<u>V. enniensis</u> (Gredler)			+		
<u>V. excentrica</u> Sterki		+	+		
<u>Punctum pygmaeum</u> (Drap.)		+	+		
<u>Discus rotundatus</u> (Müll.)			+		
<u>Nesovitrea hammonis</u> (Ström)		+			
<u>Aegopinella pura</u> (Alder)		+			
<u>Aegopinetta nitidula</u> (Drap.)		+			
<u>Oxychilus cellarius</u> (Müll.)			+		
<u>Milax</u> spp indet			+		
<u>Limax marginatus</u> Müll.			+		
<u>Deroceras</u> sp. indet		+	+		
<u>D. cf. agreste</u> (L.)		+			
<u>Euconulus fulvus</u> (Müll.)		+			
<u>Clausilia</u> sp. indet			+		
<u>Candidula</u> cf. <u>crayfordensis</u> Jackson			+		
<u>Cernuella virgata</u> (da Costa)			+		
<u>Trichia hispida</u> (L.)		+	+	+	
<u>Arianta arbustorum</u> (L.)		+			
<u>Unio</u> sp. indet			+		
<u>U. pictorum</u> (L.)			+		
<u>U. tumidus</u> Philipsson			+		
<u>Potomida littoralis</u> (Cuvier)			+	+	

Taxon	Terrace & Tributary Correlatives				
	1	2	3	4	5
<u>Corbicula fluminalis</u> (Müll.)				+	
<u>Sphaerium corneum</u> (L.)		+	+	+	
<u>S. lacustre</u> (Müll.)			+		
<u>Pisidium amnicum</u> (Müll.)		+	+	+	+
<u>P. casertanum</u> (Poli)	+	+	+	+	+
<u>P. obtusale</u> (Lamarck)	+	+	+		
<u>P. o. lapponicum</u> (Cless.) Fav. & Jay.		+			
<u>P. milium</u> Held	+	+	+		
<u>P. subtruncatum</u> Malm	+	+	+	+	+
<u>P. supinum</u> Schmidt		+	+	+	
<u>P. henslowanum</u> (Sheppard)		+	+	+	
<u>P. nitidum</u> Jenyns	+	+	+	+	+
<u>P. pulchellum</u> Jenyns			+		
<u>P. moitessierianum</u> Paladilhe			+		+
<u>P. personatum</u> Malm			+		
<u>P. vincentianum</u> Woodward				+	

Analysis

Number of species	12	38	53	21	10
Aquatic	11	17	33	18	9
Terrestrial	1	21	20	3	1

Table 3. The distribution of Quaternary Molluscs in relation to Avon Valley river terraces

[Other unpublished records occur in the contribution by Bridgland, Keen and Maddy pp. 39-67]

restricted (stenothermic) species, known from under only one terrace (e.g. Belgrandia) or at one site (Vertigo genesii).

I now discuss briefly some critical aspects of the occurrence of these taxa and faunas.

Belgrandia marginata

This species is now extinct in Britain, but occurs in southern Europe (Germain 1931). It is confined in the Avon valley to sediments beneath No. 3 Terrace, which contain an Ipswichian fauna at Eckington (Keen and Bridgland 1986), at Wick/Little Comberton (PFW unpub.), Bredon (PFW unpub.), and Evesham (Winnington-Ingram 1879). It is a clear indicator of interglacial conditions and is characteristic of the Ipswichian.

Lymnaea truncatula form X.

This very distinct form is known only from organic sample 37 at Aston Mill (= No. 2 Terrace). The spire is longer than the body whorl and the height exceeds the width by up to $2\frac{1}{2}$ times. The whorls are markedly tumid and the Index of Cylindricity is fairly high. The attributes of this form are demonstrated below by comparison with modern and more typical fossil specimens from Aston Mill.

	whorls	height	width	body whorl	spire	$\frac{\text{height}}{\text{width}}$	$\frac{\text{whorls}}{\text{width}}$
<u>Modern L. truncatula</u>							
Pershore Worcs.	4.75	4.9	3.0	2.9	2.0	1.63	1.58
Little Comberton Worcs.	4.75	7.3	3.9	5.4	1.9	1.87	1.21
Isle of Wight	4.75	7.8	4.0	5.9	1.9	1.95	1.18
Borth, Wales	4.75	6.3	3.0	4.1	2.2	2.1	1.58
Little Comberton	5.25	9.0	4.3	6.5	4.4	2.09	1.27
<u>Aston Mill fossil</u>							
Sample 31	4.75	5.6	3.2	3.8	1.8	1.75	1.48
Sample 31	4.75	5.7	2.6	4.1	1.6	2.19	1.82
Sample 31	5.25	7.4	3.4	4.5	2.9	2.17	1.54
<u>Aston Mill form X</u>							
Sample 37	5.5	7.7	3.0	4.7	5.0	2.56	1.83
Sample 37	5.75	8.3	3.5	4.9	5.4	2.37	1.64

Measurements in millimetres.

Index of Cylindricity = whorls:width

Carychium minimum and Vertigo pygmaea

These species are linked here because their thermal requirements are somewhat similar and because their existence in Carrant Brook Main Terrace sediments provided respectively their second and first mid-Devensian British records. C. minimum is known rarely from the Thames valley in this context (Sparks 1965), but more usually from there in the late-Devensian.

C. minimum was found as a single shell at Aston Mill (Sample 1, 24.12.1971). Its habitat was a moss-fringed marshy hollow at the base of the aggradation, from which sample it represented 0.3% of the terrestrial molluscs.

V. pygmaea occurred as 2 shells in sample 45 at Aston Mill (8.10.1977) in which they comprised 0.1% of the terrestrial molluscs living around a small Potentilla crantzii-covered hollow developed in the gravels. Both species are limited in the north of their west European range by the 63°N line of latitude, and must have been utilising thermally ameliorated microclimates at Aston Mill. Although V. pygmaea often behaves as a xerophile it is a mildly eurytopic taxon. Both are also known from Devensian 'hillwash' at Beckford (see under Succinea putris).

PLANORBIDAE and other aquatic bivalves from Avon No. 3 Terrace

This significant fauna can, in general terms only be paralleled (Planorbidae except G. laevis, Unionidae except P. littoralis, Pisidium except pulchellum) by that of the modern river. In its fullest expression the Ipswichian river was 'stable', the presence of Unionidae suggesting that bed sediment was not being actively eroded.

Frequent evidence indicates clean, clear, plant-rich water with negligible sediment-load. Insignificant valley-side erosion is attested to by the virtual absence of terrestrial molluscs, in otherwise very large assemblages of molluscs at Little Comberton and Wick.

Succinea putris

The Pleistocene occurrence of this species in the Avon valley, is limited to a single, very large, 25 mm shell, and its associated fauna warrants special consideration.

This fauna was located at Beckford, Worcs., (SO 9775 3629) in 'hillwash' at the footslopes of Bredon Hill on 28.6.1980. The sediment was a deep ferruginous loam, totally lacking in thermoclasts, held by PFW to be derived from the Middle Lias further upslope.

At my request these loams were sectioned by hydraulic excavator which, despite cutting down 9.58 metres into them, failed to locate their base. In these loams at a depth of 4.32 metres from the modern land surface, a white shelly band was encountered (sample 48) from which the molluscs of a 4.5 kg sample was examined by Whitehead and Shotton (unpub.).

The fauna is unique in the Avon Valley Pleistocene as being composed exclusively of terrestrial species, of which 19 have been named. They include such climatically sensitive species as Cochlicopa lubricella, Vallonia excentrica, Aegopinella pura and A. nitidula as well as further rare examples (see earlier) of Carychium minimum and Vertigo pygmaea (0.3% and 0.1% respectively).

This is the fauna of a tall-herb mire. It is matched almost exactly by species found in such a habitat by Cameron (1978) at Malham, Yorkshire. Tall-herb mires are exceedingly rare on Bredon Hill today, but at one site the correlation between its fauna and that of sample 48 is close, the two having 13 species in common (both have Euconulus fulvus; only the modern one has E. alderi (Gray)). It has not yet been possible to date this fauna isotopically. My view is that it is mid-Devensian, closer to the thermal maximum somewhat prior to 40000 bp. These colluvial sediments are complex, often remaining as isolated patches juxtaposed with or overrun by more recent sediments.

Vertigo genesii

Known only from one shell from calcareous spring-fed pools on Liassic limestone draining the valley side under No. 2 Terrace at Twynning. Main population now centred on upland Scandinavia (Kerney & Cameron 1979) and only recently rediscovered in Britain (Coles & Colville 1980).

Vallonia enniensis and Candidula crayfordensis

The respectively definite and probable occurrence of these in the Avon Valley Pleistocene, the former an obligate hygrophile, the latter an extinct xerophile, stems exclusively from the work of Keen & Bridgland (1986) in Ipswichian sediments under No. 3 Terrace at Eckington, notable also for Discus rotundatus and Clausilia sp.

Elsewhere under No. 3 Terrace I have recorded Vallonia costata (Little Comberton - large rather flat form) and V. pulchella (Cropthorne), but not yet V. enniensis. The close correlation between the fauna and flora of the Ipswichian Rivers Avon and Ouse (Preece and Ventris 1983) is noted.

Cernuella virgata is also exclusive to No. 3 Terrace at Wick (PFW April 1974), from where there is a complete shell (confirmed by Kerney) and a fragment likely to be from this taxon. C. virgata is a warm stenothermic species scarcely exceeding 52°N on the European mainland and in Britain regarded as culture-favoured (Ellis 1969, South 1974) today.

Arianta arbustorum

Unique to hillwash at Beckford, Worcs. (see S. putris earlier) representing 4.5% of specimens from a tall-herb mire. It is known (Grime et al 1970) that the phosphorus-rich foliage of Urtica dioica L. is favoured by Arianta, as it is today on Bredon Hill.

Corbicula fluminalis

Now extant in southern Palaearctic and Ethiopian regions, this is regarded as an interglacial indicator-species (Sparks 1964). It is known only from No. 4 terrace at Twynning and at Ailstone on the River Stour. At this latter site it was found with Potomida littoralis, otherwise known only from Evesham (Winnington-Ingram 1879) and with no fossil records in the Avon Valley this century.

Sphaerium corneum

In April 1974 I was able to collect mollusc samples from what has been shallow current-fed pools in depressions on the Lower Lias clay under No. 3 Terrace at Wick at SO 9779 4500.

The fauna included S. corneum represented by an odd extremely tumid form, the paired valves being almost spherical. In these tumid individuals the ligament pits are deep and prominent and the lateral teeth are strongly defined. 13 valves were measured and the Degree of Convexity ($100 \times \frac{\text{thickness}}{\text{height}}$) established. 6 valves were normal (Convexity 28.0 - 30.1); 5 were tumid, some extremely so, with marked growth interruptions (Convexity 37.5 - 46.1) and there were 2 intermediates (34.9, 36.4).

Nearer the back of the terrace, S. corneum was a component of a fully riverine fauna, and was normal (Convexity 29.2 - 32.9).

Pisidium spp.

P. pulchellum is known by only one valve from one site under No. 3 Terrace at Wick. Here, in the mollusc-rich clay fill of a substantial river channel it represented 0.6% of all the Pisidium spp. It seems that this Ipswichian specimen is its most recent known occurrence in the Avon valley, and that the species is thermophilous (Sparks & West 1959). P. moitessierianum apart from characterising sediments under No. 3 Terrace at Eckington (Keen and Bridgland 1986) and the modern river (Shotton 1972, Whitehead, unpub.), this is the best indicator of the climate of deposition of sediments at the level of the No. 5 Terrace at Pershore. Today the species barely exceeds 54°N in Britain (Kerney 1976).

P. vincentianum In the Avon valley this now Mediterranean and near Eastern species is known from 1 valve under No. 4 Terrace at Twynning. It is known fossil from a number of English vice-counties always in 'cold-climate' contexts. It dominated Band 2 in Devensian sediments at Upton Warren, Worcestershire (Dance 1961) accorded 14C dates of 41500 ± 1200 (GRO-595) and 41900 ± 800 (GRO-1245). At Twynning, the associated fauna and flora is of 'full-glacial' type (Whitehead, unpub.).

P.F. Whitehead

Years bp Lab. number	37600 Birm962	36600 Birm599	31900 Birm505
Site	Aston Mill	Twynning	Aston Mill
Reference		Williams 1976	
<u>Valvata cristata</u> Müller			
<u>Valvata piscinalis</u> (Müller)	+	+	
<u>Bithynia tentaculata</u> (Linné)		+	
<u>Bithynia leachii</u> (Sheppard)			
<u>Carychium minimum</u> Müller			
<u>Carychium tridentatum</u> (Risso)			
<u>Physa fontinalis</u> (Linné)			
<u>Lymnaea truncatula</u> (Müller)	+	+	+
<u>Lymnaea palustris</u> (Müller)		+	
<u>Lymnaea peregra</u> (Müller)	+	+	+
<u>Anisus leucostoma</u> (Millet)	+		+
<u>Bathyomphalus contortus</u> (Linné)			
<u>Gyraulus laevis</u> (Alder)	+	+	
<u>Gyraulus albus</u> (Müller)			
<u>Armiger crista</u> (Linné)			+
<u>Ancylus fluviatilis</u> Müller			
<u>Acroloxus lacustris</u> (Linné)			
<u>Succinea oblonga</u> types Draparnaud	+	+	
<u>Oxyloma pfeifferi</u> (Rossmässler)	+		+
<u>Columella columella</u> (von Martens)		+	
<u>Vertigo genesii</u> (Gredler)		+	
<u>Pupilla muscorum</u> (Linné)	+	+	+
<u>Deroceras agreste</u> (Linné)			
<u>Trichia hispida</u> (Linné)	+		
<u>Sphaerium corneum</u> (Linné)		+	
<u>Pisidium amnicum</u> (Müller)	+	+	
<u>Pisidium casertanum</u> (Poli)	+	+	
<u>Pisidium personatum</u> Malm			
<u>Pisidium obtusale</u> (Lamarck)	+		+
<u>Pisidium obtusale lapponicum</u> Clessin	+		
<u>Pisidium milium</u> Held			
<u>Pisidium subtruncatum</u> Malm	+		
<u>Pisidium henslowianum</u> (Sheppard)	+	+	
<u>Pisidium nitidum</u> Jenyns	+	+	+
Ostracoda			
<u>Candonopsis kingsleyi</u> (Brady & Robertson)		+	
<u>Candona candida</u> (Müller)			+
<u>Candona compressa</u> (Koch)			+

NOTE: Birm-655 dates Fiandrian gravels with molluscs significant to history of post-glacial fauna.

Table 4. The occurrence of Avon Valley faunas in relation to radiometrically dated sediments.

28200 NPL87	27650 Birm293	26000 Birm 382	c7000 -	8460 Birm655
Brandon	Beckford	Aston Mill	Lower Moor	Evesham
Shotton 1968	Briggs 1975		Shotton pers. com.	Whitehead 1979
				+
				+
			?	+
		+		
				+
+	+	+	+	+
+	+		+	+
	+			+
+	+			+
			+	+
				+
+	+	+		+
+		+		
+	+	+		
	+			+
				+
			+	
			+	+
			+	+
	+		+	+

THE AVON TERRACES: CROPTHORNE, AILSTONE AND ECKINGTON

Introduction

Within the River Avon catchment five terraces are traditionally identified (Fig. 9) which, since their original description by Tomlinson (1925), have been numbered upwards from 1 to 5. The highest of these terraces (No. 5) is interpreted as the oldest and was considered by Tomlinson to have been deposited during the main glaciation of the English Midlands. The work of Shotton (1953) has shown that the Avon did not exist prior to this glaciation, previous drainage being reflected by the Baginton Gravels of the Coventry area, which were deposited by a north-eastward flowing river. The occurrence of Hippopotamus at several sites in Avon Terrace No. 3 provides a clear indication that this aggradation includes Ipswichian deposits. Avon Terrace Nos. 2 and 1 are attributed to the Devensian, supporting evidence coming from Radiocarbon dating (Coope, 1962, 1968). The age of Avon Terrace No. 4 is controversial and is discussed in detail in this section.

Faunal evidence obtained in recent years from deposits underlying the gravel of Avon Terrace No. 5 (Shotton, 1983) suggests that a temperate episode is represented within the early part of the aggradation. This temperate episode was tentatively correlated by Shotton (1983) with Oxygen Isotope Stage 7, thus implying a pre-Stage 7 date for the Midlands glacial sequence. Further evidence for a temperate interval between the glaciation and the aggradation of the Avon Terrace No. 5 gravel comes from the type site of the Bushley Green Terrace of the Severn, its direct correlative according to most authors (following Wills, 1938), where a molluscan fauna of cool temperate affinities was recently obtained 4 m below the terrace surface (Bridgland, Keen and Maddy, 1986).

The Stratigraphy of Avon Terraces Nos. 3 and 4

Avon Terraces No. 3 and 4 were interpreted by Tomlinson (1925) as the result of a single aggradational sequence to the higher (4) level, into which the lower terrace surface (3) had been incised at a later date. Thus the sediments under Terrace No. 4, although higher, were considered to be younger than the (Ipswichian) deposits underlying Terrace No. 3. Terrace No. 3 deposits would, by implication, be present at depth beneath the gravels of Terrace No. 4. The latter have therefore been widely attributed to the early Devensian (Shotton, 1973).

Tomlinson cited evidence from two principal localities in support of the above model, Cropthorne, between Evesham and Pershore, and Ailstone, 2.5 km up the tributary Stour valley. Terraces 3 and 4 are both mapped in the Cropthorne area and it was here that Tomlinson believed that the higher Terrace 4 gravels could be seen to lie on top of the lower Terrace 3 deposits. At Ailstone Tomlinson recorded a temperate faunal assemblage from the base of Terrace No. 4 gravel of the River Stour. This included the bivalve Corbicula fluminalis, which now lives no closer to Britain than the Tagus. A number of fossiliferous sites were already known in Avon Terrace No. 3, many of which had yielded Hippopotamus amphibius (including the New Inn road cutting at Cropthorne and Eckington railway cutting, both described below). Sites yielding both C. fluminalis and H. amphibius had previously been described from a terrace of the River Somme (Comment, 1910), so Tomlinson correlated the Ailstone fauna with the hippopotamus-bearing deposits of Avon Terrace No. 3, despite the fact that Corbicula had never been found in the latter and Hippopotamus was absent

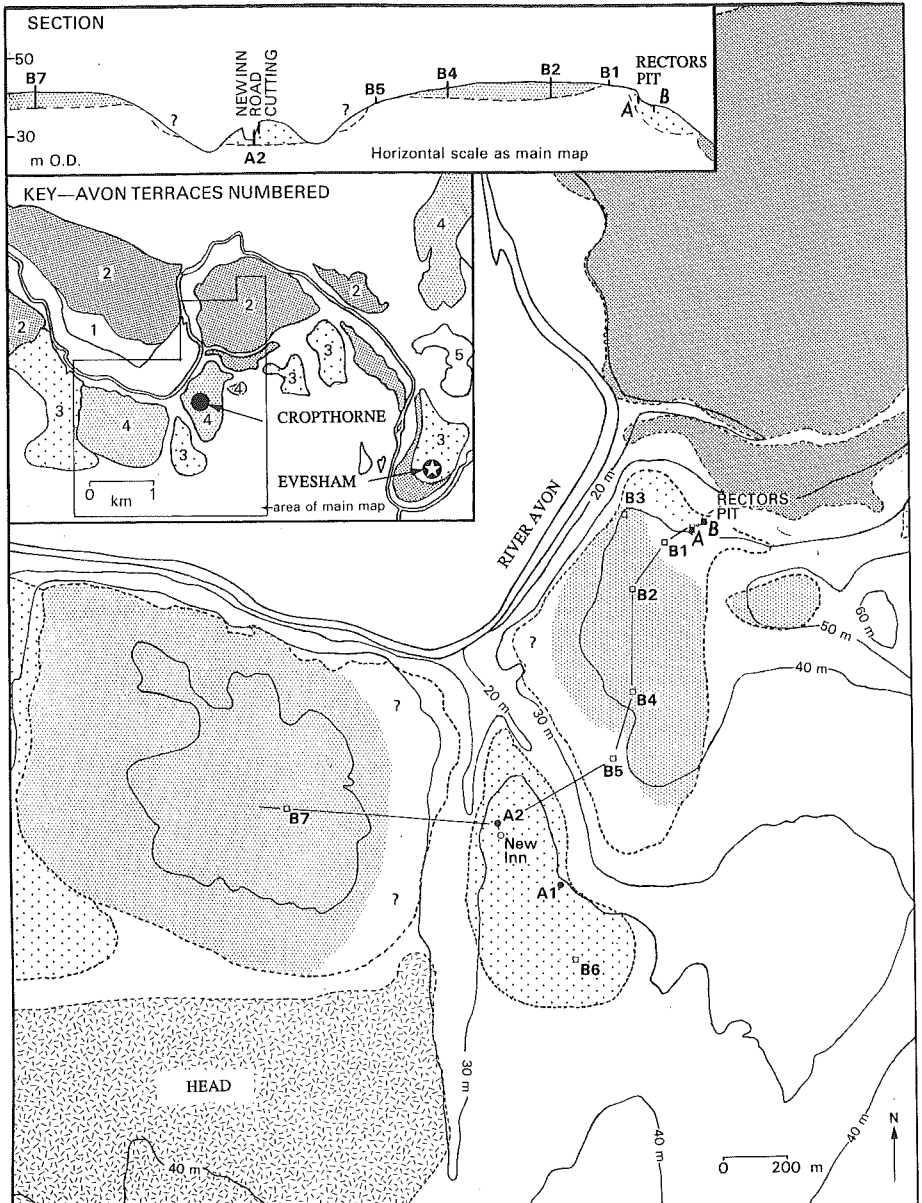


Fig. 9. Cropthorne area demonstrating the location of trial pits and boreholes and the relationship of Avon Terraces 3 and 4.

at Ailstone. This correlation appeared to confirm the continuity of aggradation from the base of the Avon Terrace 3 deposits to the surface of Terrace 4.

This interpretation of the Avon Terrace sequence has provided a basis for part of the established West Midlands Pleistocene stratigraphy for over half a century (Shotton, 1973), although other versions have been put forward (Wills, 1938; Evans, 1971). Recent studies of these two important localities has revealed that the long-standing argument for a single continuous aggradational sequence, resulting in an inversion of normal terrace stratigraphy, is entirely unfounded. A further key site in Terrace No. 3, at Eckington, has also been re-examined. All three sites are included in the excursion itinerary for Wednesday 5 April and will be described in turn.

Crothorne (Terrace Nos. 4 and 3 outcrops; New Inn road cutting)

In the Crothorne area Tomlinson's (1925) map (confirmed recently by the Geological Survey) shows two patches of Terrace No. 4 gravel capping the highest ground, with a lower Terrace No. 3 remnant between them (Fig. 9). Tributary streams have cut down into bedrock between these three terrace remnants. The fluvial deposits of this district have been a source of interest to Quaternary geologists since the early nineteenth century. The first notable description was by Strickland (1835), who recorded molluscan faunas recovered from the area. In particular, Strickland described a section near the New Inn exposed during the construction of the turnpike road, now the A44 (Fig. 9). The sediments he recorded consisted of a basal sand rich in Mollusca, also containing a few worn mammalian bones and teeth, notably *Hippopotamus*, now preserved in Worcester Museum), overlain by a sequence of sandy gravels.

More recent exposures were described by Lloyd (1870) and Lucy (1872). However, it was not until the early twentieth century that this area came to be comprehensively described and mapped in detail by Tomlinson (1925). Tomlinson ascribed the New Inn section to Terrace No. 3, but considered that the sediments here represented the lower part of a continuous aggradational sequence to the higher Terrace No. 4 surface, preserved to the west and east (Fig. 9).

A site of particular importance to Tomlinson's arguments was the 'Rector's Pit', which lay near the north-eastern edge of the eastern Terrace No. 4 outcrop and showed a series of ca 5 m of bedded sands and gravels (Tomlinson 1925). This pit lies well below the maximum level of the Terrace No. 4 surface (Fig. 9) and Tomlinson assumed that it exploited the lower part of a thick sequence which extended beneath the hill to the south-west. Recent reinvestigation of the old pit and the area to the south-west has shown that this is not the case.

Two sections were reopened in the edge of the old working (Figs. 9 and 10). The upslope section (A) revealed a series of parallel laminated medium sands interbedded with two steeply dipping (45°) diamict units (Fig. 10). These diamicts are wedge shaped, appearing to thin downslope towards the north-east. They are predominantly fine-grained and are clearly derived from the Lower Lias Clay bedrock. They contain large angular blocks of Lias limestone, also probably of immediate bedrock origin. The diamict units contain a molluscan assemblage composed entirely of *Pupilla muscorum*. The downslope section (B) showed a series of horizontally bedded sands and medium to coarse, largely matrix-supported gravels (Fig. 10).

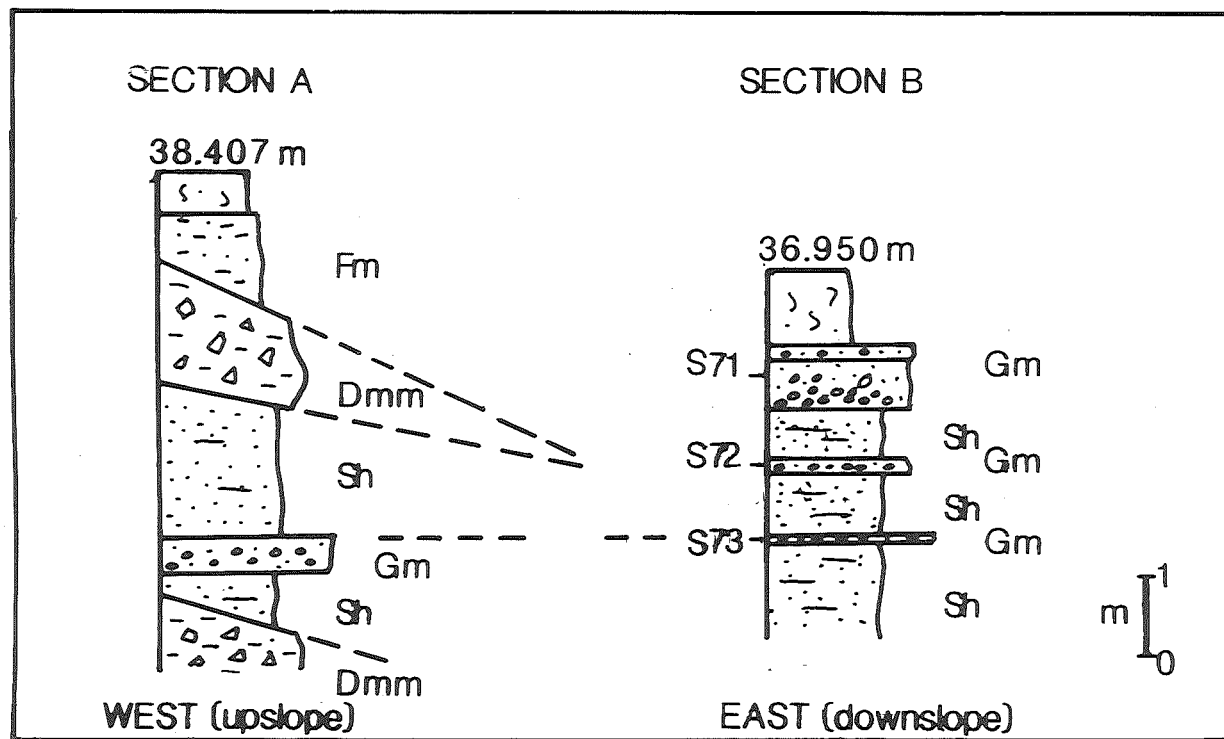


Fig. 10. Logs of sections, Rector's Pit, Cropthorne.

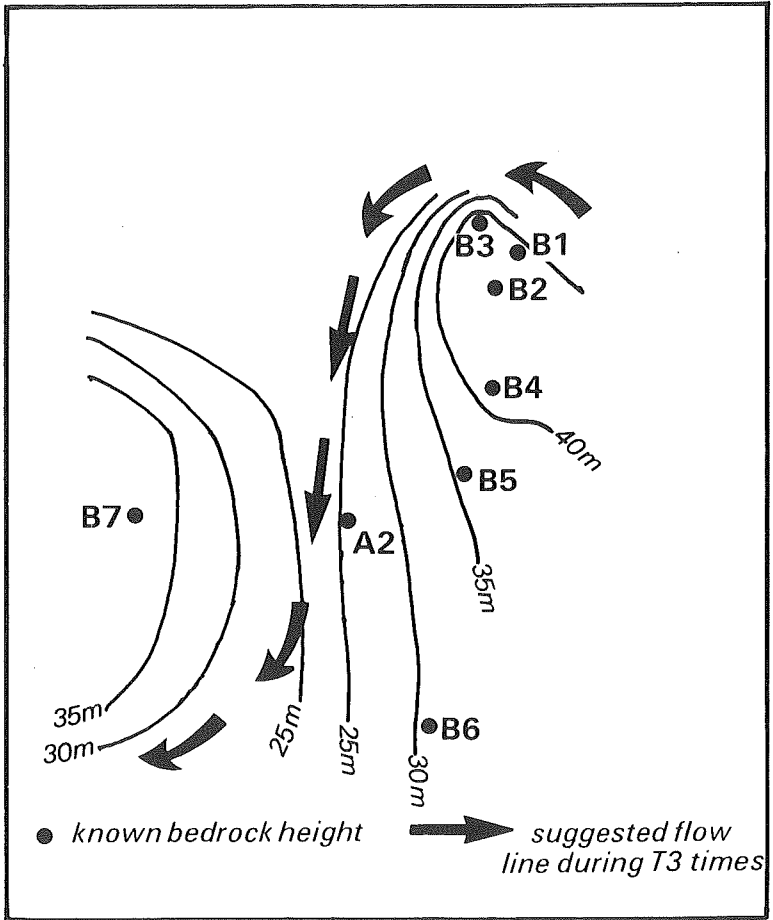


Fig. 11. Suggested flow direction of the Avon in Terrace 3 times.

The presence of *P. muscorum* in the diamict units indicates open, poorly vegetated conditions and the absence of other taxa suggests a severe climate. A solifluction origin for these sloping diamict units therefore seems probable. The parallel laminated sands may represent overbank deposits at the edge of the floodplain. The lithological content of the diamict units implies that bedrock is present immediately upslope from the site. Section A therefore appears to represent the interdigitation of slope-derived material in the bluff-edge of a terrace deposit, the latter being represented at B. This is clearly at variance with Tomlinson's (1925) interpretation of the deposits at this site.

In order to assess whether the bedrock surface rises to the south of the Rector's Pit, or whether Tomlinson's (1925) interpretation was correct, a programme of boreholes was undertaken using a percussion corer. This work, funded jointly by the Nature Conservancy Council and a QRA young researchers award (to DM), was carried out throughout the area of the Terrace No. 3 and 4 outcrops at Cropthorne (Fig. 9). The results clearly show that Tomlinson's interpretation is erroneous; two separate gravel bodies are represented at Cropthorne, an older terrace (No. 4) capping the highest ground with a later, lower aggradation (Terrace No. 3) benched into it (Fig. 9). The Rector's Pit deposits are situated at the back edge of a Terrace No. 3 remnant which has not previously been recognised, situated to the north of the Terrace 4 spread beneath Cropthorne village. Bedrock rises to the surface almost immediately upslope from Rector's Pit, as was demonstrated by borehole 2, where no *in situ* fluvial deposits were found and unweathered bedrock was only 1 m beneath the present surface. Terrace No. 4 deposits were encountered only in boreholes 2, 3 and 4 (Fig. 9), the bedrock surface sloping southwards, away from Rector's Pit, the reverse of the situation predicted by Tomlinson (1925, p. 146). These results also indicate that the Terrace No. 4 spread is very much smaller than mapped, as would be expected for a deposit with a maximum thickness of only a few metres, its base never falling below 38 m OD in the boreholes in which it was encountered. This implies that where gravel is mapped at a lower level on the sides of the hill, this indicates either slope deposits or a later gravel, such as that in the Rector's Pit. A similar interpretation for the westernmost Terrace 4 remnant was indicated by borehole 7, which reached bedrock at 37 m OD (Fig. 9).

These results suggest that the main valley axis during Terrace No. 4 times lay to the south-east of the present alignment. A meandering course appears to have been incised through the Terrace No. 4 deposits prior to the aggradation of Terrace No. 3, bringing the river across the site of Rector's Pit, southwards to rejoin the main valley, passing to the south of the westernmost Terrace 4 remnant (Fig. 11). The present outcrop of Avon Terrace No. 3 (Fig. 9) therefore represents the sedimentary fill of an abandoned meander system, with the Terrace No. 4 remnants forming meander cores. The presence of a substantial head deposit in the southernmost part of this sinuous course further suggests that the meander system was abandoned in response to blockage by this material. Indeed, a section recorded by Tomlinson (1941) from a pit near Oaklands Farm (SO 977 441), in the Terrace No. 3 outcrop to the west of the westernmost Terrace 4 outlier, confirms that this head material directly overlies bedded fluvial deposits. Both this pit and another, further south near Old Fallow Farm (SO 973 439), yielded fauna of temperate affinities, comparable to that from the New Inn section (Tomlinson, 1925, 1941).

The New Inn road cutting section, first described by Strickland (1835), was situated on the Terrace 3 remnant to the south-west of Cropthorne village, where the river was flowing southwards according to the above interpretation (Figs. 9 and 11). A ditch section opened up by the authors

on the edge of this cutting revealed a series of horizontally bedded medium to coarse clast-supported gravels alternating with massive sand beds. As with the deposits in section B in the Rector's Pit, these are interpreted as representing aggradation by the superimposition of flood cycle deposits. The sand facies may represent the waning of flood pulses or the deposits of lower energy flood events.

No fauna was found in this section, but two auger holes on this Terrace 3 remnant yielded Mollusca (A1 and A2, Fig. 9). In both cases the shells were from clayey sand and fine gravel. Auger hole A2 was situated in the New Inn road cutting and is likely to represent the sediments recorded by Strickland. This showed ca 0.5 m of gravel and wet sand (at 27.5 m OD) above Lias Clay. Auger hole A1 was in a higher part of the remnant, at nearly 31 m OD. Gravelly and sandy clay with Mollusca was encountered here above impenetrable gravel.

The Mollusca from A1 were very poorly preserved, being both broken and abraded. The poor state of preservation probably accounts for the preponderance of small bivalves in the sample, as the hinge plates of these are especially robust. Small numbers of gastropods also occur, however, and a reasonable picture of the palaeoenvironment can be built up. The assemblage is dominated by species typical of large rivers (Valvata piscinalis, Pisidium henslowianum), many of the minor constituents also indicating such conditions (e.g. Ancylus fluviatilis, Pisidium moitessierianum). Quiet water conditions are indicated by the occurrence of Pisidium casertanum, Pisidium personatum and Lymnea peregra, while weed-rich habitats are suggested by the presence of Valvata cristata and Armiger crista. Only three land shells were recovered from the sample, so it is difficult to be precise as to the types of terrestrial environment present, but both Pupilla muscorum and Vallonia pulchella indicate open conditions of grassland or marsh. It is difficult to determine the prevailing climatic conditions from this limited fauna, but interglacial conditions seem likely, given the presence of P. moitessierianum, which has been found only in interglacial contexts in the British Isles.

Sample A2 was much less shelly than A1, despite being larger, yielding only 19 identifiable shell fragments. The assemblage present tends to confirm the general environmental conclusions of A1, but the suggestion of grassland is enhanced by the occurrence of Vallonia costata and Vertigo pygmaea. The interglacial character of the deposits is also confirmed by sample A2, as this produced a single specimen of Belgrandia marginata, which is currently a southern European species found no closer to the British Isles than Catalonia and SW France (Keen and Bridgland, 1986).

The fauna from the New Inn outcrop of Avon Terrace 3 at Cropthorne is broadly similar to that recently described from the same terrace at Eckington (Keen and Bridgland, 1986), with all the major species found at Cropthorne occurring at Eckington except V. cristata. The faunal and stratigraphic similarities, as well as the record of hippopotamus from this site, suggest that it too represents the last interglacial. The new interpretation of the terrace stratigraphy in the Cropthorne area, outlined above, indicates that the Terrace 4 gravels, which were dissected by pre-Terrace 3 incision along the later meandering course, are older than previously thought. Rather than being of early Devensian age, as implied by the traditional model (Shotton, 1973), these deposits must pre-date the Ipswichian Stage. Further evidence for the age of the Terrace 4 aggradation has been derived from a re-examination of the Ailstone site (see below).

The clast composition of gravel samples from the Cropthorne area has been analysed as part of a wider study of the Avon and Severn basins (Maddy, in preparation). The results (Table 5) show that the technique cannot be used to separate individual terrace aggradations within the Avon system, as has been found throughout the catchment. The single sample from Terrace 4 at Cropthorne is indistinguishable from those from Terrace 3 from the Rector's Pit. However, the three samples from the New Inn Terrace 3 outcrop (two from the ditch section + borehole 6) are noticeably different from the Rector's Pit samples and from other counts from the Avon terraces in this area. In particular, they contain less quartzite, but higher levels of flint and chert, materials associated with the glacial deposits of the West Midlands. The increase in these lithologies between the Rector's Pit and the New Inn area is problematic, as it is difficult to envisage a source for these locally or in the area to the south, from which a tributary could have transported them. Such a tributary would have to have joined the Terrace 3 course of the Avon near the New Inn, downstream of the Rector's Pit site. The marked drop in quartzites is even more difficult to explain, particularly since that lithology is restored to its Rectors Pit level at Eckington, ca 8 km downstream (Table 5).

Ailstone

The Pleistocene deposits at Ailstone, Warwickshire (Fig. 12; SP 211 513) were first described by Tomlinson (1925). Ailstone lies on the right bank of the River Stour, an Avon tributary draining the Cotswold escarpment. Tomlinson described a pit section revealing sands and gravels underlying a terrace remnant at a level equivalent to Terrace No. 4 of the main valley. These deposits were particularly important to Tomlinson's stratigraphic model of the Avon terraces, in that they contained a temperate faunal assemblage which she considered to be equivalent to that found within the altitudinally lower deposits underlying Avon Terrace No. 3.

An investigation of the deposits at Ailstone was undertaken by the authors, with the assistance of a mechanical excavator kindly supplied by the landowner, Capt. J. West. Three sections were excavated (Fig. 12), two in Pleistocene deposits and the third (section 3), although within the area mapped as terrace sediments, in Mercia Mudstone bedrock. Fossiliferous deposits were encountered in Section 1. This section is hopefully to be reopened for the excursion and so will be described in detail.

The land surface here is at 54.92 m OD and a 2.77 m thickness of fluvial sediments is present overlying the Mercia Mudstone bedrock (Fig. 12). The sequence consists of basal fossiliferous beds overlain by high energy deposits and then a fining upwards sequence, both lacking fauna. The basal deposits (Beds a and b) are interpreted as representing as representing a gravel channel lag (Bed a) and an overbank flood deposit (Bed b), the latter consisting of weakly laminated sheet sand horizons with lenses of clayey sand perhaps representing deposition in small pools. Bed c indicates increased flow energy, representing either the migration of the active channel back into this area or a rise in energy of flood plain deposition, perhaps resulting from a worsening climate. A further increase in flow energy is indicated by the overlying, complex Bed d, which appears to reflect a dynamic, high energy environment with rapid deposition and variable flow conditions. It is difficult to ascertain the exact origin of this unit, given the limited nature of the exposure, but it may include major gravity flow components. Beds e and f probably represent a fining upwards sequence deposited as flow energy levels declined from those represented by Bed d.

Site	qtz	qtzt	sst	flint	chrt	1st ⁺	Iron	other	TOTAL
Terrace 3:									
Rectors (71)	25.6	52.1	6.5	11.1	1.2	0.0	1.6	1.9	434
Pit (72)	22.9	50.0	6.1	15.9	3.3	0.0	0.0	1.8	214
Samples* (73)	20.1	57.4	4.4	12.6	1.7	0.0	1.7	2.1	230
New Inn ¹	29.1	38.5	4.8	16.9	6.1	0.0	3.4	1.2	531
New Inn	32.0	28.3	0.3	18.2	4.5	0.0	6.0	0.7	671
Borehole 6	27.4	31.7	9.9	20.0	7.0	0.2	2.6	1.2	416
Eckington	22.4	50.1	8.5	8.5	0.0	4.9	3.3	2.3	674
Terrace 4:									
Cropthorne	26.9	54.6	2.5	11.2	3.3	0.0	0.0	1.5	242
Ailstone A	16.2	39.7	8.4	22.1	1.7	7.7	2.8	1.4	779
Ailstone bed D	10.6	18.7	1.0	9.2	1.8	54.7	3.1	0.9	509
Ailstone site 2	8.1	16.3	2.8	16.5	1.6	51.1	3.4	0.2	835

Notes: + Includes fossil shells such as Gryphaea sp.

* Sample positions indicated in Fig. 9

¹ Ditch section (see text)

Table 5 Clast lithological analysis - the Avon Terraces

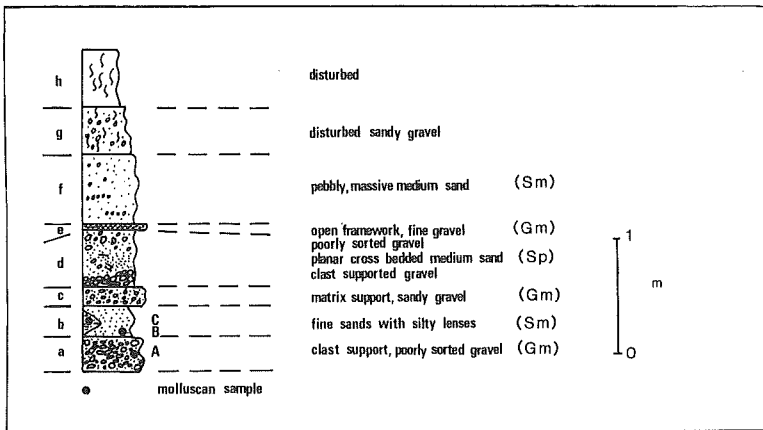
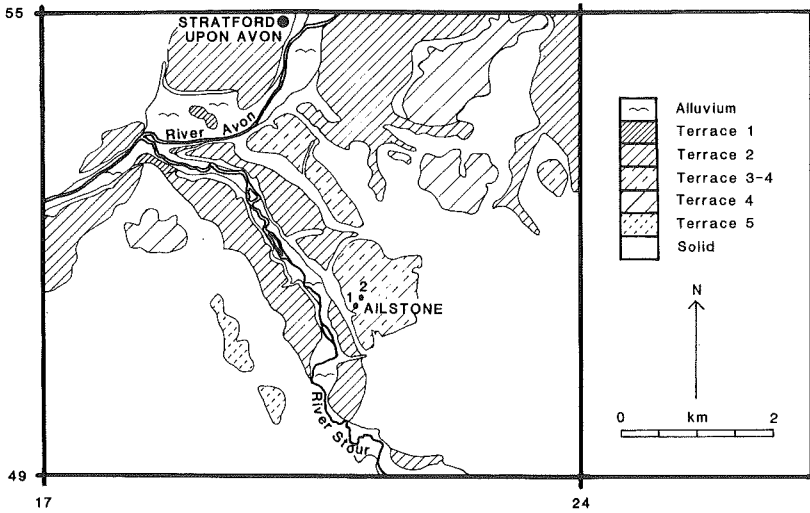


Fig. 12. Pleistocene deposits at Ailstone: (a) location map; (b) section.

Ailstone is the only site in the Avon catchment where faunal remains are recorded from Terrace No. 4 in abundance. Three faunal samples were collected from the basal gravel in section 1. The Mollusca from two samples (A and B) were counted in detail, while sample C and the balance of A were scanned for taxa not represented in the counts. Specimens were taken from sample C for amino acid analysis. In addition to the Mollusca, the basal gravel also yielded a single toe bone of Mammuthus primigenius.

A total of 2266 individuals of 40 taxa were recovered from the counts and a further three taxa were found by scanning the extra material. In addition to these 43 taxa, Potomida littoralis was recorded by Tomlinson (1925), but not found in the present investigation. As it usual with fluvial deposits, the vast majority of the shells were of aquatic habitats, with most land taxa being represented only by single specimens. Only three species in the fauna exceeded a total of 75 individuals. These three, V. piscinalis, Bithynia tentaculata and A. fluviatilis, are all members of Sparks' (1961) moving water group, and are typical indicators of the well oxygenated conditions associated with large rivers. Also indicative of such conditions are the most numerous of the small bivalves, P. henslowanum and P. moitessierianum.

There is little difference between the two samples counted, except that the more silty sample B has higher values for the standing water Planorbids Anisus leucostoma and A. crista, whereas the sandy sample A has high values for Gyraulus laevis (Alder). These differences suggest that B may represent a quieter, more weed-choked fluvial environment in comparison to the moving water affinities of sample A.

The land fauna is far more restricted than the freshwater fauna. Although the total number of individuals is only slightly fewer, the numbers of any one species never exceed ten. This phenomenon is typical of gravel bed river faunas, probably because the major source of terrestrial snails in such cases is the sweeping of the flood plain during periods of highest flow. However, sufficient land shells are present to give an indication of the conditions on the river banks. Three broad habitat groups are represented, those of marsh and grassland, both on the floodplain, and those of more shaded habitats away from the river. The marsh group (Carychium minimum, cf Oxyloma pfeifferi and V. pulchella) are the most numerous of the terrestrial shells and indicate wetland habitats along the river. Grassland indicators (P. muscorum, V. costata and Punctum pygmaeum (Draparnaud)) suggests the occurrence of shaded, damp habitats away from the flood plain, but a non-wooded environment cannot be entirely ruled out. The local environment was therefore one of a large, well oxygenated river flowing through a countryside which contained marsh and grassland, with the likelihood that some woodland was also present.

The level of species diversity at Ailstone, 43 taxa in all, is considered to indicate interglacial conditions. This interpretation is supported by the occurrence of P. moitessierianum, A. goodalli, C. fluminalis and Vallonia enniensis, all exclusive to interglacial deposits in Britain. The large bivalves Unio and Anodonta spp., are also seldom encountered outside interglacials in this country.

The suggestion, in Kennard and Woodward's appendix to Tomlinson (1925), that C. fluminalis is derived from earlier deposits, is unwarranted. In the Ailstone samples both adult and juvenile shells were recovered, indicating that a full age structure was present in the population. It is unlikely that this would be the case if the fauna has been subjected to any major phase of transport. Similarly, sample B, which was deposited in quieter water conditions than sample A, has a higher percentage of shells

of C. fluminalis than A. This is the reverse of what would be expected, given the moving water character of the fauna of sample A, if the presence of C. fluminalis resulted from reworking from earlier deposits. While it cannot be denied that all shells in bedload deposits of rivers are to some extent derived, there is no suggestion in the Ailstone fauna that any one element of it is alien to the general assemblage.

The clast lithological composition of the Ailstone gravels reflects the location of the site in the Stour valley, which has transported abundant Jurassic limestone from the Cotswold escarpment to the south. The limestone component varies significantly between the three samples analysed, however (Table 5). Bed a, in the main section (Fig. 12), is largely made up of durable, non-calcareous lithologies such as flint, quartz and quartzites. These are reworked from the local glacial deposits. In Bed d these are considerably diluted by limestone, which accounts for approximately half of the sample. The sample from the second excavation had a similar clast composition to Bed d, suggesting that the unfossiliferous gravel at both sites may be equivalent. There appears to have been a considerable input of limestone material into the Stour's bedload following the deposition of the fossiliferous basal sediments at Ailstone, which were encountered only in the main section. This may reflect increased erosion in the Cotswold uplands, perhaps as a result of a climatic deterioration. The contemporaneous increase in fluvial energy which is indicated by the sedimentology accords well with this interpretation. It can be suggested therefore that the sequence at Ailstone represents both a temperate interval and the opening of the succeeding cold stage.

Tomlinson's interpretation of the Ailstone site as evidence for the correlation of interglacial sediments beneath Terraces 4 and 3 in the Avon catchment is not supported by the recent faunal analysis. The latter highlights important differences between the molluscan faunas from Ailstone and the various Terrace 3 sites, leading to the conclusion that different temperate intervals are represented (see discussion, below). This further supports the stratigraphic evidence from Cropthorne (above), which indicates that Terrace 4 is a separate, earlier aggradation which was emplaced before the phase of incision which preceded the aggradation of the Terrace 3 deposits.

Eckington railway cutting

The first fossiliferous site within Avon Terraces 3 and 4 to be reinvestigated in recent years was the railway cutting at Eckington (SO 919 417). The section excavated here by Keen and Bridgland (1986) will hopefully be reopened for the excursion visit. The Eckington site, first recorded by Strickland (1842), lies within a small remnant of No. 3 Terrace forming the core of a present meander of the river. The section shows ca 1.5 m of sandy gravel resting on Lower Lias Clay at 23.2 m above OD (Fig. 13). The gravel is planar bedded and more sandy in its lower levels, with discrete sandy lenses intermittently visible in the lowest 60 cm. Patches of the basal gravel are weakly cemented by calcium carbonate, forming a soft conglomerate.

Details of sampling for Mollusca and discussion of taphonomy were provided by Keen and Bridgland (1986). The total number of taxa recorded was 39 (Table 6), of which 21 were freshwater and 18 terrestrial. The dominant freshwater taxa, V. piscinalis, B. tentaculata and A. fluviatilis are indicators of fully fluviatile conditions (Kerney, 1971). The other gastropods are either members of Sparks' catholic group, such as Bathyomphalus contortus, or unclassified by him, but known to live in

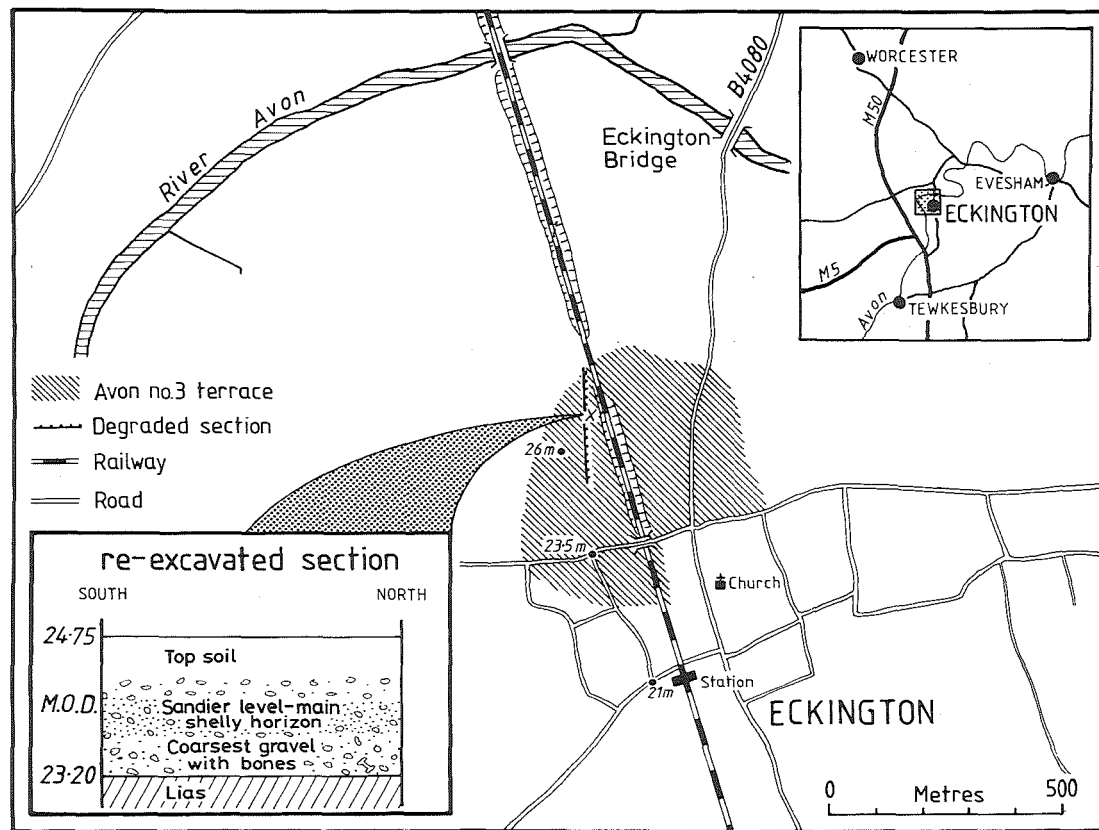


Fig. 13. Eckington, location map and section.

clear water ponds (e.g. G. laevis). The only species in the freshwater fauna currently absent from Britain was B. marginata.

Despite the evidence of well oxygenated moving water from the Gastropoda, the usual bivalves of large rivers, P. henslowianum and P. moitessierianum are present only in low numbers. Furthermore, C. fluminalis is absent entirely, despite its thick, durable shell and the abundance of its relative Sphaerium corneum. Instead, the bivalves are dominated by S. corneum and P. casertanum which are usually pond species. Keen and Bridgland (1986) considered the environmental conditions suggested by the gastropods to be more in keeping with the sedimentological evidence and concluded that the bivalve evidence was anomalous.

The terrestrial fauna from Eckington was dominated by grassland and marsh taxa, as would be expected on the banks of a large river. Such species as O. pfeifferi, Succinea oblonga, Vertigo angustior and V. pulchella exemplify the marsh component, and V. costata, P. muscorum and the helicellid tentatively identified as Candidula crayfordensis, the grassland component. The occurrence of the shade-loving Discus rotundatus and Clausilia sp. suggests that away from the river floodplain more shaded habitats of scrub, if not woodland, were present. The exact nature of this environment is difficult to suggest in view of the small number of shell fragments of these taxa preserved.

The presence of Hippopotamus amphibius at Eckington was confirmed by the discovery of an incisor from this species in the fossiliferous deposits, which also yielded part of the pelvic girdle of either Bos or Bison sp. (Currant, in Keen and Bridgland, 1986). These discoveries, from an exposure of very limited size, justify Strickland's (1842) claim that mammalian remains were found in abundance during the construction of the railway. Strickland recorded mammoth and giant deer in addition to extinct ox and hippopotamus.

Keen and Bridgland pointed to the interglacial characteristics of the Eckington fauna. Besides its diversity, the species B. marginata, P. moitessierianum, V. angustior and D. rotundatus are indicators of fully temperate conditions. The association of H. amphibius, B. marginata, G. laevis and V. enniensis led the authors to conclude that the deposits were of Ipswichian age.

Discussion of Avon Terrace 4/3 stratigraphy and dating

Reappraisal of faunal evidence from the deposits of Avon Terrace 3 has confirmed the Ipswichian age of this aggradation. However, investigation of the terrace deposits in the Cropthorne area, described above, has provided unequivocal evidence that the higher Terrace 4 deposits at this locality are not underlain by Terrace 3 sediments, as envisaged by Tomlinson (1925). Furthermore, Tomlinson's (1925) contention that the fauna from Terrace 4 at Ailstone is the same as that from Avon Terrace 3 is not supported by recent analyses. It is important to note that the various samples from Eckington, Cropthorne and Ailstone are all from similar facies; all are from sandy fluvial bedload deposits. This means that they represent equivalent ecological situations, so their faunal components should be directly comparable. All three sites yielded faunas of interglacial character, but there are important differences between the Ailstone fauna and those from Eckington and the New Inn cutting. At Ailstone C. fluminalis is present and B. marginata absent, whereas at Eckington and the New Inn the reverse is true. Although it would be unwise to claim that such differences are of clear stratigraphic significance, they clearly negate Tomlinson's argument and may be cited as

	A	C	D	D	*
<u>Valvata piscinalis</u> (Müller)	63	2	17	3	/
<u>Belgrandia marginata</u> (Michaud)	24	1	11	2	/
<u>Bithynia tentaculata</u> (Linné) shells	31		12	4	/
operculae	222	4	108	28	
<u>Lymnaea truncatula</u> (Müller)	1		2		
<u>Lymnaea peregra</u> (Müller)	3		1		
<u>Bathyomphalus contortus</u> (Linné)			1		/
<u>Cyraulys laevis</u> (Alder)	1		1		
<u>Armiger crista</u> (Linné)	2				
<u>Ancylus fluviatilis</u> (Müller)	17		6	3	
<u>Unio</u> sp	#		#	#	
<u>Sphaerium corneum</u> (Linné)	160	3	92	11	/
<u>Sphaerium lacustre</u> (Müller)	4		2	2	
<u>Pisidium amnicum</u> (Müller)	9		9	2	/
<u>Pisidium casertanum</u> (Poli)	179	5	29	7	/
<u>Pisidium personatum</u> Malm	7		1		/
<u>Pisidium obtusale</u> (Lamarck)	1				
<u>Pisidium milium</u> Held	1		1		
<u>Pisidium subtruncatum</u> Malm	118	2	62	9	/
<u>Pisidium henslowianum</u> (Sheppard)	7		3		/
<u>Pisidium nitidum</u> Jenyns	93	4	25	1	/
<u>Pisidium moitessierianum</u> Paladilh	2	1	3	4	/
<u>Pisidium</u> sp			14		
<u>Succinea oblonga</u> Draparnaud					/
<u>Oxyloma pfeifferi</u> Rossmässler	1		1		
<u>Cochlicopa lubrica</u> (Müller)	3		2	1	
<u>Vertigo angustior</u> Jeffreys	1				
<u>Vertigo</u> sp (not <u>V. angustior</u>)	1		2		
<u>Pupilla muscorum</u> (Linné)	2		1		
<u>Vallonia costata</u> (Müller)	3		3		/
<u>Vallonia pulchella</u> (Müller)	15		5	2	
<u>Vallonia enniensis</u> (Gredler)	19	1	5	1	
<u>Vallonia</u> sp	21		10		
<u>Punctum pygmaeum</u> (Draparnaud)	1				
<u>Discus rotundatus</u> (Müller)	1		1		
<u>Oxychilus cf cellarius</u> (Müller)	2				
<u>Oxychilus</u> sp	1				
<u>Milax</u> sp	1				
<u>Limax (Deroceras)</u> sp	4		2	1	/
<u>Clausilia</u> sp	1		1		
cf <u>Candidula crayfordensis</u> Jackson	24		1		
<u>Trichia hispida</u> (Linné)	4		5	1	
<u>Cepaea</u> or <u>Arianta</u>	2		4		
	1021	23	432	83	

Total 1559

39 species

Table 6. Eckington Avon Terrace No. 3 - Mollusca (from Keen and Bridgland, 1986)

fragments; all bivalve counts of individuals.

* specimens collected from the surface of the excavation by D.H. Keen and P.F. Whitehead.

evidence in support of the revised stratigraphic model presented here, in which Terraces 4 and 3 are interpreted as entirely separate aggradations, with the higher deposits the older of the two. An important stratigraphic argument in favour of this new interpretation is that the Ailstone site appears to show sediments of temperate affinities overlain by cold stage deposits, the latter forming the main Terrace 4 aggradation. This cold stage clearly separates the temperate interval represented at Ailstone from the Ipswichian Interglacial, which is represented by sediments beneath Avon Terrace 3.

Further evidence suggesting that the Terrace 4 fauna at Ailstone is older than those from Terrace 3 sites has recently been obtained from amino acid analyses. Shells from Ailstone, Cropthorne and Eckington were submitted to the Geochronology Laboratory at Royal Holloway and Bedford New College for the determination of amino acid ratios. Detailed results are not yet available, but preliminary indications are that ratios from Ailstone conform with others obtained from a small but important group of British sites, which includes Aveley, Stanton Harcourt and Stoke Goldington (Bowen et al, in preparation). These sites have all been attributed to a currently undefined interglacial, between the Hoxnian and the Ipswichian Stages of the traditional British chronology, thought to correspond with Oxygen Isotope Stage 7 (Shotton, 1983). These ratios differ markedly from those obtained from sites associated with the last interglacial, which have smaller ratios, implying less antiquity (Bowen et al, in preparation). This preliminary information appears to support the interpretation of the Ailstone deposits as earlier than the Terrace 3 aggradation, which is attributed on faunal grounds to the Ipswichian. It is hoped that amino acid ratios from Cropthorne and Eckington will be available for comparison in the near future.

The possible correlation of the fossiliferous deposits at Ailstone with a post-Hoxnian/pre-Ipswichian temperate stage appears to be further supported by particular points of similarity between the Mollusca from here and from two other sites in the above-mentioned group attributed to Oxygen Isotope Stage 7, at Stanton Harcourt (Briggs, Coope and Gilbertson, 1985) and Stoke Goldington (Green, Coope, Jones, Keen, Robinson and Young, in preparation). All three sites contain a particularly flat and globose form of V. piscinalis in assemblages with C. fluminalis but lacking B. marginata. The Stoke Goldington site has yielded uranium series dates suggesting an age between 200,000 and 180,000 years bp. The faunal similarities described above, coupled with stratigraphic evidence for a pre-Ipswichian date, may point to a similar age for the Ailstone deposits.

The above interpretations have considerable implications for the chronology of the Avon terrace system. Pre-Ipswichian temperate stages are now recognised within terraces 4 and 5. The temperate fauna from No. 5 Terrace has previously been tentatively correlated with Oxygen Isotope Stage 7, but the evidence presented above suggests that the Terrace 4 deposits belong to that stage. It is unlikely that temperate sediments beneath these two terraces could be of the same age, so an earlier temperate interval is probably represented by the Terrace 5 deposits. By counting backwards it can be suggested that this is Oxygen Isotope Stage 9. This would imply that the glaciation of the Midlands occurred in Stage 10 or earlier.

Conclusions

The evidence presented in this report indicates that the established stratigraphic model of terrace development in the Avon catchment is

erroneous. It is concluded that the deposits underlying Terrace No. 4 are older than those underlying Terrace No. 3 and that the faunal remains of two separate interglacial episodes are represented within the deposits of these two terraces. These conclusions have major repercussions for Pleistocene stratigraphy in the English Midlands.

D.R. Bridgland

D.H. Keen

D. Maddy

Thursday 6 April

1. Quinton SO 992 847
2. Stourbridge SO 895 855
3. Chelmarsh SO 743 871
4. Stourport SO 795 734
5. Grimley SO 834 614

QUINTON

The Quinton site (Fig. 14) is important to the understanding of the Pleistocene history of the West Midlands. Firstly, it is one of the few sites where interglacial sediments can be shown to intervene between glacial deposits. Secondly, these deposits are located almost on the watershed of the two most important rivers of the Midlands. To the north and south-east the streams drain to the Tame and thence to the Trent, whilst to the south and west, they flow to the Severn.

The sequence of Pleistocene deposits was proved during the site investigation for the M5 Motorway. The youngest beds were exposed during the subsequent excavation. Mapping revealed a second outcrop of organic sediments nearby. BGS drilled two continuously sampled percussion boreholes, Q1 [SO 9921 8471] on the east side of the present motorway and Q2 [SO 9954 8456] some 370 m to the ESE (Figs. 15 and 16).

The Pleistocene sequence in the Q1 borehole is:

- 4 Ridgacre Formation
- 3 Quinton Formation
- 2 Nurseries Formation
- 1 Early solifluction deposits

The early solifluction deposits (Head) consist largely of redeposited country rock, the Halesowen Beds, and contain a small number of exotic pebbles. Less than 4 m thick, it is generally poorly sorted, except near the top.

The overlying Nurseries Formation, up to 7 m thick, consists largely of medium to chocolate brown sandy boulder clay with abundant erratics. The matrix colour suggests derivation from the local Carboniferous rocks and most of the erratics are of this type. The remainder include pebbles of Rowley Regis dolerite, Triassic debris, Silurian limestone and rhyolites of North Wales origin. Indistinct bedding traces occur within the boulder clay whilst bedded sands, gravels and laminated clays occur in the upper part of the formation.

The base of the Quinton Formation is drawn at the appearance of organic sediments. The lower part of the formation comprises interlaminated sand and silt and clay with layers of plant debris. It is succeeded by a more uniform organic silty clay division and then by a bed of felted peat. This is overlain by alternations of coarse, clean, well-sorted sand and plant-rich sand with silt and clay laminae. A second bed of felted plant debris occurs near the top of the formation.

The youngest Pleistocene deposit, the Ridgacre Formation, marks the return to glacial conditions. It consists of bedded reddish brown and orange sands with clay partings, overlain by reddish brown, unbedded, sandy boulder clay with numerous Triassic and Carboniferous erratics.

The Pleistocene deposits fill an elongate depression cut into the Carboniferous rocks and extending south-eastwards from Bourne College. It has been proved over a distance of 120 m and is about 100 m wide with a floor at or below 184.6 m OD, and must extend south-eastwards beneath drift cover to California, where glacial sediments extend down to between 148 and 128 m OD. A second depression was proved by the Q2 borehole (Figs. 15 and 16).

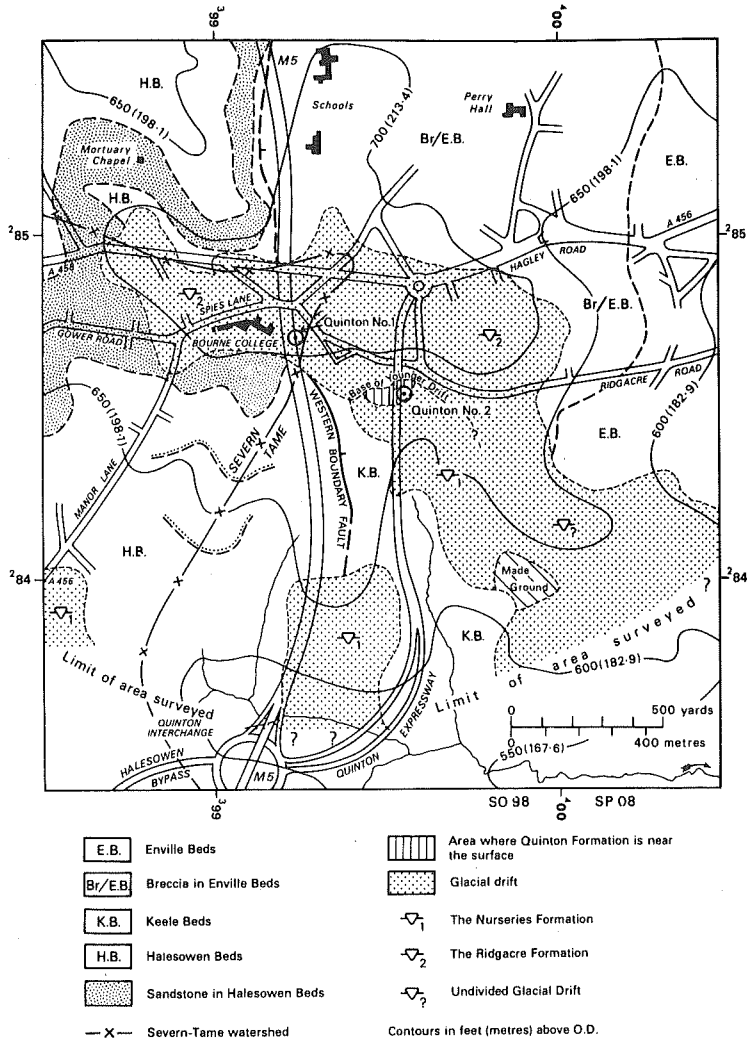


Fig. 14. Geology of the Quinton area.

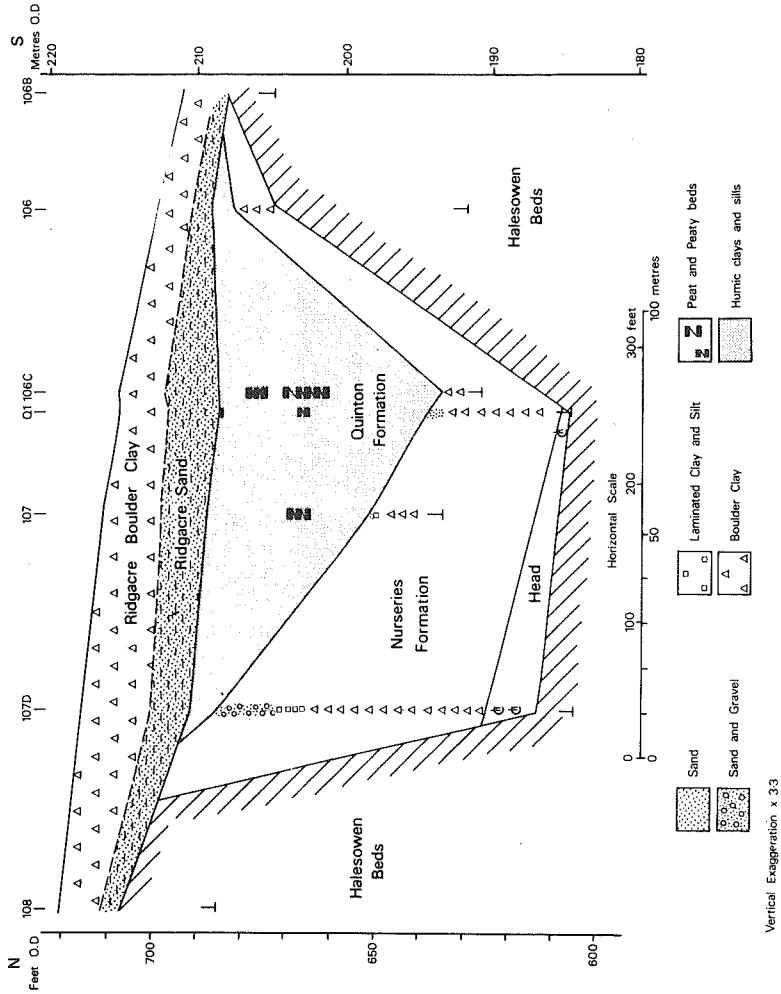


Fig. 15. Cross section of the drift-filled depression at Quinton.

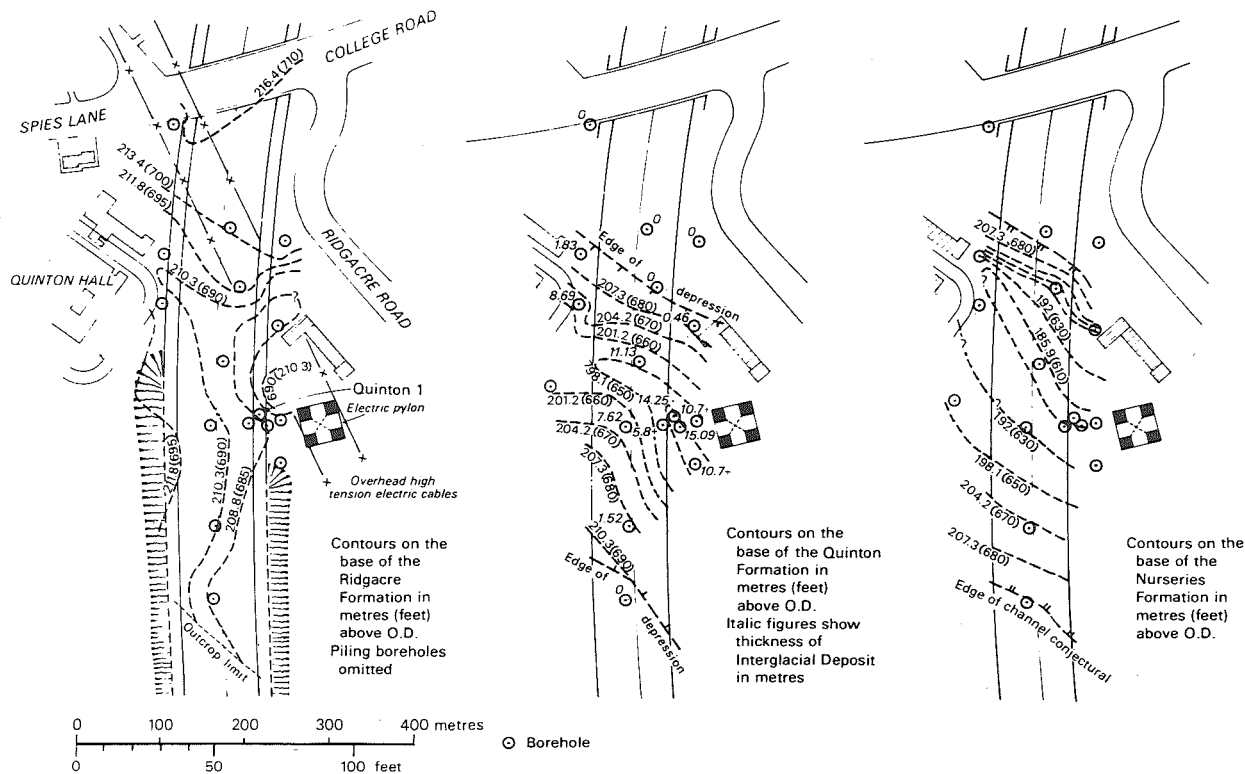


Fig. 16. Contours on the base of the Ridgacre, Quinton and Nurseries Formations.

The early solifluction deposits (Head) floor the Quinton depression (Fig. 17) and are succeeded by the Nurseries Formation. The Quinton Formation fills a channel (Fig. 17) within the Nurseries Formation, the axis of which is only slightly different from that of the older depression (Fig. 15). The Ridgacre Formation has a sheet-like form and extends over these depressions, but still infills a shallow hollow across the older features.

Dr Margaret Herbert Smith studied the pollen content of the organic sediments of the Quinton Formation and subdivided it into pollen assemblage zones, using the suffix Q. Late glacial (1An) and early glacial (eWo) pollen zones dominated by herbaceous plant assemblages have been recognised. The Quinton Formation thus represents not only a temperate episode thought to correlate with the Hoxnian, but also part of the preceding and succeeding cold stages (Fig. 18).

The pollen diagram (Fig. 18) indicates a major change in the vegetation and hence the habitat after the accumulation of the main peat horizon (Zone QIIIA).

Harry Kenward's examination of the insect faunas also recognises a major change at this level, with the sudden appearance of species which today characterise Northern Europe. The sediments show a marked increase in coarseness with the interbedding of clean and organic sands and the appearance of small erratic pebbles. It is concluded that a major pause in sedimentation occurs at the start of pollen zone QIIIB.

The history of the Quinton site records a reversal in the topography of the region. The early solifluction deposits accumulated in the floor of a valley situated in front of a glacier which advanced initially down the depression, partially infilling it and extending southwards at least as far as California. When the glacier retreated, the depression was recreated, possibly as a kettle lake created by dead-ice melting in its upper part, and then accentuated by fluvial erosion. Later, an extended lake formed and streams swept sand, silt, clay and plant detritus into it. Progressive siltation enabled a peat to develop across the entire depression. A hiatus then interrupted deposition of the Quinton Formation, after which colder conditions developed and enhanced erosion resulted in streams transporting coarser material into the depression. Soon, fully arctic conditions prevailed, and the Sand member of the Ridgacre Formation was laid down, to be overlain in time by the Boulder Clay member. Ice advanced well beyond the district. The subsequent history of the Quinton area has been one of erosion. By Ipswichian times the outlines of the modern landscape had been established. The later terrace deposits of the Severn and Tame occur well below the stranded channel of the pre-Hoxnian Quinton stream. (See below - Stourbridge, pp. 75).

The Quinton site stands as a scientific challenge to the interpretation of the glacial sequence of the surrounding areas. Studies of the deposits proved along other parts of the Birmingham Motorways show a complex sequence of lacustrine sediments and tills throughout the altitude range from the modern valley floor to the ridge at Quinton. They appear to form part of a single glacial event; the Anglian Stage? The evidence suggests that a fluctuating ice sheet impounded small peripheral water bodies (lakes?) against the Birmingham upland. This contradicts the hypotheses of Kelly (1964) and Pickering (1957) who envisages a relatively horizontal and laterally persistent sequence of quiet-water sediments which provide mappable marker horizons, and which separate tills of different ages.

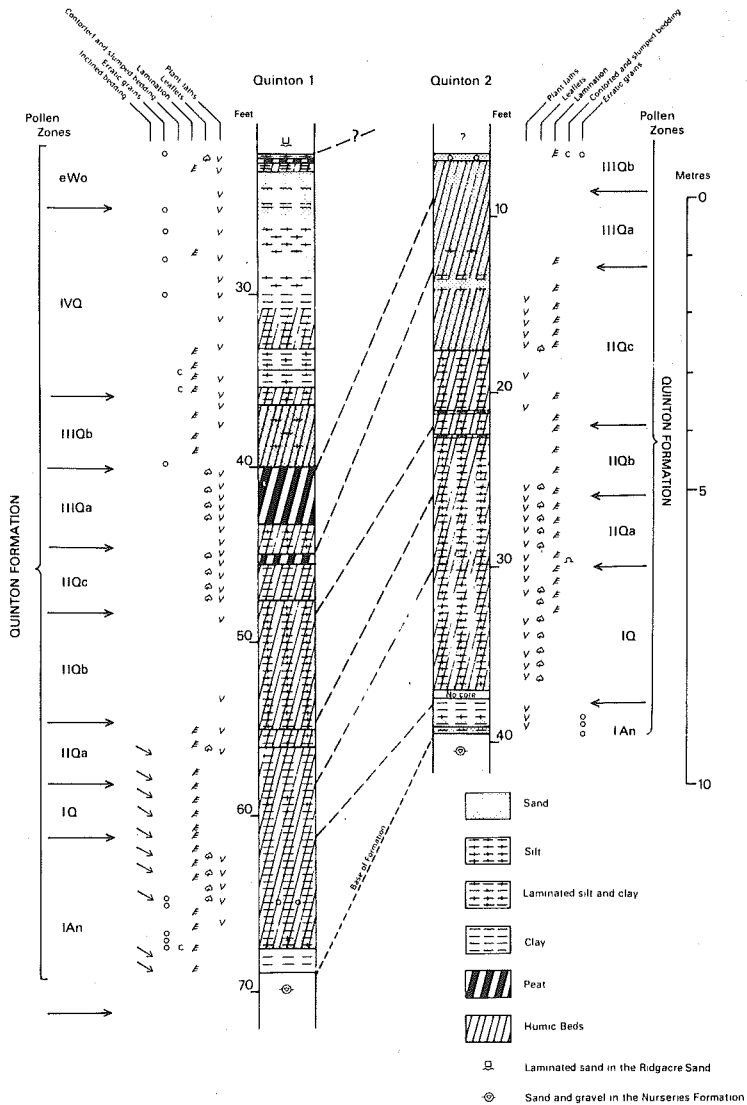


Fig. 17. Correlation and sedimentology of the Quinton Formation in the Q1 and Q2 boreholes.

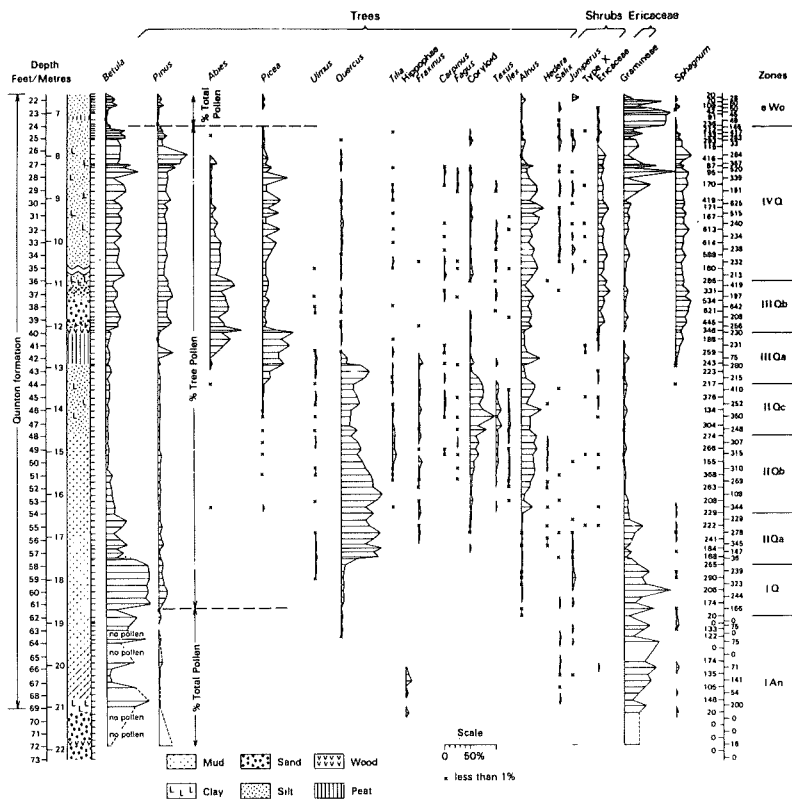


Fig. 18. Pollen diagrams (trees, shrubs and Ericaceae) of the Quinton Formation in the Q1 Borehole.

Survey work in the early 1960s convinced me that the Chalky Boulder Clay of the Anglian Stage of the type area is broadly contemporaneous with the deposits of the type Wolston 'Series'. Traced through Warwickshire towards Birmingham, the latter become increasingly diverse and complex and possibly equate with the complex drifts of the Birmingham area of which the Nurseries Formation is part. The interglacial Hoxnian sediments at Quinton and Nechells succeed Anglian glacial deposits. The Ridgacre Formation was deposited when an ice sheet advanced again to cover the entire Birmingham area. Was this during the Wolstonian Stage? The period of massive erosion which followed retreat of this ice sheet was punctuated by the accumulation of successive terrace deposits, some of which can be dated to the Ipswichian stage.

A Horton

MAMMALS FROM GRAVELS AT STOURBRIDGE

At the beginning of this century, numerous bones of large mammals were found at Amblecote Nr Stourbridge in a sand pit close to the pumping station for the Stourbridge Water-works Company. The pit worked several metres of sand and gravel overlain by up to three metres of red "India-rubber" clay devoid of stones. Most of the bones came from the lowest part of the gravels. Though the bones and teeth were broken and stained they show no signs of having been rolled and thus do not appear to have been transported very far. The following bones were recorded by Boulton (1917).

Mammuthus primigenius teeth and tusk
Hippopotamus "major": canine teeth
Tichorhinus: metacarpal and skull fragment
Equus caballus: phalange and teeth
Bison priscus: humerus, cervical vertebra
"Deer": antler and vertebrae

The location of this pit, close to the present course of the River Stour will be visited, but little can now be seen. The bones themselves were on show in Stourbridge library but have not apparently been preserved.

G R Coope

THE SEVERN VALLEY SOUTH OF BRIDGNORTH

Introduction

The lower Severn Valley lies to the south of the known limit of the Devensian Glacial maximum, although the area is likely to have been affected by pre-Devensian ice advances. The Quaternary record in the area includes:

Pre-Late Devensian terraces and higher level terrace remnants such as the Kidderminster and Bushley Green Terraces.

Pre-Late Devensian diamict deposits of probable glacial origin (Stourport).

Late-Devensian paraglacial, ice marginal and outwash sediments (Chelmarsh, Stourport and Grimley).

The Holocene Valley fill (Brown 1983).

With the exception of the diamict deposits recently described at Stourport (Dawson 1988), no pre-Devensian glacial deposits have been recorded in the lower Severn Valley and evidence of earlier glacial episodes is limited to isolated terrace remnants. The oldest deposits, the Woolridge Gravels (Wills 1938), occur in small fragments between Tewkesbury and Gloucester and in the Worcester area. These gravels have been attributed to the Anglian glacial stage by Hey (1958), having been previously ascribed to a proximal fluvioglacial origin by Wills (1938). Similar deposits are present in the Leaddon tributary. Although Wills (1938) associated these gravels with the Woolridge Gravels, Hey (1958) showed that they lie at a lower elevation and argued that they were outwash of Wolstonian age in the Severn Valley. Wills (1938) also mapped gravels, distinct from these higher deposits and the lower terraces, at Bushley Green, close to the Severn-Avon confluence. He found that this local terrace lay at a similar altitude to the Avon No. 5 Terrace mapped by Tomlinson (1925), and proposed that it was the product of aggradation at the confluence, associated with the development of a late Wolstonian outwash system.

The Kidderminster Terrace, is the oldest widely distributed terrace deposit and can be traced from the mouth of the Severn upstream to Bewdley and then extensively along the River Stour. There is little evidence of the terrace north of Bewdley along the Severn. Wills (1938) deduced from the distribution of the terrace fragments and the essentially 'local' lithologic content that the Kidderminster Terrace pre-dated the Devensian 'Irish Sea' glaciation. He proposed that the absence of terrace fragments upstream of the Stour confluence was evidence for a Devensian glacial origin for the diversion of the Severn through the Ironbridge Gorge during the Devensian glacial stage. Stephens (1970) interpreted the deposits as being of Ipswichian age, but Wills (1938) and Shotton (1973) believed that the deposit has an early Devensian origin.

The lower terraces date from the Late-Devensian glacial maximum and immediate post-glacial periods. Their scale indicates that the Severn acted as a major drainage route away from the Devensian ice sheet, although Dawson and Gardiner (1987) have suggested mean annual flood discharges during the period did not greatly exceed present values. Mapping by Wills (1924, 1938) identified three major late-Devensian levels

which he termed the Main, Worcester and Power House Terraces. Whilst this broad stratigraphy remains valid, evidence suggests that neither the Main or Power House Terraces can be regarded as a single stratigraphic unit. Furthermore the Worcester Terrace may not be traceable upstream of Bewdley.

The Main Terrace complex is traceable from Apley Park near Bridgnorth, where it lies approximately 30 m above the present floodplain, to Gloucester, where it descends beneath the modern alluvium. The deposit is extensive and, in places has a cross-valley extent of up to 1 km and thicknesses of up to 10 m. Whilst mapped as a single terrace unit, Wills (1938) divided the terrace into two units and Mitchell *et al* (1961) noted the occurrence of two surface levels in the vicinity of Stourport. The complex association of Main Terrace gravels, alluvial fan units and diamict deposits in the Eardington area supports these contentions that the terrace may have had a complex aggradational history.

Wills (1938) and Shotton (1977), noting the sizeable proportion of erratic material derived from 'Irish Sea' glacial deposits and the presence of arctic faunal remains, proposed that the terrace was correlated with the 'Irish Sea' glaciation. Wills (1938) argued that the deposition of the gravel commenced during the decay of the ice sheet and continued during the formation of the Ironbridge Gorge. However, the presence of diamict lithofacies of glacial origin interbedded with terrace deposits at Eardington and Chelmarsh indicates that the aggradation developed, at least partially, as outwash from the ice sheet at its maximal position. Based on this correlation it is believed that the Main Terrace aggradation occurred between 25000 and 18000 years BP.

The surface of the Worcester Terrace lies approximately 8 m below that of the Main Terrace, and is traceable from Tewkesbury to Bewdley and also in the Bridgnorth area, although it is not recognisable in the valley between Bridgnorth and Bewdley. The terrace, like the Main Terrace, contains a significant content of Irish Sea erratic material and a number of extremely large clasts have been identified in sites as far south as Stourport (Shotton 1977) and Grimley. Shotton (1977) and Shotton and Coope (1983) have proposed that the Worcester Terrace is an outwash terrace of the late-Devensian glaciation, possibly related to the Ellesmere (Welsh) re-advance (Beckinsale and Richardson 1964).

Altitudinally, below the Worcester Terrace, there are a number of discontinuous low terraces. Wills (1938) collectively named these the Power House Terrace, and proposed that they represented the upper part of the infilling of a channel deeper than the bed of the present river. Williams (1968) described a sand and gravel unit, up to 12 m thick, underlying most of the Lower Severn. This unit was later interpreted by Brown (1982) to be the first depositional units of the post-glacial valley fill and has been radiocarbon dated at 12570 ± 220 years BP at Stourport (Shotton and Coope 1983). Below Worcester these deposits underlie the Holocene alluvium, but in the vicinity of Bridgnorth the low terrace deposits lie approximately 8 m above the current floodplain surface and at Stourport the Power House Terrace is evident up to 2.5 m above the floodplain.

CHELMARSH (SO 743 871)

Lithofacies Characteristics

The gravel workings at Chelmarsh are located in a Main Terrace fragment 3 km south of Eardington (Fig. 19). This is well beyond the southern most limit of Devensian glacial deposits mapped by Wills (1924). Here in excess of 10 m of aggregate deposits have been proved in boreholes and are being actively worked for aggregates. Whilst the sedimentary sequence is similar to that described at Eardington (Dawson 1985), the site is significant because of the occurrence of extensive blocks of diamict and very large, angular, boulders of Old Red Sandstone.

Terrace Lithofacies

The terrace lithofacies, which may be interpreted to have a fluvial origin, are directly comparable to those present in the lower terrace unit described by Dawson (1985) at Eardington. There three lithofacies associations were identified:

1. Coarse gravel units up to 1.2 m thick comprising crudely planar stratified and tabular cross-bedded lithofacies, interpreted as non-emergent, poorly developed, gravel bars.
2. Planar stratified (upper flow regime) sands and gravels and planar cross-stratified sands, which seem to have developed in areas of shallow flow divergence on the surface of the gravel bar features.
3. Large-scale trough cross-stratified sand and gravel. Individual trough forms may be up to 1 m thick and 5 m wide. Locally, the lamination within the troughs dips at low angles, indicating local increases in flow strength causing a transition to flow over a planar bed.

The gravel bar lithofacies and the large-scale bedforms were seen to be laterally interbedded, and were locally underlain by concave-up scoured surfaces of greater extent than individual lithofacies units, suggesting counterminous formation in a broad shallow channel.

At Eardington the lithofacies assemblage was interpreted as being the product of a low sinuosity fluvial environment (Dawson 1985) as there is low directional variance in palaeocurrent direction, little consistency in vertical facies sequences, an absence of lateral accretion structures or extensive mud or silt facies and an occurrence of large clasts (Moody-Stuart 1966; Jackson 1978; Bridge 1985). Whilst the actual channel type remains uncertain, it seems that there were large channels with low width to depth ratios containing bedforms at the dune-plane bed transition and bars with well developed forest margins.

At both the Eardington and Chelmarsh sites basal lithofacies have yielded concentrations of extremely large, subrounded or angular clasts up to 2 m in diameter. The dimensions of these clasts and the large scale of the trough cross-stratification together indicate that flow depths may have exceeded 5 m. The angular nature of some of the largest clasts at Chelmarsh and their non-local provenance can only be explained by invoking a non-fluvial mechanism for their transport into the area.

THE SEVERN

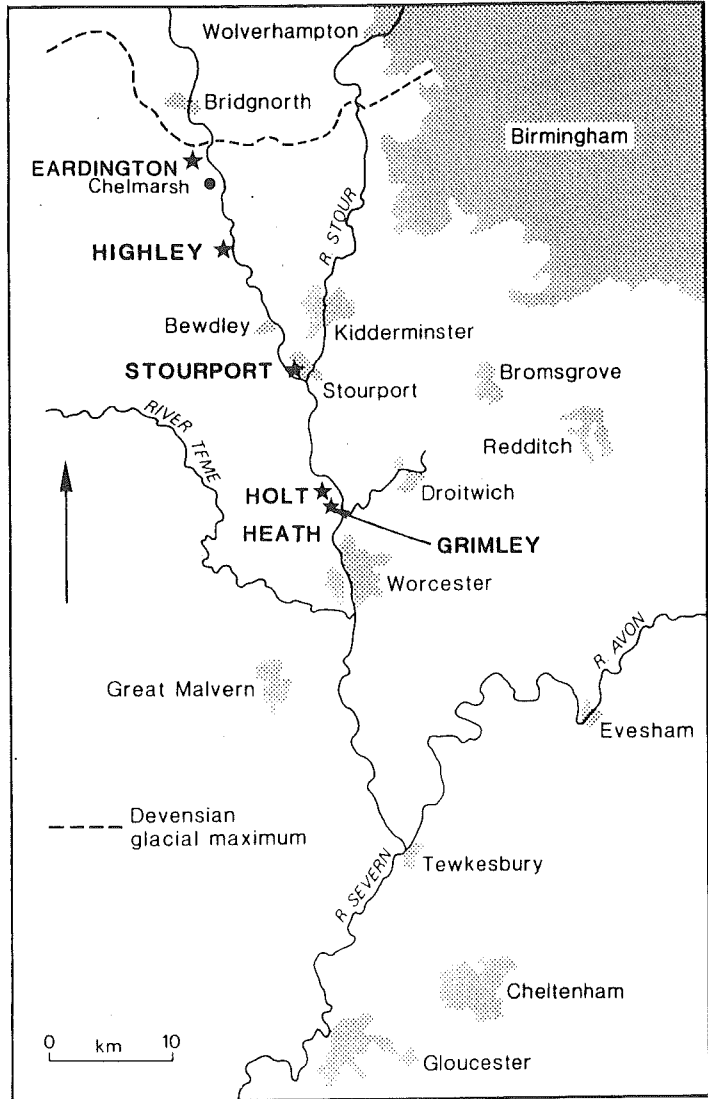


Fig. 19. Major terrace sections along the lower Severn.

Diamict Units

Exposure in May 1988 revealed a large diamict block 20 m in length and in excess of 4 m in thickness (Fig. 20) towards the base of the terrace sequence. The diamict in this block has a generally massive, blocky structure, although small (<20 cm) sand lenses are apparent. It is relatively stoneless and comprises isolated clasts supported in a poorly sorted sandy-clay matrix. The matrix has an overall red-brown colour, indicating derivation from Triassic and Carboniferous sources, whilst the clasts have a wide provenance and include erratic materials such as granites. A clast fabric obtained from this unit indicates a transport direction from the north (Vector mean = 195°), although there is a relatively high dispersal of clast orientations from this mean (Standard Deviation = 83°). Locally, particularly towards the southern end of the block, there is evidence that it has been eroded, as clast lags occur on the surface of the block.

Vertically, the unit is truncated by the overlying terrace gravels, and laterally is replaced by extensive trough cross-beds (Fig. 21). Eroded blocks of diamict up to 75 cm in diameter are present as intraclasts within these trough cross-beds. Immediately to the south of the diamict block there are extensive sets of fine grained sand, exhibiting low angle dipping, upper flow regime, plane bed lamination. These beds were observed to extend up to 30 m along the length of the section and to reach up to 3 m in thickness, before being replaced laterally and vertically by large scale trough cross-bedded lithofacies. Individual sets are up to 1 m thick with the set boundaries having an erosive, shallow, trough form. In the immediate vicinity of the diamict block, the sands have been post-depositionally disturbed and are folded and micro-faulted. Typically the folding is uniclinal and seems to have developed as a result of injection, or thrusting, of the adjacent diamict into the sand unit.

The diamict units may be interpreted as being of glacial origin, the characteristics of the diamict, which includes small stratified lenses, being comparable to melt out tills described by Haldorsen and Shaw (1982) and Shaw (1982). The diamict was clearly emplaced prior to the deposition of the adjacent terrace gravels as there is no evidence of interdigitation between the diamict and the terrace gravels, and because eroded blocks of diamict are present in laterally adjacent trough crossbeds. However, it is probable that final melt out and deposition of the diamict did not occur until after the formation of the fluvial lithofacies, as the adjacent sand beds were clearly disturbed by movement of the diamict sediments.

The diamict block shown in figure 20 seems to have acted as an obstruction to flow. The low angle dipping, planar laminated, sandy lithofacies downstream of the block seems to have formed in upper flow regime conditions in a wake area behind the block. Such flow conditions would have been induced if the flow area was locally constricted.

Interpretation

The coarse nature of the terrace sediments and the scale of the sedimentary structures has already been used as evidence that the Main Terrace complex in the Eardington area developed in a proximal location relative to the maximal position of the Devensian ice margin (Wills 1924, Dawson 1985). The interbedded nature of the diamict units and the fluvial terrace sediments at Chelmarsh indicates that a revision should now be made, not only to interpretations of the depositional environment of the

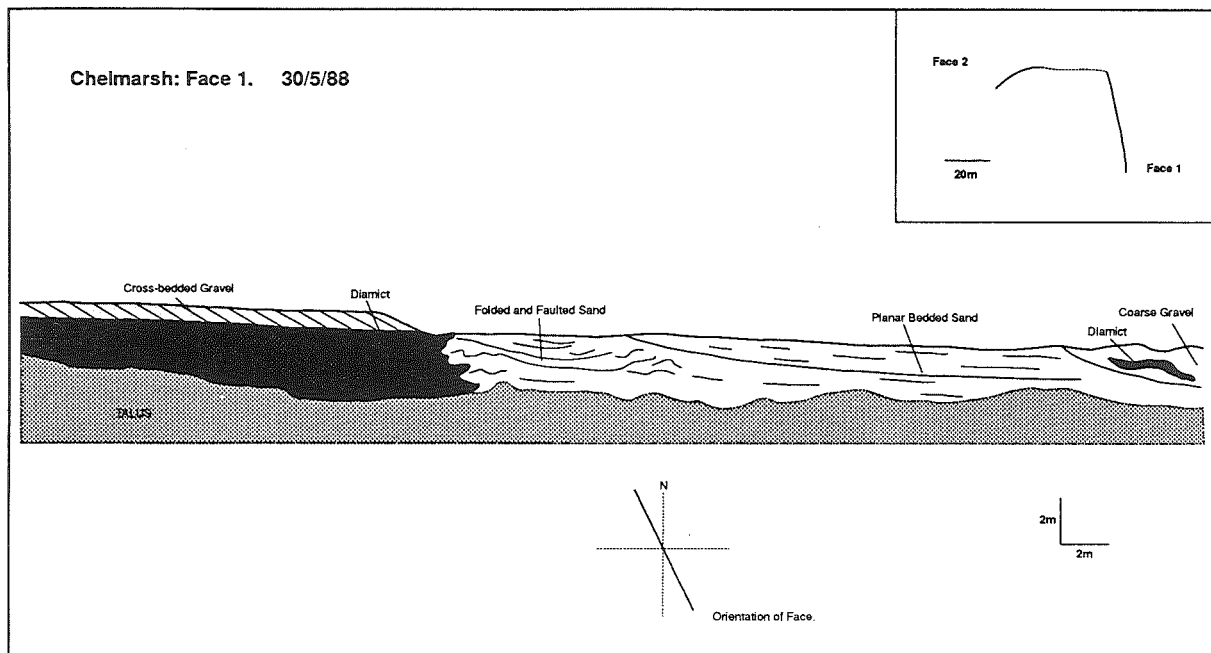


Fig. 20. Chelmarsh Face 1, showing the relationship between the diamict block and lee side sands.

Chelmarsh: Face 2. 30/5/88

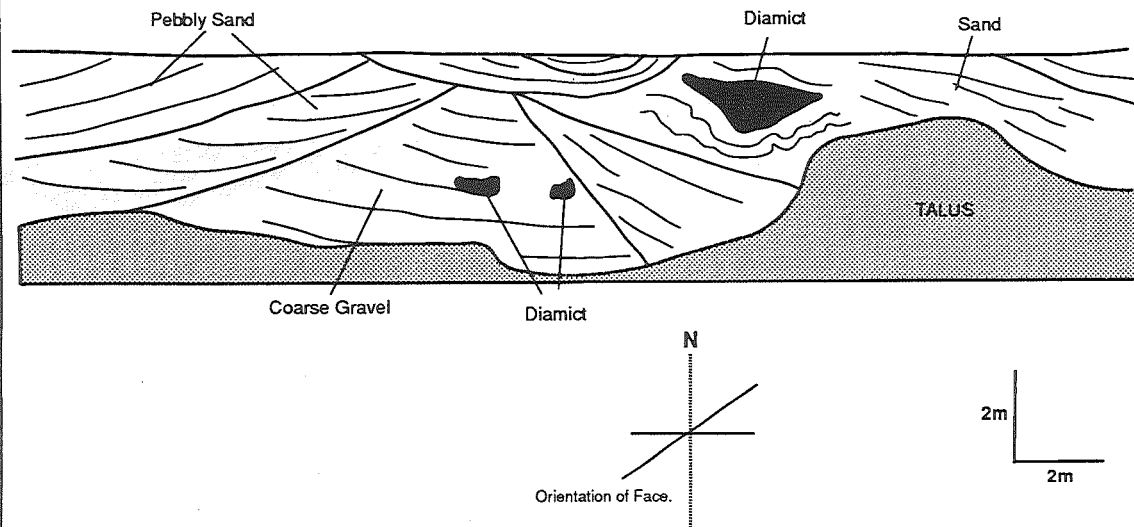


Fig. 21. Chelmarsh Face 2, large scale trough cross-bedding incorporating eroded diamict blocks.

terraces in the Eardington-Chelmarsh area but also to the, local, southern most limit of the Devensian ice margin.

It is envisaged that, at the glacial maximum, a valley glacier extended southwards along the line of the present Severn Valley. Terrace aggradation commenced in the area upon stagnation and retreat of the ice margin. Initially, fluvial sedimentation occurred beneath and between areas of stagnant ice and ice marginal sediments, possibly in a complex manner in association with fluctuations in sediment supply and the position of the ice margin. With progressive retreat of the ice margin remnant glacial sediments were buried and largely obliterated by the aggrading terrace sediments. At a late stage in the terrace aggradation, alluvial fans prograded over the terrace sediments from tributary valleys such as the Mor Brook (Dawson 1985).

M Dawson

STOURPORT (SO 795 734)

The Severn Terraces at Stourport have been extensively exploited for aggregates at the Roger Constant site over a period of 30 years, with exposures being produced in both the Main and Worcester Terraces (Fig. 22). Presently aggregate extraction is taking place in the Main Terrace, providing excellent sections through the terrace gravels and, more uniquely, through deposits preserved beneath the terrace sediments.

The present sections are located approximately 2 km upstream of the Severn-Stour confluence in a terrace flat lying between 40-45 m O.D. The surface of the terrace lies at two levels, separated by a step of up to 3 m. The base of the terrace also has a similar stepped profile, with a lower level, located towards the terrace bluff, being up to 1.2 m lower than the terrace base towards the valley sides.

The Terrace Gravels

The terrace deposits are composed of sandy gravels 3-5 m thick, which, at the top of the section show a fining up transition to cross-bedded sands overlain by up to 0.60 m of buff coloured silt.

Lithofacies Characteristics

Three lithofacies assemblages have been identified within the Main Terrace sediments (Fig. 23):

Assemblage A

Assemblage A is present in thick, often multipully stacked, coarse grained units which form laterally extensive tabular sheets up to 2 m in thickness. These often comprise almost the total thickness of the sediments exposed in section. Individual units overlie broadly planar erosive horizons which may be traceable for more than 90 m normal and parallel to the mean palaeocurrent direction.

Three lithofacies associations are apparent within the assemblage. In each assemblage crudely stratified gravel beds, 0.15 to 0.75 m thick, are the most common lithofacies type. Typically clast supported and matrix rich, these beds range from being imbricated with a well defined planar structure, to poorly organised beds with little preferred clast orientation.

Association A1: This association comprises; units of crudely stratified gravel; small, normally dipping (to channel axis) wedge like units of cross-bedded gravel; and trough cross-bedded sand. These lithofacies lie within erosive channel forms up to 0.80 m deep. The association may be regarded as having formed through the infilling of small erosive channels.

Association A2 lies above the major bounding surface separating units of the assemblage. Typically, it comprises crudely stratified gravel beds passing laterally into units of planar cross-bedded gravel up to 0.70 m thick and 20 m long. Such lithofacies associations may be the product of the formation of in-channel unit bars with the cross stratification being produced where there were well developed slip faces (Hein and Walker 1977, Steel and Thompson 1983).

Association A3 forms the bulk of the assemblage and comprises interbedded thin beds of planar bedded gravel, cross stratified

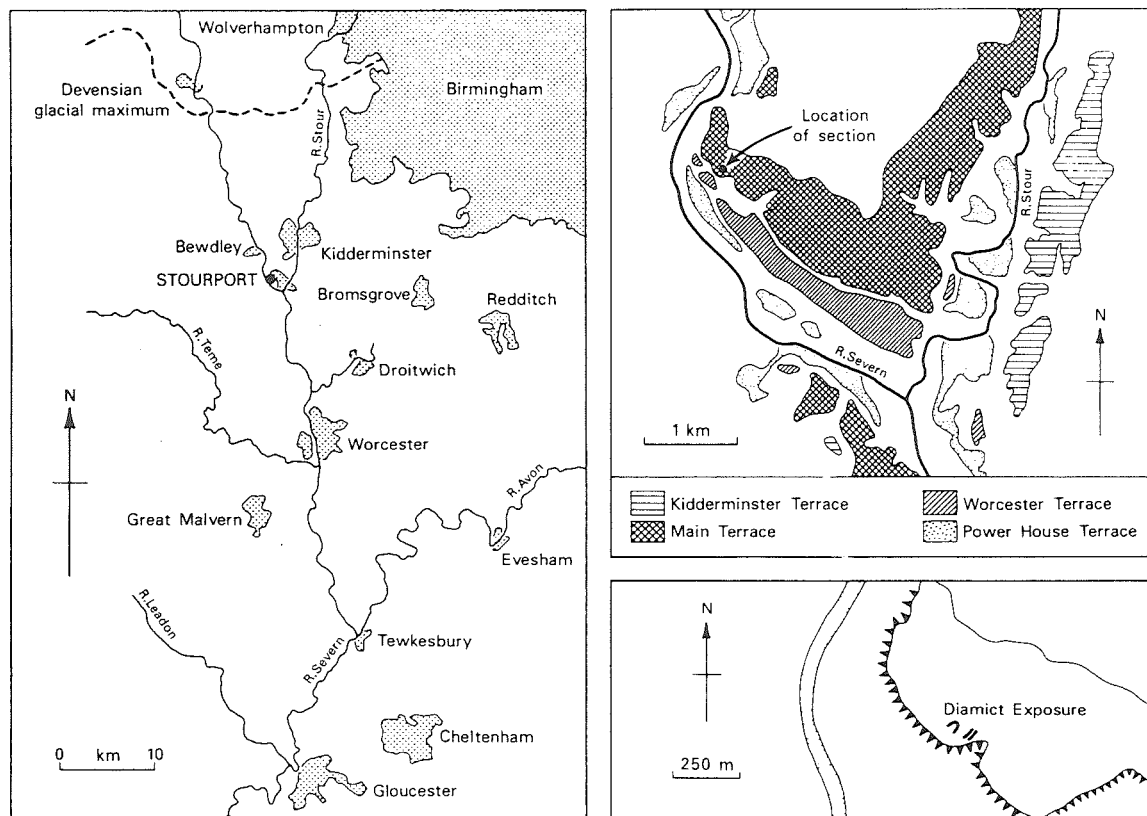


Fig. 22. Location of the diamict and terrace sections at Stourport.

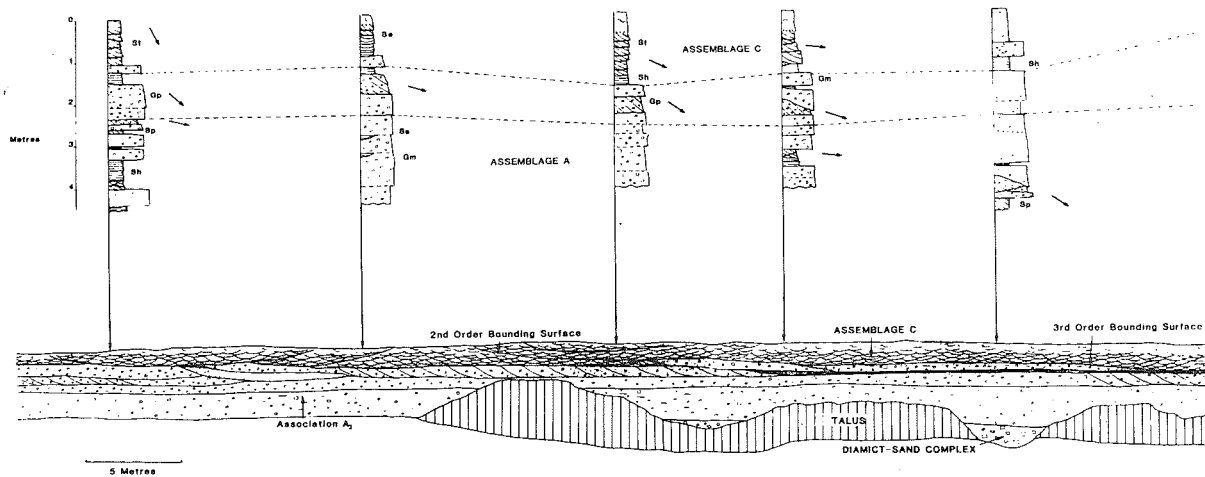


Fig. 23. Terrace gravels at Stourport. Face orientated oblique to palaeoflow (from Dawson 1988).

gravel and sand lenses. Such stratification is likely to have developed in shallower channel margins or in an exposed supra-bar position where there was migration of gravel lobes over a bar surface.

Association A1 tends to directly overlie the basal erosive surfaces separating units of the assemblage in pockets and is overlain by units of Association A2 (Fig. 23). Association A2 often shows a lateral and vertical transition to Association A3. There is a tendency for interbedding between gravel and sand lithofacies to become more common towards the valley sides.

Assemblage A may be regarded as the 'basal' assemblage in the terrace sequence, as it rests above major (3rd order) bounding surfaces. The internal characteristics of the assemblage are directly comparable with complex bar assemblages described from modern and ancient conglomerate environments (Ore 1964, Williams and Rust 1969, Rust 1972, 1978, Bluck 1979, Steel and Thompson 1983, Sopena and Ramos 1983) and may be interpreted as the product of large scale bar sedimentation in broad shallow channels.

Assemblage B

Assemblage B is the product of lithofacies development within large scale channel forms. Such lithofacies assemblages must be regarded as typical of the terrace sequence as a whole. Two particular channel forms have been observed.

1. Figure 24 depicts a large channel form 2 m in depth and traceable for more than 35 m along the length of a section excavated approximately normal to the mean palaeocurrent direction for the site. The major units forming the infill were isolated sets of cross-bedded gravel. Two large sets were observed, showing an opposite foreset dip. These interdigitated towards the centre of the channel and were truncated by concave-up erosive surfaces, 5-8 m in width, containing low angle dipping cross-stratified gravel. The dip orientation in these troughs approximated to the mean site palaeocurrent direction, whilst the dip direction of the foresets was 210° and 48° respectively. The cross-stratification in the larger, counter dipping, sets was highly irregular and showed frequent signs of reactivation, with foresets being truncated by sub-horizontal surfaces.

The occurrence of the large-scale cross-stratification is indicative of the migration of asymmetric, linguoid, simple bar forms, with well developed slipfaces, within the channel (Ashmore 1982, Steel and Thompson 1983). Flow conditions, as indicated by the occurrence of re-activation surfaces, are likely to have been highly variable. The presence of the overlying crude trough cross-stratification is indicative of continued flow within an increasingly constricted channel.

2. A temporary section exposed in April 1985 revealed a large channel 2-3 m deep present at the top of the sedimentary sequence and erosive into Assemblage A. The form was exposed over a distance of 170 m, orientated parallel to the mean site palaeocurrent direction (117°). The infill at the channel centre comprised a vertically aggraded coset of large scale trough cross-bedded sand and gravel. Individual sets were up to 1 m thick. A transition to smaller amplitude lithofacies types occurred towards the channel margins.

FIGURE 2.2.30: STOURPORT

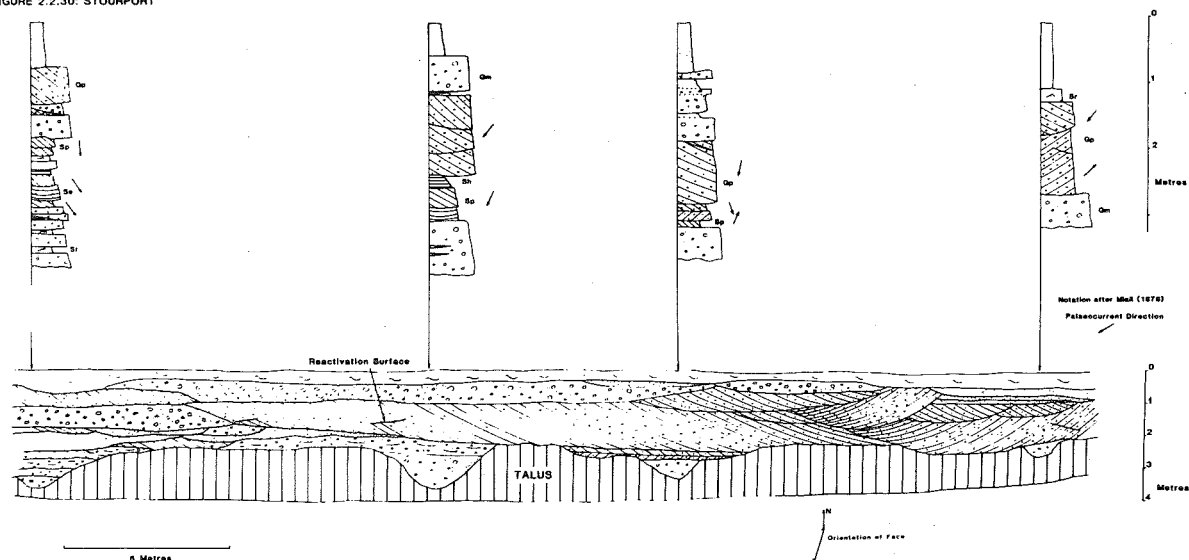


Fig. 24. Stourport: Large scale channel containing extensive cross-sets (from Dawson, 1988).

Inset within the larger channel, a smaller channel form, 20 m wide, was present. This was infilled with planar bedded sand with interbedded clay drapes.

The trough cross-stratification is indicative of large scale three-dimensional dune migration, whilst the presence of an inset channel form is indicative of late stage infilling of the channel under low flow conditions.

The isolated occurrence of large channel forms towards the terrace surface may be the product of differential preservation, but may also indicate a change in the local channel pattern as a result of altered sediment or water discharges. Such a change might be expected during the initial stages of the incision of the terraces. It is clear that both channels eroded into the underlying lithofacies and initially carried a substantial discharge. Following the aggradation of bedforms in the channel, the flow area became increasingly constricted, leading to eventual abandonment.

Assemblage C

Assemblage C is a predominantly fine-grained assemblage which overlies the underlying gravels along a distinct bounding surface. This often has a shallow channelised form. The dominant lithofacies type is cross-stratified sand which occurs in cosets up to 1.5 m thick. The geometry of the cross-stratification is highly variable, with trough and planar forms being observed. Individual sets are small 0.10-0.25 m thick and are generally formed in medium to coarse sand with gravel lags at the set bases. Minor lithofacies include; massive gravel lags, isolated sets of planar laminated sand; and ripple lamination.

The internal stratification of the assemblage is indicative of the migration of meso-scale sandy bedforms under spatial and temporal variations in discharge. The widespread distribution of the assemblage and a relatively consistent palaeocurrent direction indicates that it was deposited as a laterally extensive sheet. The assemblage may be interpreted as being either supra-bar deposits as described by Bluck (1974, 1979) or as late-stage terrace surface deposits.

Interpretation

The distribution, grade and internal structure of the lithofacies within the sedimentary sequence are indicative of a bedload dominated, low sinuosity channel system. The following sedimentary characteristics together indicate the Severn at this time had a braided planform:

1. Extensive lateral accretion structures are absent (Allen 1965, Moody-Stuart 1966, Bridge 1985).
2. Fine grained inner accretionary bank deposits (Bluck 1979) or extensive channel fill mud deposits are not apparent.
3. There is a low directional variance in palaeocurrent directions (Moody-Stuart 1966) indicating low sinuosity.
4. A sheet-like geometry of many of the larger sand and gravel bodies (Steel and Thompson 1983) suggests vertical aggradation in channels with low width to depth ratios.
5. Multiple truncated channel forms are present (Bryant 1983).

In comparison to the lithofacies models for braided environments proposed by Miall (1978), the stacked units gravel lithofacies indicate the sequence is analogous to the Scott type model erected for proximal braided stream sequences.

The presence of major (3rd order), laterally extensive, bounding surfaces between units of Assemblage A and an upward transition within the units from truncated channel fill, to tabular bar units, to fine supra-bar and clay drape lithofacies, indicate that accretion of the bar lithofacies occurred discontinuously. In a braided environment such superimposition may result from:

1. The migration of channels across the active zone of sedimentation.
2. The avulsion and migration of the active zone of sedimentation across the valley floor (Bluck 1980, Bryant 1983).
3. Changes in discharge conditions within the river.

The extent of the individual bounding surfaces, traceable across much of the terrace, indicates that the latter two causes are the most probable reasons for this cyclic sedimentation.

The occurrence of the incised and confined channel forms (Assemblage B), and the sheet like Assemblage C, towards the surface of the terrace may indicate a change in depositional conditions towards the culmination of the terrace aggradation (Maizels 1983) in response to changing discharge or sediment input.

Diamict Deposits

Excavations since 1984 have revealed local pockets of extensively deformed, interbedded, sand and diamict sediments (Fig. D7a,b). These units unconformably overlie the local Permo-Triassic Bridgnorth Sandstone and are truncated along a sub-planar erosional horizon by the overlying terrace gravels. The distribution of the diamict-sand complex is uncertain, however, earlier excavations revealed similar sediments extending beneath the lower Worcester Terrace and it is thought that the deposits form part of a pre-terrace valley fill.

Detailed examinations of the deposits were made in 1984-85 and detailed in Dawson (1988). The following lithofacies, structural and petrographic characteristics were observed.

Lithofacies Characteristics

1. Diamict

Diamict lithofacies occur as deformed beds, varying in thickness, sorting and internal organisation (Fig. D7). Three sub-facies were noted.

- (a) Poorly organised beds up to 1.5 m thick. Laterally these beds become attenuated and may interbed with adjacent sand lithofacies.
- (b) Crudely stratified beds up to 1.5 m thick. These may be erosively based, truncating structures in underlying units. Surfaces between these diamict beds and both under and overlying sand beds may be disturbed and involuted.

- (c) Thin beds of relatively well sorted diamict, 10 to 200 mm thick. These are conformably interbedded with finer grained sand lithofacies.

2. Planar bedded and massive sand

Planar bedded and massive sand was observed to occur in beds between 0.20 and 2 m thick, interbedded with, and showing a transition to, both the diamict and fine laminated lithofacies. Typically the sands are well sorted and fine grained. There is no evidence of other internal structures such as cross-bedding.

3. Fine laminated sediment

Fine grained, massive and planar laminated, sandy-silts are present in beds between 50 and 300 mm thick in association with beds of the sand lithofacies.

Structural Characteristics

The sub-terrace sediments are extensively deformed, showing both large scale and local folding, with local shearing and faulting being evident (Fig. 25). From the limited sections available it is not possible to determine a preferred direction for the strike of the folds and faults. The form of the folds is highly variable and ranges from large, simple, synclinal folds up to 30 m in length, to more complex anticlinal and uniclinal folds up to 2 to 5 m across. The smaller folds are disharmonic and locally overturned beds and recumbent drag folds are present. In places there seems to have been shearing within the complex, with adjacent beds showing orthogonal directions of dip across a highly deformed contact.

The deformation within the complex seems to have been post-depositional as there is only limited erosional truncation of large scale folded structures. However, it pre-dated the deposition of the overlying terrace gravels as the tectonic structures are truncated by the basal surface of the terrace.

Provenance

Clast samples taken from a major diamict unit indicate that the lithologies present in the complex are of local provenance. The dominant component is coarse grained Carboniferous sandstone (Cornstone) 72%. There are significant components of local Triassic sandstones and conglomerates and also a small percentage of Carboniferous limestone.

Recent Observations

More recent sections have shown that the diamict-sand unit occurs widely under the Main Terrace sediments. The lithofacies characteristics and petrographic content of the unit have remained broadly similar, although certain of the newly exposed 'diamict' beds contain a high proportion of well rounded clasts and are in part clast supported. At one location, to the northern end of the present workings, the Main Terrace sediments lie conformably upon an unit of diamict and may have been deposited around an upstanding bed.

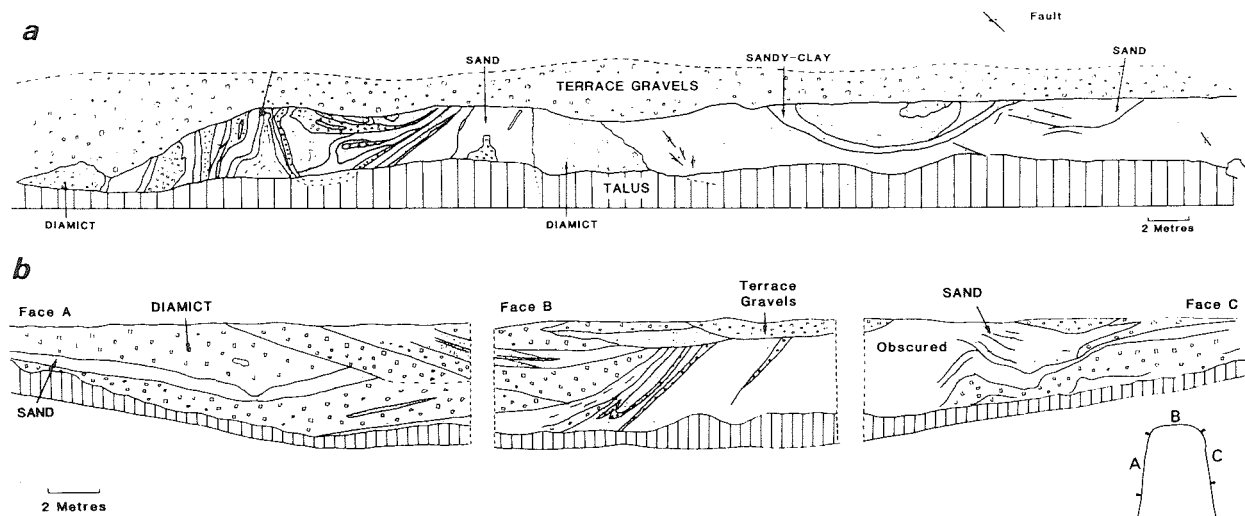


Fig. 25. Stourport: Exposures in the sub-terrace diamict-sand complex.

Interpretation

1. Depositional processes and environment

Whilst alternative explanations for the origin of the diamict-sand complex, for instance that it developed as part of an extensive area of sub-aerial mass-movement, cannot be unequivocally rejected, a glacial origin is preferred. The characteristics of the diamict lithofacies are in many ways analogous to glacial till deposits as the lithofacies is poorly sorted with clasts supported in a matrix of sandy, silty, clay. The internal deformation and interdigitation of the diamict and sand lithofacies is directly comparable to examples described from glacial assemblages involving in situ melt out and local flowage due to thaw consolidation (Shaw 1969, 1972, 1982; Boulton 1967, 1968, 1972; Morawski 1976).

The variation in the organisation and grading of the lithologically similar diamict lithofacies is indicative of sedimentation or resedimentation by a suite of dynamically variable processes. The type A and B diamict lithofacies are analogous to sub-aerial debris flows described by Lawson (1979, 1982) from ice marginal environments, the contrasting internal characteristics of the two bed types being largely explicable in terms of the differences in the fluid content of the formative debris flows. The type C diamicts, interbedded with sand lithofacies, seem to have been deposited by liquified flows, possibly sub-aqueously (Lowe 1976; Lawson 1979, 1982).

Sub-aqueous deposition may also be inferred for the deposition of the planar laminated sands and silts. These may have been deposited on low angle accretional surfaces as sheet flow deposits (Lawson 1979, 1982), or through the introduction of sediment plumes into a standing body of water.

Although, in the absence of supporting evidence, the sedimentary origin of the deposits is enigmatic, it is probable that the complex developed in an ice marginal situation during ice stagnation. In this situation, resedimentation of the diamict may have occurred by material flowage in an area of stagnant ice topography, whilst the sands were deposited in small standing water bodies present in the same area. The deformation evident in the complex indicates that many of the sand beds were deformed post-depositionally, either as a result of the further movement of debris flows or perhaps glacio-tectonically as a consequence of residual ice movement during ice melt out. Sedimentary relationships seem to indicate that initial debris flows were small scale and liquified, associated with the sand deposition. Subsequent flows were larger in scale and were more viscous, causing folding, shearing and thrusting within the complex as a whole. This sequential development could be regarded as being a result of progressive ice wasting.

2. Stratigraphic implications

The complex clearly pre-dates the formation of the Severn Main Terrace and hence, if of glacial origin, must be associated with an earlier pre-Late Devensian, glaciation. The presence of these sediments indicates that a proto-Severn valley was in existence prior to the formation of the Main Terrace. The presence of a pre-terrace valley form beneath the level of the Main Terrace is supported by observations of ice wedge casts underlying, and truncated by the Worcester Terrace sediments (P Worsley, personal communication).

GRIMLEY (SO 834 614)

The sand and gravel deposit being worked here is, currently, the only major section in the Worcester Terrace. The surface of the terrace at this location is some 12 m lower than the adjacent Main Terrace (Fig. 26). The aggradation seems to have taken place as the result of an increase in the sediment supply relative to prevalent discharges in the Lower Severn, after a period in which restricted sediment supply induced degrading conditions. The causes for such a relative increase in sediment supply are uncertain, but may be related to upstream fluctuations in the ice margin.

Lithofacies Characteristics

In excess of 10 m of sand and gravel are exposed in the section along a single face almost 300 m in length. The bottom of the workings are flooded and the base of the deposit has not been reached. The sedimentary sequence contains a number of erosive bounding surfaces which separate genetically related associations of lithofacies, each of which seem to have formed as a separate channel zone. The lithofacies characteristics of these units vary within the section, such that a threefold stratigraphic division is apparent within the exposure (Fig. D9).

The basal assemblage (A), no longer exposed in the present workings, occurs as a distinct unit towards the valley sides, resting directly on the bedrock and pinching out towards the valley centre. The unit is formed from vertically stacked, laterally traceable, gravel beds which thin and fine upwards. Bed thicknesses decrease from in excess of 1 m to 0.15 m - 0.30 m near to the contact with the overlying lithofacies assemblage. The beds show a well imbricated, framework supported structure and where they rest directly upon each other the contact is usually welded. Frequently, however, the contacts between beds are indicated by a thin clay or sand bed and locally there are beds of planar cross bedded sand or gravel. The imbrication of pebbles within the beds indicates that the flow direction paralleled the orientation of the valley axis.

Assemblage B was observed in 1983-86 to truncate and to be inset into the basal assemblage. More recent exposure has shown that either the basal lithofacies in the assemblage incorporate substantial amounts of gravel material from Assemblage A, or else laterally interdigitate with that assemblage. The assemblage forms the major sedimentary body within the present terrace exposure, and is composed mainly of cosets of cross-stratified sand and fine gravel lithofacies up to 2 m thick. Coset boundaries are typically planar or slightly concave-up and are often traceable along the section for more than 50 m. They are often overlain by a gravel lag and may be erosive into a unit of fine grained sediments up to 0.30 m thick.

Two vertical associations may be identified within the cosets:

1. Vertically aggraded channel fills, dominantly composed of trough cross-bedded sands. There are local transitions to upper flow regime planar bedded sands, cross-bedded fine gravel, and ripple laminated sands.
2. Isolated bar sequences comprising tabular cross-bedded units of sand or fine gravel up to 1 m thick, overlain by inset, thin, planar laminated or planar cross-bedded sand lithofacies.

TERRACE DEPOSITS AT HOLT HEATH

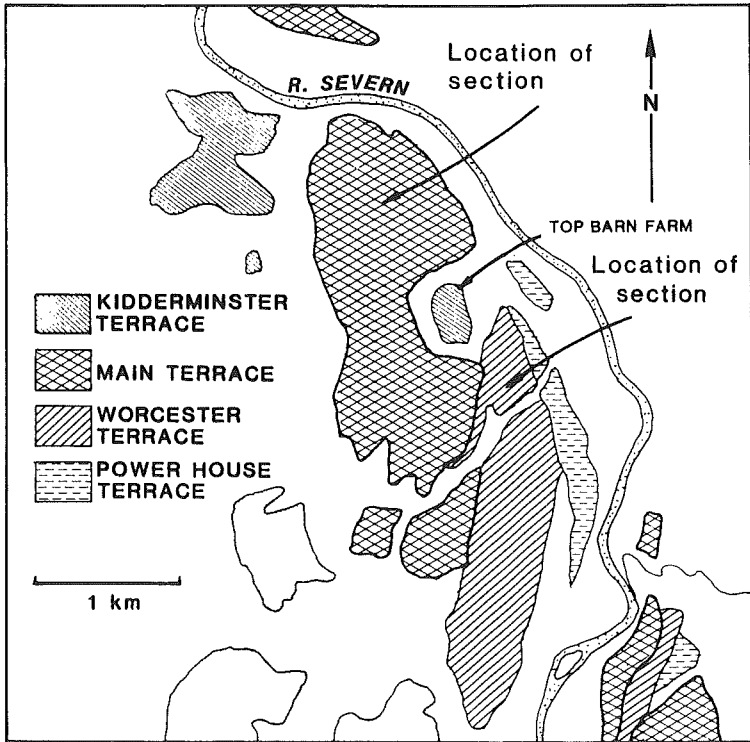


Fig. 26. Terrace deposits in the vicinity of Holt Heath.

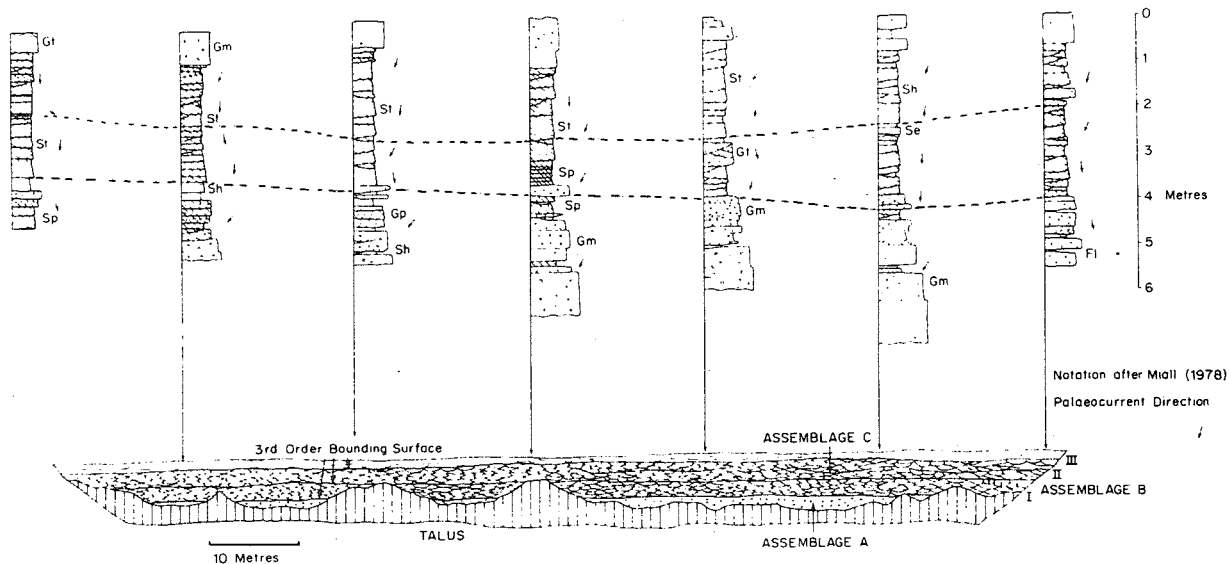


Fig. 27. Worcester Terrace exposure at Grimley (from Dawson and Gardiner, 1987).

The mean palaeocurrent direction of assemblage B closely parallels the valley axis (200° - 210°), although there are slight variations between cosets.

Assemblage B is vertically truncated by a major bounding surface marked for much of its length by a massive sandy-clay up to 0.50 m thick, resting on a gravel lag. A similar bounding surface separates two units in the overlying assemblage C.

Close to the valley centre units of Assemblage C are composed of beds of crudely planar-stratified gravel and tabular cross-stratified sand and gravel, up to 0.60 m thick. The cross-stratification has two forms; sets aligned normal to the valley axis; and small wedge-like units occupying erosive channel forms. The gravel lithofacies interdigitate towards the valley centre with cosets of cross-stratified sand, which share many similarities with the underlying Assemblage B. However, these cosets are composed almost entirely of trough cross-bedded and ripple laminated sands, set heights are small (0.10-0.30 m) and gravel lags are infrequent.

Interpretation

Units within each of the Assemblages B and C may be regarded as former channel zones and the contrasts between the units are perhaps indicative of a changing channel planform during terrace aggradation. The basal Assemblage A resembles channel zone units described from the Main Terrace, and it may be interpreted as a separate, coarse channel zone (Dawson 1986, Dawson and Gardiner 1987). However, the continuous nature of the individual beds and the possible lateral interdigitation of the unit with lithofacies of Assemblage B indicates that an alternative interpretation may be more appropriate. It is conceivable that the unit represents a complex-bar form deposited contemporaneously with the lithofacies of Assemblage B. The thinning and fining upwards within the units seem to have resulted from declining flow depths and velocities during deposition.

Much of the Assemblage B was clearly produced by aggradation in a sand-bed channel. The laterally persistent cosets of trough cross-bedded sand seem to have developed as a result of channel floor bedform migration, whilst larger scale barforms are represented by the tabular cross-bedded units with superimposed small bedforms. The dominance of vertically accreted channel bedforms, a low palaeocurrent variance and the presence of cross-cutting, sub-planar coset boundaries suggest the occurrence of sandy braided conditions, and the stratification in the assemblage closely resembles sandy braided sequences described from the ancient record (Campbell 1976, Cant and Walker 1976).

The interdigitation of cross-stratified sand beds and gravel units in the Assemblage C, and possibly between Assemblages A and B, indicates the co-existence of sandy bedforms and gravel bars within the same channel-zone. A similar interdigitation between channel floor dune forms and complex gravel bars has been described by Eynon and Walker (1974) from braided outwash sediments in Ontario.

Overbank sediments are generally absent from the sequence. However, the laterally extensive sandy clay units associated with the major bounding surfaces and coset boundaries within the terrace closely resemble bar surface and floodplain drapes described by Cant and Walker (1976) and Allen (1983) from other sandy braided sequences.

The causes for the vertical changes in the sedimentary sequence, and hence the depositing channel planform, remain unclear. It is possible the

variations were caused by a local depositional control, such as a base level induced backwater effect. However, the stratigraphic division in the terrace closely resembles that described by Shotton (1977) at Stourport, which suggests there may have been larger scale variations in sediment supply and discharge affecting the lower Severn during the aggradation of the Worcester Terrace. Such interpretations are necessarily speculative and further detailed observation at other locations in the Worcester Terrace are required to support them.

M. Dawson

Friday 7 April

1. Huncote SK 513 982
2. Melton Mowbray SK 736 176
3. Castle Bytham SK 998 184
4. Witham-on-the-Hill TF 030 177
5. Shouldham Thorpe TF 657 085

TRACING THE BAGINTON-LILLINGTON SANDS AND GRAVELS FROM THE WEST MIDLANDS TO EAST ANGLIA

Introduction

The recent discovery and study of quartz and quartzite rich sands and gravels beneath till along a belt of country that extends from Warwickshire in the west, Leicestershire, south Lincolnshire, and Norfolk and Suffolk in the east, has significant implications for the Quaternary in southern Britain (Rose, 1987):

1. It has resulted in the identification of a major lithostratigraphic unit in Midland and eastern England, and the recognition that this formed through a long period of Quaternary time, with the youngest beds of early Anglian age.
2. It requires a significant revision of the glacial sequence of the British Isles, because the sediments at the Wolstonian type site can be shown to underlie, rather than overlie deposits of Anglian age (Fig. 28). It is recommended, therefore that the term 'Wolstonian' be abandoned as a stage name (Rose, 1988).
3. The revised distribution of deposits attributable to a glaciation succeeding the Anglian, but preceding the Devensian implies that glaciation in southern Britain was generally less extensive than either of these two glacial events.
4. The position of the Baginton-Lillington Gravels in the lowland north of the Cotswold escarpment indicates a long period of Quaternary time between the deposition of the Gerrards Cross Gravels when the Thames catchment drained western midland England and Wales (conventionally attributed to the Beestonian stage) and the Anglian glacial stage when a river deposited the Baginton-Lillington Gravels in this low terrain.

Work on this subject is currently in progress at Birkbeck College (Royal Holloway and Bedford New College from 1 May 1989), London University along with Simon Lewis, Darrel Maddy and Richard Bateman. As work has progressed additional discoveries have been made that reinforce the original hypothesis, but also problems have emerged. Some of these are indicated in the site descriptions and opportunity will be taken to discuss these at the QRA Annual Meeting and in particular on the excursion for which this is the introduction.

This section is designed to outline the main evidence and implications of this work. The following site descriptions give evidence from the localities that can be visited. Because of time constraint it will not be possible to visit East Anglia, other than Shouldham Thorpe at the northwest margin of the region.

Evidence

- (1) A distinctive lithological unit composed of fluvial sands and gravels overlain by fluvial sands with silty clays in the upper part, can be traced from the West Midlands to eastern East Anglia (Fig. 29) and possibly into the region now occupied by the North Sea (B D'Olier, pers. comm.). This unit is known as the Baginton-Lillington Gravels and the Baginton Sands in Warwickshire (Shotton,

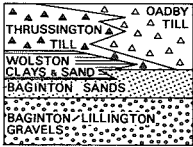
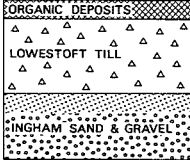
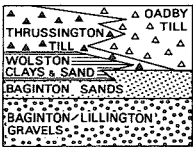
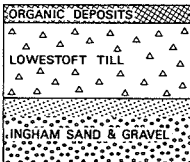
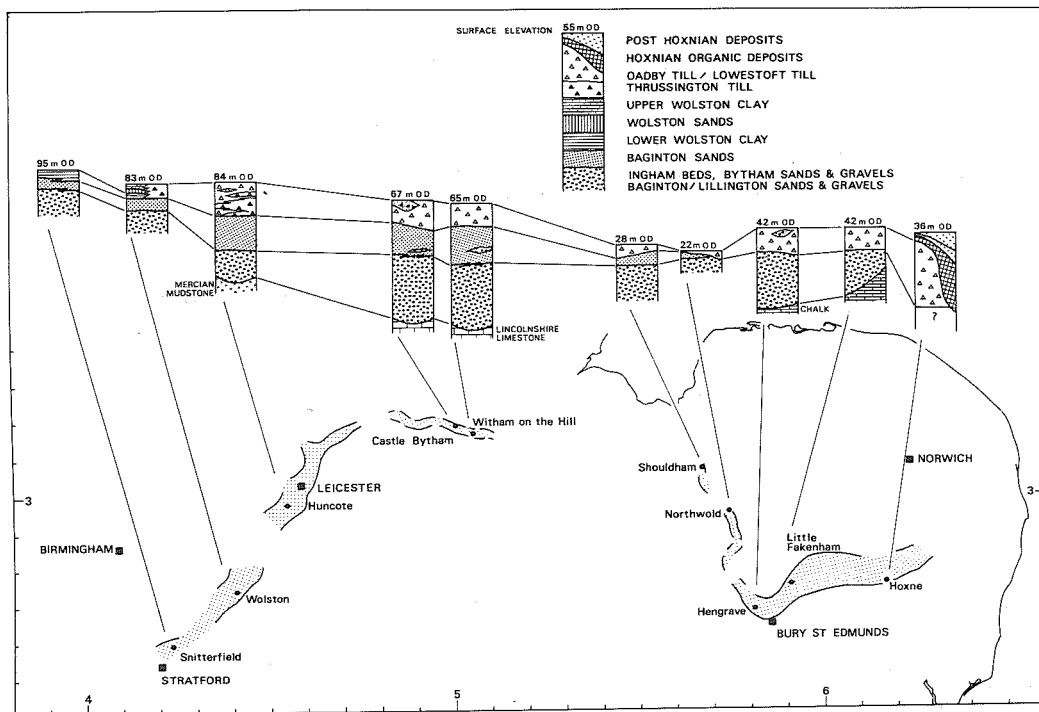
	MIDLAND ENGLAND	EAST ANGLIA	STAGE NAMES
TRADITIONAL CORRELATION			WOLSTONIAN
			HOXNIAN
			ANGLIAN
			PRE-ANGLIAN
REVISED CORRELATION			HOXNIAN
			ANGLIAN
			AND EARLIER

Fig. 28. Revised interpretation of the British Pleistocene stratigraphy in Midland England.



1953) and Leicestershire (Rice, 1981), the Bytham sands and gravels, sands and clay in south Lincolnshire (introduced informally here), and the Ingham Sand and Gravel in East Anglia (Hawkins, 1981; Clarke and Auton, 1982).

- (2) This lithological unit occupies a buried valley previously recognised by Shotton (1953), Rice (1968), Wyatt (1971), and Hopson and Bridge (1987) that slopes consistently from the west to the east (Fig. 30). Elevations at the base of this valley range from about 90 m OD near Stratford upon Avon to -8 m OD near the North Sea coast. This valley cuts through both the Jurassic and Chalk escarpments (Fig. 30) indicating that it originated on a high level land surface in which the soft-rock lowlands had not yet been eroded.
- (3) The body of sediment is located within an altitudinal 'envelope' (Fig. 31), which slopes progressively eastwards. The lower boundary is determined by the base of the buried valley, the upper by the highest elevation of the lithological unit within an area. The upper boundary slopes from about 94 m OD near Stratford upon Avon to about 50 m near Diss. Almost certainly this envelope includes deposits of a wide range of ages both in the west, where there are pre-Anglian organic deposits beneath the main body of sediment (D. Maddy, D.H. Keen, A. Currant, pers. comm.), and especially in the east where the deposits interdigitate with early units of the Kesgrave Formation and relate to early Kesgrave terraces (S. Lewis, pers. comm.). By relation to overlying glaciogenic sediments the youngermost part of the unit can be shown to be associated with the onset of local glacierization during the Anglian.
- (4) The lithology of the unit varies along the band of sediment according to the durability of the local rock type, but throughout it includes a significant contribution of far travelled material derived exclusively from a western or upstream provenance. These comprise:
 - (i) quartz and quartzite of the Kidderminster Formation (Bunter) of the West Midlands. Also reddish brown sand grains from the Triassic sandstones of the same region;
 - (ii) chert from the Carboniferous rocks of the Pennines and Warwickshire Coalfield (S. Lewis, pers. comm.);
 - (iii) flint (usually very weathered) attributed to early glacial deposits in the West Midlands (Hey, 1986);
 - (iv) Spilsby Sandstone from the Lower Cretaceous of southeast Lincolnshire and northwest Norfolk.

The first three are found throughout, with frequencies determined by the relative importance of local durable rocks (Fig. 32). The Spilsby Sandstone clasts are only found in the area south of Kings Lynn and have been discovered to date, as far east as Bury St. Edmunds.

Of equal importance is the absence from the unit, in the area roughly west of Bury St Edmunds, of rounded, chatter-marked flints from the Tertiary pebble beds of the London Basin. This indicates that the lithological unit is quite distinct from the Kesgrave Formation, which contains this material, and that the Ingham Sand

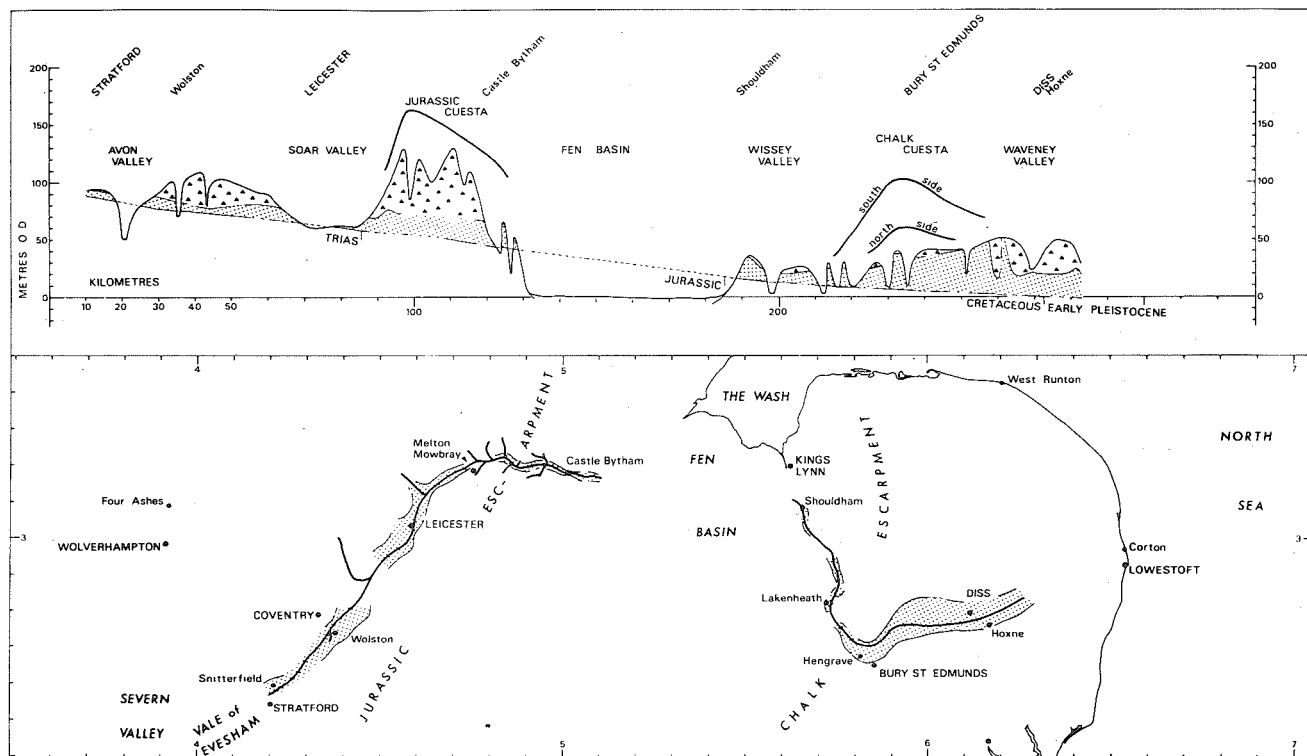


Fig. 30. Geographical and altitudinal position of the quartz/quartzite rich sand and gravels. This sediment is shown by the stipple in both the upper and lower diagram. Relief forms are greatly exaggerated in order to demonstrate the location and thickness of the Quaternary sediments. Scale and orientation are given by National Grid coordinates.

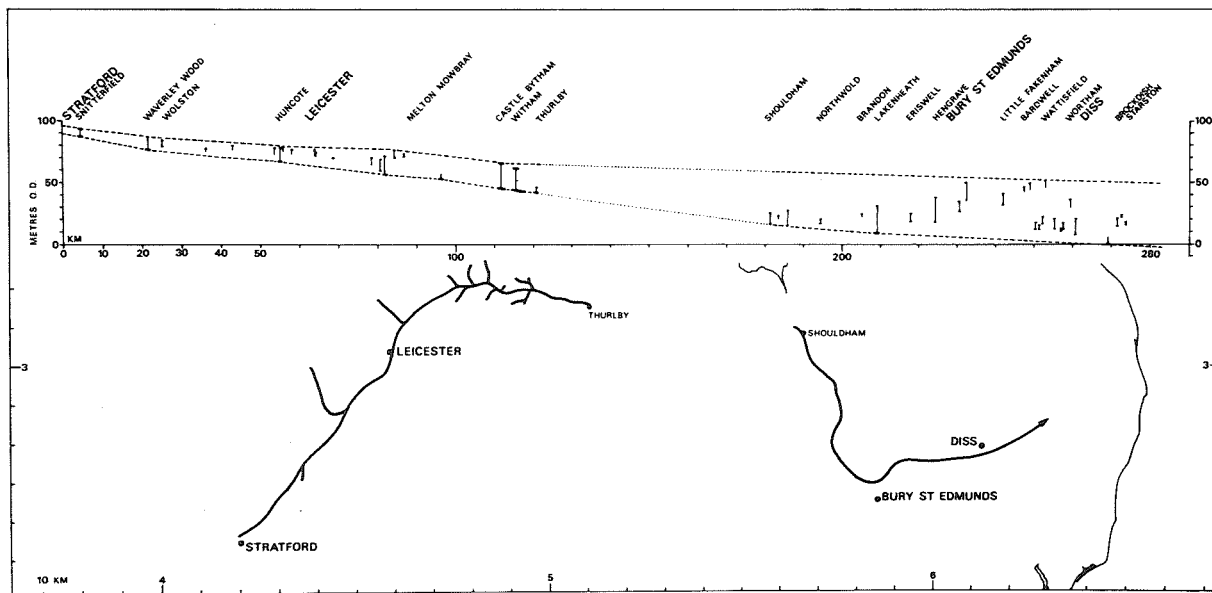


Fig. 31. Altitudinal distribution of the quartz/quartzite rich sands and gravels across midland and eastern England. The sediments are represented as an 'envelope' in which the lower boundary is the base of the buried channel, and the upper boundary is the highest elevation of the top of the sediment found within a region. The thickness of individual bodies of sediment within the envelope is shown by the vertical lines which represent measured thickness. Scale and orientation is shown by National Grid coordinates.

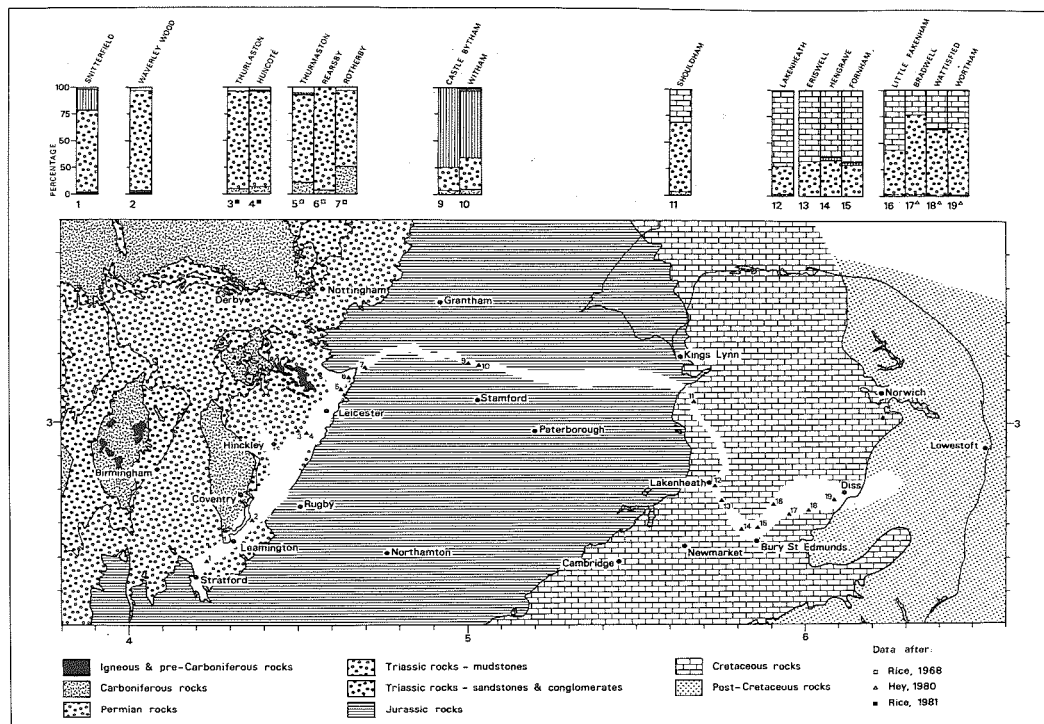


Fig. 32. Lithology of the clasts within the quartz/quartzite rich sands and gravel. The size range studied by the author is 16-32 mm. Different size ranges may be recorded in other sources of information utilised in the construction of this figure. Scale and orientation are given by National Grid coordinates.

and Gravel, at least in its western part could not have been transported through the London Basin.

- (5) Palaeocurrent measurements taken on planar cross-set structures from the fluvial deposit indicate a generally eastward flow direction, parallel with the slope and direction of the buried valley and the envelope of sediment.
- (6) Ice wedge casts and frost cracks at sites such as Huncote (S. Lewis, pers. comm.) and Witham on the Hill (Lewis, 1989) indicate that at least during part of the depositional history, the body of sediment accumulated during periglacial conditions.

Implications for the Quaternary History of Southern Britain

Putting the evidence together, as it is recorded in this paper, it is possible to reconstruct the following sequence of landscape evolution as represented diagrammatically in Figure 33. (It should be noted that important refinements have already been proposed by C.A. Whiteman and S.G. Lewis.)

- (A) A small river drains the high land of the southern Pennines and East Midlands supplying quartz/quartzite gravels to East Anglia. This river is a tributary of an early stage of the Thames which deposited the Kesgrave Formation, and was at this time supplied by an ice sheet in Wales and the West Midlands (Bowen et al, 1986).
- (B) The midland river extended its catchment size as it incised its valley. It continued to form as a tributary of the Thames which continued to deposit the Kesgrave Formation with a glacial contribution from the western uplands. There is no evidence of a glacial contribution to the midland river.
- (C) Extension of the Baginton-Lillington catchment into the West Midlands resulted in the beheading of the upper part of the Thames catchment and the erosion of the lowlands of the Middle Severn and Avon valleys, and the formation of the Cotswold escarpment. With this event the Thames acquired a relatively small catchment and the Baginton-Lillington river became dominant. The main body of the Baginton-Lillington Sands and Gravels, the Baginton Sands, and the Bytham series were deposited within this environmental framework, under cold climate conditions during the early part of the Anglian Stage.
- (D) Obstruction of the river which deposited the Baginton Sands and the Bytham sands, by the Anglian Ice Sheet. Blockage occurred in a westward direction upstream from the Wash resulting in local ice-dammed lakes in which the Lower Wolston clays and Bytham clays were deposited. This glacial event also contributed to erosion of the deposit, and in places to its complete destruction with the excavation of Fen Basin. This glacial episode was also responsible for the burial of the quartz/quartzite sand beneath glaciogenic sediments.

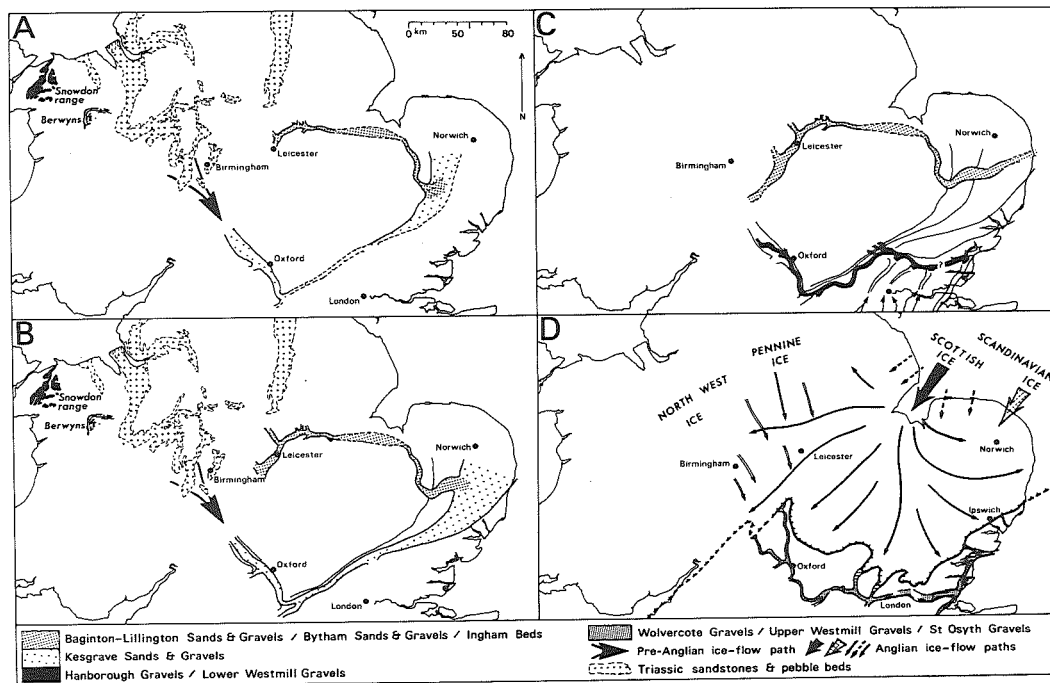


Fig. 33. A scheme for landscape evolution in southern Britain.
Details of Figures A-D are given in the text.

HUNCOTE, LEICESTERSHIRE (SK 513 982)

The sequence of deposits at this site has been described by Rice (1981) as part of a regional study of the Quaternary stratigraphy of central Leicestershire. The following description is based upon the published information of Rice (1981) supplemented by data collected during the present study of the Baginton-Lillington Gravels and Baginton Sands.

Stratigraphy

The sequence at Huncote is shown in Fig. 34. Overlying Mercia Mudstone bedrock is a unit of fluvial sands and gravels. Clast lithological analysis of the 11.2-16.0 mm size fraction (Table 7) indicates that this unit is made up predominantly of quartz (20.37%) and quartzite (48.06%) clasts derived (with trace amounts of schorl) from the Kidderminster Formation which crops out to the west of this site. Carboniferous chert, and locally derived lithologies make up the remainder of the material.

Overlying the sand and gravel is a unit of cross stratified sand predominately red in colour (2.5YR 6/4). In places coal fragments lie along bedding places. The unit is dominated by trough cross bedding with some planar cross bedding (Rice, 1981, p. 389; Fig. 34). Measurement of the orientation of planar foresets indicates flow in a northerly direction (Rice, 1981; Fig 1).

Intra-formational frost fissure structures observed and recorded from within the sand unit (Fig. 35) suggest deposition in a cold, permafrost environment with thermal contraction processes operating on parts of the flood plain.

The sand is overlain by an assemblage of glacial sediments (Fig. 34). These deposits demonstrate the stratigraphic relationship of eastern, chalky tills and northern Trias-rich tills. The initial advance of the Thrusington Till into the area was followed by deposition of chalky Oadby Till by ice advancing from the east (Rice, 1981).

Discussion

The fluvial deposits laying beneath the glacial sediments are correlated with the Baginton-Lillington Gravels and Baginton Sands of the Coventry area (Shotton, 1953; Rice, 1981). These indicate that a river system drained eastwards prior to the deposition of the main-glacial sequence of the west Midlands represented by the deposits at Wolston. This river has conventionally been regarded as the "proto-Soar" which followed a course similar to the modern River Soar into the Trent Basin (Shotton, 1983; Rice, 1968, 1981). However, the verification of this course downstream of the modern Soar-Wreake confluence remains elusive and evidence of the alternative route for the river is examined below.

S.G. Lewis

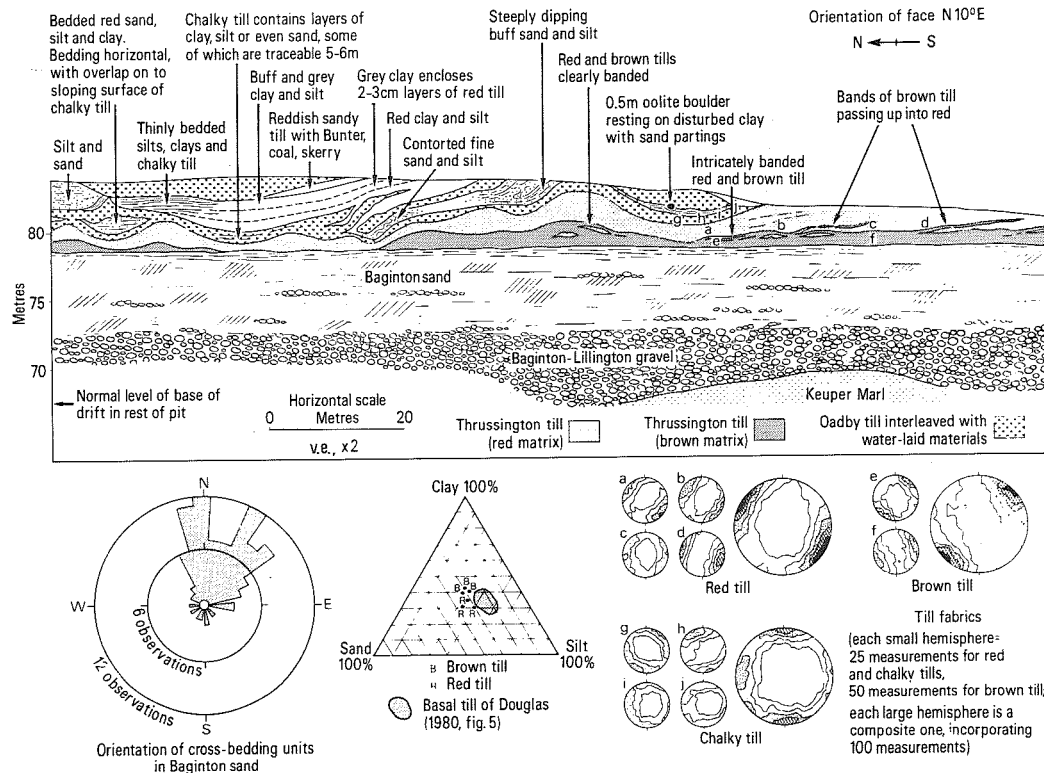


Fig. 34. Huncote; characteristic section through Baginton-Lillington Gravels, Baginton Sands and glacigenic sediments. (After Rice, 1981).

SITE	QTZ	QTZTE	SCHL	SST	CHERT	FLINT	LST	IRONST	SHELL	IG	OTHER	TOTAL
Huncote	20.37	48.06	0.43	14.35	6.60	0.00	4.66	2.51	0.72	0.86	1.87	1394
Witham 1	3.72	13.43	0.00	6.83	7.07	0.24	52.88	14.75	0.48	0.00	0.60	834
Witham 2	3.55	11.90	0.00	2.63	4.02	0.15	58.27	10.18	0.46	0.00	0.94	647
Shouldham Thorpe	10.33	51.36	1.09	0.27	8.15	15.76	0.00	11.96	0.00	0.00	1.08	368

Table 7 Clast Lithological Analysis of the 11.2-16.5 mm size Fraction
Huncote, Witham 1 and 2, Shouldham Thorpe

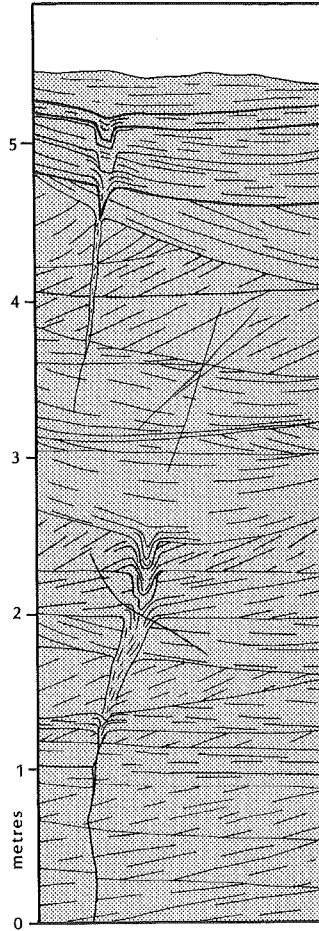


Fig. 35. Section through Baginton Sand showing periglacial frost fissure structures.

LEICESTER ROAD, MELTON MOWBRAY, LEICESTERSHIRE (SK 736 176)

Exposure on the construction site of the Leicester Road Industrial Park west of Melton Mowbray (Fig. 36a) revealed about 2 m of Pleistocene deposits in a stream section. At the base of the section are 1-1.5 m of dark brown (5YR 4/4-4/6) sands which are planar cross-stratified at the base becoming ripple laminated towards the top. Coal fragments are common along the foresets of the planar and ripple bedded facies. Palaeocurrent measurements on individual planar foresets and ripples (Fig. 36b) indicates a flow direction from west-south-west to east-north-east.

The sand is overlain by a diamict, which contains clasts of Jurassic limestone, some Triassic quartzite and quartz, and Cretaceous flint. This unit is probably a debris flow deposit, lying in the lowest part of a small valley. The lithological composition would suggest that it is derived from the till which is exposed on the valley flanks.

Discussion

The basal Pleistocene unit in the Wreake Valley is the Thurmaston Sands and Gravels which are correlated with the Baginton-Lillington Gravels and Baginton Sands (Rice, 1968). These units underlie glacial sediments of which the northern Thrusington Till and the eastern Oadby Till are most significant (Rice, 1968, 1981).

The lithological composition of clasts in the diamict overlying the sands suggests that it is derived from a unit deposited by ice rich in Jurassic and Cretaceous lithologies to the east which should be equated with the Oadby Till. In other parts of the site the sand is exposed beneath in situ Oadby Till. On the basis of its position beneath the Oadby Till, its westerly derivation, indicated by lithology and palaeocurrents and the absence of any evidence for glacial input the sand unit at this site, is most likely to be equivalent to the Baginton Sands.

The significance of the Baginton-Lillington Gravels and Baginton Sands in the Wreake Valley is the subject of some debate and the evidence in the area is equivocal. Reconstruction of the pre-main glacial relief in the Wreake Valley (Rice, 1968) does not demonstrate convincingly the course of the river, and despite the subsequent addition of more borehole data in the Wreake Valley (Engineering Geology Ltd., 1985), the control on the possible valley geometry is still poor. However, the sand unit at this site and evidence from an old sand pit near Frisby where pebbly sand was observed in the last century (Deeley, 1886, p.446) in which "the false bedding indicates currents from the west", indicates that at some time prior to glaciation of the area drainage through this locality was from west to east (opposite to the present day drainage pattern). On the basis of the geographical and altitudinal distribution of the sediment body and its palaeoflow direction, it is likely that it was deposited by the river which deposited the Baginton-Lillington Gravels and Baginton Sands, which occupied a route somewhat south of the present River Wreake and flowed eastwards towards the gap in the Jurassic escarpment (Rose, 1987).

S.G. Lewis

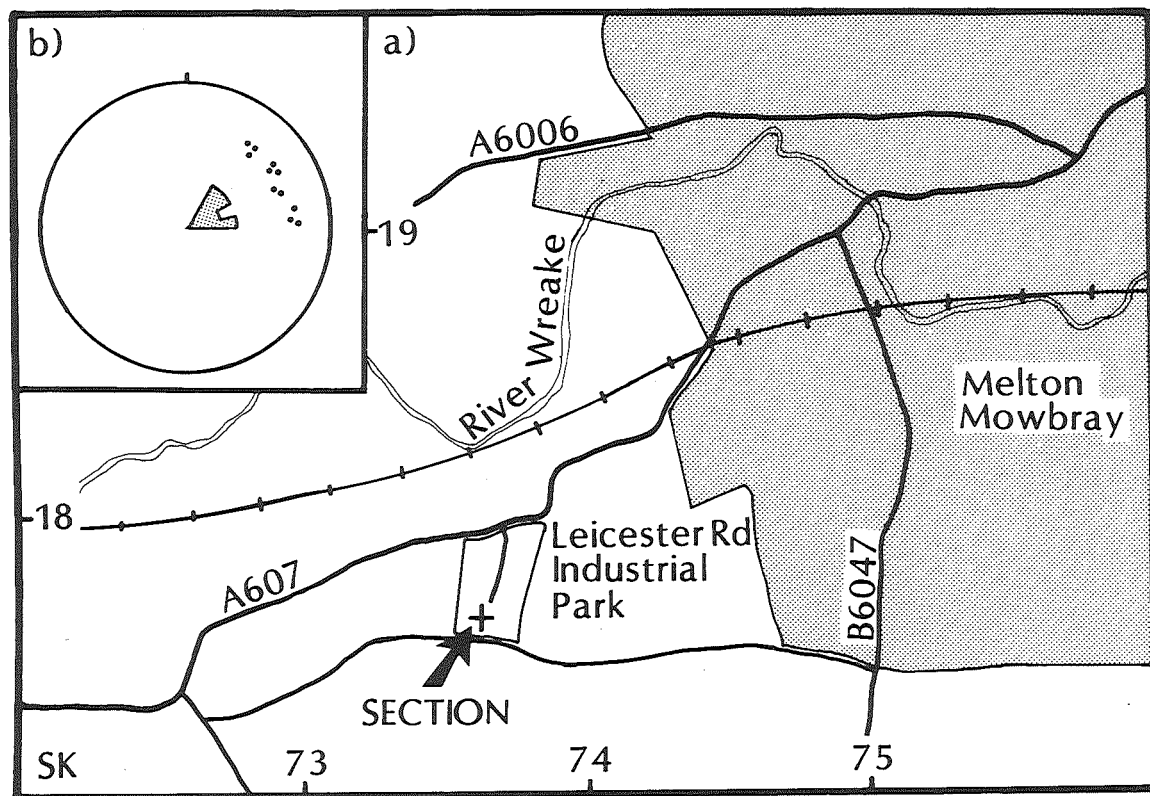


Fig. 36. Leicester Road Industrial Park: (a) Location Map (b) Palaeocurrent Diagram ($n = 11$).

CASTLE BYTHAM

Introduction

This description is based on evidence collected from the 'Thunderbolt' Pit (SK 998 184) at Castle Bytham village in south Lincolnshire, and the results of field mapping, drilling with a shell and auger rig and observations from trial pits. These results are reported with the kind permission of Bullimores Sand and Gravel Ltd. During the excursion, Thunderbolt Pit will be visited where it will be possible to examine the Bytham sands and gravels, the Bytham sands and clays, and the overlying glaciogenic sediments, and therefore demonstrate evidence for an eastward flowing river in the region prior to glaciation.

The Quaternary sediments occupy a buried valley cut into the local Jurassic limestones and ironstones, and are exposed on the sides of a small west-east trending valley that drains into the West Glen River at Little Bytham (Fig. 37). Preservation of the buried valley deposits varies from good where the present valley is offset from the present valley, to poor where the two valleys coincide and the unconsolidated sediments have been extensively removed by the present stream.

The sequence preserved within the region of Castle Bytham is as follows:

- Glaciogenic sediments (till, sands and gravels, laminated silts).
- Bytham sands and clays.
- Bytham sands and gravels.
- Pre-Quaternary bedrock forming a buried valley.

Description

Buried valley. The rockhead contours on the buried valley in the area of Castle Bytham are shown in Fig. 37. In this region it is about 0.5 km wide with an elevation at the base of about 45 m OD. In places, such as the southwest corner of the Thunderbolt pit, where the bedrock is Lincolnshire Limestone, trial pits show that the valley side is almost vertical, with a thin veneer of angular limestone talus. This landform is part of the major east-west valley recognised by Wyatt (1971) from Melton Mowbray in the east, to Thurlby in the west.

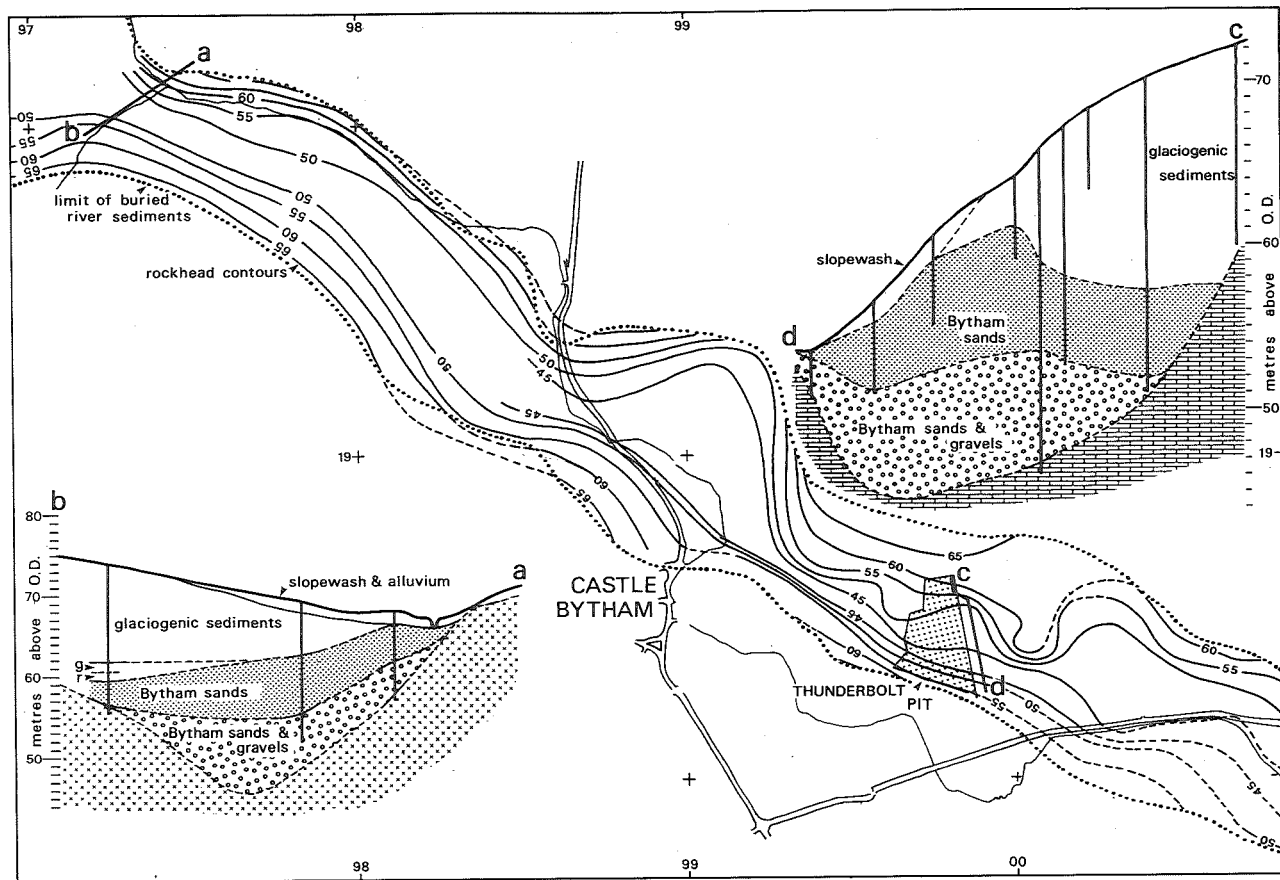
Bytham sands and gravels. These consist of interbedded gravelly sands and sands (Fig. 38) arranged as planar and trough cross bedded units. Directional measurements on planar cross-sets show a south easterly mode (Fig. 39). Stone counts from 6 sites within the area show that the bulk of the clasts are composed of the local rock (ironstone or limestone depending on decalcification), but at all sites there are appreciable quantities of far travelled materials (Table 8). These include:

Quartz and quartzite from the Kidderminster Fm (Bunter).

Chert from the Carboniferous of the Pennines and Warwickshire coalfield.

Flint, assumed to be from Quaternary sediments, having been transported into the West Midlands from the Irish Sea region by glaciation.

These sands and gravels are interpreted as having been deposited by an eastward flowing braided river that occupied the (now) buried channel.



Opposite:

Fig. 37. Form and extent of the buried valley in the area of Castle Bytham, south Lincolnshire. The map shows the extent of the buried river sediments filling the valley and the interpolated contours. The dashed lines are where the base of the channel has been exposed by subsequent erosion. Also shown are two cross sections through the buried river sediments and overlying glaciogenic deposits. Note that the vertical scales of the two cross sections differ. Bedrock in the west is ironstone, in the east it is limestone. g and r, on the western cross section relate respectively to red and grey lacustrine sediments, discussed in the text. Orientation and scale is given by 1 km National Grid coordinates.

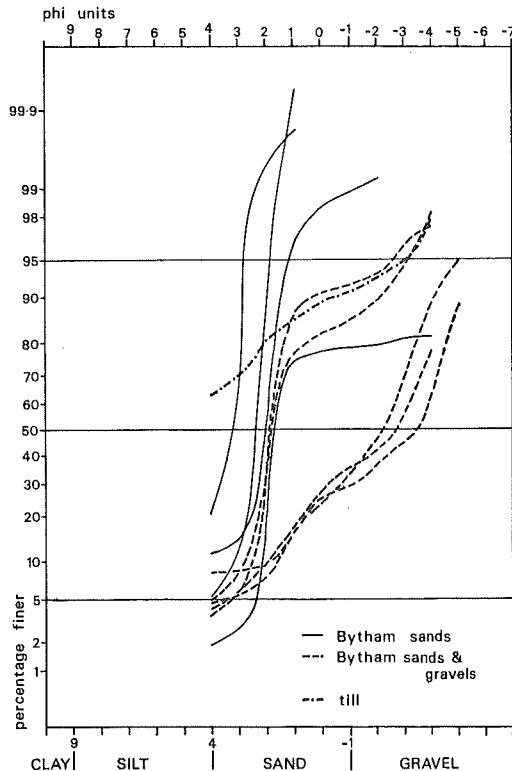


Fig. 38. Particle size distribution of the Bytham sands and gravels, the Bytham sands and the overlying till.

Sample No	Red Barn	Red Barn	Red Barn	Castle Bytham	Castle Bytham	Castle Bytham
	7/2	7/3	1/2	2/1	24	21
n	748	904	1025	790	243	205
Lithology (percentage)						
Carboniferous chert	4.6	3.2	2.9	2.9	2.1	3.4
Triassic quartzite	19.1	7.6	20.0	14.9	16.5	16.6
quartz	18.1	6.0	14.5	11.0	10.7	9.8
schorl	1.2	1.0	1.7	1.0	0.0	0.0
red & green sandstone	0.7	1.0	1.7	0.0	0.0	0.0
Total	(39.9)	(15.6)	(37.9)	(26.9)	(27.2)	(26.4)
Jurassic limestone + shells	0.0	49.7	0.0	32.9	21.4	32.7
ironstone	36.5	24.3	46.5	26.5	39.1	27.3
sandstone + mudstone	15.8	5.1	9.7	7.9	6.2	4.4
Total	(52.3)	(79.1)	(56.2)	(67.3)	(66.7)	(64.4)
Cretaceous flint	2.3	0.8	2.2	1.0	2.5	3.4
Igneous	0.1	0.2	0.2	0.0	0.4	0.5
Unknown	0.8	1.1	0.6	1.9	1.1	1.9

Table 8. Lithology of 8-16 mm fraction from the Bytham sands and gravels in the area of Castle Bytham.

Much of the sediment load was derived from local bedrock either from the valley side or local tributaries, but an appreciable proportion of gravel and sand were transported into the region from the west. Locally these sands and gravels are indurated by calcareous cement to form massive blocks.

Bytham sands and clays. The Bytham Sands represent a facies change from the underlying sands and gravels. They consist of a yellowish red (5YR 5/8) to strong brown (7.5YR 5/6) fine sand (Fig. 38), composed of well developed planar and trough cross set structures. Measurements on tabular cross sets show an easterly mode (Fig. 39). In places, particularly at the east side of Thunderbolt Pit, the sands interdigitate with dark red (2.5YR 3/6) and dark yellowish brown (10YR 4/4) silty clays forming persistent beds ranging from 0.3 to 1.7 m thick. In places these clays show lamination, but they are predominantly massive. The Bytham sands and clays are interpreted as sandy braided river sediments with localised slackwater accumulations. A palaeomagnetic determination on the clays shows that they have normal polarity.

Near Red Barns (SK 973 202) a borehole was sunk through glaciogenic sediments into Bytham Sands and Clays. At this site the dark reddish grey (5YR 4/2) laminated silty clay changed gradually into very dark grey (5YR 3/1) laminated silt which, in turn, were followed by laminated sands and silts then very dark grayish brown (10YR 3/2) till. The very dark grey laminated silt is lithologically similar to the overlying glaciogenic materials and is attributed to a glacial meltwater source. This succession is considered important as it demonstrates uninterrupted sedimentation between the silty clays laid down by the eastward flowing river and the silts derived from sediment transported by an ice sheet indicating that they were both deposited in the same period of Quaternary time.

Glaciogenic sediments. These comprise diamicton, sands and gravels and laminated silts, of which the diamicton is the most extensive and covers much of the interfluvial region. The glaciofluvial sands and gravels consist of lithologies found in both the Bytham series and the glaciogenic deposits. The diamicton is a very dark grayish brown (10YR 3/2 - 2.5Y 3/2) clayey silt with clasts of Jurassic limestone, sandstone and ironstone, Triassic quartz, quartzite and red sandstone, Cretaceous flint and Carboniferous limestone. This deposit is interpreted as a till derived from ice that flowed across the region with an ice flow path that is still far from clear as regional studies (Perrin *et al*, 1979) and microfaunal content (J. Bramley, pers. comm.) suggest an easterly source, local macro- and microfabric and structural measurements suggest a northerly source (S. Lewis, pers. comm. and 1989), and clasts of Triassic sandstone and Carboniferous limestone may indicate a more westerly provenance. Local evidence of glacial erosion and deformation is abundant. For instance, just west of the Thunderbolt Pit the Bytham Sands and sands and gravels are cut-out and the Bytham Clays are intensively sheared.

Conclusions

The Quaternary geology at, and around, Castle Bytham shows evidence of a buried valley and associated fluvial sediments formed by an eastward flowing river. A significant proportion of the river deposits were transported into the region from the west. Fluvial and slackwater sedimentation by this river were replaced without interruption by glaciolacustrine sedimentation and finally by glaciation. The till is considered to be the lateral equivalent of the Lowestoft Till of East Anglia (Perrin *et al*, 1979) and it is therefore attributed to the Anglian Glaciation (Rose, 1987, 1989). As continuous sedimentation is demonstrated between the laminated glaciolacustrine silts and the fluvial slackwater silty clays, the Bytham series of sediments are attributed also to the earliest part of the Anglian Stage.

J. Rose

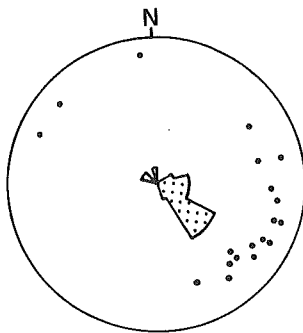


Fig. 39. Palaeocurrent measurements on the planar cross set structure in the Bytham sands and gravels and the Bytham sands.

WITHAM ON THE HILL, LINCOLNSHIRE (TF 030 177)

Introduction

Commercial extraction of sand and gravel at Witham on the Hill (Fig. 40) has exposed a sequence of fluvial sands and gravels overlain by a sequence of glacial deposits.

The site lies east of the Jurassic escarpment which forms an area of ground running north-south at +120 m in altitude. It is about 8 km west of the western margin of the low ground of the Fen basin. It occupies an interfluve position, lying on the watershed between the West and East Glen Rivers, the surface altitude at this locality is about 64 m OD.

A system of drift-filled valleys has been identified in the area (Kellaway and Taylor 1948; Rice, 1965; Wyatt, 1971), and the major valley was mapped from the vicinity of Melton Mowbray running east towards the Wash (Wyatt, 1971). The sediments at Witham on the Hill occupy this valley which is approximately 500 m wide, with the base at approximately 45 m OD in the Castle Bytham/Witham on the Hill area (J. Rose, unpubl. data). The basic stratigraphy is shown in Fig. 41.

Stratigraphy

In the pit north of the road from Little Bytham to Witham on the Hill the following succession is exposed:

- Massive Diamict
- Laminated Diamict
- Laminated Silt/Clay with Sand Lenses
- Cross-bedded Sand
- Cross-bedded Sand and Gravel
- Blisworth Limestone

Sand and Gravel

This unit consists predominantly of planar cross-bedded gravel, with subsidiary trough stratified beds (Fig. 42), and is interpreted as the result of deposition over prograding gravel bars (Miall, 1977) and vertical aggradation of sediment in channels formed by avulsion or dissection (Collinson, 1970; Williams and Rust, 1969). Palaeocurrent measurements on individual foreset units of facies Gp indicate a flow direction from the north west (Fig. 43).

Intra-formational ice wedge casts in the gravels (Fig. 42) suggest that the gravels were deposited in an environment where thermal contraction was taking place and areas of the river bed were exposed to rapid sub-aerial cooling in a permafrost environment.

Clast lithological analysis of the 11.2-16.0 mm size fraction (Table 8) indicates that the gravel is composed primarily of local Jurassic limestone (52-58%) and ironstone (14-18%). However, there is also a significant proportion of Triassic quartzite, quartz and chert (up to 30%; Table 8). The most likely source of the quartz and quartzite is the Kidderminster Formation of the west Midlands with sources of chert in the Carboniferous of the Warwickshire coalfield (Shotton, 1929; Old *et al.*, 1987), and the southern Pennines. Among the trace lithologies flint is a significant component, although in so small amounts it is unlikely to indicate input of material from the flint rich eastern ice which deposited the tills which cap the sequence (Straw, 1983). Shotton (1953, p. 214)

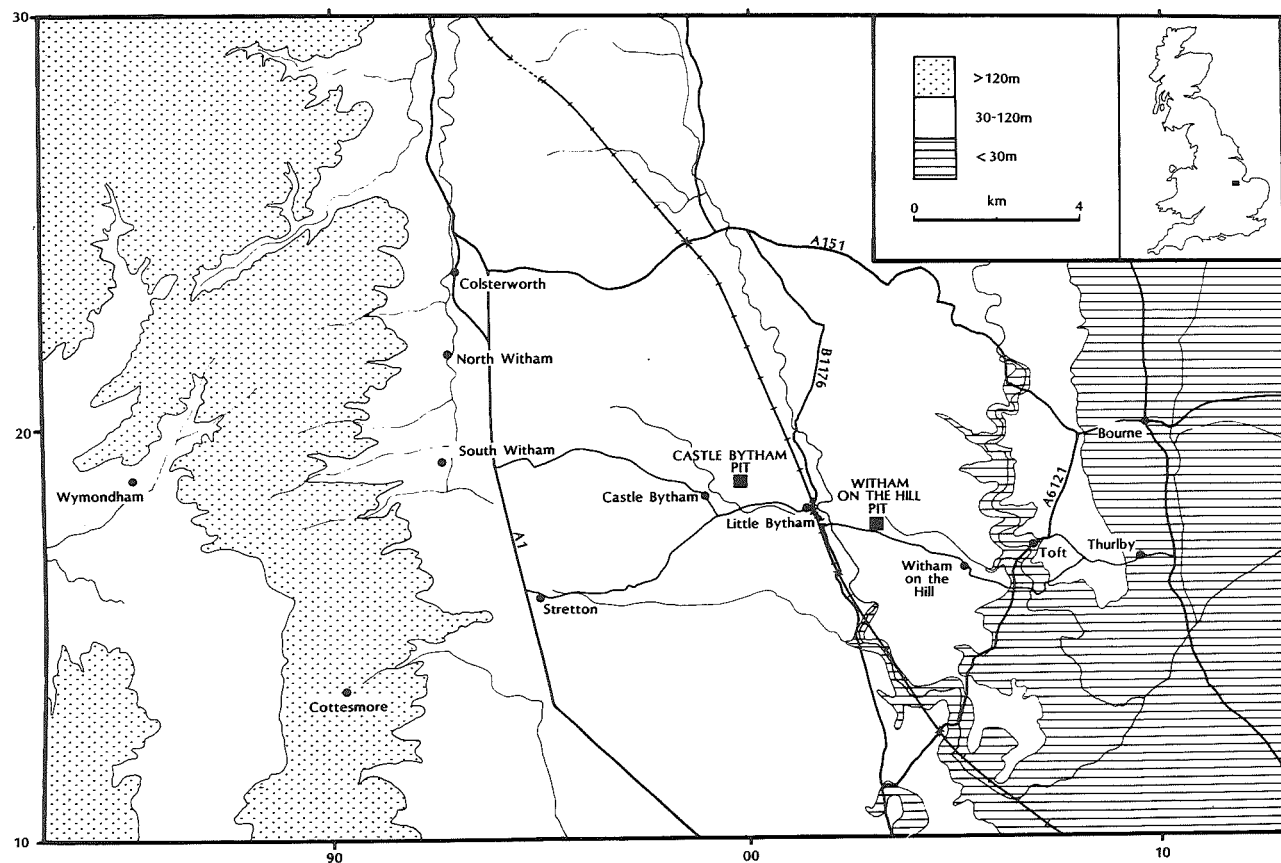


Fig. 40. Map showing main elements of relief in south Lincolnshire and location of Castle Bytham and Witham on the Hill Pits.

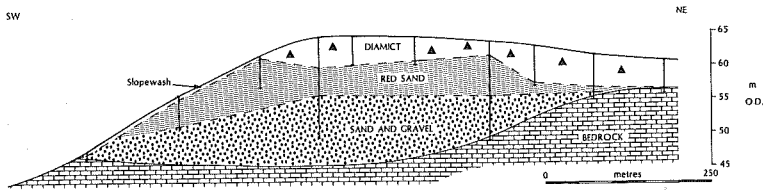


Fig. 41. Vertical cross-section through sediments exposed at Witham on the Hill Pit.

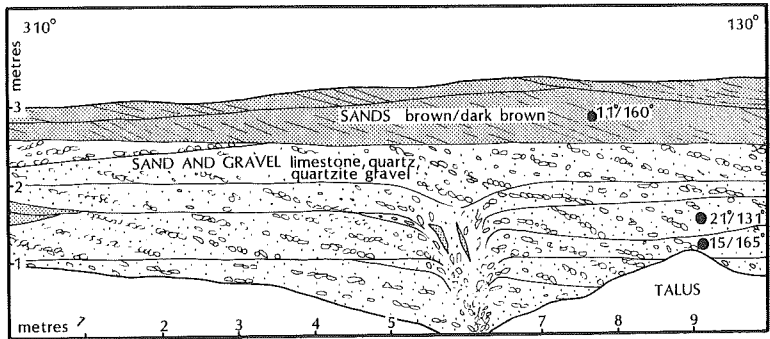


Fig. 42. Witham on the Hill. Sands and gravels and sands.

records the occurrence of flint in the Baginton-Lillington Gravels and considers it to be derived from the Irish Sea.

Sand

Overlying the sandy gravel is a sequence of trough and planar cross-stratified sands. The sand is brown to strong brown in colour (7.5YR 4/4-4/6). Gravel lithofacies are rare, though thin gravel layers often occur as lag deposits associated with channelled erosion surfaces. This unit represents a transition to a sand-dominated system in which formation and migration of dune bedforms is the main process of deposition, with Facies Sp representing subsidiary development of lingoid bar forms (Miall, 1977). Palaeocurrent measurements on facies Sp again indicates flow from the north west (Fig. 43).

A fossiliferous horizon was identified within the sand and gravel during a borehole survey of the area (J. Rose, unpubl. data). From the borehole alone it is difficult to establish the three dimensional geometry of the organic horizon, however it occurs between the sand and gravel and cross-bedded sand.

The sample was submitted to Dr. P. Gibbard and S.M. Peglar (Cambridge University) for palynological analysis. Preliminary results are discussed below (pp. 132-134).

Laminated Silt/Clay with Sand Lenses

Overlying the cross-bedded sands is a thin diamict layer above an erosional contact (Fig. 44). The base of this unit probably acted as a plane of decollement, along which movement of the overlying sediments occurred as they were sheared and folded over the undisturbed cross-bedded sands. The silt/clay unit itself has been sheared and folded to give a laminated appearance. The laminae range in colour from dark reddish brown (5YR 3/4) to brown (7.5YR 4/4). It is suggested that these silt/clay sediments were initially the result of deposition in a very low energy environment on the river floodplain. Interlaminated with the red/brown sediments are layers of olive (5YR 4/3) diamict with clasts of quartzite, limestone and flint. The diamict layers are interpreted as the result of shearing in of allochthonous sediments from the base of the glacier.

The laminated silt/clay in places separates into two (Fig. 44) and the upper layer rises steeply through the overlying sand to merge with the laminated diamict which overlies the lenses of deformed sands.

The lenses of red/brown sands, overlying the laminated silt/clay are similar in appearance to the cross-bedded sands lower in the sequence. The bedding is not typical of fluvial deposition and the structures can be interpreted as the results of deformation of the sediments and internal shearing to produce "foliations". A large compressive fold structure with associated faulting in this unit was also observed and recorded (Fig. 45). The structures in this unit and its relation to the underlying units suggest that fluvial sand, deposited at this locality before ice occupied the area was deformed by the imposition of stress by glacier ice.

Laminated diamict

Overlying the glacially deformed sand is a laminated diamict of fine-grained sediments with clasts of quartzite, limestone and a few flints. It is characterised by highly attenuated folds giving the appearance of laminations. The colour of each lamination ranges from yellowish red (5YR 4/6) to strong brown (7.5YR 4/6). The different colour

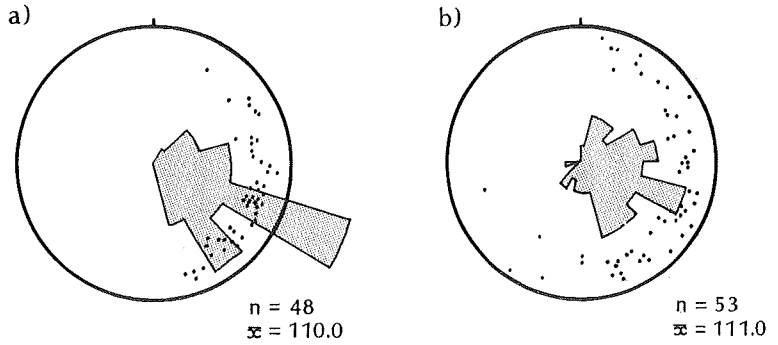


Fig. 43. Witham on the Hill palaeocurrent diagrams.

(a) Sand and gravel (b) Sand.

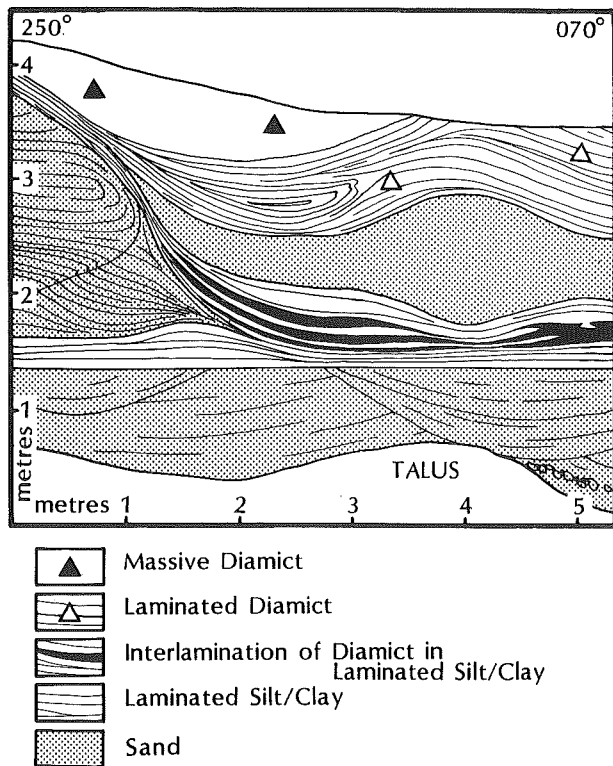


Fig. 44. Witham on the Hill. Cross bedded sands and glaciogenic sediments.

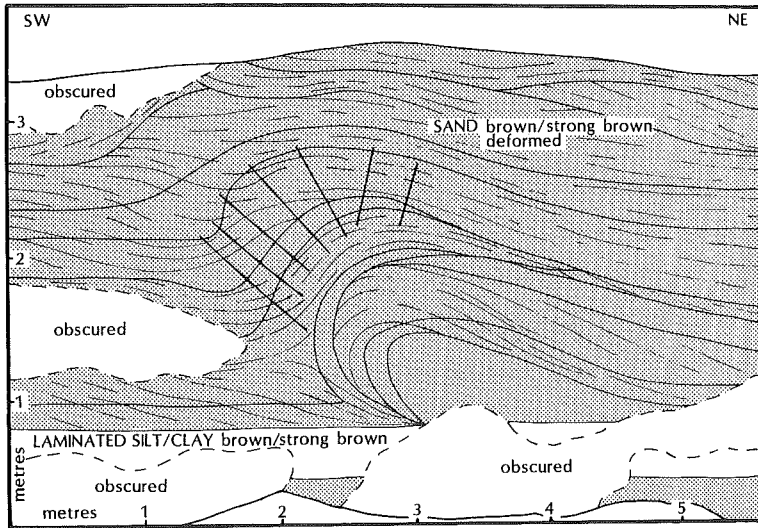


Fig. 45. Witham on the Hill. Large scale deformation structure.

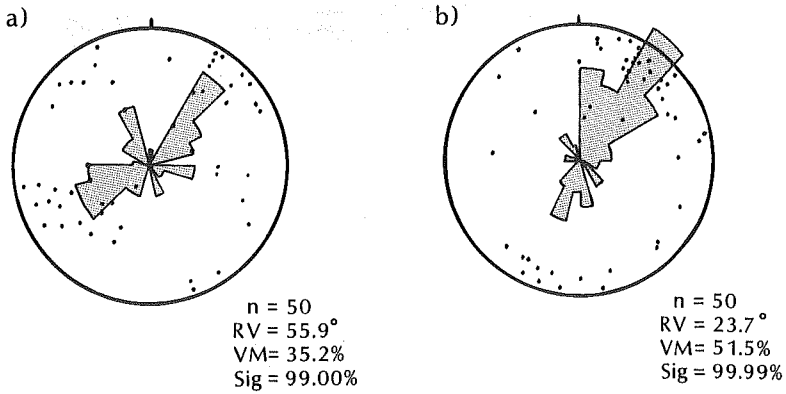


Fig. 46. Witham on the Hill. Massive Diamict; macrofabric diagrams.

probably reflects derivation of the material from the underlying sands and gravels and red clays and from more distant sources eroded from Jurassic clays and Cretaceous chalk and transported to the area by glacier ice.

Measurement of the orientation of both the small scale fold structures in the laminated diamict and the orientation of the folded contact between the glacially deformed sands and the laminated diamict indicates a stress direction in a north-south plane.

The assemblage of structures in the glacially deformed sands and the laminated diamict suggests that the passage of ice over this area from north to south caused major large scale deformation of the unconsolidated sediments. This may be related to different subglacial drainage conditions on the limestone plateau to the north and the fluvial sand and gravel at the site, and the susceptibility of unconsolidated sediments to deformation.

Deformation also occurred at a smaller scale to produce the attenuated folds in the laminated diamict. This is thought to be the result of variations in the rate of deformation of a heterogeneous sediment in response to applied shear-stress (Boulton, 1987).

Massive diamict

A unit of massive, dark olive grey diamict (5Y 3/2) caps the sequence. Its sedimentology and macrofabric characteristics suggest that the unit should conventionally be regarded as a lodgement till, however its close association with sediments which are the results of glacial deformation may suggest that processes other than lodgement were involved in its formation. The fabrics (Fig. 46) indicate a NE-SW local stress direction which agrees with the general north-south stress direction indicated by structures in the underlying laminated diamicts.

Discussion

The sequence of deposits at Witham on the Hill suggest that a river flowing from west to east occupied the channel in the Jurassic bedrock, depositing a sequence of sands and gravels fining upwards into cross bedded sands (Fig. 41). This channel has been traced west to the vicinity of Melton Mowbray (Kellaway and Taylor, 1948; Rice, 1965; Wyatt, 1971), but lack of data in critical areas around Melton Mowbray has prevented confident reconstruction of the drainage pattern further west.

Consideration of the lithological and sedimentological characteristics of the deposits at Witham on the Hill allows some stratigraphic context of these deposits to be established. The significant proportion of lithologies derived from west of the Jurassic escarpment and the well defined facies change from gravel- to sand-dominated sedimentation, in conjunction with the known altitudinal distribution of the sediment body in the Castle Bytham/Witham on the Hill area (Rose, 1987; this volume pp. 117-123) suggests that the deposits represent deposition in the same river system as the Baginton-Lillington Gravels and Baginton Sands. The presence of a channel traceable westwards to Melton Mowbray and the similar sedimentological and lithological properties of the Baginton-Lillington Gravels and Baginton Sands in the Wreake Valley (eg Leicester Road Industrial Park) provides strong evidence for the existence of an easterly flowing river from the west Midlands through the Wreake Valley area into south Lincolnshire at some time prior to glaciation of the area.

Glacial activity in the area resulted in deformation of the upper part of the sands and the formation of a sequence of laminated diamicts, continued glacial deposition in a high shear stress environment produced a massive diamict. Flow direction was north-east to south-west. Perrin et al (1979) considered these tills to be the lateral equivalent of the Anglian Lowestoft Till.

S.G. Lewis

PALYNOLOGY OF THE FOSSILIFEROUS DEPOSITS AT WITHAM-ON-THE-HILL,
LINCOLNSHIRE

Palynological investigations were carried out on samples from a 112 cm long section of borehole supplied by S. Lewis and J. Rose (Birkbeck College, London).

The sediments rest on 30 cm of limestone gravel. The matrix of the upper few cms of the gravel comprises the lowermost fossiliferous sediment, a yellow-grey silty sand. This grades upwards at 10 cm (above the base) into a light grey sandy silt, that becomes very sand-rich in the upper 10-13 cm of the profile.

Pollen analysis

The results of the palynological analyses are shown in Fig 47.

All the spectra obtained from this sequence can be assigned to a single Pinus-Picea pollen assemblage biozone (p.a.b.).

The pollen of coniferous trees dominates this assemblage. That of Pinus is the most abundant, as throughout most of the diagram frequencies of this taxon reach 25-30%. However, in the upper and lowermost samples frequencies rise to over 50% total land pollen and spores. This phenomenon may either be an artefact of increased contemporary sedimentary sorting at these levels from the sandier sediments, or possibly the effects of differential destruction of grains of other taxa by oxidation resulting from ground water migration. That sorting may be the explanation is suggested by the parallel rise of the morphologically similar bisaccate Picea pollen. The latter is present throughout at relatively high frequencies. This strongly suggests that spruce trees were growing in the immediate area. Of the remaining tree pollen recovered only Alnus and Betula were found in sufficient enough numbers to indicate that they grew locally.

The presence of dry ground grass meadows with a variety of herbs is indicated, together with a damp ground community, possibly adjacent to the water body. The possible occurrence of Alder carr in the vicinity may be reflected by the curve for undifferentiated filicales (fern) spores which parallels that for Alnus throughout. Acid heath soils were also present locally to judge from the records of Ericales pollen and Pteridium, Sphagnum and Lycopodium annotinum type spores.

On the basis of the indeterminate pollen and pre-Pleistocene palynomorph spectra, a background inwash of locally eroded material occurred throughout the period represented. Moreover, a marked increase, particularly in the pre-Pleistocene component, in the upper half of the sequence is accompanied by a gradual increase in the coarsening of the sediments. Whether this phenomenon reflects a climatic deterioration that gave rise to a retreat of the local vegetation or a change in local stream flow patterns cannot be stated with certainty.

To summarise, the vegetation represented by this assemblage is regional boreal forest, comparable with that growing today in central Fennoscandia. The local river floodplain and adjacent ground supported a range of damp and dry ground herb-dominated communities. Acid heath was present nearby. No significant vegetational change is recorded in the assemblage.

WITHAM - ON - THE - HILL

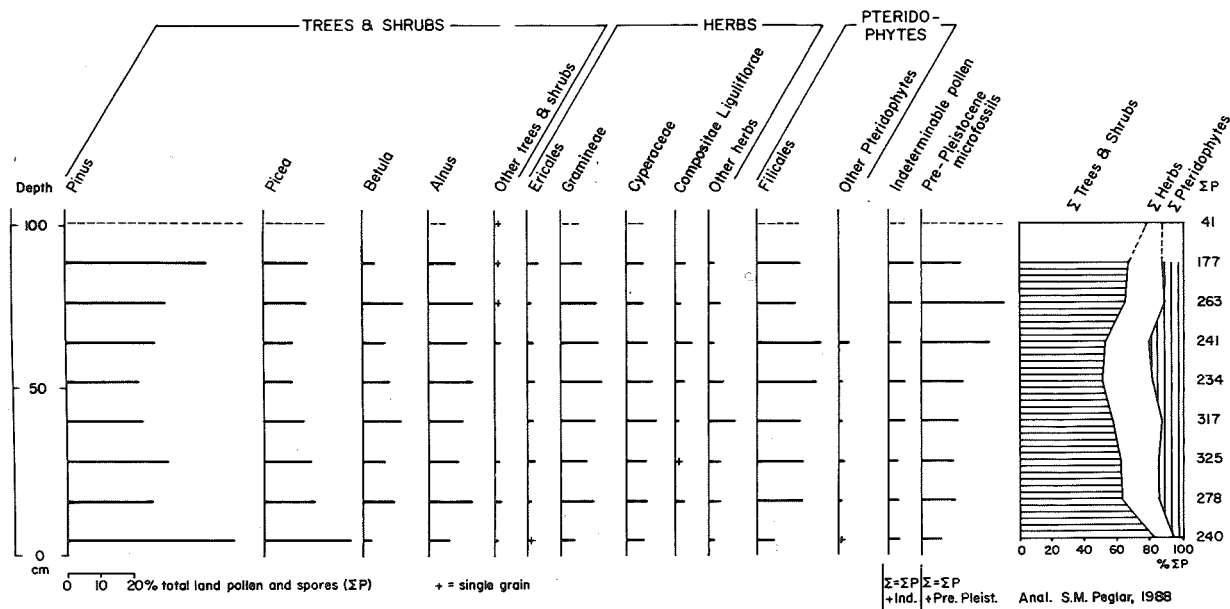


Fig. 47. Pollen spectra from Witham on the Hill.

Stratigraphical significance of the sequence

This sequence contains no evidence of biostratigraphical significance. As previously noted above (Gibbard & Peglar pp. 23-25), boreal forest floras occur frequently in the Middle and Upper Pleistocene of southern England. Indeed they are present both at the beginning and the end of temperate stages and in forested interstadial events (West, 1980). Little can therefore be said about the age of the sequence.

Nevertheless, the similarity of this sequence to those from Waverley Wood and Brandon A (see pp. 23-25) is striking. If in the future, the sequences are all shown to be associated with the same sediment members, then the finds of organic deposits of approximately the same age would imply a uniformity of events in this depositional system across the whole of central England.

P.L. Gibbard
S.M. Peglar

SHOULDHAM THORPE, NORFOLK (TF 657 085)

Introduction

The site is located on the eastern side of the main A134, Thetford to Kings Lynn road to the west of the village of Shouldham Thorpe (Fig. 47a). It lies approximately 4 km east of the eastern margin of the low-lying Fen basin. The original 1" Geological Survey (Whitaker, *et al*, 1893) mapped the deposits as glacial sand and gravel, the only reference to the site being a note from Reid; "a quarter of a mile S of Fodderstone Gap, a thickness of 20 feet of sandy gravel was seen in a pit" (Whitaker *et al*, 1893, p. 73).

Stratigraphy

Cross-bedded Sand	5-6 m
Massive/Bedded Sand and Gravel	> 1 m

The lower sand and gravel is made up of massive or crudely horizontally bedded sandy gravel, in places displaying an open framework structure. Clast lithological analysis of the 11.2-16.0 mm size fraction (Table 8) indicates that the gravel is composed primarily of quartzose lithologies (61.69%) derived from sources west of the Wash. Quartzite and quartz clasts from the Triassic Kidderminster Formation and chert (8.10%) from the Carboniferous outcrops of the Warwickshire coalfield and/or the southern Pennines. Local ironstone (12.29%) also forms a significant proportion of the lithologies represented.

Overlying the lower sand and gravel is a sequence of yellowish brown (10YR 5/8) cross-bedded sands. Palaeocurrent measurements on individual planar foresets within this unit (Fig. 47b), suggest a flow direction from the north-west. Within this unit fine grained facies of yellowish red (5YR 4/6) clay were also observed.

Discussion

The lower sand and gravel indicates that initially a gravel-dominated river crossed this area, transporting substantial quantities of Triassic and Carboniferous material. The lithological composition of this unit and palaeocurrent measurements from the overlying cross-bedded sand suggest that the river was flowing from the north-west to south-east, across the area now occupied by the Fen basin, and into north-west Norfolk. The cross-bedded sands suggest a transition to sand-dominated sedimentation.

On the basis of the succession of gravels containing significant quantities of quartzite and quartz, overlain by cross-bedded sands the sediments at Shouldham Thorpe are thought to be the easterly continuation of the sands and gravels which underlie till at Witham on the Hill and Castle Bytham, which have in turn been correlated with the Baginton Sands and Gravels of the West Midlands (Rose, 1987). During the present study of quartzose gravels in the Midlands and East Anglia possible downstream equivalents of the Baginton Sands and Gravels have not (to date) been identified east of Shouldham Thorpe, although Rose (1987) correlated these gravels with the Ingham Sands and Gravels (Clarke and Auton, 1982) which are quartz/quartzite-rich gravels in southern Norfolk and northern Suffolk. The altitudinal distribution of the Ingham Sands and Gravels and their relationship to the Kesgrave Sands and Gravels suggests that the Baginton-Lillington Gravels and their proposed downstream equivalents at Castle Bytham, Witham on the Hill and Shouldham Thorpe may represent a later, possibly unrelated river system to that which deposited the Ingham Sands and Gravels.

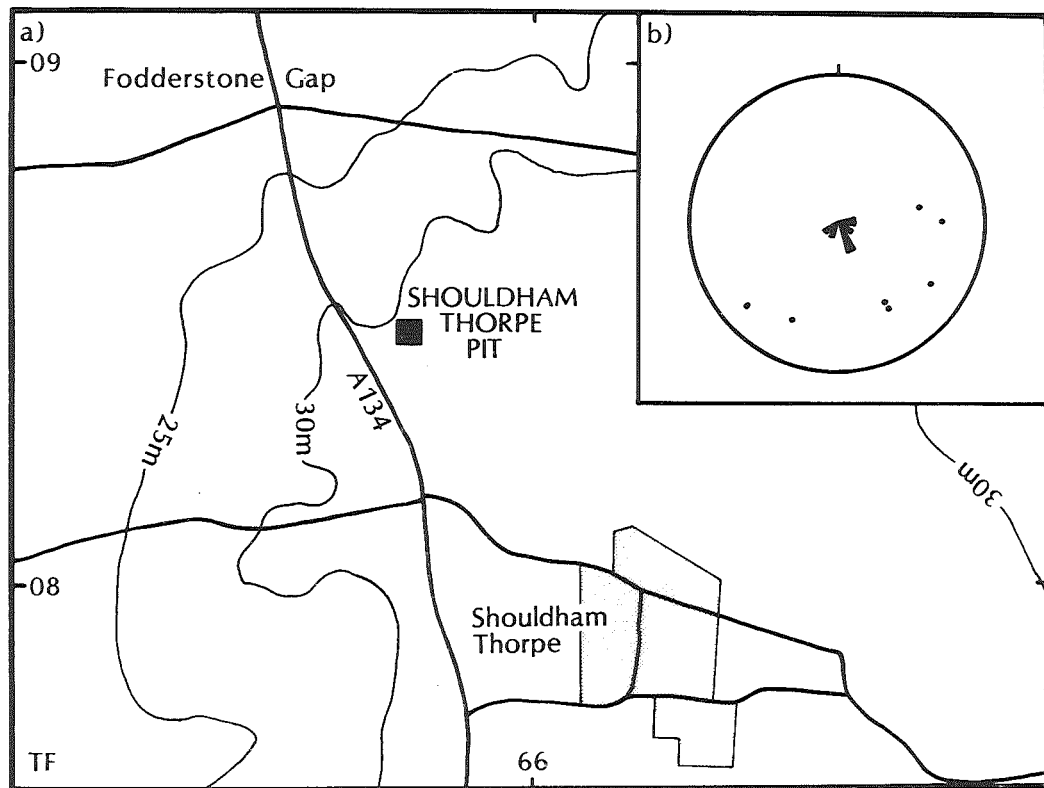


Fig. 48. Shouldham Thorpe:

(a) Location Map

(b) Paleocurrent Diagram (n = 7).

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