QUATERNARY ENVIRONMENTAL CHANGES IN THE FLUVIAL AND FAUNAL HISTORY OF CENTRAL NORTHAMPTONSHIRE.

Thesis submitted for the degree of
Doctor of Philosophy
at the University of Leicester

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In recognition of his early insight into the development of
the Northamptonshire landscape

this thesis is dedicated to

Beeby Thompson F.C.S., F.G.S.

Postscript: The river system of Northamptonshire (1930b).

"Since It Is likely that this is the last paper I shall be able to write and publish in this journal on the River System of Northamptonshire, the following skeleton notes are added.

A general idea of what further would be said about River Gravels and their contents may be found in the article "Geology" in Vol. 1 of the Victoria History of the Counties of England, Northamptonshire, pp 28-31. A few points that I would have liked to further elaborate with examples are mentioned below.

1. So far as present evidence goes, confirmed by excavations for wells and foundations of buildings and recent extensive dredging of gravel below river level at Little Billing:- No palaeolithic implements or remains of mammoth, etc., occur in gravels below present stream level, showing these particular gravels to have been deposited previous to the mid-glacial period.

2. At Northampton (the Cow Meadow) tusks and teeth of the mammoth (and palaeoliths rarely) appear to occur above, but not much above ordinary stream level, on the valley margin. Farther down the Nene Valley, say at Higham Ferrers and other places, equivalent deposits occur at higher levels relative to that of the present stream.

3. The wash-out of an inter-glacial gravel with removal of everything down to the underlying earlier gravel in central parts of the Nene Valley, but with residues left on the flood margins, seems to fit the case best.

4. In Northamptonshire the earliest evidences of man are decidedly interglacial."

Mr. Beeby Thompson's Geological collection was purchased by the Northampton Museum Committee in 1922. The collection is housed at the Central Museum, Northampton.

The manuscript collection was purchased by the Northampton Public Libraries Committee in 1932 and is housed in the Local Room at the Central Library, Northampton.

QUATERNARY ENVIRONMENTAL CHANGES IN THE FLUVIAL AND FAUNAL HISTORY OF CENTRAL NORTHAMPTONSHIRE.

KATHLEEN ANN SMITH

ABSTRACT.

This dissertation is an analysis of the Quaternary fluvial history of central Northamptonshire. It uses new freshwater ostracod data which are interpreted using information on Quaternary and present day habitats and examines in detail associated patterns of environmental change in coarse sediments from which the ostracods were extracted.

Stratigraphic, lithological and sedimentological data, supported by a study of geological maps, borehole logs and papers, are employed to produce a new hypothesis to explain the Quaternary development of the Milton River and the River Nene.

The alignment of the Milton Formation Valley is established to have proceeded to the east of, but parallel with, the Nene Valley between Northampton and Higham Ferrers, where it turned to the south-east. It comprises locally derived deposits which are shown to be pre-Anglian Glaciation and, at the time of the deposition of the ostracods studied here, an interglacial environment prevailed. However, during a "cooling phase", Milton Formation sediments were incised and the channel became partially infilled with fossiliferous boreal sediments. Further sedimentation continued to produce a non-fossiliferous, periglacial sand, which is typical of the Milton Formation. It is argued that this period of deposition was followed by two glacial episodes, the latter relating to the Lowestoft Formation.

Stratigraphic, sedimentological and lithological evidence from the Nene valley shows vestigial terrace gravels exist between Northampton and Wellingborough. The oldest gravels of these features pre-date the Anglian age, sub-glacial "tunnel valley" at Northampton, implying the Nene Valley existed prior to glaciation. Before glaciation it is suggested that the Milton River became confluent with the Nene at Northampton and, concurrently, diverted to the north-east at Higham Ferrers. This is believed to be associated with the simultaneous abandonment of the Milton Valley to the south-east of Higham Ferrers and the upstream stretch at Northampton.

Evidence presented of downcutting, lateral migration, gravel reworking and changes in the ostracod assemblages in the Nene Valley confirm a history of several climatic oscillations which took place in the pre-Devensian, Devensian and Holocene. These oscillations are tentatively correlated with stages of deposition in the Nene established downstream at Peterborough.

This revised fluvial history elaborates the course and age of the Milton River and establishes a pre-Devensian age for much of the Nene Valley sediment. The significance of this new understanding of the upper Nene Valley has been compared with that of the lower Nene Valley at Peterborough, Cambridgeshire. The combined evidence is used to produce a pattern of river development within the Quaternary which may be used as a model when reconstructing the palaeogeography of other rivers and their floodplains by means of their sedimentary structures and related fossils. This idea is explored to a small extent in the thesis, but is more applicable to future work.

The new ostracod data throws new light on previous studies from other sites in England. Ostracod species new to the Pleistocene record are to be added to a worldwide data base.

QUATERNARY ENVIRONMENTAL CHANGES IN THE FLUVIAL AND FAUNAL HISTORY OF CENTRAL NORTHAMPTONSHIRE.

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CHAPTER 1. THE LOCATION, GEOLOGY AND TOPOGRAPHY OF THE STUDY AREA AND AIMS OF PRESENT RESEARCH.

1.01.1 Introduction.

The Quaternary history of Northamptonshire is not well understood due to limited and unco-ordinated coverage. Consequently a coherent history of Quaternary landscape change within the county is lacking. This study presents a fuller picture than hitherto, co-ordinating previous work and drawing fresh conclusions from that work, as well as advancing the body of knowledge by a considerable input of new field and laboratory work.

It stresses particularly the uniqueness of the Quaternary fluvial history of Northamptonshire. It investigates the importance of the pre-glacial Milton palaeoriver and the effects that the following erosive and depositional glacial episodes had upon it. It also examines evidence of other preglacial buried valleys, which may have drained the landscape as consequent streams flowing from the north-west to the south-east of the county. It concludes with an investigation of the Nene Valley Sands and Gravels within the confines of the modern Nene Valley.

The history of the two sequences of deposits is demonstrated, through their stratigraphy, sedimentology, lithology and Quaternary fossils, to be more intimately linked than thought possible in the past.

The fresh evidence offers an alternative interpretation for the fluvial history of central Northamptonshire.

In central Northamptonshire the preglacial, glacial and post-glacial valleys are infilled by one or more of the following four distinct lithological units: the pre-glacial Milton Formation, two tills, and the post-Anglian glacial Nene Valley deposits. The age of the deposits and the direction in which the rivers flowed have long been a source of debate

(Thompson, 1902, 1930a, 1930b; Castleden, 1976, 1980a, 1980b; Perrin, Rose, and Davies, 1979).

As for the modern drainage of Northamptonshire, it is best described by Beeby Thompson, to whom this work is dedicated: "*the north-westerly side of Northamptonshire is mainly bounded by streams at the base of short-slope hills, or escarpments, so that the 'water divide' is in the county, whereas on the south-easterly side of Northamptonshire the 'divide' itself is mainly the (county) boundary, with the short slope into the Nene river and the long slope to the Ouse.*" (Thompson, 1930a).

Faunal evidence from the local Quaternary deposits shows that, in common with large parts of Britain, species such as elephant, bovids, rhinoceros, hippopotamus, and deer once lived in this county. Many of these species are now extinct, and this is the same for much of the smaller fauna, such as some species of beetles, molluscs and ostracods.

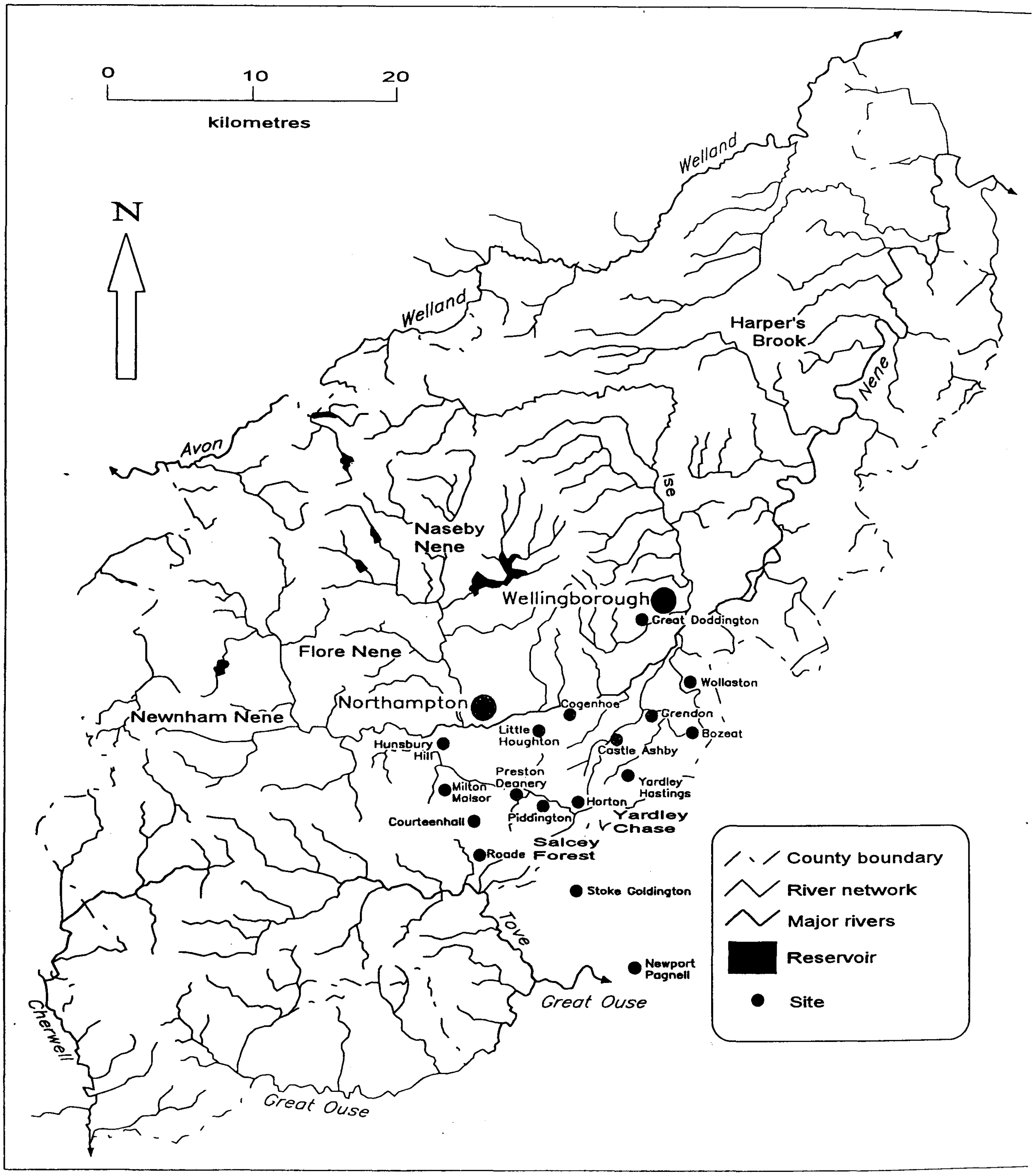
From the smaller fauna, ostracods, which have only recently been recovered for the first time from sites in both the Milton Formation and the Nene Valley Gravels of Central Northamptonshire (Figure 1.01.1), will be utilized in this research. However, as suitable models of present and Quaternary ostracod environments (Figure 1.01.2) are few, descriptions of freshwater ostracods, their modern day environmental requirements and their position in Quaternary fossiliferous sediments have been developed (Chapter 5).

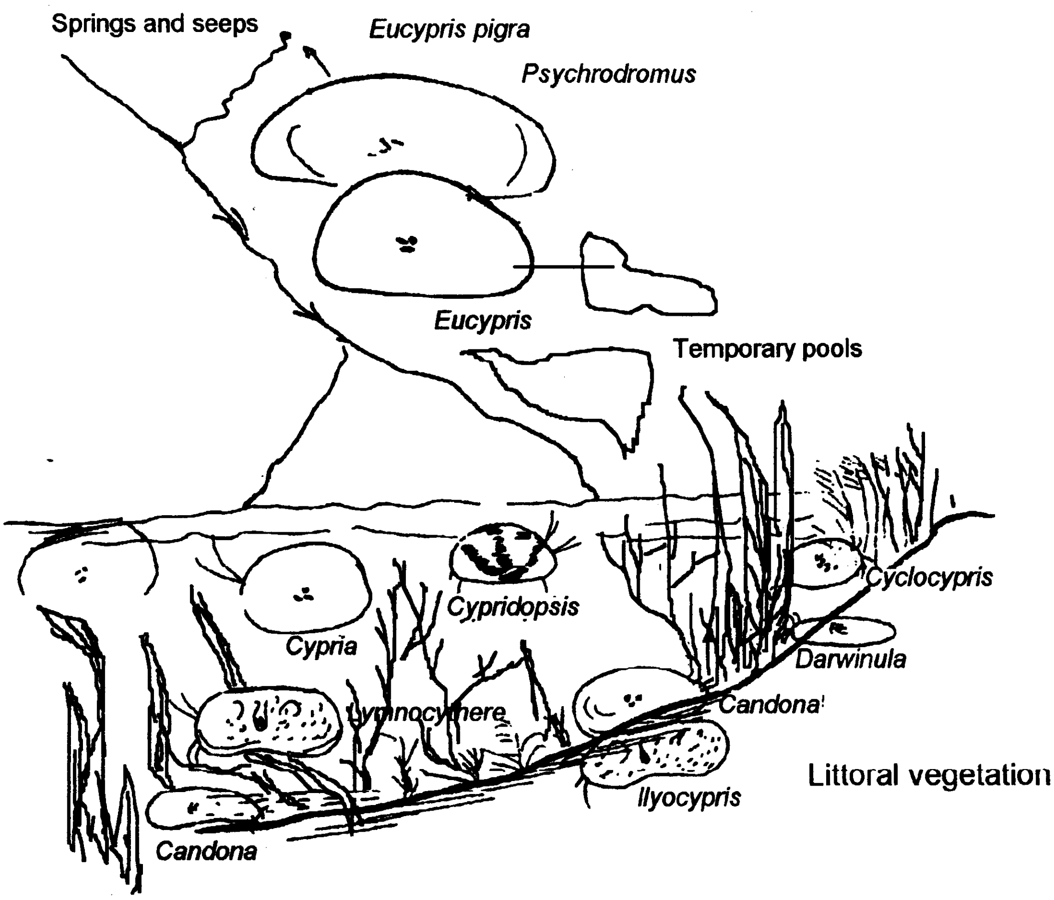
Most ostracod studies have been conducted on specimens from sediments of still-water ponds and lakes; only a few, as will be seen in the literature review, have been carried out in the coarse sediments of braided streams and rivers (Figure 1.01.3). It is anticipated, from the study of ostracods from the coarse palaeoenvironments of the Milton Formation and Nene Valley Gravels, that the value of ostracods for palaeoenvironmental reconstruction will be enhanced.

1.01.2 Specific aims of research.

This thesis is concerned with the evidence of Quaternary environmental and faunal change as demonstrated by the stratigraphical, lithological, sedimentological and faunal (in particular, that of ostracods) information obtained from the glacial and fluvial sediments of

Figure 1.01.1 Location map of the rivers and sites referred to in Chapter 1.





A. FREE SWIMMERS
Littoral area of water-body.

Cypria
Cypridopsis
Notodromus
Cyclocypris/ Pptamocypris

B. BENTHIC SPECIES
(surface of vegetation,
mud and stones,
occasional and permanent
burrowing species.)

Herpetocypris
Candona spp.
Ilyocypris spp.
Limnocythere spp.
Darwinula
Candona spp.

Figure 1.01.2. Distribution of the main groups of freshwater ostracods in Britain (after Griffiths, Horne and Robinson, pers. comms.).

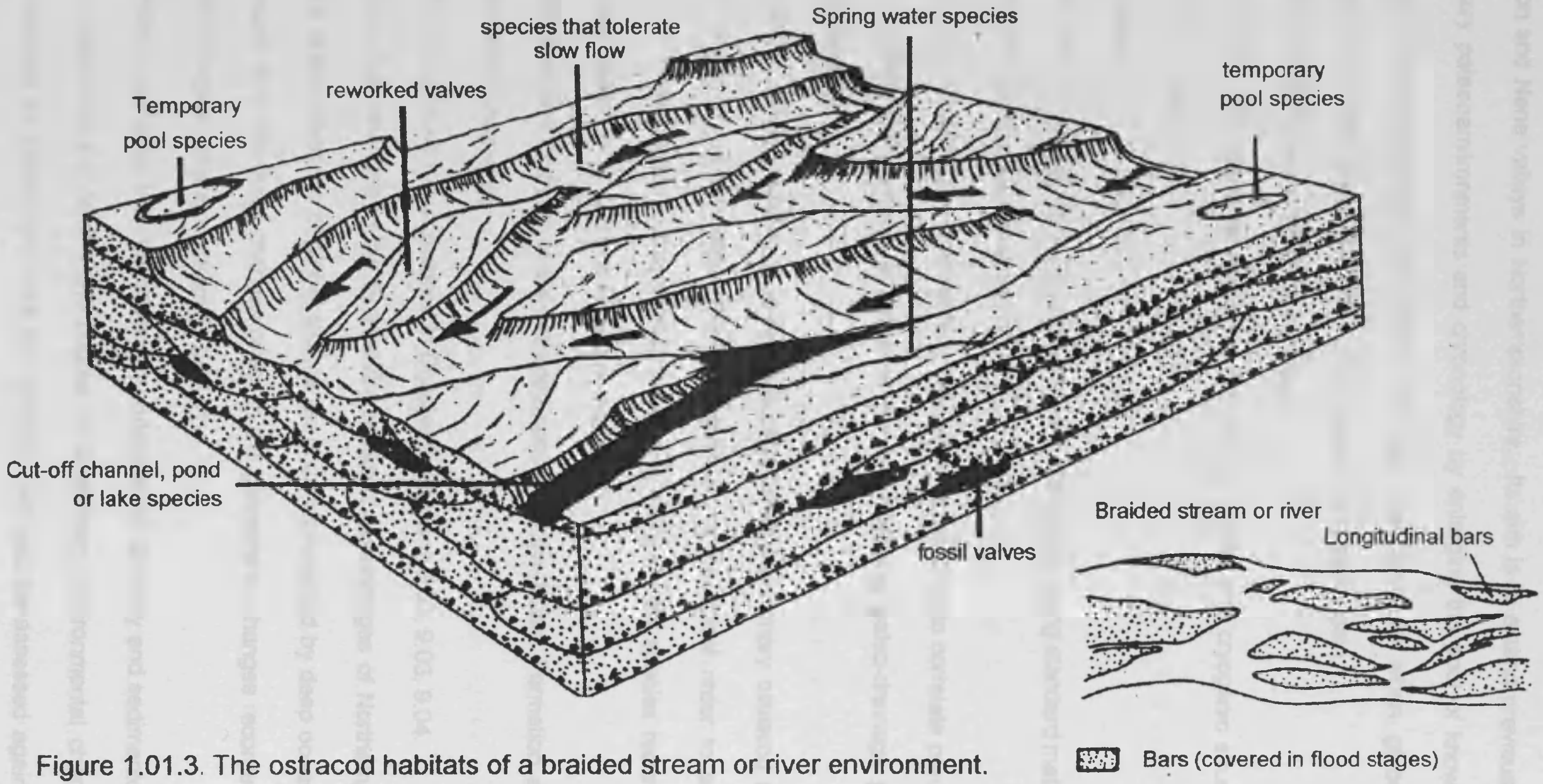


Figure 1.01.3. The ostracod habitats of a braided stream or river environment.

(After Selby (1985): modified to include ostracod habitats synthesised from data in Chapter 5).

the Milton and Nene valleys in Northamptonshire. Its aim is to extend previous studies of Quaternary palaeoenvironments and chronology by enlarging the pool of knowledge now available on environmental and faunal changes that occurred when global climatic temperatures changed from temperate to extreme cold and back again.

This aim will be achieved in the following ways.

A) Establishing a stratigraphic sequence from fluvial, glacial and cryogenic structures and sediments by means of:

i) Field evidence.

ii) identification and analyses of the clasts from the sediments, using standard methods.

iii) sedimentary particle size analyses.

iv) Desk study of maps, bore-hole records and previous research to correlate previous work into a chronological framework in which to set the changing paleo-drainage pattern of Northamptonshire.

v) Desk study: After examination of relevant established Quaternary ostracod data, new tables are drawn up which collate the information in chronological order to see if any patterns exist in the British ostracod extinctions and entry of new species records. New patterns have been also shown in the present research.

vi) Identification and analysis of the ostracod species in the Milton Formation and Nene Valley sediments (Chapter 5).

The above study is summarised in Chapter 9: Sections 9.02, 9.03, 9.04.

B) Determine how changes in the Quaternary ostracod assemblages of Northamptonshire relate to the known episodes of global change (e. g. as represented by deep ocean oxygen isotope stages) and how these changes relate to the geomorphic changes recorded in past research of the region (Chapter 9: Section 9.05.1).

C) The evidence collected from the ostracods, stratigraphy, lithology and sedimentology will be used to determine the nature and course of Quaternary environmental change. To ascertain its value for Quaternary work the evidence will also be assessed against ideas already expressed in previously published literature (Chapter 9: Section 9.05.2).

D) Formal names will be proposed for the members of the Milton Formation (Chapter 9: Section 9.06) and the Nene Valley (Chapter 9.07).

F) Future lines of research suggested by this thesis will be assessed (Chapter 9: Section 9.07).

1.01.3. Palaeodrainage of Northamptonshire.

Of particular significance in this work has been the tracing of a palaeodrainage system, named here the Milton River.

Over the last 100 years remnants of a pre-glacial river system have been identified (Figure 1.01.4) between Kilsby, to the north-west of the Watford Gap, and Preston Deanery, to the south-east of Northampton (Castleden, 1980a). These deposits were described by Thompson (1902, 1930a, 1930b) and termed the Milton Sand (Horton, 1970). Castleden (1980a) suggested they were laid down by a proto-Nene which was a tributary of the River Ouse. Analysis of borehole data and the re-evaluation of past literature has shown a more complex palaeotopography and drainage existed (Chapter 4). In this thesis the Milton Sand is referred to as the Milton Formation. This is in line with the current practice as defined by Bowen *et al.*, in press.

The Milton Formation, in Northamptonshire, rests on the Lower Jurassic 'Blue' Lias bedrock and consists of locally derived material: sands and ironstones. Unless exposed at the surface in local stream valleys, it is capped by chalky till.

The Proto-Nene (hereafter termed the Milton River) is said, in some literature (Thompson, 1930a; Castleden, 1980a), to have followed a significantly different course from the modern Nene, but as its course direction is still in doubt, the evolution of the river and the chronology of change are discussed further in this thesis.

Previously, the Milton Formation has been found to be virtually fossil-free. In the past century only two finds have been recorded, a fossil metacarpal of a horse (*Equus* sp.) at Milton (Thompson, 1902) and, at Courteenhall Grange Farm Quarry, a tusk of a woolly mammoth (*Mammuthus primigenius*) (Botting, pers. comm.). unobtainable.

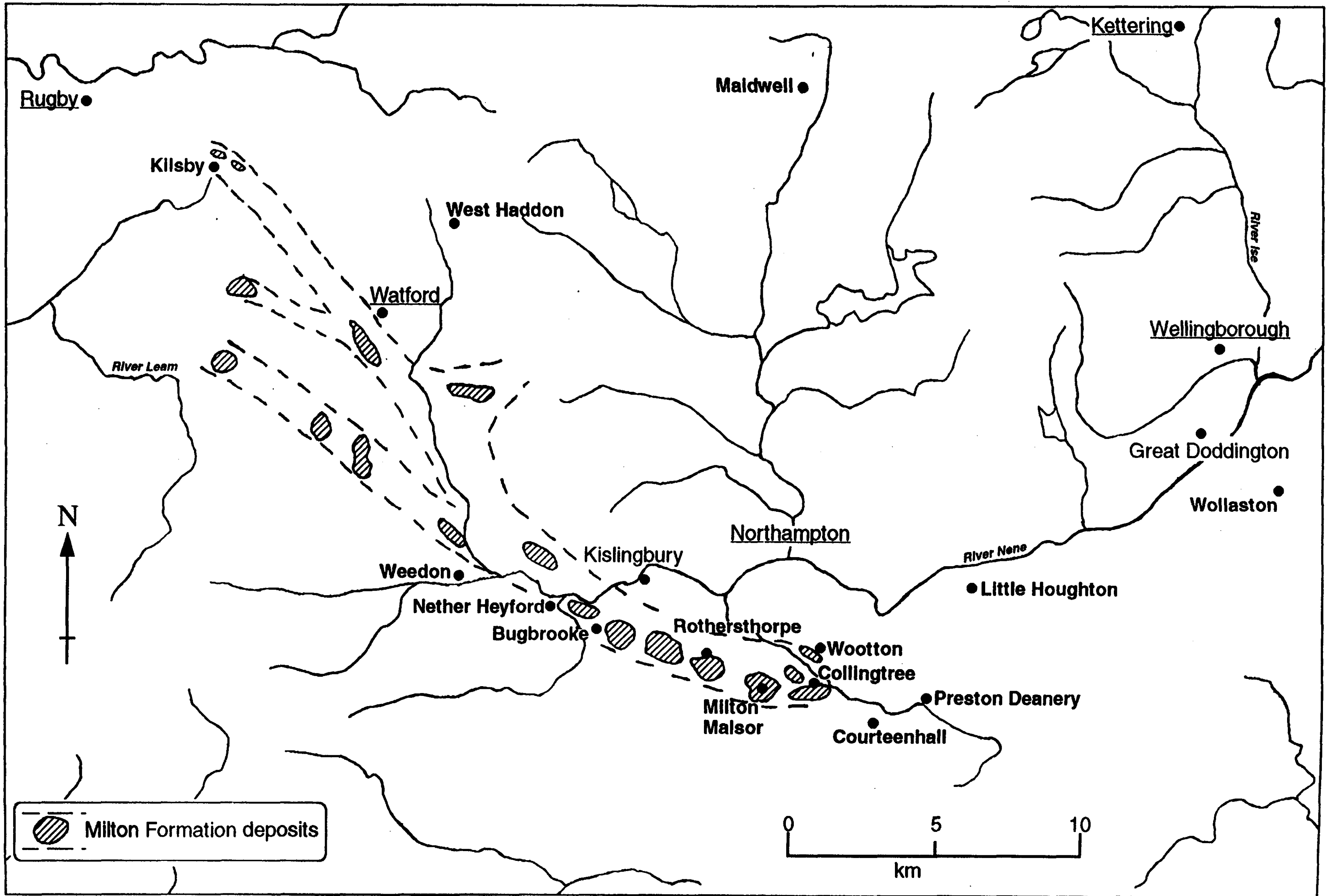


Figure 1.01.4. The pre-glacial Milton River deposits within the drainage pattern of the upper and upper middle River Nene (after Belshaw, 1989).

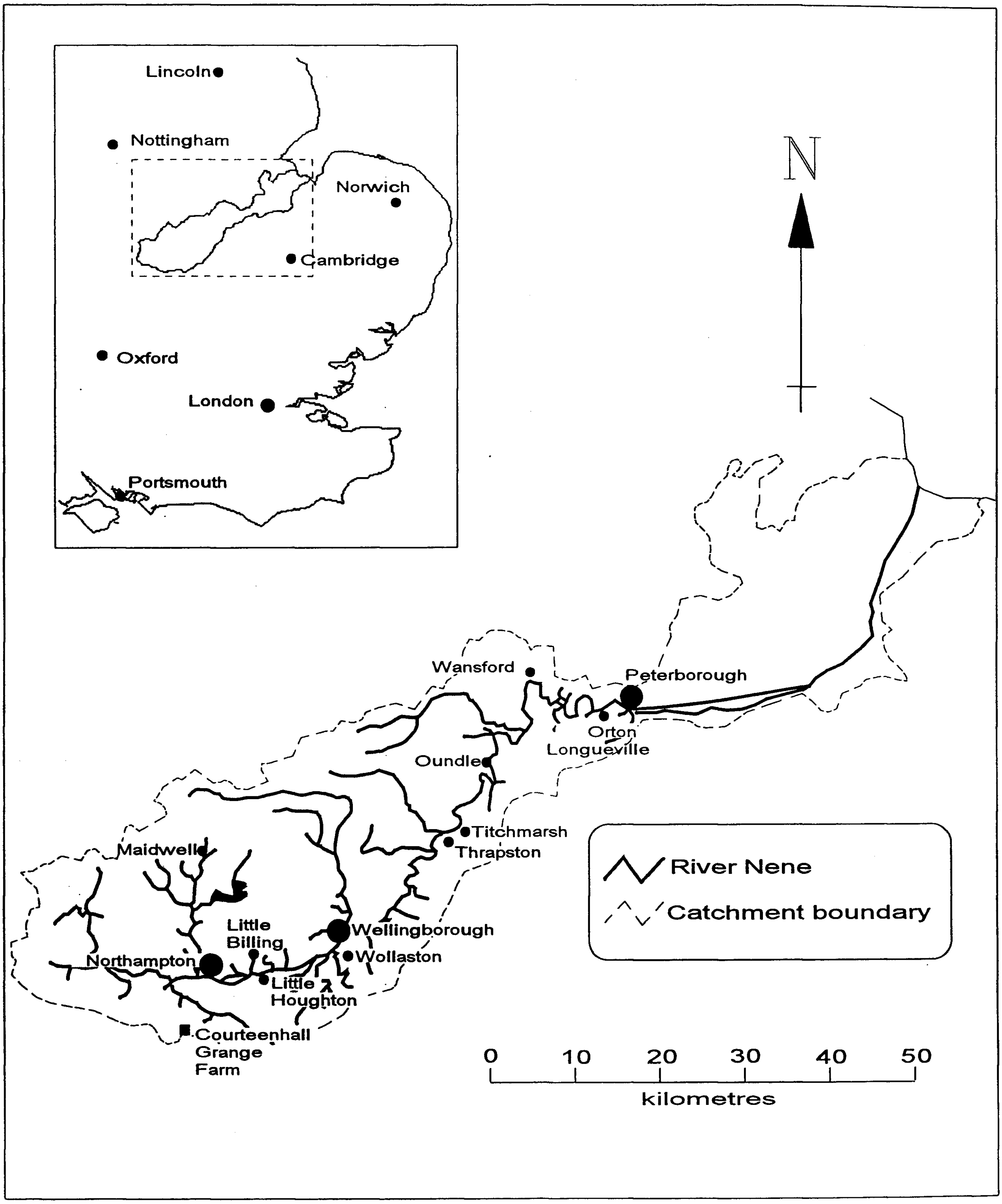
However, in 1992 the author found fossiliferous organic sediments at the base of the Milton Formation at Courteenhall Grange Farm quarry near Collingtree (Figures 1.01.1 & 1.01.4). The lowest 1.0 m of material, although it may have contained ostracods, was unobtainable. Six organic samples were, however, collected from strata above these lower sediments. From this material, ostracods and some mammal remains were extracted and identified. From the interpretation of this palaeobiological evidence, and, in particular, the ostracod analyses, an important contribution has been made towards the interpretation of the environmental history and age of the Milton Formation. It is important to note that this is the first time any microfossils have been found in the Milton Formation.

1.01.4 Location and lithological composition of the Nene Valley deposits.

The modern, meandering River Nene flows over a floodplain composed of sand and gravel overlying the Lower Jurassic 'Blue' Lias Clay mudrock. These sands and gravels are generally coarser than those of the Milton Formation (Castleden 1976, 1980b) and contain, in addition to locally derived sands and ironstones, flint, chalk and quartzites derived from the tills and glacial gravels deposited on the valley sides and hilltops (Thompson, 1902; Smith, 1995). These sands and gravels are referred to as the Nene Valley Sands and Gravels in this thesis.

The River Nene flows through Northampton to Wellingborough and Rushden and at this point changes to a north-easterly direction to flow through Peterborough to the Wash (Figure 1.01.5). The altitude of the Nene Valley at Northampton is 53-55 m O.D., approximately 20 m lower in the landscape than the Milton Formation (Chapter 4). One source of the River Nene is at Newnham (Staverton Nene of Thompson, 1930a, 1930b), to the west of Northampton. The northern arm of the River Nene, variously known as the Maidwell or Brampton Nene (i.e. the Naseby Nene of Thompson, 1930a, 1930b), drains the central area of the Northamptonshire uplands and contributes a major input to the waters of the River Nene at Northampton. It is likely that the Naseby Nene, which flows southwards through till-capped Northamptonshire ironstone, contributed much of the gravel found in the Nene Valley, particularly the ironstone element. As a result the Nene Valley Gravels, usually

Figure 1.01.5. The Nene floodplain between Northampton and the Wash.



2-3 m thick, are 13 m thick at the junction of the Naseby Nene and the River Nene (Horton, 1970).

There are glacial lake clays beneath the Nene Valley Gravels in Central Northamptonshire. These are at their thickest at Northampton and thin out towards Kislingbury, to the west of Northampton, and at Great Doddington, to the north-east of Northampton. These lake clays are generally believed to fill a buried tunnel valley (Horton, 1970). The term 'tunnel valley' is generally used to describe the basin eroded by a sub-glacial stream under hydrostatic pressure which debouches at an ice margin. Woodland (1970) described how, in Alaska and Greenland, subglacial streams have been observed to gush up at the ice-margin as fountains reaching heights of three to five metres. The debris debouched under pressure spreads in a fan around the outfall of the stream. A similar deposit was described by Aitken (1993) as "*a fan at the mouth of a conduit which, on glacial retreat, became an elongate cone or series of cones of gravel with opposed bedding.*" Debris of similar deposition has been found at the western limit of the tunnel valley in the Nene Valley at Kislingbury, 4 km west of Northampton (discussed in Chapter 4, sections 4.10 & 11).

The effect that successive cold and warm periods may have had on the post-tunnel valley landscape of the Nene valley, based on work by Castleden (1976 & 1980b), was used by Ballantyne and Harris (1994) to model the evolution of the Nene Valley between Wellingborough and Peterborough (Figure 1.01.6).

Evidence, which includes sediments, fauna and flora, has been used to suggest a similarity between the Quaternary sequences identified in the lower reaches of the Nene and the pattern of the deep sea oxygen isotope stages of Shackleton and Opdyke (1973). At Peterborough, the River Nene's Third, Second, and First Terraces and Floodplain sediments have been correlated by Bridgland *et al.* (1991) with the Oxygen Isotope Stages1-12 (Table 1.01.1).

The gravels of the Nene Valley at Little Houghton contain a wide variety of fossils. These include large mammals, such as woolly rhinoceros (Morgan, 1969; Smith, 1995) and straight-tusked elephant (Smith,1995), and small fauna such as beetles (Morgan 1969), and

	Deposits	Climate	Stage	O. I. Stage
15	Fenland alluvium etc.	temperate	Flandrian	1
14	upper First Terrace gravels	cold	Devensian	4-2
13	Maxey interstadial deposits	cool temp.	Devensian	5c?
12	First Terrace gravels	cold	Devensian	5d?
11	Maxey interglacial deposits	temperate	Ipswichian	5e
10	Abbey gravels?			
9	First Terrace gravels	cold	late Saalian	6
8	Maxey basal channel(s)	cool temp.?	intra-Saalian	7?
7	lag gravel in 3; upper Second terrace gravels	cold	intra-Saalian	8?
6	March Gravel	temperate	intra-Saalian	10
5	basal Second Terrace and	cold	intra-Saalian	10?
4	upper Third Terrace gravels			
3	Woodston Beds	temperate	Hoxnian	11?
2	basal Third Terrace gravel	cold	Anglian	12
1	Lowestoft Till			

Table 1.01.5. The Pleistocene sequence in the Peterborough district and its possible correlation with the oxygen isotope record (after Bridgland *et al.*, 1991).

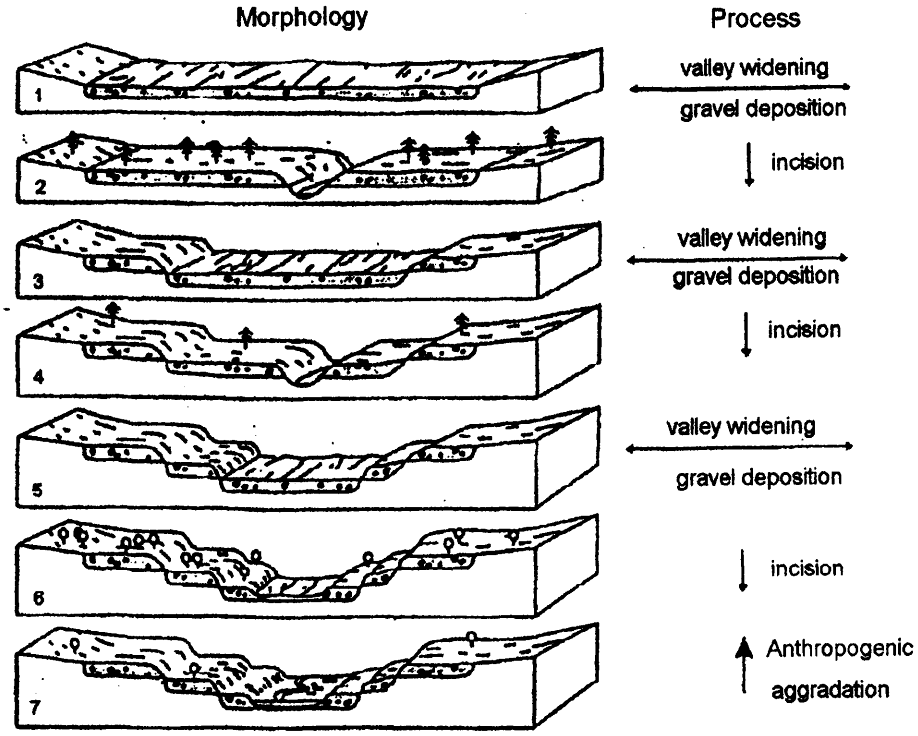


Figure 1.01.6. Model of the evolution of the Nene Valley according to Castleden (1980b) (after Ballantyne and Harris, 1994).

molluscs (Holyoak and Seddon, 1984). Pollen and plant macro fossils have also been identified (Morgan, 1969; Holyoak and Seddon, 1984). Fossiliferous material found in the lower reaches of the Nene at Peterborough has been analysed by Keen, Coope, Currant and Robinson (in Horton *et al.*, 1991).

Comparable research has been conducted in sections from the gravels of the River Avon (Maddy *et al.*, 1991), River Thames (Kerney *et al.*, 1982; Aalto *et al.*, 1984), and River Ouse (Rogerson *et al.*, 1992; Green *et al.*, 1996).

1.01.5 Ostracoda: Ostracods as palaeoenvironmental indicators.

Ostracods have long been studied in their present day habitats and within the context of the Quaternary. Analyses of ostracod biology and ecology are provided by Barnes (1974); Henderson (1990); and Gillmore and Smith (1996). It is only recently, however, that fossil ostracod analysis has come into its own. It is an increasingly important tool of palaeoenvironmental reconstruction and is used worldwide to study both marine and freshwater sediments. However, a comprehensive collection of ostracod data covering the full range of Quaternary environments and their time ranges is lacking. Consequently a desk study of the literature was necessary before the ostracod evidence could be evaluated.

1.01.6. Conclusion.

This work, therefore, aims to make a significant contribution to our knowledge of the Quaternary stratigraphy and evolution of Northamptonshire and to improve and enlarge upon the Freshwater Ostracoda data used in Quaternary Science.

CHAPTER 2: REVIEW OF PREVIOUS RESEARCH: GEOLOGY, STRATIGRAPHY AND LITHOLOGY.

2.01. Introduction

The following chapter gives a brief introduction to the solid geology of Northamptonshire and the published interpretations of the drift covering the solid geology (including changes in the fluvial environments). It concludes with a brief summary of conclusions drawn from sites already investigated in the Nene Valley.

It is written in preparation for the desk study of the subject material discussed in Chapter 4, the discussion of previous research on ostracods being reserved for Chapter 5.

2.01.1 The solid geology of Northamptonshire.

The geological succession of Northamptonshire is Lower to Middle Jurassic in age (Figure 2.01.1). It ranges from the Lower Lias to the Cornbrash of the Great Oolite Series, and, in the extreme east of the county, the Oxford Clay. The county to the west and north-west is bordered by a range of hills (the northern limit of the Cotswolds), the Northamptonshire Uplands or Heights (Figure 2.01.2). The hills may have been uplifted during the Miocene (or early Pliocene) period (Thompson, 1902). Many of the hills exceed 168 m O.D., the highest point being Arbury Hill, 246.0 m O.D. The hills form the water-partings (watersheds) of the River Avon to the west, Tove to the south, Welland to the north and Nene to the east (Thompson, 1930a, 1930b).

The strike of the Northamptonshire bedrock is from approximately north-east to south-west and, in general, the dip of the beds is towards the south-east. However, at Northampton, the Nene receives water from upper drainage basins which slope from the south-west through to the west and the north of Northampton. This is indicated by the direction of flow of the two main sources (The Staverton Nene and the Naseby Nene) and the Flore Nene, which all flow towards Northampton. The Nene then flows, in a north-easterly direction, to the Wash, north-east of Peterborough, England (Figure 1.01.5).

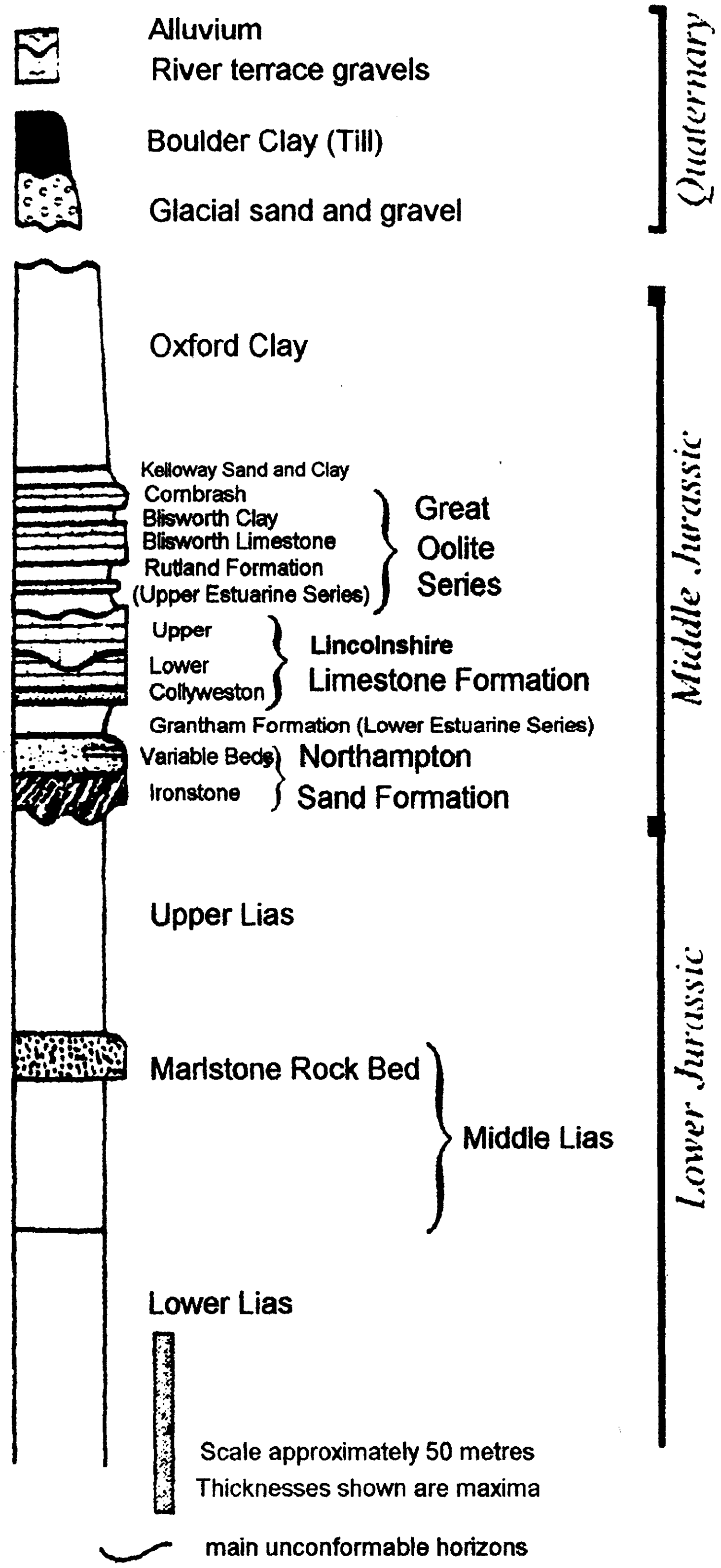


Figure 2.01.1. The geological succession in Northamptonshire. (after Sutherland and Sharman, 1996).

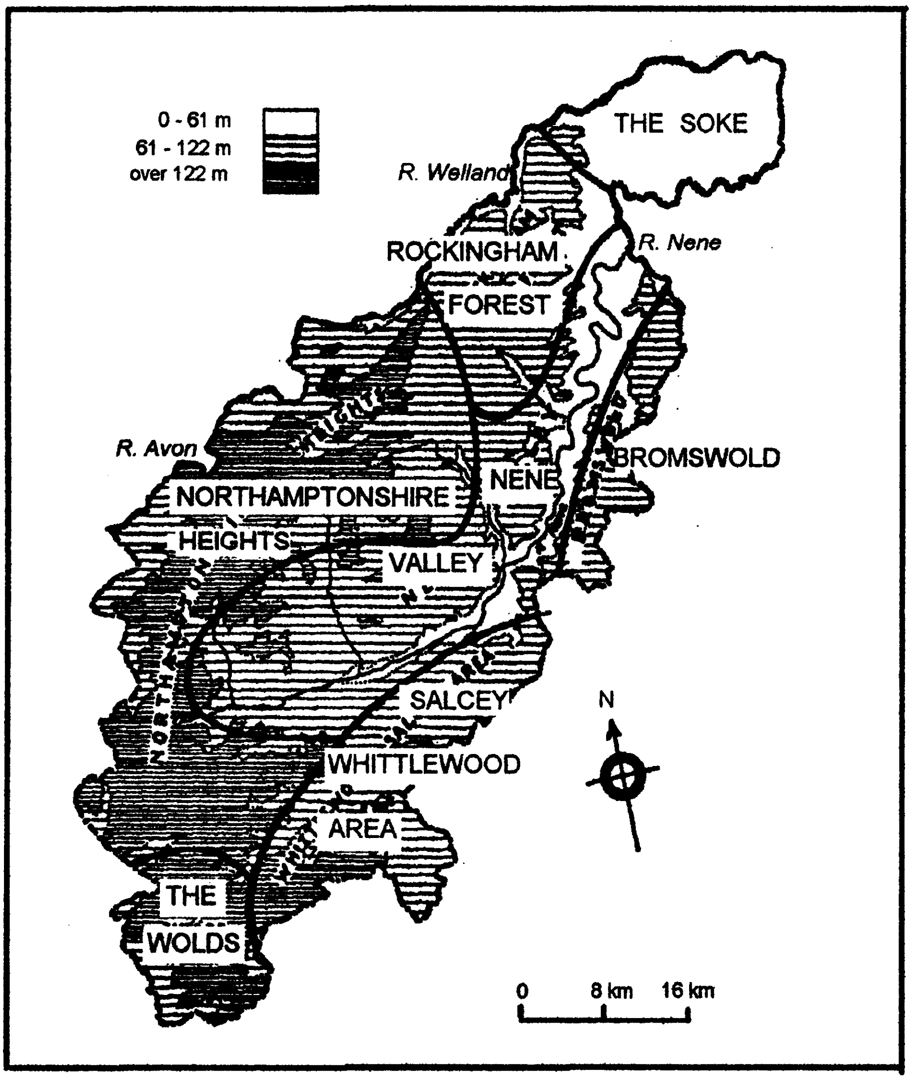


Figure 2.01.2. The natural regions of Northamptonshire, after Steane, 1974.

2.01.2 Lower Lias

"The term 'Lias' is usually understood to be a corruption of the word 'liers ' or 'layers', which was applied to this group of beds by quarrymen and others, because of its striped appearance when viewed from a short distance." (Thompson, 1880).

There are few exposures of the Lower Lias in Northamptonshire, although there is some in the western and north-western parts of the county. It is mainly argillaceous, but diagenetic beds of nodular concretions of limestone and limestone rock occur at intervals throughout the deposit (Thompson, 1880).

2.01.3 Middle Lias

The main exposures of the Middle Lias are seen in the western parts of Northamptonshire. The deposit contains both fossiliferous limestones and ironstones and clay beds. Any of the hard rocks may yield water, the most notable being the Marlstone Rock Bed (Figure 2.01.1). The alternate soft and hard beds form steep slopes with intersecting valleys.

2.01.4 Upper Lias

The Upper Lias is exposed at the surface in the valleys of the Nene and its tributaries, to the south-east of the county. The deposit consists of fossiliferous limestone and calcareous clay beds. Where they outcrop, the Upper and Lower Lias beds form undulating, well-rounded hills.

2.01.5 Northampton Sand and Limestones

These rocks, described below, rest on the Upper Lias, and consist, in varying thickness, of oolitic ironstones, sandstones, clays, marls and limestones.

2.01.5a) The 'Inferior Oolite' is now renamed The Northampton Sand Formation, Grantham Formation and the Lincolnshire Formation (Sutherland and Sharman, 1996).

The Northampton Sand comprises ironstone Beds overlain by the Variable Beds and the Lower Estuarine Series (Grantham Formation) (Figure 2.01.1). There is much variation in the character, thickness and extent of the beds. The Ironstone varies from zero to ten metres in thickness, but is mostly between four and seven metres (Hollingworth and Taylor, 1946a). Ironstone caps the hills in western and northern parts of the county, forming flat topped hills with steep scarp slopes. The Lower Estuarine Series consist of white or light purplish sands. Above this, in the north-eastern part of Northamptonshire, the extreme westerly and southerly limits of the Lincolnshire Limestone Formation crops out beneath tills.

2.01.5b) The Great Oolite Series.

The Great Oolite Series consists of the Rutland Formation (Upper Estuarine Series), Blisworth Limestone, Blisworth Clay, and Cornbrash and (in east Northamptonshire) Oxford Clay outcrops from Yardley Chase to Peterborough. The most noticeable of these deposits is the Blisworth Limestone as it is of a regular character and thickness throughout the county (Thompson, 1902). However, much of it is capped with glacial deposits. The limestones tend to form wide plains and the slopes may have a stepped appearance due the presence of faults and hard and soft beds. The overlying tills have, in places, filled in former valleys and changed the drainage pattern of the limestones (Thompson, 1902).

2.01.6 The Northamptonshire Faults.

Thompson (1902) traced the largest and longest fault, the Nene or Northampton Fault, from Weedon, in the west, to Northampton, a distance of 17.5 km. At Northampton (Figure 2.01.3), it has a throw to the north of at least 23.5 m, but evidence from well records has shown the throw to be up to 40.0 m in parts. For instance, in Bridge Street, Northampton, the Middle Lias Marlstone rock-bed, at the base of the Upper Lias, yields water as low as 16.5 m O.D. and forms a deep-seated water supply for the town. In Commercial Street, adjoining the southern end of Bridge Street, wells reached the Middle Lias beds at 52.0 m O.D., a difference of 35.5 m (Thompson, 1930a, 1930b).

The base of the Ironstone at Hopping Hill, Northampton, to the north of the Northampton Fault, is 68.0 m O.D., whereas, to the south of the fault, the base of the ironstone is elevated to 95 m O.D. a difference of 27 m (Figure 2.01.3). Hunsbury Hill, one

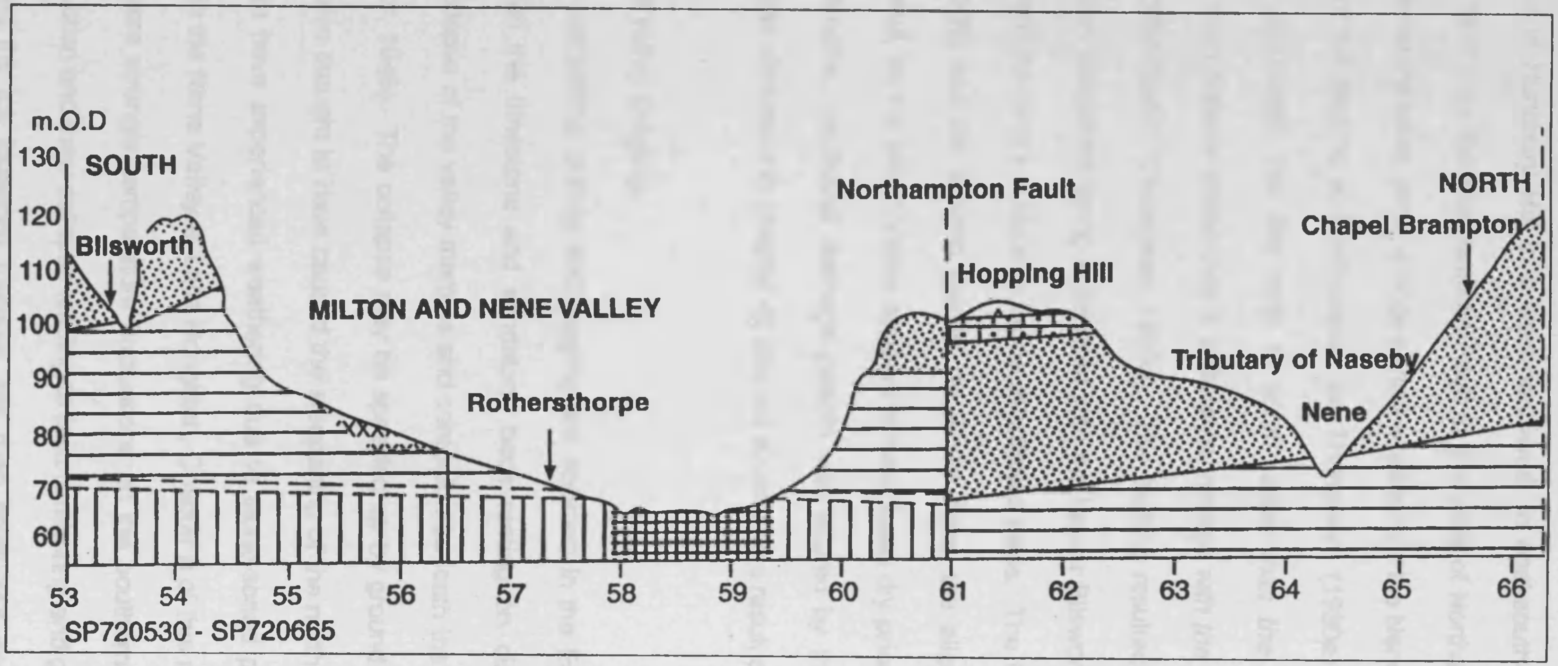


Figure 2.01.3 A section across the Northampton Fault at Hopping Hill, Northampton. The base of the Ironstone shows a throw of 25m. (For legend, see Figure 4.01.3)

and a half miles to the south west of the Northampton Fault, is also faulted. This second fault crosses the area of Hunsbury Hill in a west-north-west to east-south-east direction (Figure 2.01.4). The fault joins the Northampton Fault to the west of Northampton and its position points to there having been, once, a ridge across what is now the Nene Valley.

The position of the faulting at Northampton led Thompson, (1930a) to believe *"It might be, with much plausibility, that the north to south rather than the north-west to south-east flow of the main Naseby stream has a definite connection with the faulting which occurs in and near Northampton."* (Thompson, 1930a). The faulting resulted in the softer, more friable Northampton Sandstone being juxtaposed with the harder Blisworth Limestone, which would have caused the land's surface to erode at different rates. The fluvial erosion exploited the softer rocks and the faulting guided, as it still does, the alignment of the drainage. In all likelihood, as the Milton Valley appears to have been dry prior to the onset of glaciation at Northampton, the fluvial drainage pattern was altered by the differential erosion of the bedrock (as discussed in Chapter 4), and not directly as a result of glaciation.

2.01.6 Cambering and valley bulging.

Valley bulging, cambering, gulling and sagging are common in the East Midlands and are associated with the limestone and sandstone beds resting on clays. These processes cause the collapse of the valley margins and contortion beneath the valley floors (Hollingworth and Taylor, 1946). The collapse may be speeded up by ground ice thawing. Past cold climates are also thought to have caused the steepening of the north valley-sides which are more likely to have experienced weathering due to stone-sorted polygons (as would have been seen in the Nene Valley at Little Houghton, Chapter 8 of this research). It is possible that there were stronger temperature fluctuations on the southern valley-side, which gave rise to solifluction and thaw collapse leading to fault cambering and gulling of the Ironstone. It is believed the ice loosened material was then soliflucted into the rivers (Kellaway and Taylor, 1952). Such evidence of past cold conditions is frequently seen in Northamptonshire. In reality, there may be evidence of more than one former period of

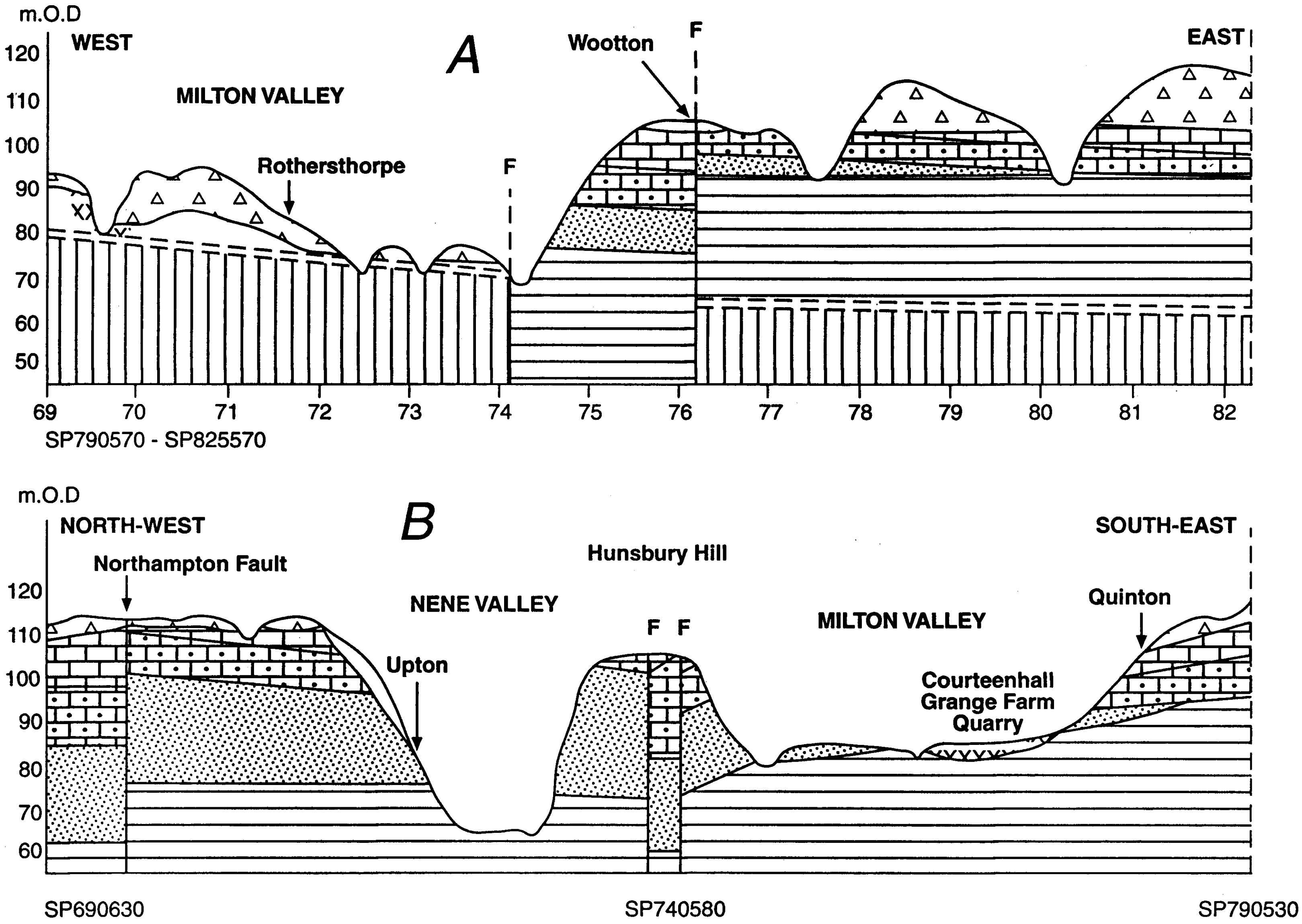


Figure 2.01.4 Section A: Faulting to the south-west of Hunsbury Hill, as described in text.
Section B: The Ironstone ridge to the north-east of the faulting, first described by Thompson, 1930a. (For key, see Figure 2.01.3)

periglacial deep-freezing and thawing. It appears, from this research, that the English Midlands may have been subject to several episodes of periglacial periods during and after a glacial period, and between past interglacials. At these times, when ice sheets did not extend over the land surface, a cold climate flora and fauna flourished, some fossils of which are discussed further in this paper.

Past clay bulging was most likely caused by water seeping from the Northampton Sands into the clay joints, forming a lubricant clay which increases the outflow towards the valley. Hollingworth and Taylor (1946) noticed that where valley floors cut into Blue Lias they were often irregular due to lateral squeezing of the clay from the valley-sides due to differential pressure. It is thought that continued outflow of the clay then lowered the supra-Liassic strata. The Blue Lias clay may have bulged and erosion of this formed 'sagging' depressions. Several of these basin shaped structures are found along the Nene Valley between Wollaston and Ringstead.

2.02. Pre-glacial river deposits

"From the fact that the Lias clays are met with in the valleys, and newer formations on the hills in these districts, we conclude that the valleys are newer than the newest of the formations, and that they have been cut out by running water." (B. B. Thompson, 1880).

2.02.1 Milton Formation.

The Milton Formation deposit, between the Watford Gap and Northampton, forms a linear feature up to 1.5 km wide and 20.0 km in length (Figures 1.01.4 and 2.02.1). It passes through the parishes of Weedon, Heyford, Bugbrooke, Kislingbury, Rothersthorpe, Milton, Collingtree and Courteenhall and on to Preston Deanery (Thompson, 1925, 1930a &b; Belshaw, 1989). The base of the Milton Formation is at 87.0 m O.D. at Nether Heyford, 77.0 m O.D. at Rothersthorpe and 72 m O.D. at Preston Deanery (Thompson, 1930a). Near Northampton, the Milton Formation, at 73.0-75.0 m O.D., is cut into Upper Lias and

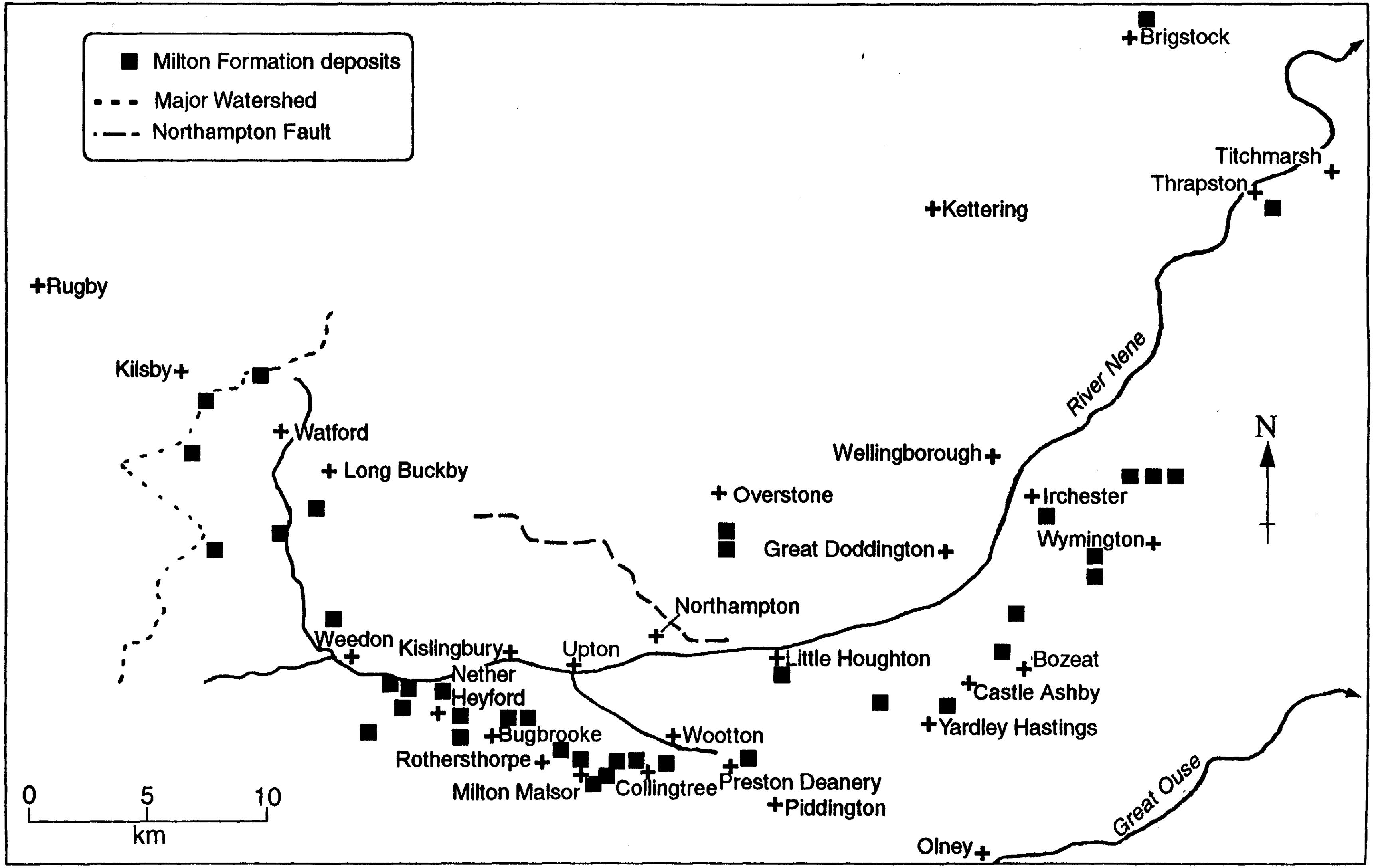


Figure 2.02.1. Place names and pre-glacial sand and gravel deposits referred to in Chapters 2 and 4.

Northampton Sands. To the west and north-west of Collingtree, the Milton Formation rests on Middle Lias and Marlstone bedrock. The maximum thickness of the Milton Formation deposit is 13.0 m, but 5.0-7.0 m is more usual (Clarke and Moczarski, 1982; Belshaw, 1989). At Northampton, the sands are approximately 20.0 m higher than the deposits of the Nene Valley. Upstream, at Flore, where the modern Newnham Nene first bisects the Milton Formation (SP655597), the Milton Formation is only two or three metres higher than the floodplain of the Staverton Nene. This may be due to undulation of the bedrock or, as the Newnham Nene streambed is narrower upstream, an increase in stream velocity causing deeper erosion down through the Milton Formation and the bedrock.

Thompson (1930a) also noted the steep sides of the Milton river valley at Milton. He was inclined to think that the steep sides, at Milton and at Yardley Hastings, where he had also observed them, were due to erosion by torrential streams created by massive increases in precipitation, particularly snowfall.

There is some confusion over the lithology of the Milton Formation. Thompson (1902) noted that the sands consisted of washed and re-deposited material from the local bedrocks. He observed ironstone, notably of "*broken box structure*," sandstone and limestone material, with fragments of fossils derived from the limestones at the base of the Upper Lias. The fossils include belemnites, ammonites and *Gryphaea*. However, Horton (1970), in contradiction to Thompson (1930a, 1930b), noted the presence of well rounded and large clasts of quartz and quartzites and weathered flint and concluded that the sediments of the Milton Formation were derived from the local rock and the lower till deposited on the valley-sides. Castleden (1980a), in contradiction to both the previous authors, said there was a lower till beneath the Milton Formation although he found no far-travelled lithologies in the deposit. Finally, Belshaw (1989) confirmed that there were no erratic lithologies present in the Milton Formation, that there were few clasts larger than -5 phi (32.0 mm) and, except in rare silt layers towards the base of the deposit,that there was little material finer than 3 phi (0.125 mm) and that any unusual clay or 'diamict' beneath the sands was possibly reworked Lias clay.

The grain size of the constituents of the Milton Formation has also led to much discussion. It appears that the modal size (3 to 4 phi) of the sediments of the Variable Beds of the Northampton Sands are finer than the modal size (2 phi) of the Milton Formation (Belshaw, 1989), but Thompson (1902) said much of the Marlstone Rock and the Middle Lias Formation, which also entered the deposits, has coarse grained sediments. The grain size of these do not appear to have been analysed.

Thompson (1902) first discussed the Milton Formation after a visit to the Courteenhall pit in 1891, but he had little to say until after his return in 1897, when he examined a cutting made for drainage purposes. The ditch had revealed highly disturbed sand deposits containing boulders of weathered Lias clay, some of which had "*vegetation*" within them. He decided that such disturbance could have been caused only by summer flooding after severe frost, such as may occur with increasingly cold climatic conditions and he concluded, that the Milton Formation was more likely to be "*pre-glacial*" than "*interglacial*" in origin (Thompson, 1930a, 1930b). He concluded that, because of the evidence for colder conditions seen at Courteenhall, 'Preliminary glacial' would be a more appropriate term (Thompson, 1925, 1930a, 1930b; Thompson and Crick, 1891). He also said that, as the Milton Formation contained no erratics, they were older than both the lower till exposed at sites between Towcester, Buckingham and Newport Pagnell (which contains Bunter quartzite, but no chalk or flint) and the upper chalky till (which contains all of these plus other erratics (Thompson, 1902, 1930a, 1930b). In conclusion, he suggested that the Milton River was not related to the present day River Nene, but was a river which flowed through a now buried valley under Yardley Chase, to enter, as a tributary branch, the River Ouse, Bedfordshire. In contrast, Horton (1970) came to the conclusion that the Milton River could not have eroded through the solid rock to the south of Northampton, and suggested that the river followed the route of the modern Nene.

Later, on the basis of borehole evidence across Yardley Chase, Castleden (1980a) confirmed that there was a buried valley and, agreeing with Thompson, wrote that the Milton River could have flowed through the valley as a tributary of the River Ouse. However, he maintained, as discussed above, that the Milton Formation overlay the lower till, although "*it* *contains no erratic material derived from it*". As the opinion of the time was that the upper chalky till was deposited during the 'Wolstonian' (Oxygen Isotope Stage 6) Castleden assumed that the Milton Formation must be the deposit of a periglacial river active in the period between that glacial episode and the previous glaciation which deposited the lower till (for further discussion see Chapter 4).

Clarke and Moczarski (1982) concluded that "*deposits of fine and medium grained sand, previously mapped as fluvio-glacial gravel, in the area around Milton appear to represent a deeply dissected, continuous spread of early Pleistocene fluvial material*" and that "*the Milton Sand deposits pre-date the main glacial events in the area*".

In 1989 Belshaw proposed that i) the Milton Formation was probably deposited in the latter part of the Tertiary and the early part of the Quaternary periods, ii) it was a low energy environment in an extremely flat landscape, iii) an earlier disruption of the Jurassic strata allowed considerable alteration of the landscape by periglacial activity before the actual glacial event occurred, iv) the Milton Formation was then preserved by a capping of lodgement till, v) the landscape was further modified in the post-Anglian glacial phase and subsequent periglacial stages.

2.02.2 Fossiliferous evidence from the Milton Formation.

In 1835, as reported by Baker (1836), bones were recovered from a "*diluvial bed*" between Gayton and Milton Malsor. The assemblage consisted of a humerus bone and fragments of teeth of mastodon; the tibia of a full grown, and a portion of a tooth of a young elephant; parts of the tibia, teeth and tusks of hippopotamus; parts of the skull, humerus, tibia, vertebrae, and teeth of ox, teeth and tibia of the elk, and horn and prong and portions of the ribs of deer.

2.02.3 Other pre-glacial buried channels and valleys.

In Northamptonshire, several buried valleys, filled with "*pre-glacial*" sands and gravels, have been found and recorded by Thompson (1895, 1896, 1925, 1930c), Hollingworth and Taylor (1946a, 1946b), Kellaway and Taylor (1952) and Horton, (1970)

(Figure 2.02.1). Some are situated on the sides of the Nene Valley between Northampton and Wellingborough. However, these deposits are not distinguished from the glacial gravels on the Wellingborough Geological Sheet (Sheet 186, Wellingborough: Geological Survey, 1974). The deposits on the south side of the Nene crop out at Bozeat (between 68-80.0 m O.D.) (Kendrick, 1993), Yardley Hastings (between 73-82.0 m O.D.) Chadstone Farm, Castle Ashby (between 73-82.0 m O.D.) (Thompson, 1930a, 1930b) and Little Houghton (between 73-84.0 m O.D.) (Thompson, 1930a, 1930b; Dury, 1949) (Figure 2.02.1). Thompson considered that these sand beds occupied depressions which were remains of consequent stream valleys that crossed the area before the streams were beheaded by the development of the longitudinal Nene Valley. There is little evidence of "*pre-glacial*" sand deposits to the north of the Nene, but if what Thompson suggested is correct, then the deposit at Overstone (between 105-110.0 m O.D.) (Kendrick, 1993) may be the upper reach of a consequent stream that flowed eastwards through the area of Little Houghton (Figure 2.02.1) to join a major river.

Hollingworth and Taylor (1946b) recorded the discovery of a 2.5 m section of pre-glacial gravels of wholly local origin beneath the lower till, two miles south of Irchester. Hollingworth and Taylor (1946a) also reported a channel-fill of limestone gravel, 1.70 m thick, which was overlain by one metre of peat and peaty alluvium capped with 2.0 m of loamy soil. This was in the face of a brick pit in Upper Lias clay at Rushden Grange Farm, near Wellingborough. A deposit found at Wymington, Bedfordshire, to the south of Rushden (Dury, 1949) may be an extension of the deposit at Rushden. The Wymington boring, 100 m deep, revealed 7.5 m of a pre-glacial ironstone gravel and sand deposit directly on Blue Lias bedrock (at what height above sea level is not stated).

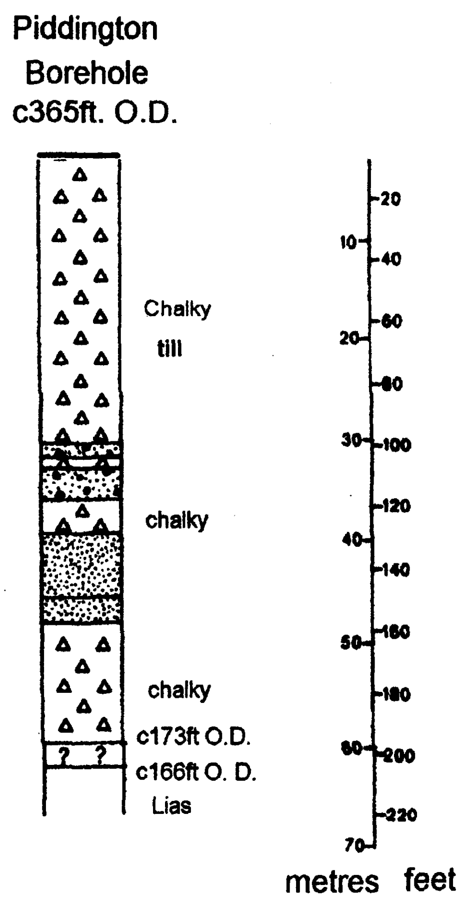
Near Kettering, to the north of Wellingborough, at Brigstock, between 70 and 80.0 m O.D., there is a thick deposit of limestone gravel found beneath lower till capped with chalky till (Taylor, 1963).

2.02.4.The valley under Yardley Chase.

Despite Thompson's theory that there was probably a buried valley under Yardley Chase, Dury (1949) considered it was unlikely as there was no surficial evidence of a channel of any kind.

Borehole evidence used by Castleden (1980a) shows that there was a valley and it contained a plugged valley segment which contained till to a depth of over 25.0 m in places. One of the borelogs he used as evidence was that of Horton (1970). This borehole at Tart's Barn, near Piddington (SP829554), showed chalky till and sands at the base of which there was 1.0 m of calcareous material with fragments of grey, pyritic oolitic limestone (Figure 2.02.2). The floor of the valley was at 53 m O.D. or lower (Castleden, 1980a). Horton, however, did not use this as evidence for a channel for the Milton River, but as part of his discussion on the chalky tills of Northamptonshire. It was Castleden (1980a) who used, and added to, Horton's borehole evidence to prove the base of a valley down to 53 m O.D., or lower, of which the width, depth and altitude is similar to the present Nene Valley. The valley form, blocked by till, was shown to persist for 6.5 km east-south-east from Preston Deanery (SP790558). To the west of Piddington, at point SP789559 (borehole SP 75 NE 396) Clarke and Moczarski (1982) described a section of preglacial sand of local origin sandwiched between two sections of chalky boulder clay (till). The base of the lower section of till was at 62 m O.D. Although this sand deposit is described as Glacial Sand and Gravel by Clarke and Moczarski (1982) they suggest it could be reclassified as sand of the Milton Formation only if Castleden (1980a) was correct in his assumptions. Alternatively, as both the till sections are chalky Anglian till, the sands may have been incorporated into the Anglian till as the ice sheet passed over the Milton Formation beds. It would have the been transported and deposited with the chalky (Anglian) till into its present position (Belshaw, pers. comm.).

The blocking of the valley, as envisaged by Thompson (1930a, 1930b), was by glacial ice which spread from the area of the Wash and caused the Milton River to back up and form a lake to the south-west of Northampton (in the area of Bugbrooke, Rothersthorpe, Milton and Collingtree). Eventually, he proposed, the lake waters would have eroded the hardrock bedrock to the north of Hunsbury Hill and entered the Nene Valley. Alternatively,



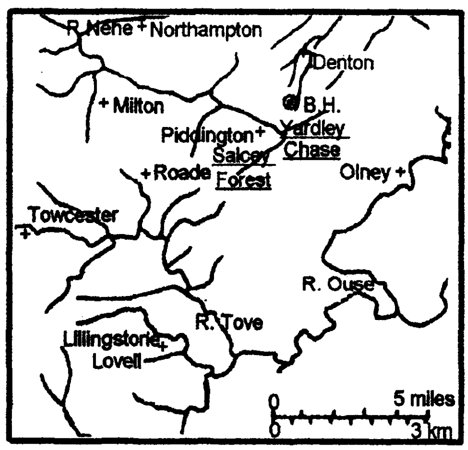


Figure 2.02.2. The bore hole log (Horton, 1970) used by Castleden (1980a) as evidence for the continuation of the Milton Valley across Yardley Chase, to the south-east of Northampton. (Labelling of diagram as by Horton, 1970).

Castleden (1980a) suggested that during an early stadial of the 'Wolstonian,' immediately after the Yardley Chase valley was blocked by ice, a deep, drift-filled depression was excavated at Northampton. This linked the upper and middle Nene Valleys. Later, when the glacial lake clays had dried out and settled, they formed an alternative route to the plugged valley segment at Yardley Chase. Thus the diversion of the Milton River (Castleden's Proto-Nene) into the valley of what is now the River Nene occurred at the beginning of the Ispwichian interglacial (Castleden, 1980a). Horton (1970), not accepting the idea of a buried valley, believed the Milton River was already in the present Nene Valley at the time of the deposition of the Milton Formation and linked the deposit with similar deposits found in the Kettering area. A new interpretation of the buried valley is discussed in Chapter 4 of this research.

Following any of the above events the Staverton Stream (present day Nene), which previously entered the Ouse stream (the Milton River), then developed a more easterly flow from Weedon to Northampton (Thompson, 1930a, 1930b).

2.03 Tills and 'Mid-glacial gravels.

"To understand the sequence in occurrence of deposits in the Nene and other river valleys, it is necessary to picture events which could have produced such, and which may reasonably be presumed to have occurred. This necessarily brings us up against the Glacial Interference: and a consideration of all the phenomena associated with what are known as Glacial Deposits in Northamptonshire, which leads to a belief that 1) There were two distinct Glacial Periods or Glacial Episodes, separated by a correspondingly long intervening mild period, and 2) That in each Glacial Episode great floods preceded and succeeded the advent and recession respectively of the ice sheet itself." (Thompson, 1930a).

2.03.1 Evidence for two glacial events.

Thompson was one of the first to suggest that the far-travelled lithological element of the tills and post-glacial gravels of Northamptonshire was due to transport by ice sheets.

Many of the erratic rock types noted by Thompson (1902) are not found in the lower till. This was later confirmed by Taylor (1963) and Sabine (1949). Thompson deduced that there had been two glacial episodes, the decay of the second one forming the present-day Nene Valley (Thompson, 1893). Sabine (1949) said that the drifts of Northampton suggest there was more than one glaciation. He noted that the lower till was free of chalk and flint, but there were abundant Bunter pebbles present among the local material, especially in the Oundle region. He suggested a derivation from the north along a route lying wholly west of the Lincolnshire Wolds, subsequent reworking of the lower till producing Thompson type 'mid-glacial' gravels, particularly to the south of Kettering. It was the presence of two tills and radiocarbon dates of Devensian age of certain sediments in the Nene Valley that convinced Castleden (1980a and b) that the chalky upper till was of 'Wolstonian' age and the lower till of Anglian age. This is at odds with Perrin, Rose and Davies (1979) who a) consider the Chalky Boulder Clay (till) to be of Anglian Age and b) ignored the evidence of tills from earlier glacial episodes. From their conclusion it can be deduced that the later 'Wolstonian' and Devensian glacial episodes were of a periglacial nature in Northamptonshire.

2.03.2 Lower Till

Near Long Buckby, Northamptonshire, Thompson (1897) saw "*10 feet of boulder clay of ruddy hue, and unlike any other clay in the district. I presume it was older than other clays illustrated.*" In 1930 he also reported finding pockets of red clay full of Bunter pebbles and well worn flints beneath a till with a few large stones, Kimmeridge Clay fossils, gastropods and serpulids. Hollingworth and Taylor (1946b) described the lower till as free from chalk and flint. West and Donner (1956) thought that the lower till and part of the Pennine Drift of the East Midlands entered Northamptonshire from the north-west and were the products of the upstream part of the ice which deposited the lower (Baden-Powell, 1948) Lowestoft Advance Chalky Till of East Anglia. Although, in the past, the status of the lower till has not been fixed (e.g. Taylor, 1963) recently there has been growing support for a significant Anglian ice advance before that which led to the deposition of the Lowestoft Till (e.g. Rose, 1992). The upper till was thought the equivalent of Baden-Powell's (1948) Gipping Till. Taylor (1963) asked for further details of the gravel face seen by West and Donner as, in Taylor's experience, the gravels with only local clasts antedated the glacial deposits (no erratics), and the gravels found overlying the early till had been found to contain some erratics particularly quartzite, but had no chalk or flint from the later glaciation. He considered the deposits, identified as Pennine Drift by West and Donner (1956), were not true till, but fluvio-glacial in origin. Thus the gravels above these sediments were the Thompson type mid-glacial gravels and not preglacial nor derived from the chalky till. Where seen, the till is usually described as a thin deposit thickening into hollows of the pre-glacial surface. It is absent over considerable areas, but present for many miles south of Kettering in Northamptonshire. In the ironstone quarries north of Brixworth both the lower and upper tills were reportedly clearly visible (Hollingworth and Taylor, 1946). The lower till was characterized by its leaden grey colour (although occasionally brown or red), gritty texture, presence of ironstone and quartzite pebbles and fossil serpulids. The same lower till was seen to cap Jurassic Estuarine Clays and Northampton Sands in quarries near Scaldwell, south and east of Moulton, and between Overstone and Sywell. Remnants of the same till were seen beneath chalky till west of Great and Little Addington, downstream of Wellingborough, in the Nene Valley. Hollingworth and Taylor (1946b) mapped the lower till for many miles and suggested that its *"derivation is from northerly sources along a route lying west of the chalk wolds of Lincolnshire"*. Nearer to Northampton, in the areas surrounding both Yardley Hastings (Thompson, 1930a, Harrison, 1983) and Brixworth (Taylor, 1963), the lower till was seen to contain some rotted flint which was suggested by Taylor (1963) to have possibly been worked in during the deposition of the upper till.

Later, Horton (1970) was to report the existence of lower till on the valley sides of streams north of Buckingham. Although not usually thick, a borehole at Lillingstone Lovell (SP719419) proved lower till to a depth of 26.8 m resting on Great Oolite Limestone. It was largely of local material, but was distinguished from any local deposits or chalky till by its gritty texture, derived fossils, particularly serpulids, infrequent quartzite pebbles, and the absence of chalk, though some rotted flint was present. The lower till was also found beneath chalky till at Hanslope (SP828476) and in several site investigations for the M1 motorway between Newport Pagnell and Collingtree. Similar tills have been recorded at Castle Bytham (Rose, 1989a), Huncote, Leicestershire (Lewis, 1989) and Cumnor, Oxfordshire (SP476042) (West and Donner, 1956). The Cretaceous flint in lower sediments at Castle Bytham is suggested by Rose to have been transported via the West Midlands from the Irish Sea region by glaciation (Rose, 1989a). Thompson (1902, 1904, 1930a, 1930b) hypothesized that, following the deposition of the lower till, there was a lengthy interglacial period in which most of the till was eroded away.

Kellaway and Taylor (1952) suggested that a considerable amount of erosion occurred before the deposition of the chalky till. This was probably due to a period of river development and slope activity during which the older, lower till was largely removed. The possibility of mass-wasting through the agency of cryoplanation under cold conditions cannot be ignored.

2.03.3 Mid-glacial gravels.

Earlier authors when referring to 'mid-glacial' gravels, a term given to them by Thompson, are discussing gravels that consist of clasts from local rocks and the earlier, lower till. Thompson (1893), referred to gravels that range "*from five feet above to thirty feet below present water level*" at the junction of the Naseby Nene and the Staverton Nene at Northampton (see also, Thompson, 1904, 1930a, 1930b). As the present water level at Northampton is 52-53 m O.D. this indicates a valley base at about 45 m O.D.. He described the lower eight metres of gravel as Mid-glacial in origin: quartz and quartzite-rich but not containing any chalk and rarely any flint. Mid-glacial gravel was also found below 29.6 m of chalky till in a borehole at Horton Station. The one metre-thick gravel was at 68.7 m O.D., slightly lower than those of the Milton Formation at Preston Deanery.

There are, in the Kettering area (Kellaway and Taylor, 1952; Horton, 1970), several buried pre-glacial valleys which contain younger deposits of gravel derived from the lower till. This type of gravel can also be found in both the Harper Brook and the Ise valleys. Its probable source, the lower till, is exposed at Brigstock Country Park where, above pre-glacial gravel similar to that of the Milton Formation. To the south of this park, at Cat's Head Farm (SP955836), Taylor (1963) reported finding, in a small pit, an ironstone-limestone-Bunter Quartzite gravel beneath lower and upper tills which, combined were over 30.0 m thick. Nearby, at Sudborough and along the edge of the lower till west of the Aldwinkles, similar gravels can be seen close to the Nene Valley. Discussing the Ise valley, south of the Harper Brook, Hollingworth and Taylor (1946b) wrote, " *Outcrops along the Ise valley are preserved as outliers on the ends of short spurs on the valley-sides and resting on Lias clay - higher on the valley-side both the upper and lower boulder clays [tills] have been mapped with no intervening gravels.*" The source of the River Ise (SP698783) is at 180 m O.D.

Kellaway and Taylor (1952) hypothesized that the drift filled pre-glacial valleys may have been beheaded and unlikely to hold much water at the time of freezing, but following deglaciation and erosion, the melt-waters and their gravels, would be canalized in the old valleys leading to their re-excavation. They also suggested that glacial gravels may have been formed in the later periglacial periods as well as during the glacial periods.

The quartz / quartzite gravels discussed above are interpreted as representing a valley bottom deposit formed during the interval between the two till depositions which have survived both the burial by chalky till, post-Anglian glacial erosion and deepening of the old valley (Taylor, 1963).

2.04 Tunnel valley and glacial lake sediments.

Although unaware of the glacial lake sediments beneath the gravels at Northampton, Thompson (1904) was the first to describe them. He saw an unusual bluish clay which formed a ridge beneath the gravels at Cow Meadow, Northampton. It, perhaps, would be recognised today as a diapir. Modern boreholes have shown that extensive deposits of glacial lake sediments are found in this area of Northampton: Rushmere Road, Northampton Borough Council,1972; Nene river towpath, N. B. C., 1988; St. John's Car Park, N. B. C., 1989; Riverside Park, N. B. C., 1991; Northampton Nene Park (Sixfields), N. B. C., 1991;

Cattle Market area, N. B. C.,1993, 1995. Evidence from these borehole logs is discussed in Chapter 4.

Early (1956) estimated that the microlaminations, which suggested daily cycles within annual varves of the glacial lake clays, represented 500-1,000 years of deposition. At Early's exhibition of the clays, Hollingworth suggested several modes of origin: a) an ice eroded depression left in the surface of the chalky till; b) a deep, water-eroded sub-glacial hollow of the tunnel valley type; c) a hollow produced by melting and collapse of a substantial amount of ground-ice in the valley floor. In the last case the Marlstone could have provided the ground water for a considerable ice mass. An overdeepened valley is unlikely unless there is evidence of a deep channel crossing under the Yardley Chase surface. The possibility of the depression being a ground ice feature is supported by Belshaw (pers. comm.).

Horton (1970) recorded borehole evidence which showed brownish grey, laminated clay with silt partings, interpreted as glacial lake sediments, at Northampton Power Station and along the Southern Relief Road (SP750594 to SP750601) (Figure 2.04.1).

Castleden (1980a) said the depression (he did not it describe it as a tunnel valley), which he proved to be 14 miles long, was excavated during the 'Wolstonian' glacial. It was then lined with till deposits and filled with glacial lake clays to well above the modern floodplain surface. After drying out the depression became the route of the present day Nene.

2.05 The chalky upper till and glacial gravels.

Thompson (1902) and Sabine (1949) observed that the mass of clay resting on the older formations of Northamptonshire contained erratics of chalk and flint, Bunter pebbles and a smaller number of granite, greenstone, jasper, white quartz, mica schist, gritstone, Carboniferous Limestone, sandstones and shales. Horton (1989) distinguished the glacial gravels, outwash from the Anglian ice-sheet, from the younger river terrace gravels by the presence of larger quantities of chalk with a relatively low content of local Jurassic material

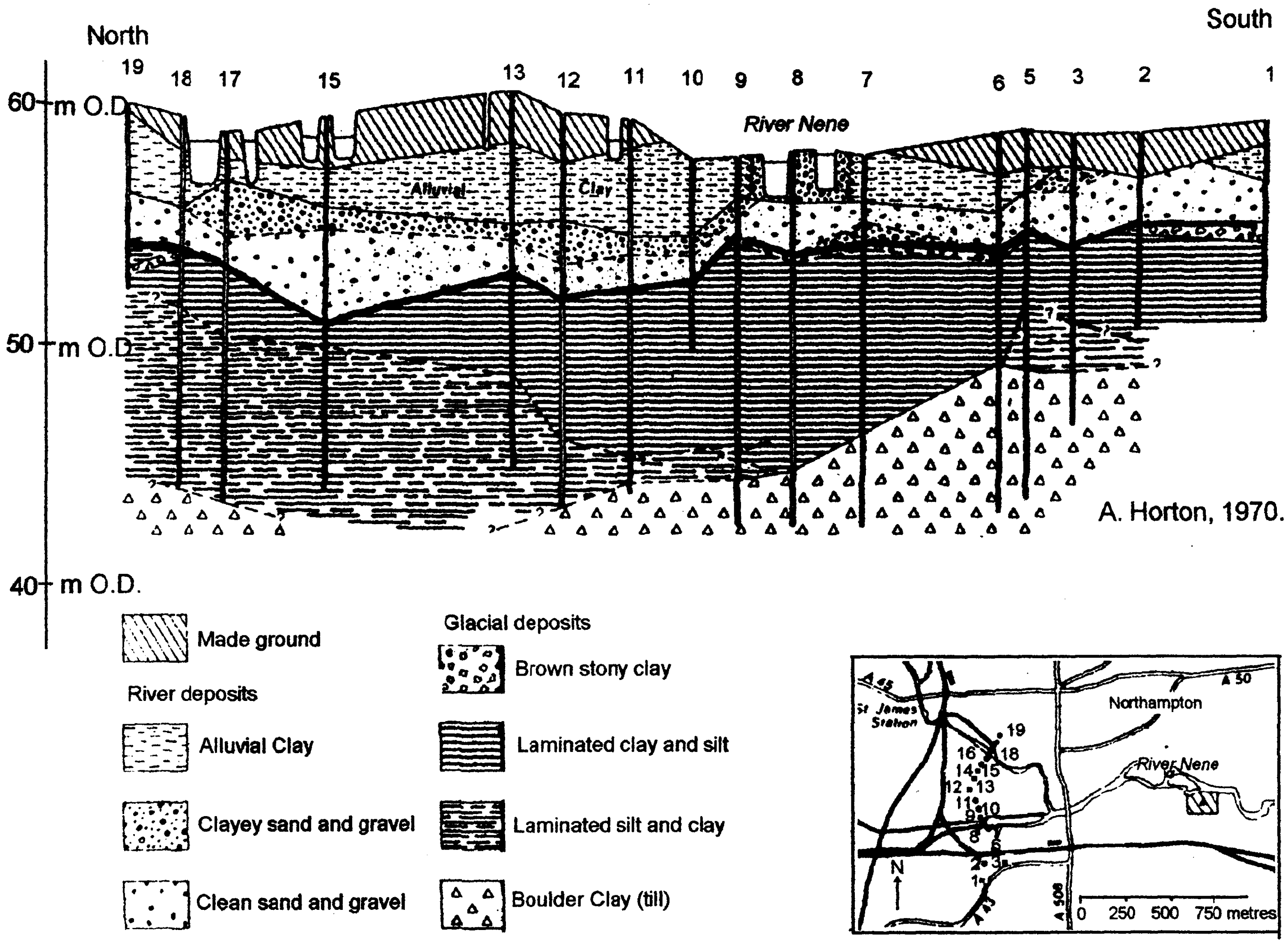


Figure 2.04.1. The drift deposits beneath the River Nene floodplain, showing the tunnel valley glacial lacustrine clays. (after Horton, 1970)

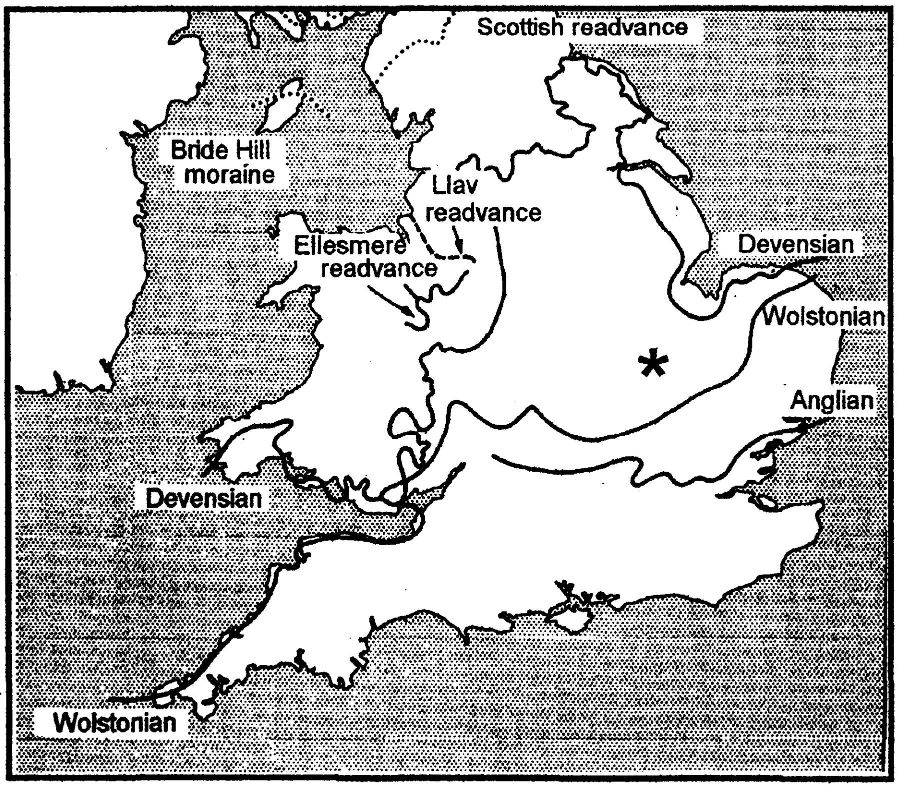
when compared with the latter. Hollingworth and Taylor (1946b) also observed, *"Where material resembling the lower till contains some flint and chalk it may be interpreted as lower till re-sorted and redeposited at the time when the chalky till was formed."* Hollingworth and Taylor (1946a) described the tills as up to 33.5 m thick with glacial gravels, in places, up to 7.0 m thick. The base of the tills is at 168.0 m. O.D. to the west and 67.0 m O.D. to the east of the Northamptonshire Ironstone Field. They cover the "*Jurassic landscape*", the exposures of Jurassic rocks being confined mainly to the valley-sides.

Sabine (1949) considered the abundance of Bunter clasts in the till to indicate derivation from the Kidderminster Formation in the north-west and this proposition was the most widely accepted point of view. However, Rose (1987) suggested that much of the Bunter in the chalky till may have been derived from local concentrations of gravel in East Anglia, which are equivalent to the Ingham Sands and Gravels of Suffolk, and that derivation was from the east. The clasts were picked up by the ice as it moved across the eastern areas of England prior to the Anglian glaciation.

As there is no terminal moraine Woodland (1970) suggested that the chalky till became separated from its source and melted out as a great mass of stagnant ice in which a tunnel valley system developed. He described the chalky till as Devensian in age due to the lack of "*degradation*" that he saw in the Saale ('Wolstonian') deposits of Denmark. The age of the chalky till has raised a great deal of controversy and the following authors, listed with their suggested age for the Chalky Boulder Clay till, have published their findings: Bristow and Cox (1973) - Saalian (= Wolstonian); Shotton *et al.* (1977) - Wolstonian; Perrin *et al.* (1979) - Anglian; Horton (1989) also followed Perrin *et al.* (1979) in considering the till in the Fenland to be a product of the Anglian glaciation (Oxygen Isotope Stage 12). The Oxygen Isotope Age of Stage 12 (based on Oxygen Isotope and palaeomagnetic stratigraphy of Equatorial Pacific core V28 - 238) is between 443,000 and 467,000 years B.P. (Figure 2.05.1) (Shackleton and Opdyke, 1973).

It is now thought that Thompson's 'Great' Chalky till is till of Anglian age (Perrin *et al.*, 1979), leaving a question mark against the age of the lower till.

A



Limits of glaciation in England during the Anglian, Wolstonian and Devensian (last) glacial stages, and readvances of the last ice sheet (after Lowe and Walker. 1984).
* area of current research.

B Approximate Age of Stage 12 in Cores from the Pacific.

Core no.	Depth to Stage 12 (cm)	TiO_2 to Stage 12 (mg cm^{-2})	Depth to Stage 19 (cm)	TiO_2 to Stage 19 (mg cm^{-2})	Age (yr)
58	230	360	400	540	467.000
59	570	260	970	380	461,000
62	320	190	600	300	443,000

Age of Stage 12 (Anglian) glaciation, assuming that Stage 19 is 700,000 yr (after Shackleton and Updyke, 1973).

Figure 2.05.1. A) The limits of glaciation in England. B) the approximate age of the Anglian Glaciation (Oxygen Isotope Stage 12).

2.06 Valleys filled with Anglian chalky glacial and post-Anglian glacial gravels.

Thompson (1895b) traced a drift filled valley for a distance of about 2.0 km from Abington Park eastwards towards Weston Favell Mill. The valley, 5.0 m deep, was infilled with chalky till and gravel containing large boulders and occasional great blocks of oolitic limestone. The same, or similar, valley deposits were seen at Bass's Stone Pit near the Racecourse and at Mr. Ireson's Brickyard, near the Kingsthorpe Road, Northampton. There are no mid-glacial gravel deposits recorded, but Thompson (1930a, 1930b) considered this channel to be of Mid-glacial origin. This channel is eroded to a lower level in the Nene Valley than those containing pre-glacial deposits.

Thompson (1896) described two dry valleys both near Towcester, Northamptonshire. The first one, high on a hill at Silverstone, was filled with 7.0 m of chalky gravel, A similar chalky gravel-filled valley, in which all the oolitic bedrock material had been eroded away, was discovered at Furtho. He considered both valleys were cut at the end of the last glaciation.

Thompson (1930a, 1930b) also noted that present day streams were flowing over and through drift (of chalky till or glacial gravel) filled valleys at Naseby and Cold Ashby.

2.07 Nene Valley Sands and Gravels

2.07.1 Stratigraphy and lithology.

The river terrace gravels in the Nene Valley are the result of erosion and redeposition of the tills and glacial gravels and the local Jurassic rocks following the retreat of the Anglian ice-sheet. The dominant components of the gravel are flint, Jurassic Iron-Sand- and Limestone, and Bunter quartz and quartzite clasts. Derived Jurassic fossils, such as belemnites and *Gryphaea*, are commonplace throughout the sediments and many Quaternary faunal and floral remains are found within the gravels (Morgan, 1969; Holyoak and Seddon, 1984; Smith, 1995).

Thompson began his work on the Nene Valley sediments in the 1890s, but wrote up the major part of his findings in 1930 a few years before he died. Thompson (1902) found that these gravels were remarkably different from those of the Milton Formation. The gravels contain, besides locally derived ironstone, sandstone and limestone, a large quantity of Bunter quartz and quartzite, chalk, flint and other far travelled erratics derived from the tills capping the Nene valley-sides.

Of the two major sources of the Nene River, Thompson (1930a, 1930b) considered that, as gravels were seen to extend several kilometres further upstream in the Naseby stream, the Naseby Nene was older than the Staverton Nene. The discovery of gravels that range "*from five feet above to thirty feet below present water level*" (Thompson, 1930a) at the junction of the Naseby Nene and Staverton Nene at Northampton led Thompson to suggest that deep erosion occurred due to a "*great swirl*" of gravel laden water being constrained suddenly to take an easterly course by impinging upon Hunsbury Hill. The lower eight metres, he said, were "*Mid-glacial*" gravels "*free from all traces of indigenous animal or vegetable life*" and they lay beneath two metres of fossiliferous post-chalky till gravel. Thompson (1904) suggested that the lower gravels were deposited in a glacial period prior to the one that deposited the chalky tills. He assigned the upper gravel to a later period of glaciation following an interglacial period in which the remains "*of an older fauna, such as the mammoth, elephant, rhinoceros, hippopotamus, reindeer, wild hog, ox and horse*" accumulated in the alluvium of the interglacial flood plain. The remains were washed from the alluvium into the younger, upper, gravel as the second ice-sheet ice sheet melted away (Thompson, 1904).

In the 1970s, Castleden (1970, 1980b) examined the stratigraphy of the Nene Valley from Northampton to Peterborough. As it was believed then that the 'Wolstonian' ice sheet covered the area as far as Northampton, Castleden (1980b) established early Holocene and Devensian dates for the floodplain and First (8, 920-28, 225 B.P.), and Devensian for the Second (between 57,000 and 45,000 B.P.) and Third (between 87,000 and 65,00 B. P.) Terraces of the River Nene. His theory was backed up by what was thought then to be infallible radiocarbon dating of the organic material from the gravel beds. There is still no available dating to suggest that the Nene Valley gravels are of an older than the Devensian Stage. Castleden (1976) envisaged the early River Nene as a braided river flowing over an uncohesive surface. He suggested it would be flowing through a tundra landscape with the river's maximum run-off occurring in the late spring and summer months. He believed the involutions seen in the upper gravels were induced during the late Devensian.

Shotton (1973) said the Second Terrace of the Nene was firmly fixed as Middle Devensian by its beetle fauna and floral evidence found at Great Billing (Morgan, 1969) which was radiocarbon dated at 28,225 +/- 330 years B.P. (Birm. 75).

2.07.2 Fossiliferous evidence from the Nene Valley Gravels (Map: Figure 1.01.5).

One of the earliest fossil finds in the Nene Valley was a tooth of *Elephas primigenius,* found in gravels at a junction of a tributary which joined the Naseby Nene at Northampton (Thompson, 1897). Earlier, in 1881, Thompson, (1904) had obtained five tusks, nine teeth and two fragments of limb bones in a terrace of post-Anglian glacial gravels at Cow Meadow gravel pit in Northampton. From the fossil evidence (identified as woolly mammoth and woolly rhinoceros) he deduced the following, *"The sequence of events.....is this:- on the breaking up of the first Glacial Period, prolonged and terrific floods deepened the Nene Valley to its greatest depth and left its lowest parts filled, near to Northampton, with 30 feet [9.5 m] or more of gravel, free from all traces of indigenous animal or vegetable life. Upon this, during the inter-glacial period, alluvium accumulated, and in it was buried a portion of the indigenous flora and fauna. Glacial conditions again prevailed, and the Nene Valley was once again filled with Boulder Clay. On its breaking up a second wash-out occurred. The resultant floods were probably less violent than before...but more prolonged. This gave us the river gravel with its Mammmoth remains &c.........".* As Thompson was not aware that these two species usually represent a cold, periglacial climate, he suggested that the two species co-existed with interglacial species typical of the modern British fauna.

2.07.3 Little Houghton (Holyoak and Seddon, 1984) (Figure 1.01.5).

The fossiliferous samples from Little Houghton gravel pit, near Weston Favell, Northampton, (c. TQ 7960) were recovered from two channel-fills beneath 3.0 m of gravel. The channels cut into the bedrock of Lower Jurassic Blue Lias mudrock and were 2.0-3.0 m in width and no more than 0.5 m in depth. There was evidence of periglacial activity within the gravels above including an ice wedge cast. Identification of plant macrofossils and analysis of pollen grains from the deposits indicated that at the time of deposition there was a cold, dry, tree-less landscape similar to those of modern northern or montane ranges. The molluscan fauna comprised a few cold tolerant species. These, the remains of *Microtus* sp. and a molar of *Mammuthus primigenius* (Blumenbach) gave evidence that cold climatic conditions were prevailing at the time. The presence of the ice wedge cast within the gravels shows that the cold conditions may have continued throughout the deposition of the gravels. It was concluded that the Little Houghton site was of simiiar Mid-Devensian age to the examined at nearby Great Billing (Morgan, 1969).

2.07.4 Little Houghton (Smith,1995) (Figure 1.01.5).

This deposit, at Clifford Hill gravel pit, Little Houghton, Northampton, was interpreted as a warm stage pond sediment, possibly pre-stage 5e (Ipswichian) in age, overlain by cold stage deposits of sand and gravel.

Fossil species recorded at this Little Houghton site include:

Molluscs (warm stage pond sediments): *Lymnaea stagnalis, Lymnaea trunculata, Bithynia tentaculata, Succinia oblonga, Sphaerium comeum, Trichia plebia* and *Pupilla muscorum.*

Mammals (warm stage pond sediments): *Mammuthus primigenius,* bison sp.

Mammals (Cold stage gravels): *Palaeloxodon antiquus, Coelodonta antiquitatis,* bison sp. and *Lemmus lemus.*

2.07.5 Great Billing. (Morgan, 1969). (Shotton's second Terrace, 1973) (Figure 1.01.5).

Carbonaceous sandy clay deposits in the lowest 1.5 m of horizontally bedded gravels at Great Billing (SP617826) showed evidence of post-depositional periglacial activity. Plant and beetle remains extracted from these deposits were identified as species found in cold, dry, open treeless landscapes similar to that of the tundra regions of Northern Europe today. Bones found at the site were identified as belonging to the species *Coelodonta antiquitatis, Mammuthus primigenius* and *Rangifer tarandus.* Molluscs, beetles and flora were frequently of cold stenothermal forms. A sample of the organics gave a radiocarbon date of 28,225 +/- 330 years B.P. (Birm. 75). From the evidence collected it was concluded that, at the time of gravel deposition, the climate was severe with an average annual temperature of -6^{o}C. and an average July temperature of 10^{o}C. The high proportion of stenotherm faunas suggests that this is one of the coldest sites investigated in England for that time and correlates with Brandon Terrace (Coope, 1968) radiocarbon dated to ~ 30,000 years B.P. (N.P.L.87; Birm 10; Birm 27).

2.07.6 Titchmarsh (Holyoak and Seddon, 1984) (Figure 1.01.5).

At Titchmarsh (TL 0980) no evidence of periglacial activity has been found within the gravels. The fossiliferous samples were collected from an upper and a lower channel within gravels 4.0 m thick. The lower channel, interbedded with the gravels, was 2.5 m above bedrock. The upper channel was situated within the surface gravels beneath floodplain silts and clays. The species of pollen and molluscs recovered from the lower channel indicated an open tree-less environment; the absence of periglacial features and the molluscan fauna were considered to indicate a Late Devensian, rather than a Mid Devensian age. The pollen and molluscan assemblages from the upper channel implied there had been extensive grassland and some cereal production near the channel floodplain. Forest clearance may have also taken place at the time the channel was active. The presence of cereal suggests a Holocene (Flandrian) date for the upper channel.

2.07.7 Orton Longueville (Holyoak and Seddon, 1984) (Figure 1.01.5).

The gravels at Orton Longueville (c. TL165971) showed no evidence of periglacial activity and, as at Titchmarsh, an upper and lower channel were present in the gravel. The lower channel, beneath 1.0 m of gravel in gravel 2.5 m thick, yielded species of flora and fauna usually associated with a Late Devensian age. The molluscan fauna did not contain any woodland species. A marked unconformity existed between the Late Devensian and the upper channel, which contained many shells of freshwater Mollusca, truncated tree roots and fragments of pottery typical of the Iron Age. The pottery was unlikely to have been made before 500 B.C. or after 400 A. D. The upper channel was considered to post-date forest clearance in the area. This was thought to have given rise to soil erosion and the development of a silty alluvium across the Nene Valley.

2.07.8 Nene Valley: Conclusions.

It has been seen, so far, that much of the gravel deposit in the middle reaches of the Nene Valley, Central England, has indicated a mid-Devensian or later date for the deposit. The landscape, at the time of deposition of the gravels, has been interpreted as one that was extremely cold, open, tree-less and periglacial in form. The flora and fauna analysed were consistently cold climate species typical of an arctic tundra environment. Some of the species are now extinct or can only be found in cold northern regions. Radiocarbon dating of material taken from Great Billing gave a date of ~ 28,225 B.P (Birm. 75). The recent finds of *Palaeoloxodon antiquus* and other temperate fossil remains below the gravels at Clifford Hill (Smith, 1995) indicate that there is, in fact, good reason to conclude that an Ipswichian or older date can be applied to at least some of the deposits in the Nene Valley. It is probable that the gravels are not all of one depositional phase, it seems very unlikely that all date to the Brandon / Great Billing Stage.

CHAPTER 3: APPROACHES TO THE RESEARCH: DESK-TOP STUDY METHODS AND TECHNIQUES.

3.01.0. Introduction.

The desk -study was directed towards the following:

a) A reappraisal of past research of the Northamptonshire fluvial sediments and tills (Chapter 4).

b) A reappraisal of published ostracod data particularly relating to fine sediments within coarse fluvial sediments, but some still-water sediments were also covered (Past research: Chapter 5).

3.01.1. Desk study of geology and palaeo-topography (Chapter 4).

The desk study of Northamptonshire topography was aimed, particularly, at finding out how much the changing climate has affected the palaeodrainage patterns of the county. To meet this objective it was necessary to collate the findings in the old literature with new borehole information collected from recent roadway extensions and building sites within the Nene Valley, Northamptonshire. Use has been made of aerial photographs and records kept at the Borough's Archaeological unit.

To work out the topography of the landscape beneath the tills it was necessary to draw sections from the local geology maps and 1:50 000 Landranger maps (Chapter 4).

The scale of the sections are: horizontal - 1cm = 1 km, vertical - 5x the horizontal.

It is, however, realised that evidence from the maps is only as accurate as the geological and topographical information within them.

A new possible chronological order of events has been proposed (see Chapter 4).

3.02.1. Desk-top Ostracod analyses (Chapter 5).

The aims of the study of the ostracod literature was:

a) To collate the ostracod data and environmental information from studies conducted in Central England and East Anglia, in particular those from sites with coarse sediments.

b) To establish i) what species of ostracod were likely to be encountered in similar sediments to those of the present research, ii) the habitats used by ostracods in braided stream environments, iii) which species became extinct in the Quaternary and the period in which they become extinct, iv) what the number of fossil species and their relative abundance within the sediments tell us about the environment of deposition.

c) To put together new tables, drawing upon the ostracod data available from past and current research (Chapter 5).

3.02.2) Presentation of results from desk study.

From this data the desk study tables were designed to produce criteria by which the past analyses could be applied to the present fossiliferous deposits (Chapter 5, section 5.02.1). Tables were put together from the past research data to show the chronological order in which the freshwater ostracod species fluctuated or became extinct in the Quaternary of Central England and East Anglia (Chapter 5, section 5.02.2). Also, tables were drawn up describing the present day habits and habitats of ostracod species found in the sediments of the Milton Formation and Nene Valley (Chapter 5, section 5.02.3).

If the past and present ostracod data did not appear to correlate then a new standard would be set out whereby past research could be reaccessed against the data from this research.

CHAPTER 4. THE RELATIONSHIP BETWEEN THE GEOLOGICAL STRUCTURES, PALEOVALLEYS AND PALAEO-INTERFLUVES IN CENTRAL NORTHAMPTONSHIRE: A DESK STUDY.

4.01. Introduction

The aim of this desk study is to clarify the underlying geological structure and the distribution of the palaeo-valleys and palaeo-interfluves in central Northamptonshire. The desk study also includes an examination of published and unpublished reports on the upper and lower tills and their associated glacial and preglacial features as seen in the landscape of central Northamptonshire. From this evidence a suggested chronological order has been given to the erosional and depositional events that concern the Quaternary fluvial system of central Northamptonshire.

Figure 4.01.1 shows a plan of the cross sections drawn up to examine the geology of central Northamptonshire for discussion in this chapter. The cross sections drawn not only include the evidence from Ordnance Survey and Geological Survey maps, but also borehole information from both unpublished and published works. The discussion also draws upon and occasionally reinterprets the information from past research discussed in Chapter 2. The modern drainage basins of the area discussed are illustrated in Figure 4.01.2.

4.01.1. The early drainage system

Prior to the Pleistocene, the early flat topography of central Northamptonshire was considerably altered by the breaking up and faulting of its limestone platform (Thompson, 1902). This led to the uplifting of the Northamptonshire Uplands and the development of synclines in the Lower Jurassic clays. Thompson (1902) suggested some major faulting may have occurred as late as the Pliocene.

a) Synclines

The rivers, as shown on the Geological Survey sheets, appear to follow synclines in Northamptonshire. Such is the case for the modern River Nene between Northampton and

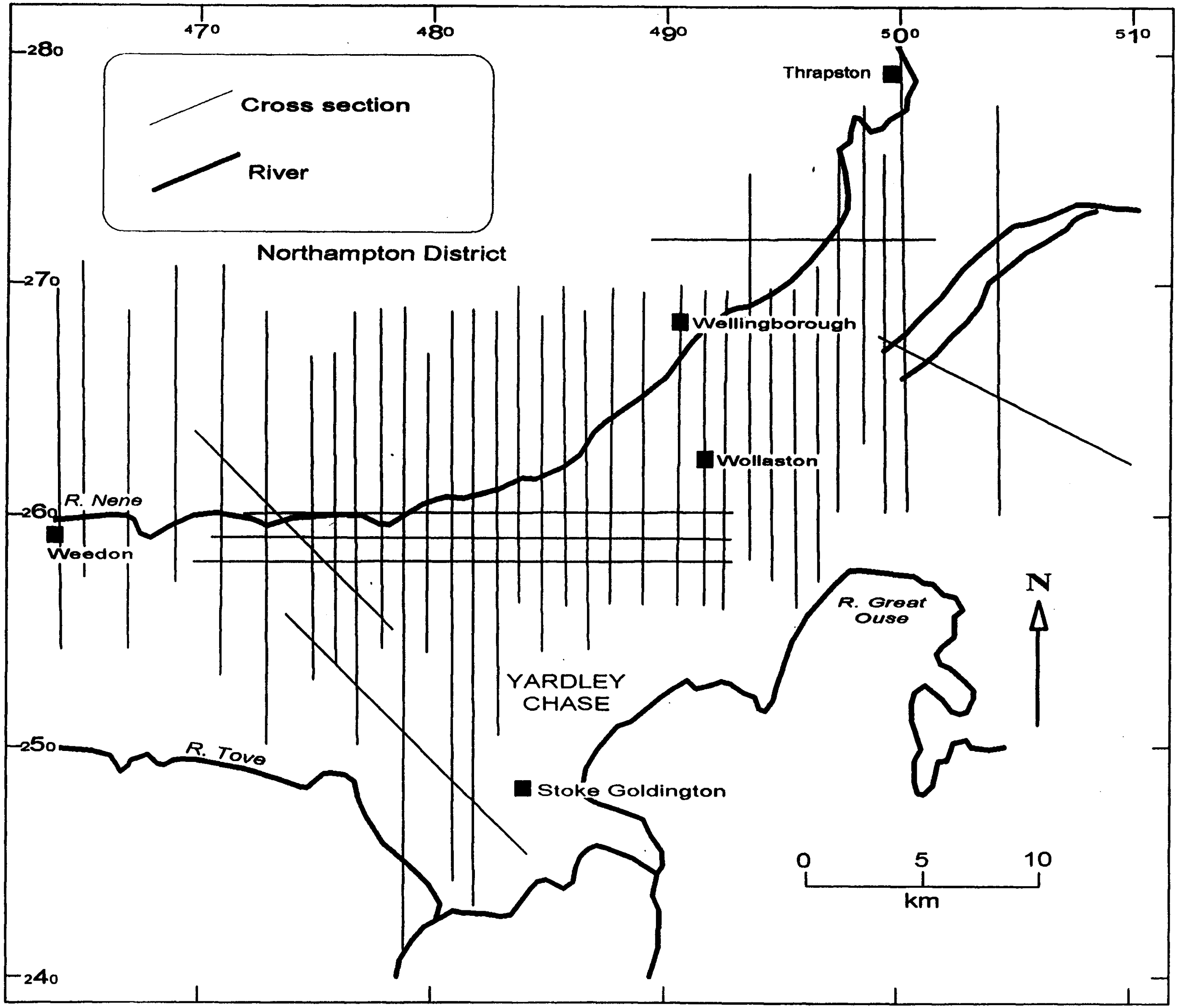


Figure 4.01.1. Plan of sections drawn up and discussed in Chapter 4. The numbers used are map reference numbers of the area investigated.

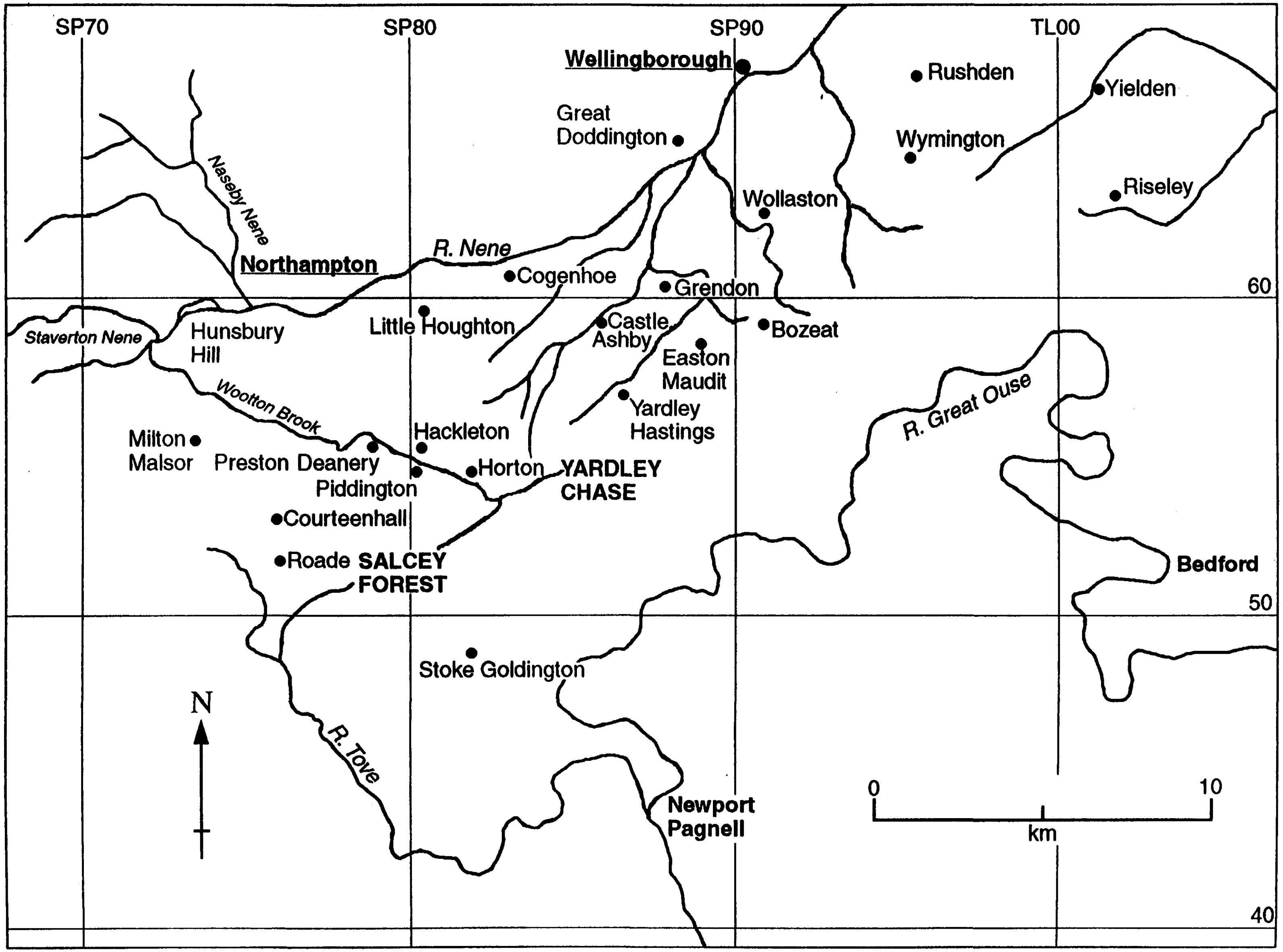


Figure 4.01.2: Map of the drainage basins discussed in Chapter 4.

Wellingborough, (Sheet 186, Wellingborough: Geological Survey, 1974), the River Tove (Sheet 202, Towcester: Geological Survey, 1969) and the Naseby Nene (Sheet 185, Northampton: Geological Survey, 1960).

Between Northampton and Wellingborough the River Nene follows the axis of a south-west - north-east trending syncline and forms the main natural drainage basin for the Northamptonshire Uplands. From the distribution of the Milton Formation east of Northampton it is to be seen that the Milton River also followed the axis of the same syncline downstream of Hunsbury Hill. The inward dips of the syncline, for example in the Nene Valley at Great Houghton, Northampton, (Figures 4.01.3 (Key to all sections) and 4.01.4) make the beds above the Lias clays susceptible to cambering and sagging due to down-dip movement (Hollingworth and Taylor, 1946).

b) Faults.

Central Northamptonshire has been subjected to much faulting; the largest, the Northampton Fault, lies to the west of Northampton, between Northampton and Weedon. It stretches a distance of 17.5 km and, at Northampton, it has a downthrow of at least 21.5 m to the north (Thompson, 1902). Hunsbury Hill, Northampton, at the eastern end of the fault, has a maximum throw of 49 m. Discontinuous faulting to the south shows a downthrow to the south. The downthrows to the north and south created a relative uplift to the land between the faults, that is, the strip of land south of the Northampton Fault. The faulting is featured in cross-sections A & B of Figures 4.01.5 and in Figure 4.04.1 of Section 4.04. The raised land would have formed an interfluve that kept the early Northampton upland drainage channels (which included the early Nene) separate from the southern valley. The drainage water to the north of the relatively uplifted land may have entered the Milton Valley, as a tributary, eastwards of Northampton. The Milton Formation is found in the area south of the Northampton Fault, south of what was once the relatively uplifted land, which is now, apart from Hunsbury Hill, eroded down to valley bottom level

The erosion of the relatively uplifted land created a situation where, at the ground surface, hard rocks were juxtaposed to softer, more friable rock.

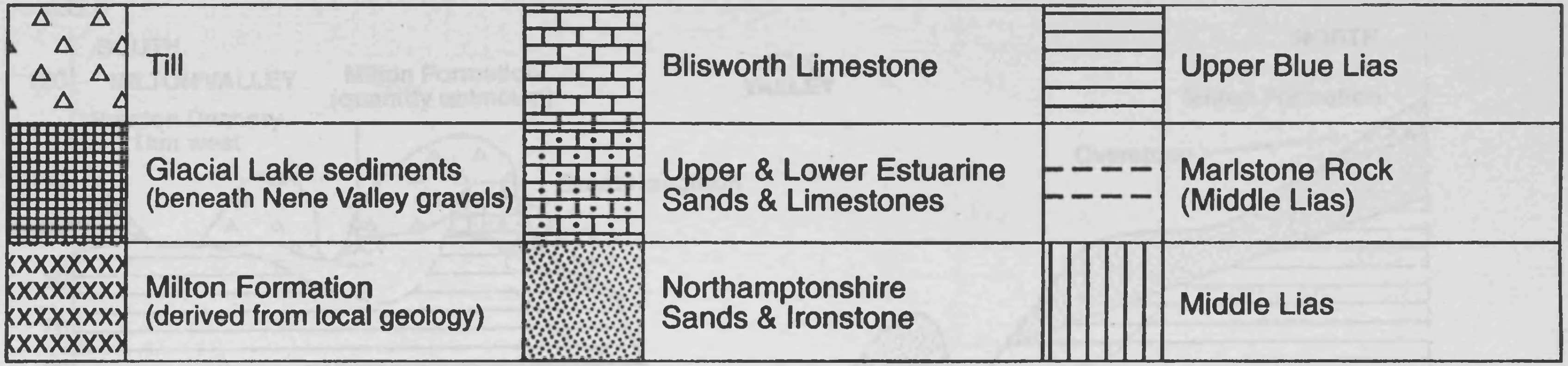


Figure 4.01.3 Legend to geological cross sections.

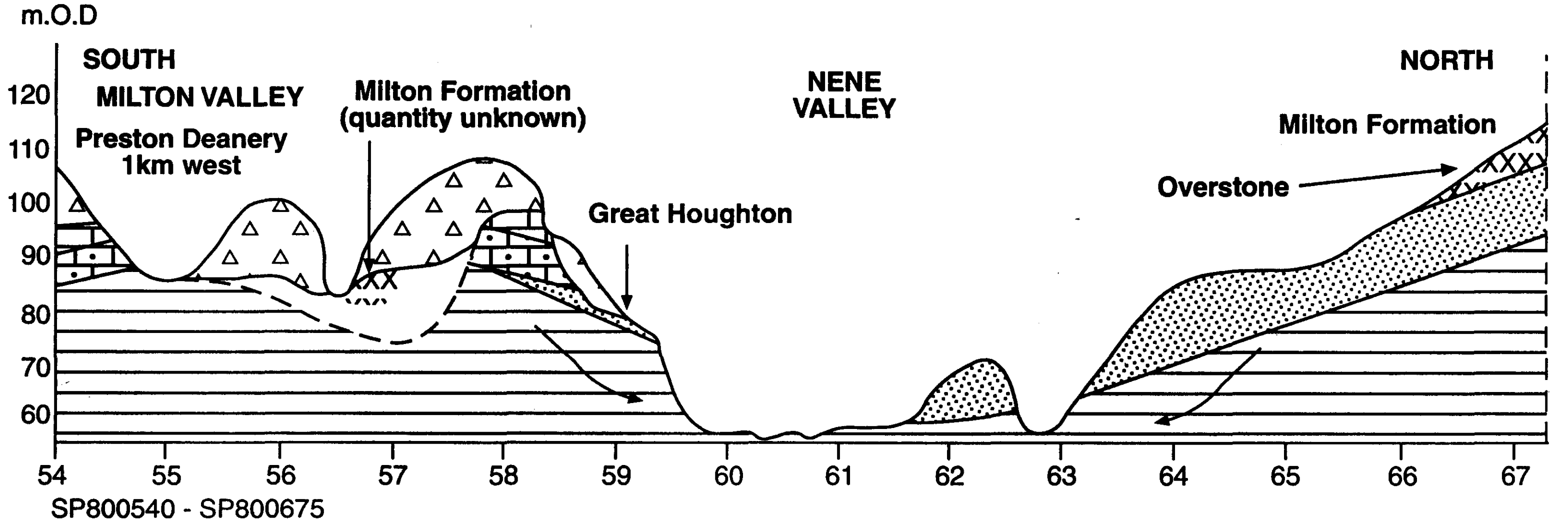


Figure 4.01.4 Section showing the synclinal form of the Nene Valley between Northampton and Wellingborough. Arrows indicate lie of bedding in the geological formation. (For key, see Figure 4.01.3)

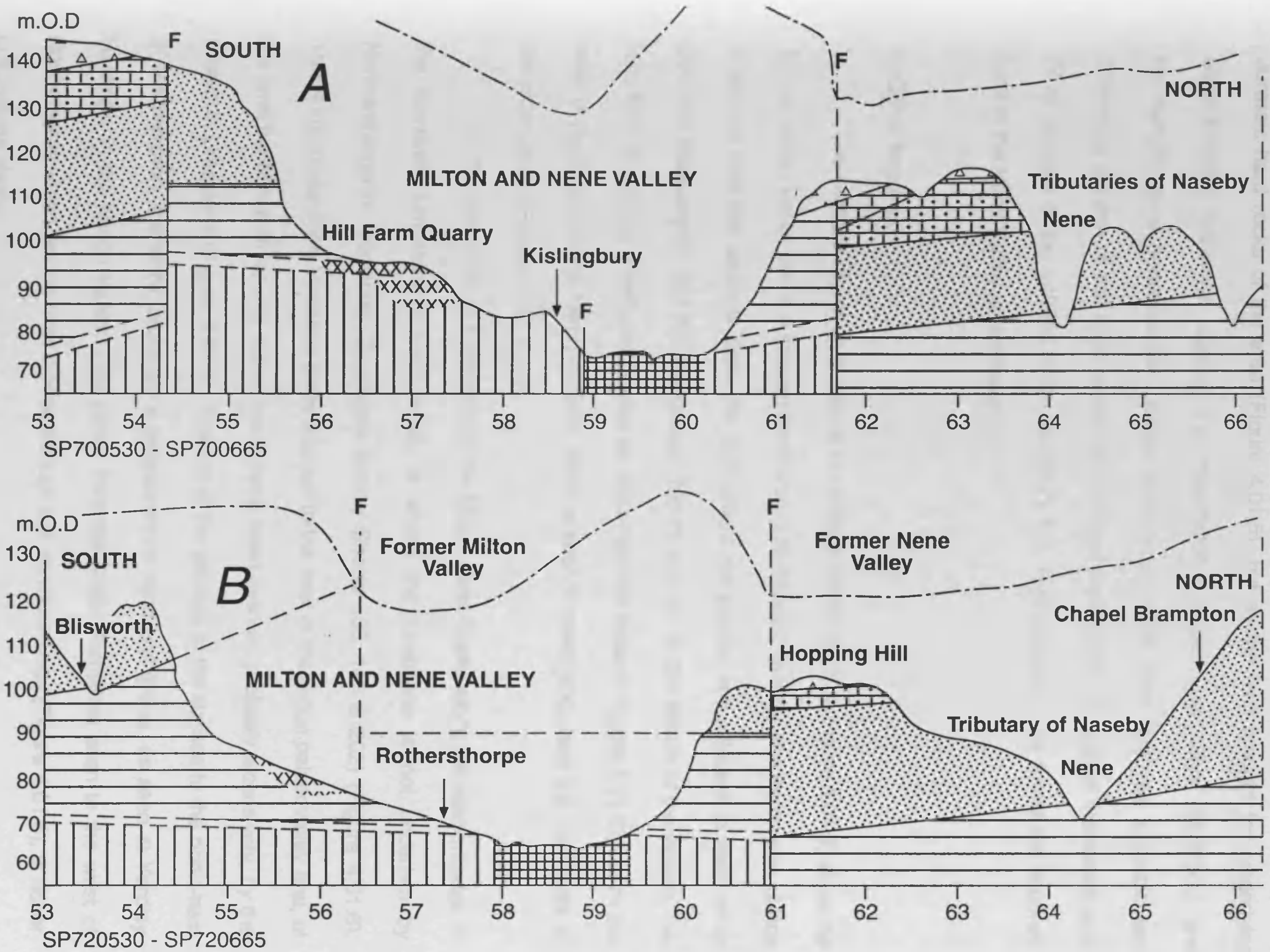


Figure 4.01.5 The sections above, 2.5 and 1.5 km upstream of Hunsbury Hill, demonstrate the amount of erosion that may have occurred since faulting took place. After erosion, the two valleys became one, causing the Milton River to divert northwards. (For key, see Figure 4.01.3)

The uplifted hills to the west of Northampton would have been capped with the Jurassic hard rocks of the area (Figure 4.01.5), but as the fault brought the underlying water-bearing Marlstone against the impermeable Upper Lias clays (mudrock) and Northamptonshire Ironstone the uplifted area would have been relatively unstable and differential erosion of soft rocks would have caused rapid decay of much of the raised land. What remains of the uplifted land - Hunsbury Hill, Northampton - now forms the southern flank of the Nene Valley at Northampton.

c) Other features.

The sections drawn up of central Northamptonshire (such as Figure 4.01.5) show the former Milton Valley and the modern Nene Valley at different levels in the landscape. Maps drawn up from the sections show the two valleys are parallel and adjacent to each other between Northampton and Wellingborough (Figure 4.01.6). In this stretch of the valleys, the hills form occasional interfluves (shown as cross-hatched areas in Figure 4.01.6), but to the west of Northampton the lower, modern, valley is seen to bisect and share the interfluves of the older valley (Figures 4.01.5 & 6).

To the north-east of Northampton the Milton River flowed along the eastern edge of the Blisworth Limestone outcrop which is where the Limestone is not underlain by Northamptonshire Ironstone (Geological Survey Sheets 185, 186 & 202) (Figure 4.01.6). The Northamptonshire Ironstone Beds crop just to the west of the Milton palaeovalley and, at the time the Milton River was active, would have been overlain, probably extensively, by the Blisworth Limestone (Figure 4.01.6). Erosion of the geology at the surface to the north-east of Northampton, therefore, produced a limestone-rich sand and gravel, as seen at Yardley Hastings, in the Milton Valley. This varies from the Milton Formation seen to the west of Northampton which, as the river eroded through the Ironstone beds (Figure 4.01.6), is richer in Ironstone clasts.

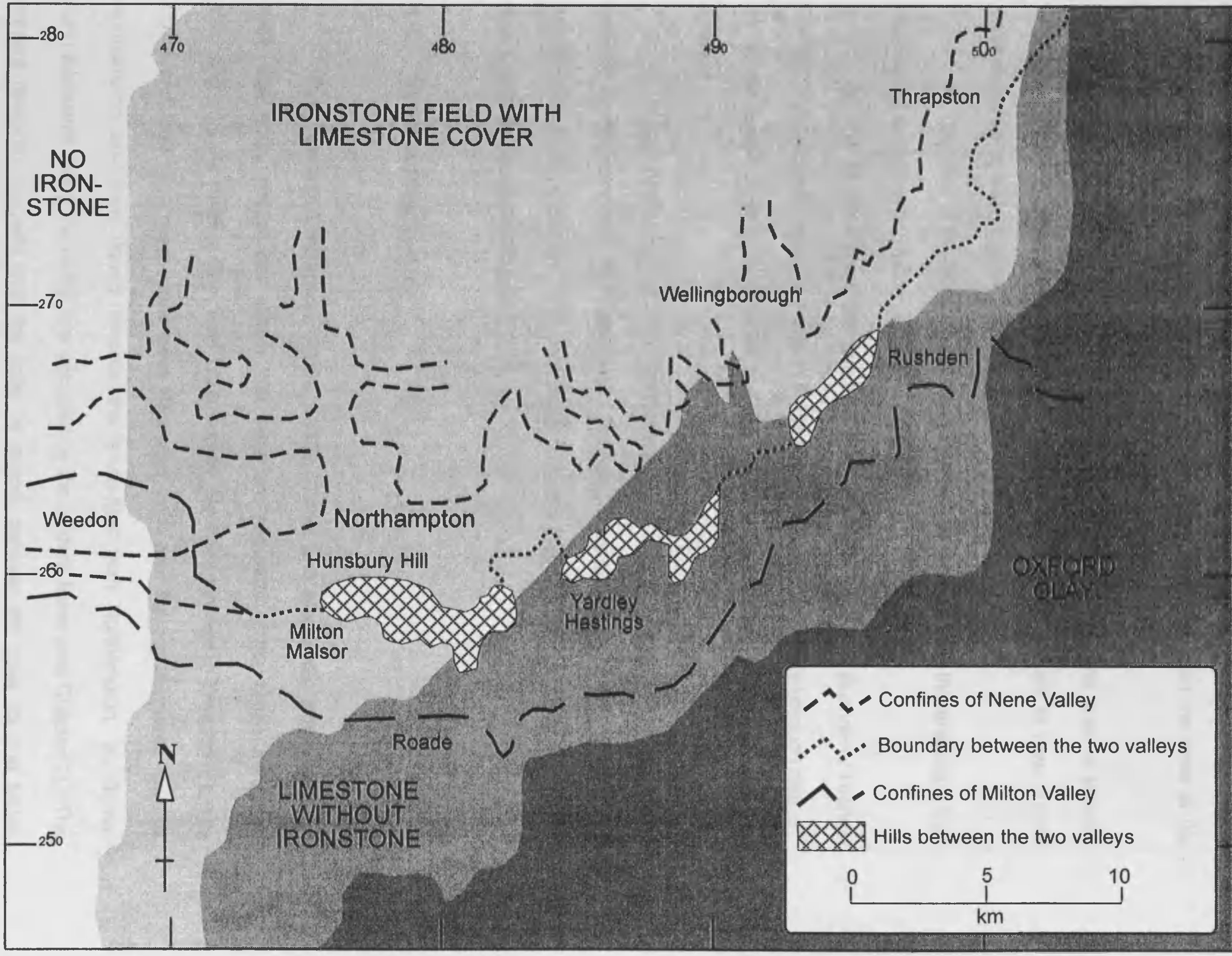


Figure 4.01.6 The position of the Milton palaeovalley in relation to the modern Nene Valley within the hard rock geology.

d) The sections indicate the following:-

i) That the tops of the hills flanking the older valley-bottom, where not breached by ancient or modern tributaries, are 20 m or higher in the landscape than the base of the Milton Formation.

ii) That the Milton River flowed in a valley passing through the area of Preston Deanery then north-eastwards towards Rushden. At Rushden it appears to have turned towards the south-east (Figure 4.01.6 and Figure 4.05.2 of Section 4.05).

iii) The base of the Nene Gravels is approximately 20 m lower in the landscape than the base of the Milton Formation (Figures 4.01.5 & 4.01.7).

iv) That at some stage the 'Milton' Nene River was diverted at Rushden / Higham Ferrers, from the south-easterly direction it was following, towards the Peterborough district in the north-east of Northamptonshire and then to the modern Wash on the east coast of England.

The topography and geology therefore suggests that in central Northamptonshire, between Northampton and Wellingborough / Rushden, there may have been in the past two parallel river systems present. The desk study suggests they may be distinguished by time, space, altitude and sediment type.

4.02. The Milton River system

Past research (Thompson, 1930a, 1930b; Clarke and Moczarski, 1982; Belshaw, 1989, Castleden, 1980a) has shown that there are remnants of the Milton Formation extending from the Watford Gap, near Long Buckby, Northamptonshire to Weedon (Figures 1.01.4 and 2.02.1). These sands were deposited by a river flowing eastwards towards Northampton and then flowed towards the south-east from Northampton, or, flowed north-eastwards along the valley now occupied by the modern Nene (see Chapter 2). The present research suggests that the latter is almost certainly the case for the Milton Formation, the Milton Valley being parallel, but to the south and south-east of, the modern

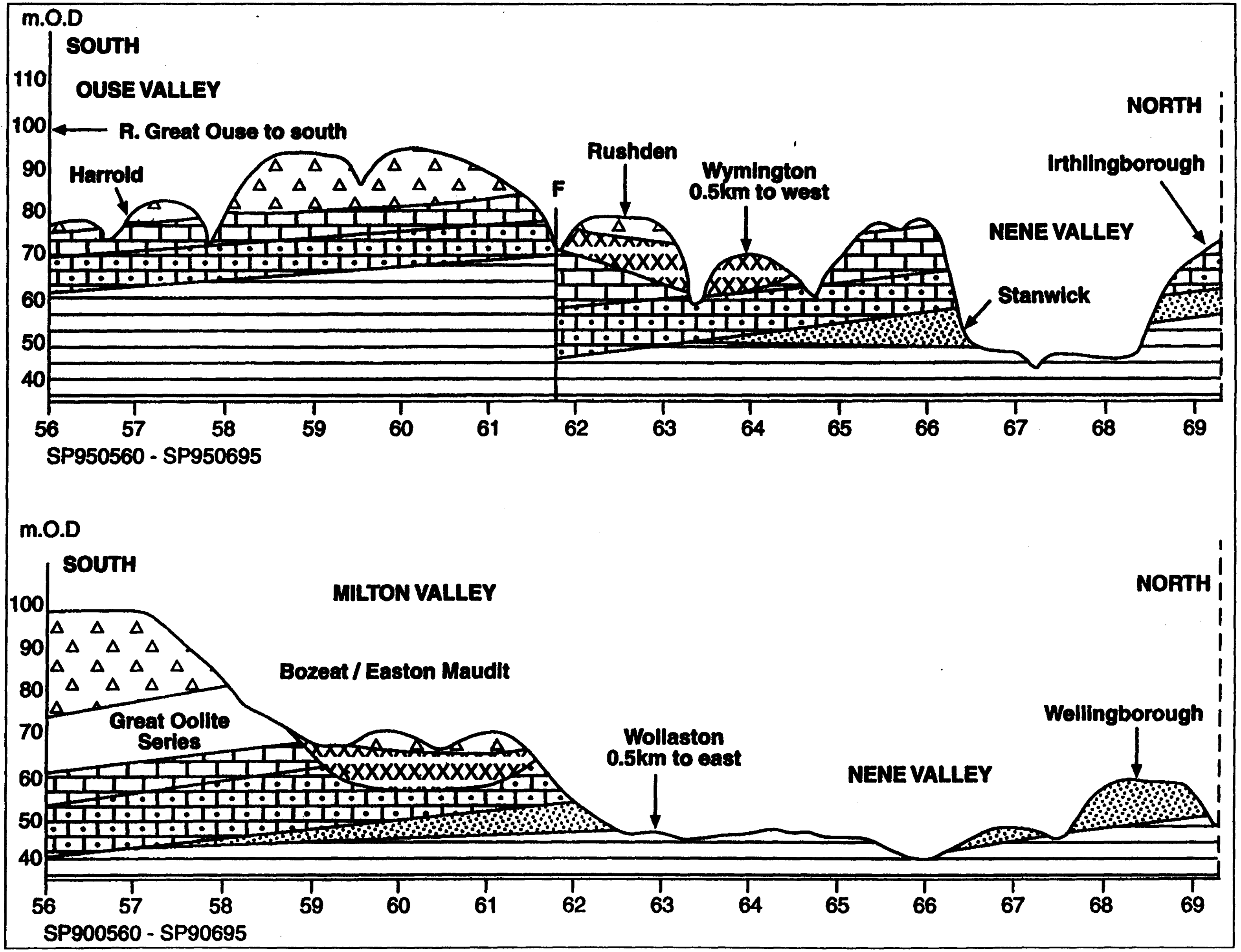


Figure 4.01.7 Two sections between Northampton and Rushden which show the difference in elevation between the Milton and Nene valleys. (For legend see Figure 4.01.3)

River Nene. The Milton Formation crops out near Bozeat (Section B of Figure 4.01.7) at between 63-70 m O.D. (SP897595), near Wymington (Section A of Figure 4.01.7), at 62-75 m (SP952645) and around Rushden / Higham Ferrers, at 62-65 m (SP980689). The outcrops south-eastwards from Rushden are seen under chalky till at ever-decreasing altitude, for example, between Risley and Swineshead, Bedfordshire, at 61-72 m (TL045648) and near Keysoe, Bedfordshire, between 59 and 76 m (TL090627).

A key point of discussion in past research (Thompson, 1930a, 1930b; Horton, 1970; Castleden, 1980a) is the role the range of hills, including Hunsbury Hill, Northampton, may have played in the development of the Milton River. Hunsbury Hill is the eastern remnant of a range of hills, now eroded away, that was upraised along the Northampton Fault to the west of Northampton. There was also a range of hills to the east, between Northampton and Wellingborough, much of which still occupies the landscape (cross-hatched areas of Figure 4.01.6). From the desk study, assuming the eastern hills are of the same age as those associated with the Northampton Fault, it is likely that these hills, like the fault raised hills to the west of Northampton, once formed the watershed to the north of the Milton River. The Milton River appears to have flowed in a north-easterly direction through central Northamptonshire, changing its course to the south-east at Rushden / Higham Ferrers.

At Little Houghton, to the east of Northampton, the Milton Formation occurs at a slightly higher level, 73-78 m O.D. (SP807594), than the general trend of the outcrop would suggest. This outcrop could be linked with two other Milton Formation-like deposits occurring to the north of the main deposit, in the Overstone area at 110 m O.D (Figure 4.01.4). However, the full thickness of the preglacial sands and gravels are not known at this point and these remaining sediments may have been the upper part of the valley fill, the Milton Valley being up to 15 to 20 m deep in parts (Figure 4.05.1 of Section 4.05).

4.03. The Anglian glacial and post-glacial drainage system.

The modern drainage system, though still flowing north-eastwards from Northampton to Wellingborough, differs from the original system in that the main river, the River Nene, is

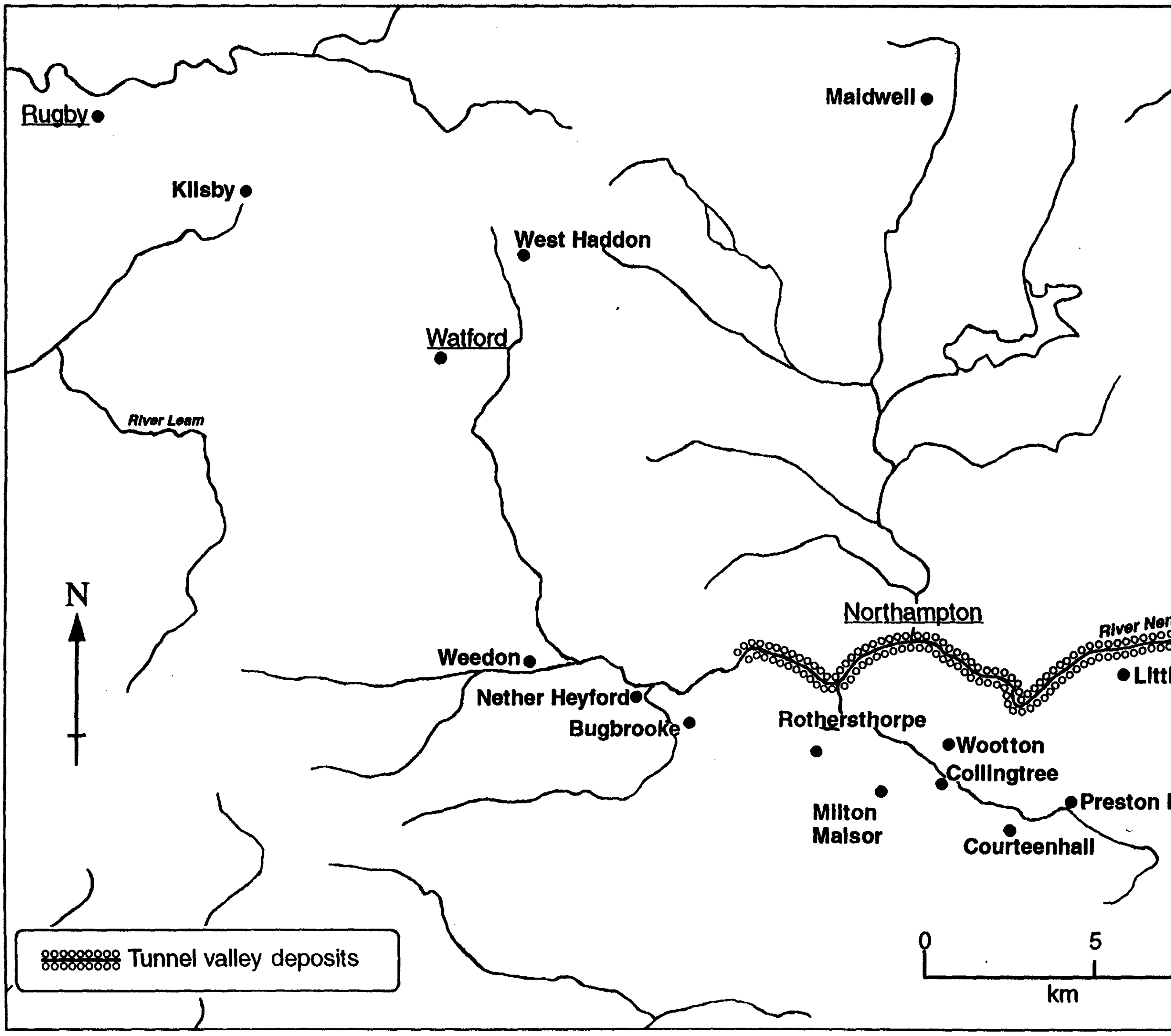


Figure 4.02.1. The drainage basin of the upper and upper middle River Nene and tunnel val

approximately 20 m lower in the landscape. It also flows in a valley parallel to, and to the north and north-west of, the former Milton River Valley.

Much of the water in the modern Nene Valley now flows off the surface of the till-covered interfluves and the till-filled valley of the old Milton River system. For example, the Wootton Brook of the Salcey Forest area south-east of Northampton (Figure 4.01.2) and the tributaries crossing the Wollaston area near Wellingborough (Figure 4.01.2). The Salcey Forest area is the modern watershed of the rivers Nene, to the north, the Great Ouse, to the south and south-east, and the Tove to the south-west.

The sections in this area revealed a large till-filled channel (Figure 4.03.1) which once contained a river, or a tributary, flowing to the south. Two smaller tributaries now cut down through the till and flow south-westwards to join the River Tove, a south-eastwards flowing river in the bottom of a syncline to the south-west of the area described.

As current thinking is that the route of the River Great Ouse between Newport Pagnell and Bedford developed during or after the Anglian period (Belshaw, pers. comm.), it is possible that the River Tove may have been an ancient river that drained the southern banks of the hills of the water parting between it and the Milton River to the north. If so, it would have flowed at a higher altitude, as did the Milton River at that time.

The sections across the area south of the Milton Formation deposits at Northampton (A of Figure 4.03.2) show that, apart from where a buried channel crosses the Yardley Chase area (discussed later in this chapter), the limestone ridge between the valleys of the Tove and Great Ouse is too high to have allowed the Milton River to flow southwards (B of Figure 4.03.2). Unfortunately, the core geological information for the south-eastern area was destroyed in World War II and the only geological information traced by the author was from Horton (1970) and Castleden (1980a). The borehole and well record evidence discussed by Castleden lie within the present predicted boundaries of the Milton Valley (Figure 4.01.6) and so can contribute to the explanatory model being developed here, although the interpretation of the till-filled valley to the south-east is different. Because the River Great Ouse, in pre-Anglian times, flowed to the south of its present course in the Olney area (Rogerson *et al.*, 1992; Green *et al.*, 1996), the interfluve to be crossed between the earlier

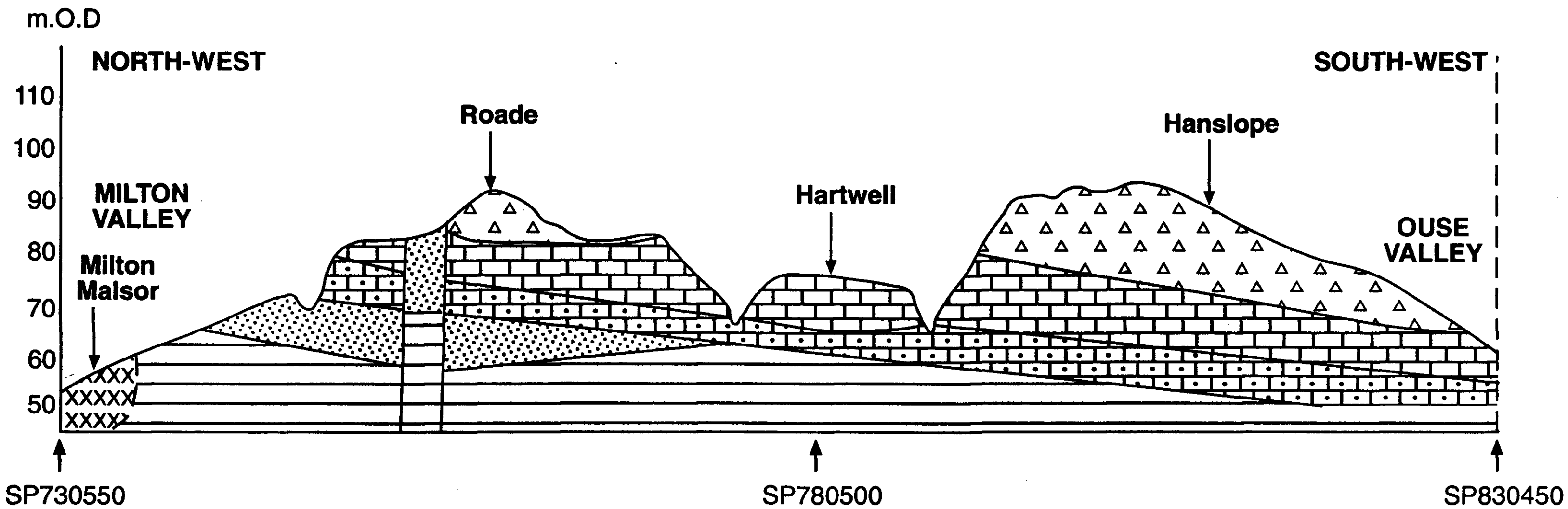


Figure 4.03.1 A section across the Salcey Forest area from the Milton Valley in the north-west to the Ouse Valley in the south-east. The section shows a till-filled valley, but it is at too high an elevation to be either the Milton valley or the Yardley Chase Valley. (For key, see Figure 4.01.3)

River Great Ouse and the Milton River would have been more extensive and higher in altitude than that of today. If this was so, it is likely that Castleden's proposal (1980a), that the Milton River flowed south-eastwards to the River Great Ouse through the now till-filled valley of Yardley Chase, is incorrect. That a buried valley exists, dropping in altitude towards the River Great Ouse at Olney, Bedfordshire, cannot be refuted. However, if there is a buried valley, the section of the channel at Piddington, Northampton, discussed by Castleden (1980a), but first examined by Horton (1970), cuts deeper into the bedrock and contains sediments younger than that of the Milton River deposits (Horton, 1970). The evidence for a buried valley is, therefore, open to further interpretation. This topic will be discussed further, and a new interpretation proposed, later in this chapter.

4.04. The diversion of the Milton River at Northampton.

Having proposed in the preceding sections (4.02 & 3) that the early Milton Valley travels in a north-easterly direction, between Northampton and Rushden / Higham Ferrers it is necessary to resolve the questions as to why, how and when the Milton River was diverted at both Hunsbury Hill, Northampton and Rushden / Higham Ferrers. Both Thompson (1930a, 1930b) and Castleden (1980a) proposed that the Milton River once flowed towards the south-east across the Yardley Chase area to the south-east of Northampton. The river was then either destroyed or diverted into the Nene after the valley to the south-east was blocked with till during a glacial period (suggested as the Wolstonian by Castleden, 1980a). Horton (1970), however did not share this idea. He suggested that, as the interfluve between the Great Ouse and the Milton River was of hardrock geology (Blisworth Limestone), the Milton River would have flowed north-eastwards in the region between Northampton and Wellingborough, turning towards the south-east north of Wellingborough. The Milton River, if not destroyed by glaciation, was diverted from its south-easterly flow beyond Wellingborough towards the north-east, eroding what is now known as the Nene Valley. This idea has not been discussed before, but is explored later in this chapter (Section 4.08).

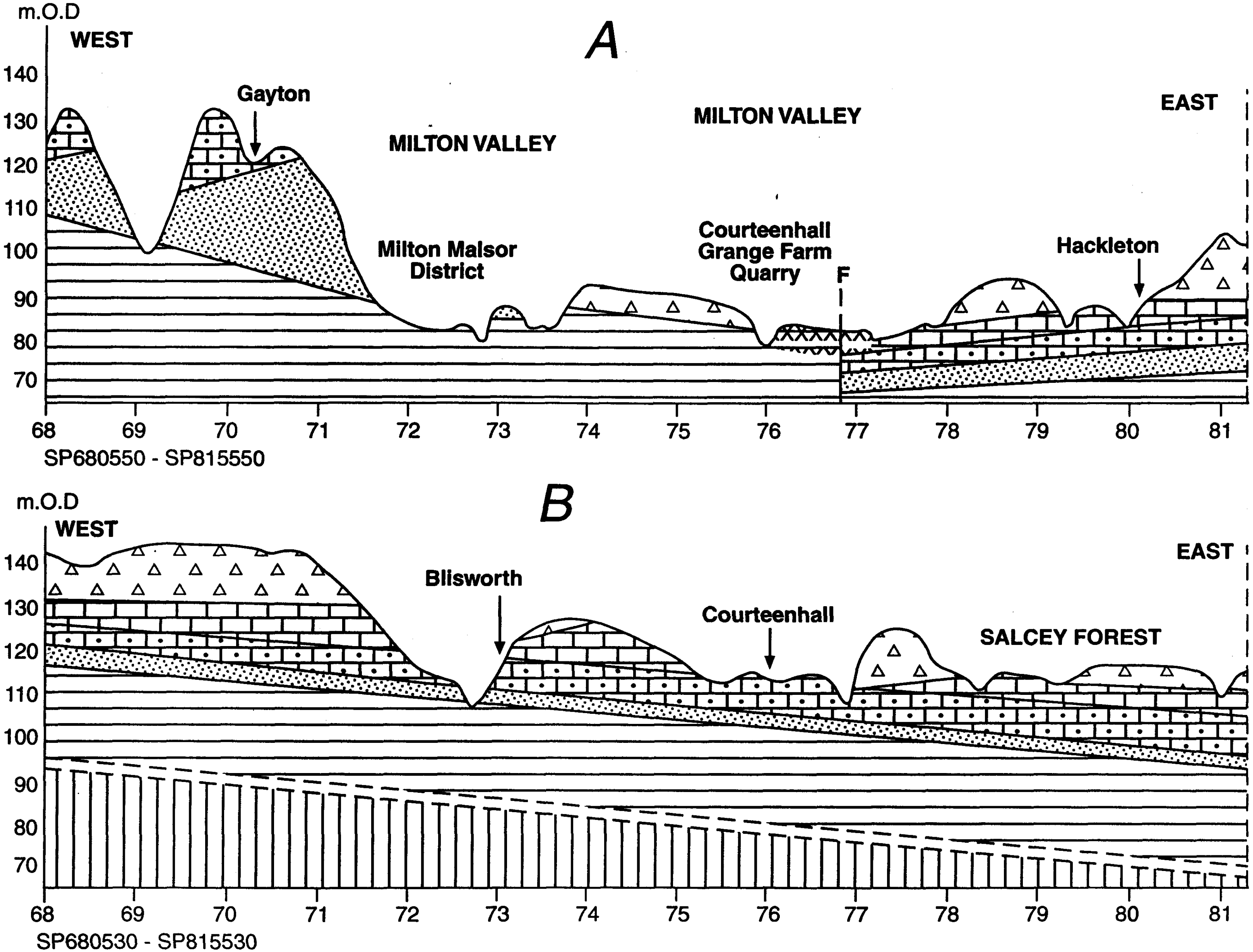


Figure 4.03.2 Sections, based on Geological Survey Sheet 202, which show the limestone outcrops at a higher altitude to the south of the Milton Valley at Northampton. (For key, see Figure 4.01.3)

It is proposed here that the evolution of the drainage system from the Milton River to the present configuration can be explained as a response to differential erosion upstream of Northampton / Hunsbury Hill and that this occurred before the onset of glaciation and deposition of the lower till. This is contrary to Castleden's (1980a) proposal that the Milton Formation is of interstadial or early post-glacial origin and was deposited in a valley lined with lower till of Anglian age (at the time of publication it was believed the chalky till in Northamptonshire was of Wolstonian age).

Lithological variation and faulting are likely to have caused differential erosion which controlled the drainage. At the stage in the evolution of the landscape that the land surface was at the height of the summit of Hunsbury Hill, to the south of Hunsbury Hill (Figure 4.04.1) the Milton River would have cut through the Northamptonshire Ironstone, probably a rapid process given its fractured (due to faulting) and friable nature. The next stage would be for it to cut into the Lias Clay, a much slower process. At approximately the same time the Nene would have been about to start eroding into the Northamptonshire Ironstone to the north of Hunsbury Hill and so would incise into the landscape more rapidly than the Milton River and thereby become the dominant river, with the major valley (Figure 4.01.6) to the north of Hunsbury Hill. Localized faulting to the north of Hunsbury Hill (SP 730620) (Figure 4.04.1) had further weakened the geological structure enabling the Nene River to deepen its valley to a point lower in the landscape than that of the River Milton. Thus the Milton River was diverted from its original course into a course very similar to that of the modern Nene, the exception being that the diverted Milton River probably still crossed the limestone platform towards the south-east. This was at a point downstream of Bozeat, between and including, Wymington (Dury, 1949) and Rushden / Higham Ferrers (Figures 4.01.2 & 4).

The above research shows that it is feasible to say that ice, as suggested by Thompson (1930a, 1930b) and Castleden (1980a), was not a factor in the diversion of the Milton River, especially as there is no evidence of far travelled clasts within its deposits. The diversion of the Milton River into the modern Nene Valley at Hunsbury Hill, Northampton, is much more simply explained above.

The palaeovalley of the Milton River, bearing south-eastwards from the Rushden / Higham Ferrers area of the Nene Valley, bears a strong resemblance to its upstream stretch between and to the south of Little Houghton and Wollaston. Both areas of the valley exhibit a wide, flat landsurface, up to 1km or more, with ridges of low hills, divided by ancient and modern tributaries, either to the left or the right of the valley.

One such ancient tributary (here named the Early Naseby Nene) flowed from the east and entered the Milton River to the south of Long Buckby. It eroded a large valley which would have partially filled with pre-glacial sands and gravels. Most of these were eroded away and the valley was eventually filled with till (Figure 4.04.2). However, 1.5 km to the south of Long Buckby (Figure 2.02.1) a large deposit of Milton Formation type exists south of Long Buckby Station (SP630658). That a large till filled valley also exists in this area is indicated by borehole data (SP66 NE5) recorded by Harrisson (1983) which included in the valley-fill both glacial lake clays and gravels to a depth of 10 m, base: 97 m O.D. The section in Figure 4.04.2 shows that the modern Naseby Nene erodes through a till-filled palaeovalley as described above.

The upland drainage pattern of the Early Naseby Nene may have been disrupted as a response to the Milton River moving northwards and joining the Nene (as described above). The extra discharge would have lowered the bed of the early Nene, creating steeper valley-sides. To the north, the steepening and consequently erosion of the valley-side would eventually breach the valley of the eastward flowing Early Naseby Nene. This would cause the same tributary to flow southwards, therefore becoming the modern Naseby Nene, to join the main river at Northampton (Figure 4.01.2) instead of at Long Buckby. The consequence of this would be to reduce the discharge in the upper reaches of the Milton River between Long Buckby and Northampton without affecting the amount of discharge downstream of Northampton. At present, the modern Staverton Nene, flowing from the west, enters the old Milton Valley at Weedon and downcuts into it as it flows towards Northampton where it joins the Naseby Nene.

It is difficult to suggest a time for the diversion of the Naseby Nene and the resultant abandoning of the older valley, but as Thompson (1930a, 1930b) reports finding up to 10 m

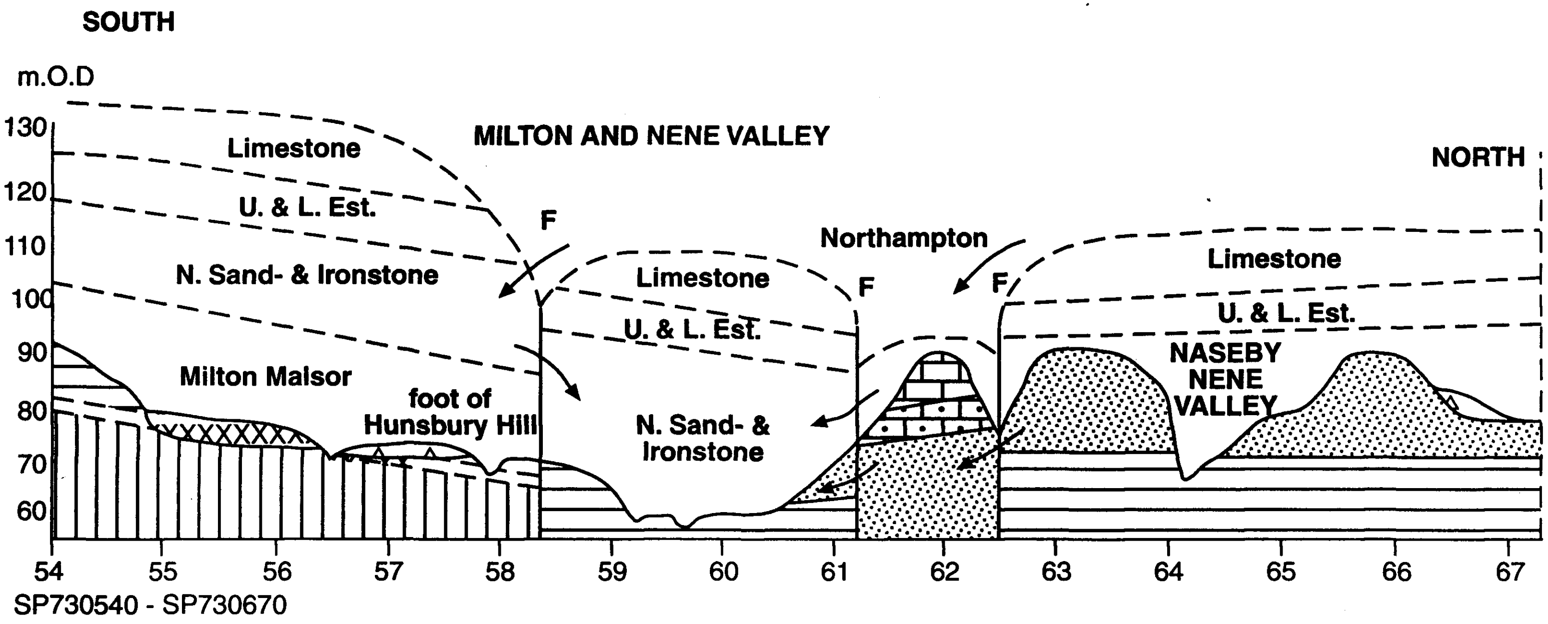


Figure 4.04.1 Section across the foot of Hunsbury Hill where the Milton River, after erosion of the bedrock, was captured by the River Nene. The arrows indicate the direction of drainage through the Northamptonshire Sands- & Ironstone. U. & L. Est: Upper and Lower Estuarine Series. (For key, see Figure 4.01.3)

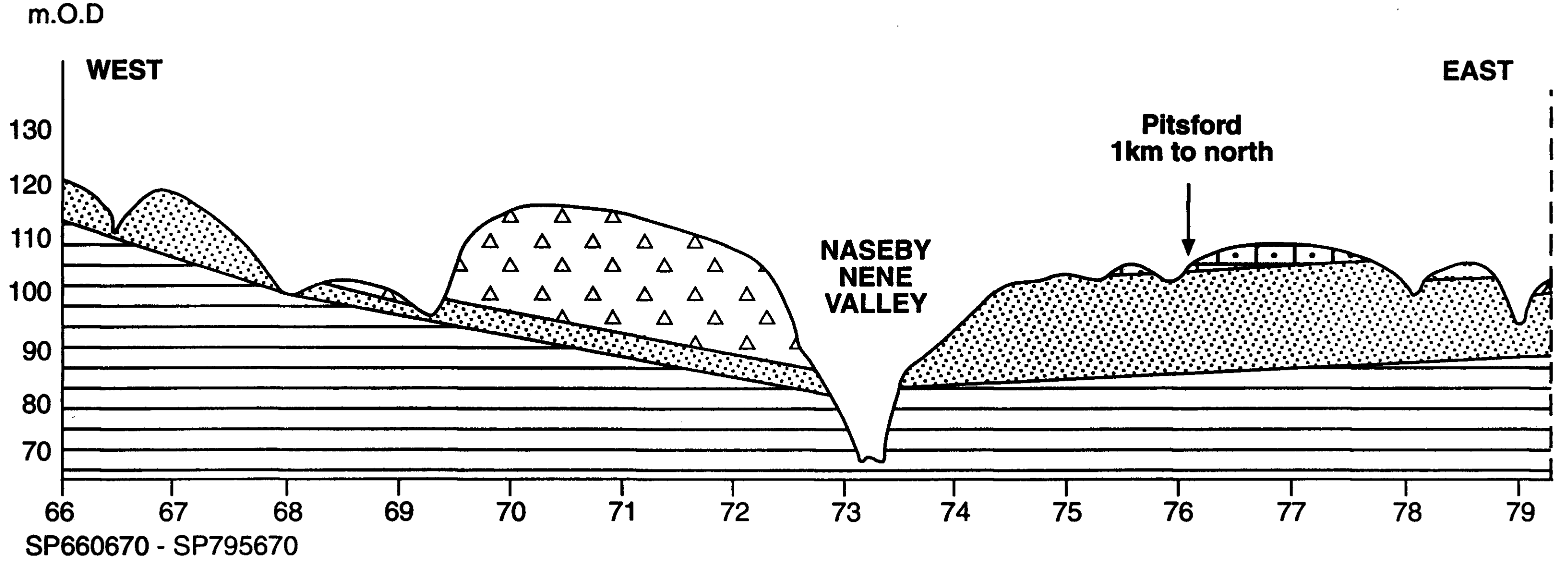


Figure 4.04.2 Section showing a till-filled valley once a westerly-flowing tributary of the Milton River. The Naseby Nene, although appearing to flow in the same direction, is cutting through the valley towards the south. This infers the section is cutting longitudinally through a bend in the old valley. (For key, see Figure 4.01.3)

of 'Mid-glacial' gravel, that is, gravel from the lower till, beneath 2-3 m of gravel from the upper chalky till in the Naseby Nene at Northampton (SP753598) (Figure 4.01.2), the change of flow direction, from westwards to southwards, probably occurred as early as the onset of the first glaciation.

Evidence that the erosional process and diversion of the Milton River may have been speeded up by a considerable deterioration in the climate comes from the present research. The fossiliferous Milton Formation at Courteenhall (Chapter 7) show that, following a long period of warm climatic conditions, the temperature cooled causing a change in vegetation and the development of spruce and pine woodland. As the climate cooled further the woodland died. Following this destruction the fossiliferous deposits were covered by the unfossiliferous Milton Formation, and the valley was widened, up to 0.66 km at Courteenhall, probably by increasing discharge.

The fossiliferous evidence combined with the geological and topographic evidence points to the Milton Formation (see Chapter 7) being much older than the age given by Castleden, who envisaged deposition taking place in a stadial of the 'Wolstonian' period.

Tributaries flowing from the south, might have eroded the pre-glacial sands from the abandoned channel and deposited them in the 'Milton' Nene channel. These sediments, as seen and interpreted at Little Houghton (Clifford Hill gravel pit) and Cringle Farm, Wollaston (Chapter 8), were reworked into what would have been, at that time, more locally derived sand and gravel, just as they were in the later, post-Anglian glacial gravels (see Chapters 7, 8 and 9). At Clifford Hill, pre-glacial sand was seen beneath decalcified gravels and colluvial sediment (discussed below). Several hectares of valley bottom along the southern edge of the Nene Valley, at approximately 58 m O.D, were covered with this reworked pre-glacial sand. The remaining sediments, as proved by the lithological evidence, were derived from the later glacial events and deposition of the tills. Similar pre-glacial gravels were found resting on the 'Blue' Lias bedrock at Sixfields (discussed further in the section on the tunnel valley below).

When and how the river was diverted to the north-east towards Peterborough is discussed later in the chapter.

4.05. Post-diversion drainage of the former Milton Valley and its relation to the buried valley of Yardley Chase.

The Milton Valley, then, may have followed its former drainage line through the whole of the Pleistocene prior to its diversion and the onset of the glaciation that deposited the lower till. Figure 4.05.1 shows a section of the valley where preglacial sand and gravel has been found under the lower and upper till (Thompson, 1930a, Harrisson, 1983).

The fact that the maximum thickness of the Milton Formation deposited in the former valley is 13.0 m, and yet the thickness usually seen is 7.0 m, indicates that vast quantities of sand have been eroded away since the river's diversion or that the sands surface was irregular e. g. as a result of terracing. Due to erosion of the lower till before and during the later glaciation, the amount of lower till deposited in the Milton Valley and the surrounding area is unknown. This makes it difficult to estimate how long the lower till was subject to erosion.

There are few lower till deposits found in the upper and middle reaches of the Nene and Milton Valleys. Thompson (1930a) has recorded what appears to be lower till deposited on the Milton Formation at Yardley Hastings (Figures 4.01.2 and 6) and, in Mineral Assessment Report 114, Harrisson (1983) reports finding, near Irchester (SP925658), *'a locally-derived limestone and Ironstone gravel underlying Boulder Clay (the Lower Boulder Clay of Hollingworth and Taylor, 1946).* Harrison does not describe the till but Thompson (1930a) describes it as follows: *"The clay is patchy and variable, not everywhere present. In it are a few large stones and some Kimmeridge Clay fossils, gastropods and Serpulae. A curious feature is here and there pockets of red clay full of Bunter pebbles and well-worn flints, nothing else scarcely. The pockets are from 3 feet to 6 feet wide, and in one place go right down to the sand. At another place is a pocket of red sand without erratics."* This description is very much like lower till described by Horton (below) and by other authors at other sites (see chapter 2).

The Yardley Chase [buried] valley, as described by Castleden (1980a), appears to be related to this, earlier, glacial event. But, contrary to Castleden's opinion that the Milton

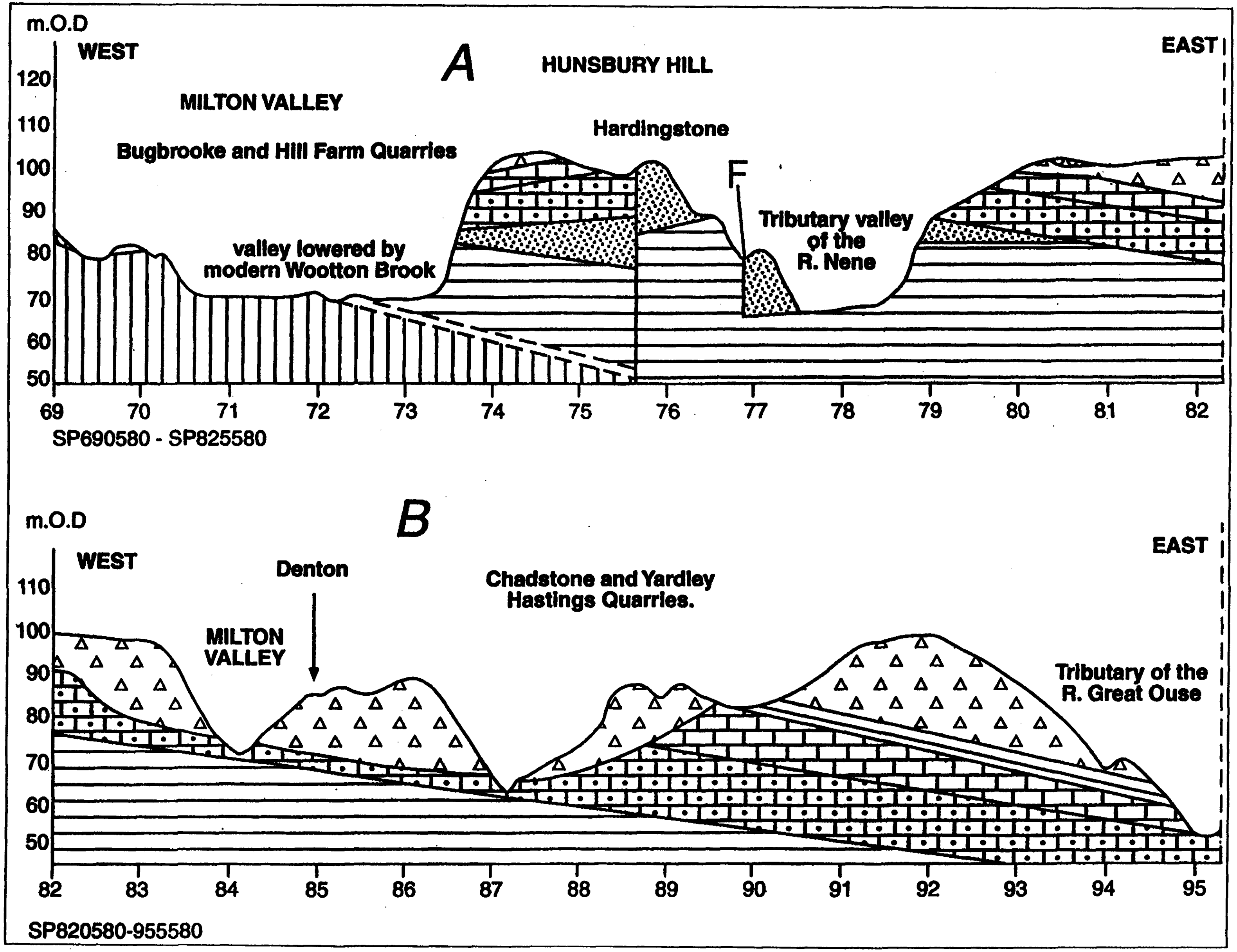


Figure 4.05.1 This continuous section from west to east along gridline SP580 shows the Milton valley at a lower elevation due east of Northampton indicating the valley falls to the north-east as it nears Rushden. (For legend see Figure 4.01.3)

Valley flowed to the south-east at this point, the sections drawn up for this area indicate the Milton Valley was following the structural syncline to the north-east and was bisected later by the channel flowing to the south-east (Figure 4.05.2).

To be fair to Castleden he writes in his concluding remarks, *"It could be argued that the depression discovered under Yardley Chase was formed, like the Northampton depression, as an ice-way or as a tunnel valley, but its alignment with the Milton Sand train and the morphology of the Milton Sand itself indicate a probable genetic relationship between the two."*

Horton's borehole evidence (1970) (Table 4.05.1) from this area was first discussed in relation to the Yardley Chase valley by Castleden (1980a) and, in this context it is necessary, first, to look at Horton's (1970) descriptions of the tills.

Horton (1970): Definition of Lower Till

"Because of the low proportion of erratics and the preponderance of local material the outcrop of the Lower Boulder Clay may be mistaken for one of the argillaceous Jurassic formations. It can be distinguished, however, by its tenacious character and gritty texture, and frequently contains a high proportion of derived shells, particularly oysters, crinoid ossicles and serpulids. Chalk is invariably absent, though rotten flint-like particles may be present."

Horton (1970): Definition of Upper (Chalky) Till

"Chalky till is the most widespread and most readily recognized drift deposit. It is usually medium bluish grey and contains an abundance of chalk pebbles and flour (comminuted silt-grade chalk grains) with a high proportion of flint and with Jurassic fossils, particularly Gryphaea. Fresh unweathered chalk is usually present within 2 ft 6 ins [0.75 m] of the surface. The weathering zone, shown by pale grey and yellow mottling, may extend down to a depth of 5 ft [1.5 m], the material below being usually uniform medium to dark grey clay with erratics. In most exposures the till remains uniform to within a foot [0.3 m] of its basal junction. The lowest bed, however, often contains a high proportion of local material."

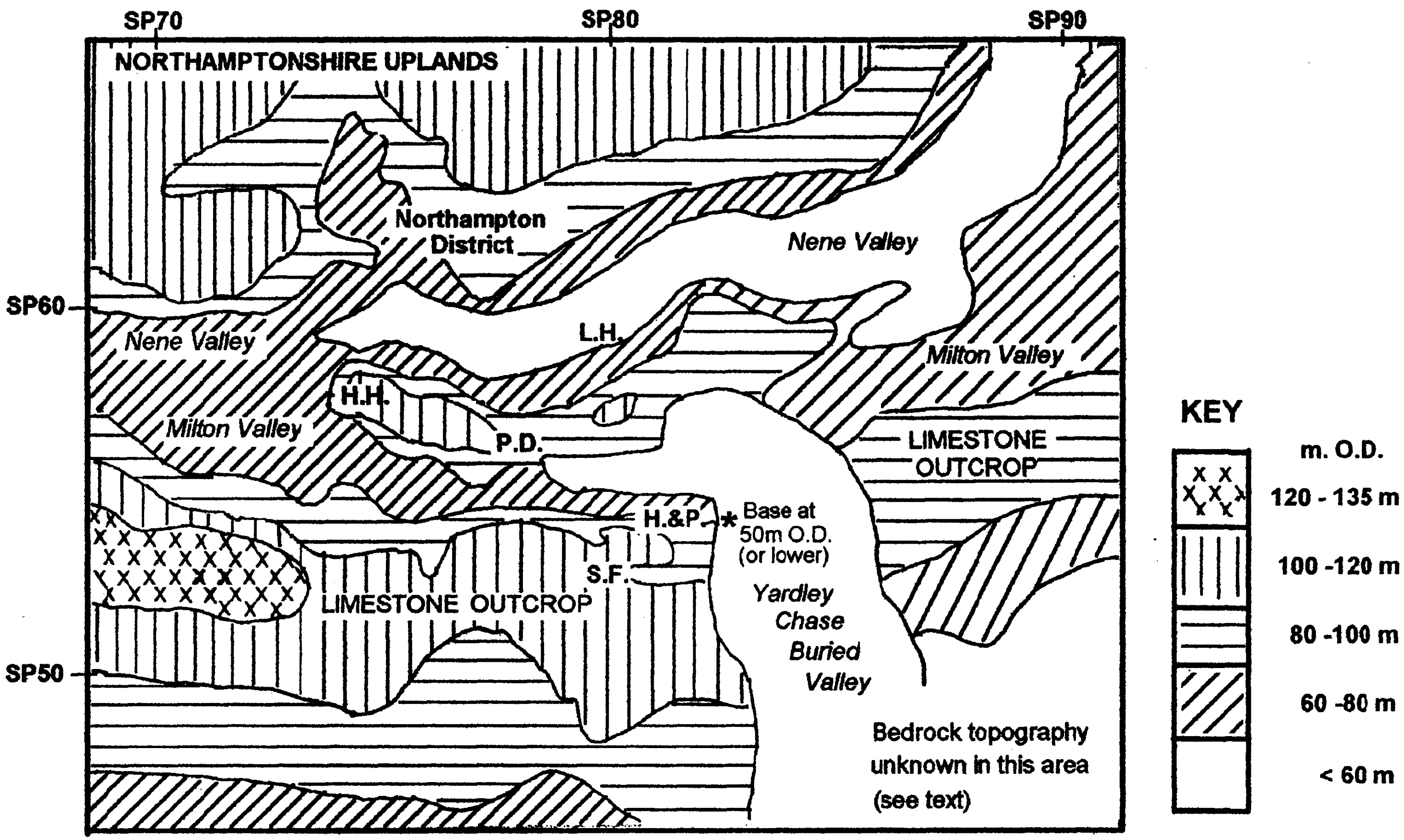


Figure 4.05.2. The topography of the bedrock surface in the area surrounding Northampton.

H.H.: Hunsbury Hill; P.D.: Preston Deanery; L.H.: Little Houghton; H.& P.: Horton and Piddington; S.F.: Salcey Forest.

To confirm the presence of a lower till in Northamptonshire, a visit was made by Allen, Rose and Smith (author) to examine an exposure at Brigstock (SP955852). The colour of the lower till was a dark greyish brown (Munsell colour 10YR4/2), which contrasted sharply with the light yellowish brown (10YR6/4) of the upper till. The presence of Mercia Mudstone (Keuper Marl), quartz and quartzite and the absence of chalk and flint in the lower till led to the conclusion that this till had come from north to north-west of the area. The upper till was rich in chalk and flint and was typical of the Anglian tills of the East Midlands and East Anglia (Perrin, Rose, and Davies, 1979).

Thompson (1930a, 1930b), who had no evidence of a valley but suggested one probably existed, provides evidence for the Milton Valley being in place before the onset of the two glacial events. He reports a well record showing one metre of "*Mid-glacial gravels*" beneath 29.6 m of chalky till near Horton Station (Figure 4.01.2), the base of the gravels being at approximately 78.9 m O. D.; a height appropriate for a valley-side of the Milton Valley passing through Preston Deanery at 72 m O.D. Thompson (1930a, 1930b) describes the "*Mid-glacial gravels*" as coming from local material and "*the Lower Boulder Clays and gravels with much local material and some erratics... of the First Glacial Episode.*", signifying the lower till might be present nearby. Indeed, there may be a considerable amount of lower till above the Milton Formation and the surrounding area.

These gravels from the lower till must have been deposited after the Milton Formation as the Milton Formation does not contain any erratic clasts. This is contrary to the stratigraphic relationship suggested by Castleden (1980a).

That the younger Yardley Chase channel discussed below, existed before the lower till is not so clear. If it did exist, then it may have been infilled with lower till which was later eroded and reworked to produce the sediments described by Horton (1970) (Table 4.05.1). This occurrence would have been prior to the deposition of the chalky, flint-rich upper till (Figure 4.05.3) (see discussion below).

The sections drawn up by Castleden (1980a) from Roade (SP760515), through Hackleton (SP810550) to Castle Ashby Lodge (SP854584) (Figure 4.05.4) showed a buried

Height at landsurface: 365ft (111.3 m) O.D.	thickness	thickness	depth	depth
Chalky boulder clay,brown weathering at top, typical grey clay with chalk and flint erratics below	98 ft	29.9 m	98 ft	29.0 m
Glacial gravel; clean gravel with Bunter, stained quartz and ironstones and occasional chalk and brown flints.	4 ft.	1.2 m	102 ft	31.1 m
Boulder Clay; greenish grey. gritty, with occasional chalk, much sand, quartzite and jaspery quartz.	2 ft	0.6 m	104 ft	31.7 m
Sand; dull grey with pebbles including soft, buff argillaceous cementstone, quartzite and vein quartz.	10 ft	3.1 m	114 ft	34.8 m
Boulder Clay; grey, gritty, very sandy with some chalk, oysters. Less gritty from 128 ft with traces of lamination.	31 ft	9.5	145 ft	44.2 m
Sand; fine loamy sand and laminated clay. greyish clean quartoze sand for 8 ft at base with half inch quartzite pebbles.	8 ft	2.4 m	153 ft	46.7 m
Boulder Clay; dark gritty clay with few small chalks, occasional polished limonite and quartzite grains.	39 ft	11.9 m	192 ft	58.6 m
?Drift; calcareous sandy material with fragments of grey oolitic pyritic limestone Seen	7 ft	2.1 m	199 ft	60.7 m
?Lias; dark grey clay	15 ft	4.6 m	214 ft	65.27 m

Table 4.05.1. Glacial deposits in the area between Salcey Forest and Yardley Chase, Northampton (SP829554): after Horton, 1970

valley which he interpreted as the base of the Milton Valley *"although a denser network of bores in this area would be invaluable in showing the detailed form of the valley..."*.

The central part of the section (SP829554) was interpreted using the bore-log evidence collected at Piddington Station by Horton (1970) (Table 4.05.1 and Figure 4.05.3). This evidence alone shows it is unlikely to be the base of the Milton River because the base of the Milton Formation is at 72 m O.D. at Preston Deanery (Thompson, 1930a, 1930b; Clarke and Moczarski, 1982) (Figure 4.05.5), whereas the section referred to, less than 2 km south of Preston Deanery, shows sediments of a fluvial or glacial nature at 53 m O.D. or lower (Figure 4.05.2). Also, at Piddington (Figure 4.01.2), Thompson records a well reaching down to the Upper Estuarine Beds (SP814533) at 89.7 m O.D. less than 1 km to the north-west of the "*Mid-glacial gravels*" discussed above.

The altitude of the lower valley base (as also remarked on by Castleden in the same paper) corresponds more to the base of the present Nene and is, in fact, lower than the modern Nene, but higher than the base of the tunnel valley of the Nene described later in the chapter.

To add to the confusion, Thompson and Horton refer to the same railway station by different names, that is, Thompson as Horton Station and Horton as Piddington Station (Figure 4.01.2). Once realised (the author has since discovered that Horton station had its name changed to Piddington after Thompson died in 1930, but before the railway was closed) the evidence from Thompson's well record (SP827553), less than 0.25 km to the west of the borehole of Horton (1970) (SP829554), and the bore log evidence were put together to show the existence of a steep sided valley very similar to that of the tunnel valley of the Nene (for example as seen at Sixfields: Section 4.11).

Thompson (1930a, 1930b) and Castleden (1980a) suggested that the Yardley Chase valley (as the Milton Valley flowing to the south-east) was blocked by ice which forced the Milton River to the north of Hunsbury Hill, leaving the Milton Formation as a bench on the hillside to the south-west and west of Northampton.

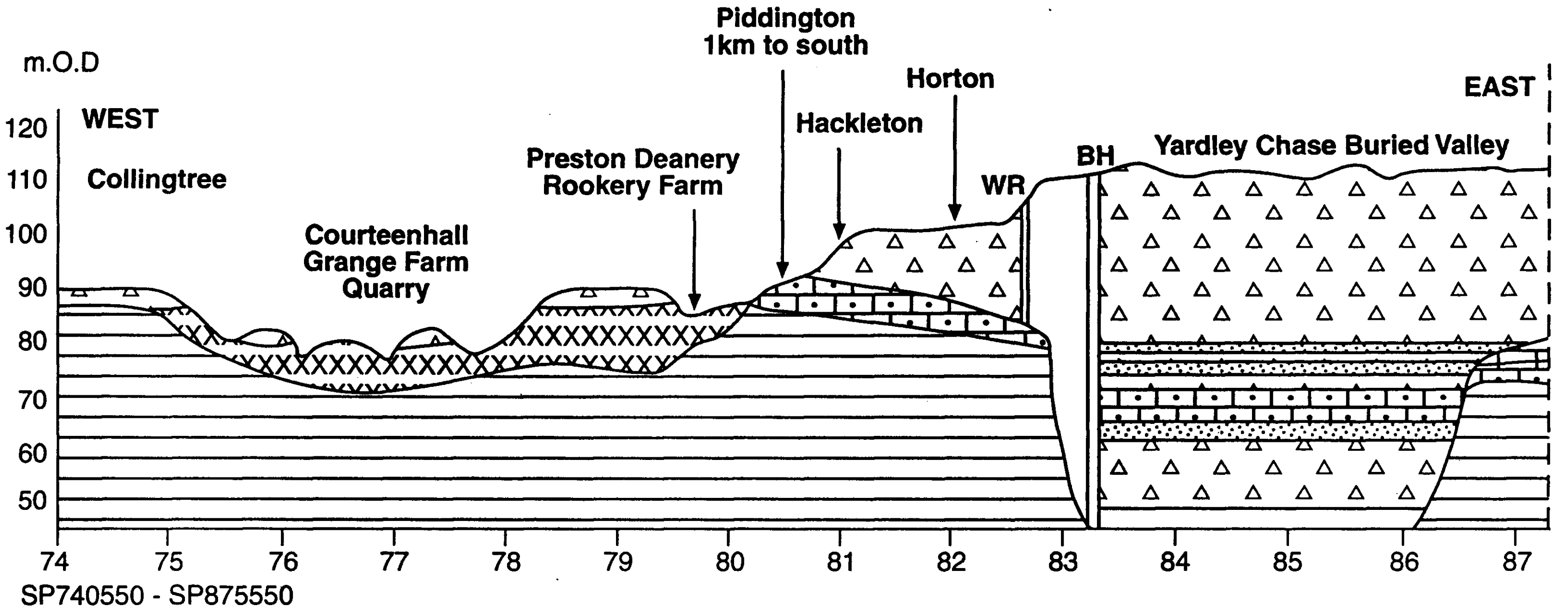
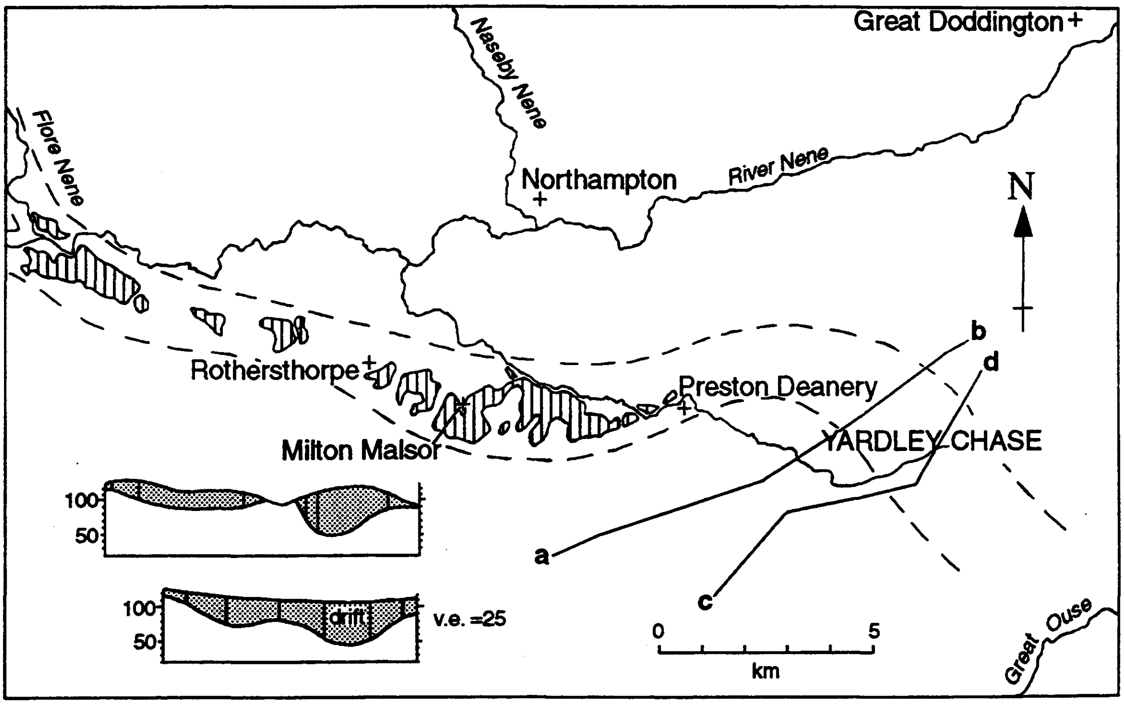


Figure 4.05.3 The Milton Valley bisected by the valley described by Castleden. The valley has been illustrated using the sedimentary evidence from Horton's bore log of 1970. BH: Horton's borehole. WR: Thompson's well record. (For key, see Figure 4.01.3)

Figure 4.05.4. The distribution of the Milton Formation and its relationship to the buried valley at Yardley Chase (after Castleden, 1980a).



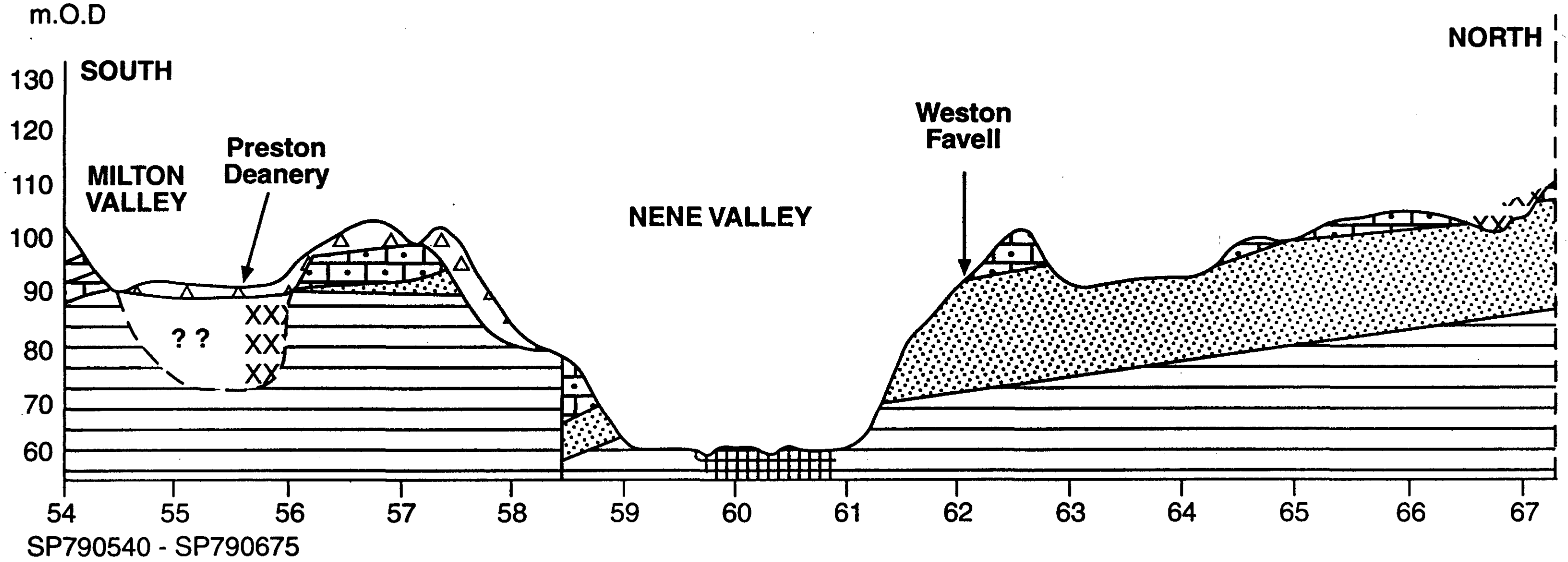


Figure 4.05.5 Section across the area of Preston Deanery, showing the Milton Valley as described by Thompson (1930). This section also demonstrates the difference in elevation between the Milton and Nene Valleys. (For key, see Figure 4.01.3)

4.06. The Yardley Chase valley re-interpreted.

Within this area there is no positive evidence that the Yardley Chase valley was of Milton River age. In fact, the till-filled valley cuts down to 53 m O.D. or lower and at right angles through the Milton Formation (at 72 m O.D.;-Thompson, 1930a, 1930b) and starts abruptly at the foot of Hunsbury Hill (SP790560-SP830590) (Figure 4.05.2). To the north of Hunsbury Hill (SP750660) the Naseby Nene, in which Thompson (1930a, 1930b) recorded having found gravel associated with the lower till, also abuts Hunsbury Hill, and at an even greater depth of 45m O.D (see Chapter 2). There may be a link between the earlier Naseby Nene and the Yardley Chase buried valley, probably glacial in origin.

The evidence as presented suggests that the Yardley Chase valley was eroded later than the Milton Valley and, therefore, although it may have drained the area later, it could not have been the Milton Valley itself.

Its erosion appears to have been intimately associated in some way with the first glaciation after which the valley was infilled with reworked Milton Formation and lower till from the surrounding area. The latter occurring possibly as late as the early stages of the second glaciation (hence the lack of flint and small amounts of chalk in the lower till of the deposit (Horton, 1970). This was followed by the over-riding of the ice as the uppermost gravel and chalky till with flint rests as a hill 30 m thick, on the limestone platform to either side and across (above) the valley-fill (Figure 4.05.3). There may or may not be an unconformity between the upper and lower sediments, but the great difference in the lithology of the lower valley-fill and the upper till suggests that there was a time lapse between the two.

4.07. The modern drainage of Yardley Chase

Sections across Wootton Brook (such as A & B of Figure 4.07.1) (a tributary that flows across Yardley Chase, northwards and north-westwards towards Hunsbury Hill and enters the Nene Valley to the west of Northampton, SP724589), show the valley was

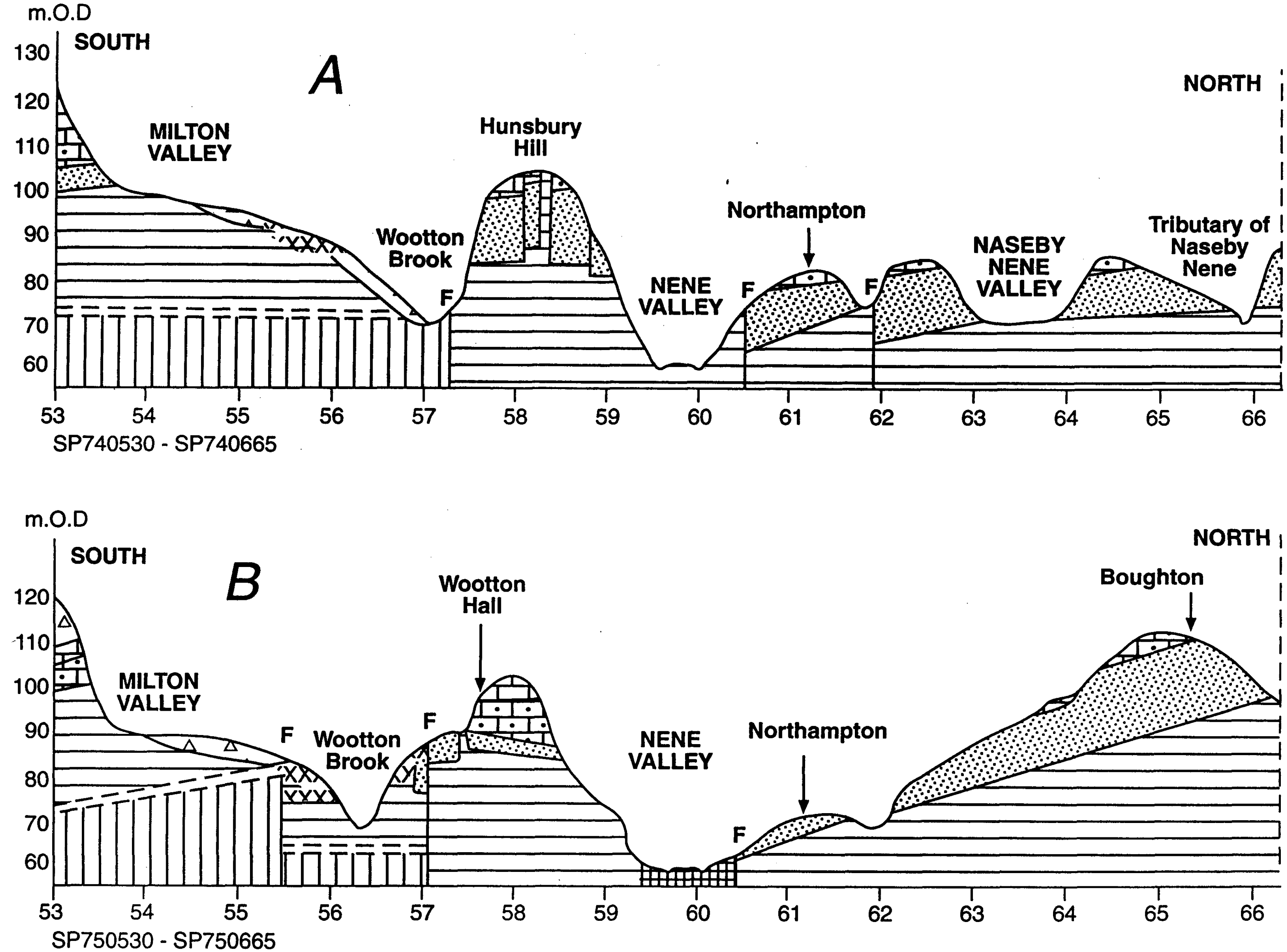


Figure 4.07.1 Sections show the erosion of Wootton Brook through the Milton Valley at Northampton. These sections also demonstrate the fault-bound geology at Northampton. (For key, see Figure 4.01.3)

formerly eroded down and then infilled with till. The erosion prior to the infilling by till suggests the Wootton Brook may have drained the abandoned Milton Valley area before the onset of glaciation.

4.08. Diversion of Milton /Nene River to the north-east at Rushden / Higham Ferrers and the relevance of the Brigstock River.

Having established that the diversion of the Milton River at Northampton was pre-glacial the next step is to establish the timing and the reason for the diversion of both the Milton and Brigstock Rivers from their south-easterly direction to the north-east of the county (from Rushden / Higham Ferrers and Thrapston). As the evidence from Courteenhall (Chapter 7) indicates the sands are of Cromerian Complex age or younger, the diversion of the two rivers to the north-east is likely to be due to glacial interference.

The pre-glacial sands and gravels, containing no erratics, of both the Milton and Brigstock Rivers, crop out from under the till (Figures 4.08.1 & 2), and are marked as 'glacial sand and gravel' on Sheet 186, Wellingborough: Geological Survey, 1974).

The palaeocurrent direction of the pre-glacial Brigstock Sands and Gravels (Hackney, 1989) suggests streamflow from west or west-north-west to east or east-south-east across the north of Northamptonshire, through the gap between Thrapston and Ringstead (Hackney, 1989; Belshaw, 1989). During the building of the A14 dual carriage way pre-glacial sand and gravel, part of the Brigstock deposits, was uncovered at the Thrapston roundabout (TL005781) and further east-south-east at Bythorne (TL059750) (Belshaw, pers. comm). Sections across the area between Higham Ferrers and St. Neots, Bedfordshire, show further deposits of pre-glacial sands overlain by till (Figures 4.08.1 & 2).

Using evidence from the earlier discussion on the Hunsbury Hill diversion and the rapid downcutting of the 'Milton' Nene Valley, one would not expect the diversion to the north-east to be much later than that at Hunsbury Hill. If the diversion had occurred much later than the diversion at Hunsbury Hill, there would have been evidence of a lowered stream bed towards the south-east from Rushden / Higham Ferrers corresponding to the

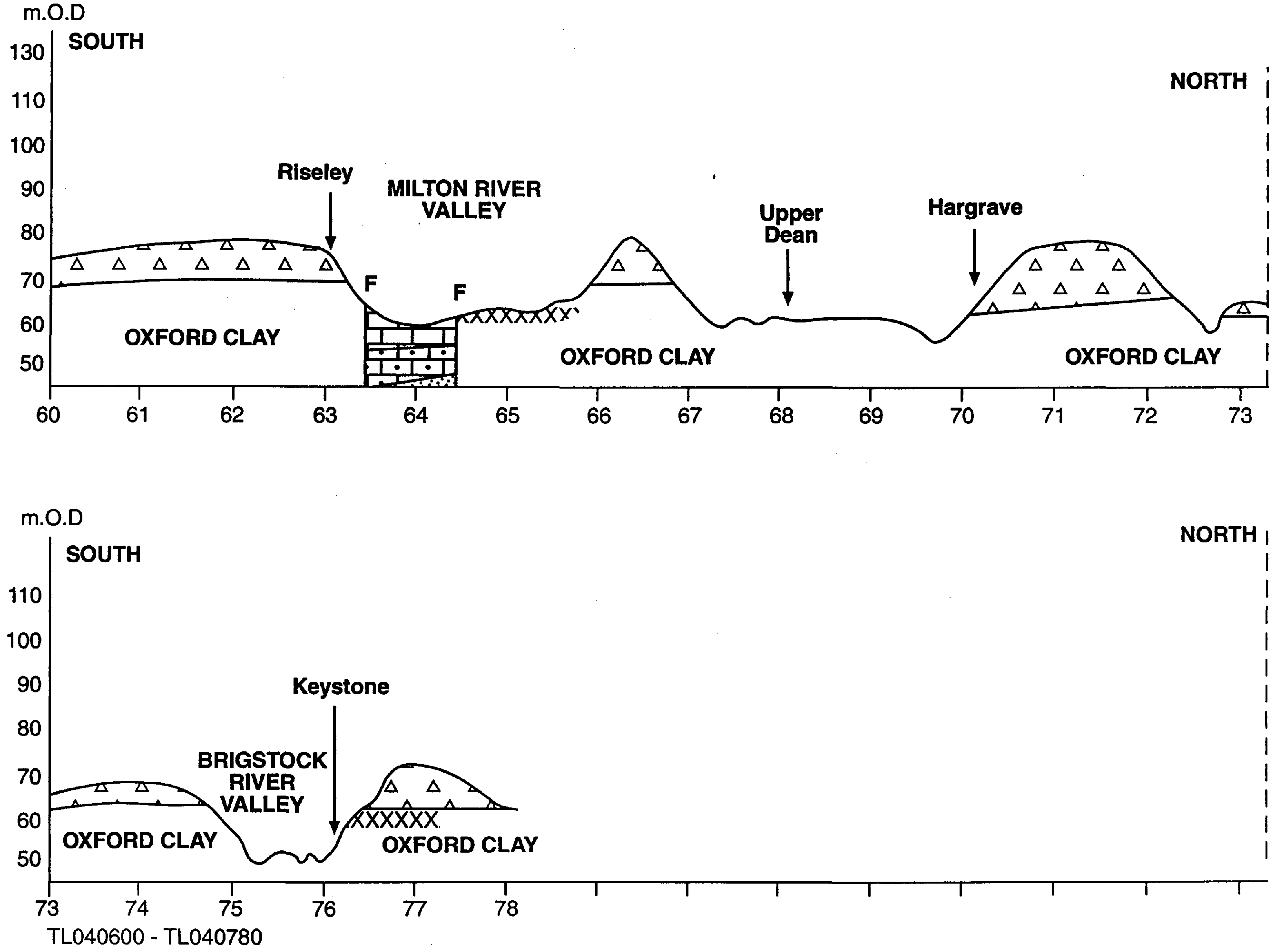


Figure 4.08.1 Section showing the similarity of the Milton and Brigstock River Valleys as they leave the Jurassic Limestone plateau and migrate south-eastwards across the Oxford Clay. (For key, see Figure 4.01.3)

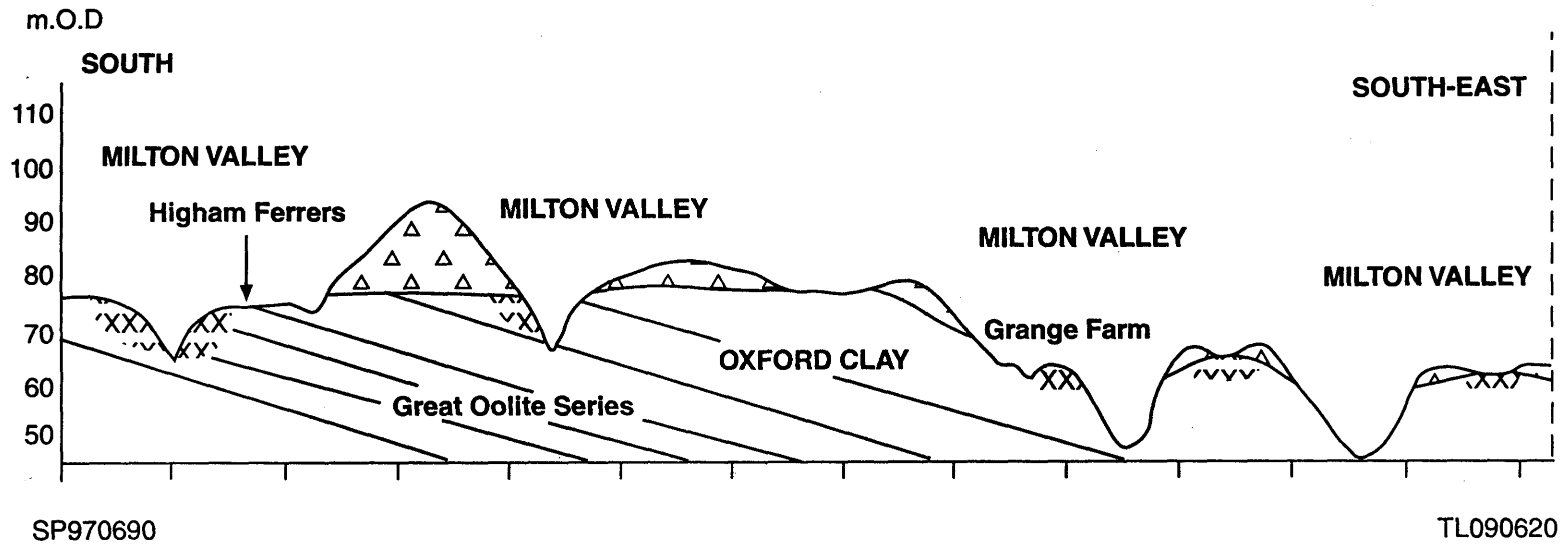


Figure 4.08.2 Cross section from Higham Ferrers in the north-west to the area of St Neots, Bedfordshire, 13.5km to the south-east of Higham Ferrers. The diagram illustrates the fall of the Milton Valley towards the south-east. (For key, see Figure 4.01.3)

deepening of the 'Milton' Nene Valley. As the sections record, this is not so. This suggests the diversion of the Nene to the north-east at Rushden / Higham was most likely to have happened at the onset of the earliest glaciation, which approached from the north or north-west, and the deposition of the lower till. This is surprising as one would have expected the diversion to occur later, upon the arrival of the eastern (Anglian) ice sheet from the North Sea. This could have prevented both rivers from flowing to the south-east and forced them along the ice margins towards the north-east.

As the present River Nene between Thrapston and Wansford has the general character of a subsequent stream following the strike of the Oxford Clay, Kellaway and Taylor (1952, p. 357) concluded that this stretch of the Nene was established before any glacial disruption of the Nene. If this was so, it is likely that the stream would have been flowing towards the south-west as a tributary of the Brigstock River rather than towards the north-east as part of the River Nene. The pre-glacial valley would have formed a natural channel into which the rivers, swollen with meltwater, could have debouched.

4.09. The first ice advance and its effect on the 'Milton' Nene River

As there are few deposits of gravels associated with the lower till found in central Northamptonshire, it is difficult to establish how the first glacial event affected the 'Milton' Nene Valley. Thompson (1893, 1904, 1930a, 1930b) reports having seen gravel that he described as "*Mid-glacial*", associated with the lower till, as being quartz and quartzite-rich but not containing any chalk and rarely any flint. This gravel, discussed in Chapter 2, formed the lower eight metres of a gravel deposit approximately 10.5 m thick at the junction of the Naseby Nene and the Staverton Nene at Northampton (SP746597). The valley base at this point has been overdeepened down to about 45 m O. D. and, if related, it implies that the combined 'Milton' Nene Valley was subject to a high discharge at the time of deposition of these lower gravels. It is important to note that the depth of the valley being discussed is, in fact, lower than that of the valley beneath Yardley Chase (53 m O.D. or lower) and which may be of similar age.

Several pre-glacial valleys in the Kettering area (as discussed in chapter 2) are also recorded to contain an ironstone-limestone-Bunter quartzite gravel derived from the lower till (Kellaway and Taylor, 1952; Horton, 1970). Kellaway and Taylor hypothesized that following deglaciation and erosion, the melt-waters depositing the lower till and its gravel, would have been confined in the old valleys, leading to their re-excavation. This is similar to what has been discussed for the palaeo-Wootton Brook and, likewise, may have occurred in the 'Milton' Nene Valley, although there is little evidence remaining to prove so.

4.10. The earliest Anglian deposits.

After the lower tills were deposited, the Milton River and other fluvial deposits would have become rich in quartz and quartzite clasts, but most of these deposits of this time would, later, have been intermixed with outwash material from the second advancing ice sheet. As these deposits are part of the current research, for further discussion go to Site E, Clifford Hill, Little Houghton in Chapter 8.

Again most of the evidence for such a sequence of events has been destroyed by erosion, but in support of the idea of pro-glacial gravels being present in the Nene Valley bottom there is Thompson's report (1930c) of a till-filled valley to the north of the Nene, near Weston Favell Mill, Northampton. The till- and glacial gravel-filled valley to the north of the modern Nene was traced from Kingsthorpe Road (SP755627), through Abington Park, Northampton and to the south of Billing Road, Northampton (SP790612). The valley entered the Nene Valley north of Weston Favell Mill (SP795605). The altitude at this point is about 57 m O.D., roughly the altitude of the decalcified tills at Clifford Hill quarry, Little Houghton (discussed later in the chapter). The valley at Abington Park, infilled with both glacial gravel and chalky boulder clay, was believed, by Thompson, to have discharged its water into the Nene between the two glacial periods.

The argument for gravels, now decalcified, having been deposited before the tunnel valley formed is part of this research: for further the discussion on this topic go to Site E, Clifford Hill, Little Houghton, Chapter 8.

Following the deposition of the glacial lake clays a period of erosion occurred in which the clays were eroded down to their present level. After the erosion of the clays the gravels derived from the Anglian till were deposited.

4.11. The tunnel valley and glacial lake sedimentation.

A tunnel valley in Northamptonshire extends along the Nene Valley from Kislingbury (SP700599) through Northampton to Great Doddington (SP880641) a distance of 23 km (Figure 4.02.1) (Early, 1956: Horton, 1970; Castleden, 1980a; Manning, 1989). Previous research shows the tunnel valley to have been steep sided, in places 1 km wide by 20 m deep. The borehole logs of Sixfields (this research) show the tunnel valley deposits go down to an even greater depth of 26+ m.

Recent boreholes have confirmed that extensive deposits, of what are described in the literature as glacial lake sediments, are found in this area of the Nene Valley. Of these, the following bore-log records were examined:- Rushmere Road, (R. M. Douglas Construction Ltd, 1972); Nene River Towpath, (N. B. C. Engineers, 1988); St. John's Multistory Car Park, (Engineering Services Laboratory, 1989); Northampton Nene Park Sixfields, (Geotechnics, 1991); Cattle Market area, (Engineering Services Laboratory, 1993, 1995). The stretch of the Nene concerned is at Northampton, to the north of Hunsbury Hill (Figure 4.11.1).

Sixfields (SP729604), now Northampton Nene Park, is a south facing valley flank of the River Nene, 100 m south of Weedon Road, Northampton, and is predominantly gently sloping ground, maximum height 80 m O.D., minimum height 68.25 m O.D.

Part of the area had been quarried for ironstone and later used as a landfill site. The Northampton Sand Formation, where it crops out, is 6.55 m thick. Upper 'Blue' Lias crops out beneath the Ironstone and at the base of a depression to the south of the site. The base of the depression, when reached, was at 38 m O.D. The depression appears to have been filled with laminated silts and clays up to 26 m thick. These were interpreted as

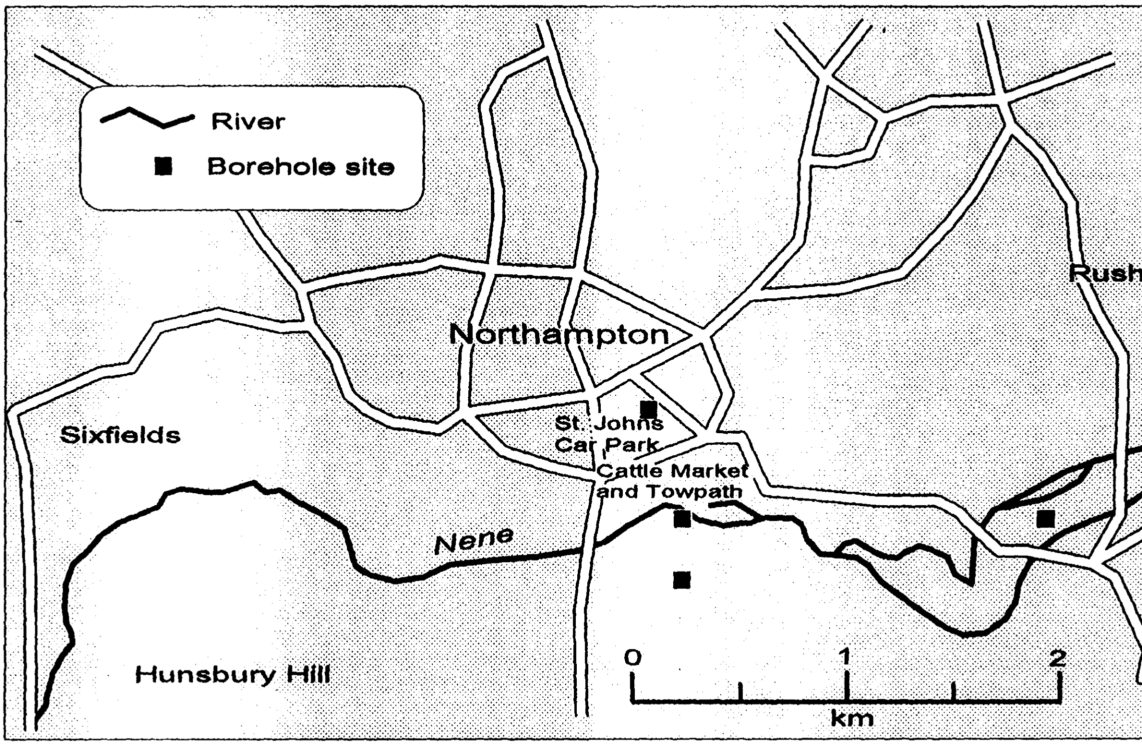


Figure 4.11.1 Map of the Nene Valley and associated tunnel valle
deposits at Northampton (tunnel valley deposits
occur beneath fluvial gravels throughout).

glacial lake deposits by Early (1956) and Horton (1970). As the 'Blue' Lias was not reached in some boreholes the base of the lowest glacial lake sediments are not known.

The sediments at St. John's Car Park (SP756603), the Cattle Market area (SP758595), Nene River Towpath (SP758598), and Rushmere Road (SP775598) show similarities to the sediments of Sixfields. These sediments are in accord with those described by Early (1956) and Horton (1970). The steep sides of the valley were indicated by the sudden drop in the surface of the 'Blue' Lias clays at Sixfields. The inferred tunnel valley is filled with a mixture of greeny-grey, or weathered brown clay and very clayey silts. The lower silts and clays in the bore material were laminated and often steeply inclined. Downstream at other sites, such as those of the Cattle Market and Rushmere Road, chalky tills were sometimes encountered in the tunnel valley sediments. Where seen, the till deposits appeared to be in a slumped position in the angles formed by the sides and base of the tunnel valley basin (R. M. Douglas Construction Ltd, 1972).

The surface of the glacial lake clays at Sixfields were recorded to be between 60 and 63 m O.D. and at St. John's Car Park 58.75 m O.D. Similar measurements were recorded for the sites at Rushmere Road, Nene River Towpath, and the Cattle Market area.

Further upstream at Kislingbury, at the upper limit of the tunnel valley, a large raft of Estuarine Limestone and other large boulders were seen to form a fan shaped deposit across the valley floor (Belshaw, pers. comm.).

In an ice contact situation sediment would have been plentiful with rock flour and other fine sediments. As it would seem reasonable to expect the surface of the lake sediments to be level across the whole body of a mature lacustrine system, it is possible the lake sediments were at their final elevation at 63 m O. D. at Northampton, the highest level at which lacustrine sediments were found being at Sixfields (above).

One hypothesis is that the fan of boulders and other rock debris at Kislingbury might have been emplaced by at the outlet of a subglacial stream under hydrostatic pressure as described by Woodland (1970) and Aitken (1993).

The highest possible fluvial, probably pre-glacial, material was found lying on the 'Blue' Lias (between 67-73 m O.D.) beneath landfill material at Sixfields. The material, recorded as a gravel, of local derivation only, was recovered from Sixfields in boreholes 13, 14, 15, 25 and 28. It was described as follows: "*In general the material was found to be medium dense, orange, very sandy silt or clay with gravel or, very silty sandy gravel, the gravels being Ironstone. It is possible that the materials in borehole 13, 25 and 28, if not an unquarried highly weathered Ironstone are, in fact, quarry waste.*" The description of the gravel seen in BH 13, 14 and 15 is very similar to, and could be, that of a late pre-glacial gravel resting on an earlier floodplain of the 'Milton' Nene River.

4.11.1. Timing of the tunnel valley episode.

Castleden (1980a) proposed the Milton Formation represented a river which was in existence throughout the Pleistocene until the early Wolstonian and that the Nene Valley would have been lined with till and lake clays well above today's level during the Wolstonian period.

As the original valley was bisected by the tunnel valley it is quite possible that the glacial lake sediments would have extended over the tunnel valley deposits on to any low lying sediments of the older valley. In fact, sediments which could well have been lake sediments, were seen resting on the decalcified gravels at Clifford Hill (Site E, Clifford Hill, Little Houghton, Chapter 8).

Other evidence that there was already an established valley prior to the second ice sheet is seen at Cringle Farm gravel pit, Wollaston (SP890628) (Site G2, Cringle Farm, Wollaston, Chapter 8). Here a chalky till deposit was seen to rest on the valley floor beneath fluvial gravels, and, in this research, it was the only place where till was seen at such a low altitude. Thus the valley may not necessarily have been initiated by glacial erosion as suggested by Castleden. In fact, the till appears to fill a hollow in the valley side and may even have been soliflucted from the valleyside above.

It is suggested by the author that the tunnel valley was an Anglian mid-glacial, or late-glacial event. This would involve the early deposition of chalky gravel followed by glaciation. The tunnel valley would have been excavated during the glacial period, the glacial lake clays then being deposited as the ice sheet was in retreat. The till found in the tunnel valley sediments may have deposited either as melt-out from ice trapped in the valley during the decay phase, or have slipped down the valley-sides later as the valley continued to infill with sediments.

4.12. The possibility of an intervening interglacial between the two tills

Thompson (1930a, 1930b) was convinced there were two distinct glacial periods or episodes, separated by a long intervening mild period. Using fossiliferous evidence (identified as woolly mammoth and woolly rhinoceros) he decided that there was an extensive period of time between the deposition of the two tills. However, not aware that these two species usually represent a cold, periglacial climate, he suggested an interglacial had occurred where these two species co-existed with the typical British fauna of today. If the mammoth and rhinoceros remains were found between two tills this would make the second till post-Anglian in age. However, later, including the authors', research has shown that Thompson was incorrect in his stratigraphy, there being no evidence of interglacial deposits between the tills in the Northampton area.

Although there appears to be no fossiliferous evidence to indicate a long warm period between the deposition of the two tills, there has been considerable erosion or cryoplanation of the lower till in central Northamptonshire. Erosion may have occurred over a long period of time, which may have included periods of both warm and cold climate, or it may have been removed and reworked into the upper till fairly rapidly as part of the process of cryoplanation by the following ice-sheet.

4.13. Post-Anglian interglacial and cold periods, Holocene

Following the deposition of the lower and upper (Anglian) tills, there have been several major climatic changes (Table 4.13.1).

Approximate age of commencement (MA BP)	Period	Epochs	Subdivision	Stages: Britain
0.01		Holocene		Flandrian (t)
0.115			Upper (Late)	Devensian (c)
				Ipswichian (t)
				Wolstonian (c)
0.3			Middle	Hoxnian (t)
0.5				Anglian (c)
				Cromerian (t)
	Quaternary	Pleistocene		Beestonian (c)
			Lower (Early)	Pastonian (t)
				Pre-Pastonian (c)
				Baventonian (c)
				Bramertonian (t)
				Antian (t)
				Thurnian (t)
				Ludhamian (t)
2				Pre-Ludhamian

t, temperate; c, cold

Table 4.13.1. Major divisions of and gross timescales for the latter part of the Cenozoic Pleistocene divisions in the British Isles: Adapted from Jones and Keen, 1993, revised after Zalasewicz *et al.*,1992.

During post-Anglian periglacial stages, the Nene Valley experienced the formation of steeper north valley-sides which have stone-sorted polygons (as seen in the Nene Valley at Little Houghton, this research), and strong temperature fluctuations on the southern valley-side giving rise to Arctic creep and thaw collapse and leading to fault cambering and gulling of the Ironstone, the loosened material being soliflucted into the river (Kellaway and Taylor, 1952). Large boulders, transported downstream from the deposit of chalky till at Wollaston, were seen beneath gravels of the first and second terraces at Vicarage Farm, near Wellingborough. These, in turn, were seen to be bisected by a younger deposit which, having eroded to a lower level, has cut through and removed all the large chalk and other boulders within its path.

Tributaries transported, and still do transport to a much lesser degree, fresh calcareous sands and gravels of the Milton Formation into the Nene Valley. As this is part of the current research, for further discussion go to Site A3, Yardley Hastings, Chapter 7.

The River Tove and the River Great Ouse also underwent major changes during the glacial and post-glacial periods. In particular, the Great Ouse between Newport Pagnell and Bedford (Figure 4.01.2), was diverted towards the north west, bringing it closer to Northampton (Belshaw pers. comm.). The fossil evidence from the River Great Ouse at Stoke Goldington, (SP851488) indicates the deposits are of post- Anglian age (Green *et al.*, 1996).

The lithological and fossiliferous evidence examined in later chapters indicates several major changes in climate that complement the desk top study discussed here. So far, it seems the English Midlands have been subject to periods of erosion and movement of sediments that indicate long cold, possibly periglacial, periods between both glacial and interglacial periods of time.

4.14. Conclusions

A desk-top study of existing published and unpublished evidence has suggested the following conclusions. Remnants of locally derived deposits of the Milton Formation have been found in a pre-glacial sand- and till-filled valley, the Milton Valley, which extends from the Watford Gap, Long Buckby, through Northampton and Wellingborough to Rushden / Higham Ferrers. At this point the valley turns south-eastwards across Bedfordshire.

Differential erosion of the faulted bedrock and the Milton River, formerly flowing to the south of Hunsbury Hill at Northampton, diverted to the north of the hill into what is now the modern Nene Valley.

As the diverted Milton River eroded its new channel, the tributaries that entered the valley from the south crossed the abandoned former valley and interfluve into the combined Milton / Nene Valley (what is now known as the Nene Valley). They would have followed similar directions to those of the modern Wootton Brook and the unnamed streams entering the Nene at Little Houghton, Wollaston and Wellingborough (Figure 4.01.2). At this time, the upland drainage became more like the present day drainage. From that time forwards, the main alterations to the drainage, including the diversion of the river north-eastwards at Rushden / Higham Ferrers, were due to the movement of ice across the area and the deposition of the tills. It appears that there was very little erosion of the bedrock during the glacial periods. The bedrock being further protected from erosion by the later glaciation by the lower till. The first glaciation may not have been so damaging to the landscape as the later one, as suggested by the preservation of so much of the Milton Formation. Evidence for the lower till remains only in the buried valleys, such as the sediments under the upper till in the Yardley Chase valley, or as thin deposits beneath the upper till, as is seen at Brigstock Country Park. The effects of the Anglian glaciation, which deposited the upper chalky till, can be seen from the deep tunnel valley in the Nene.

CHAPTER 5: REVIEW OF PREVIOUS RESEARCH: BRITISH QUATERNARY FRESHWATER OSTRACODS AND THEIR ENVIRONMENT.

5.01. Introduction

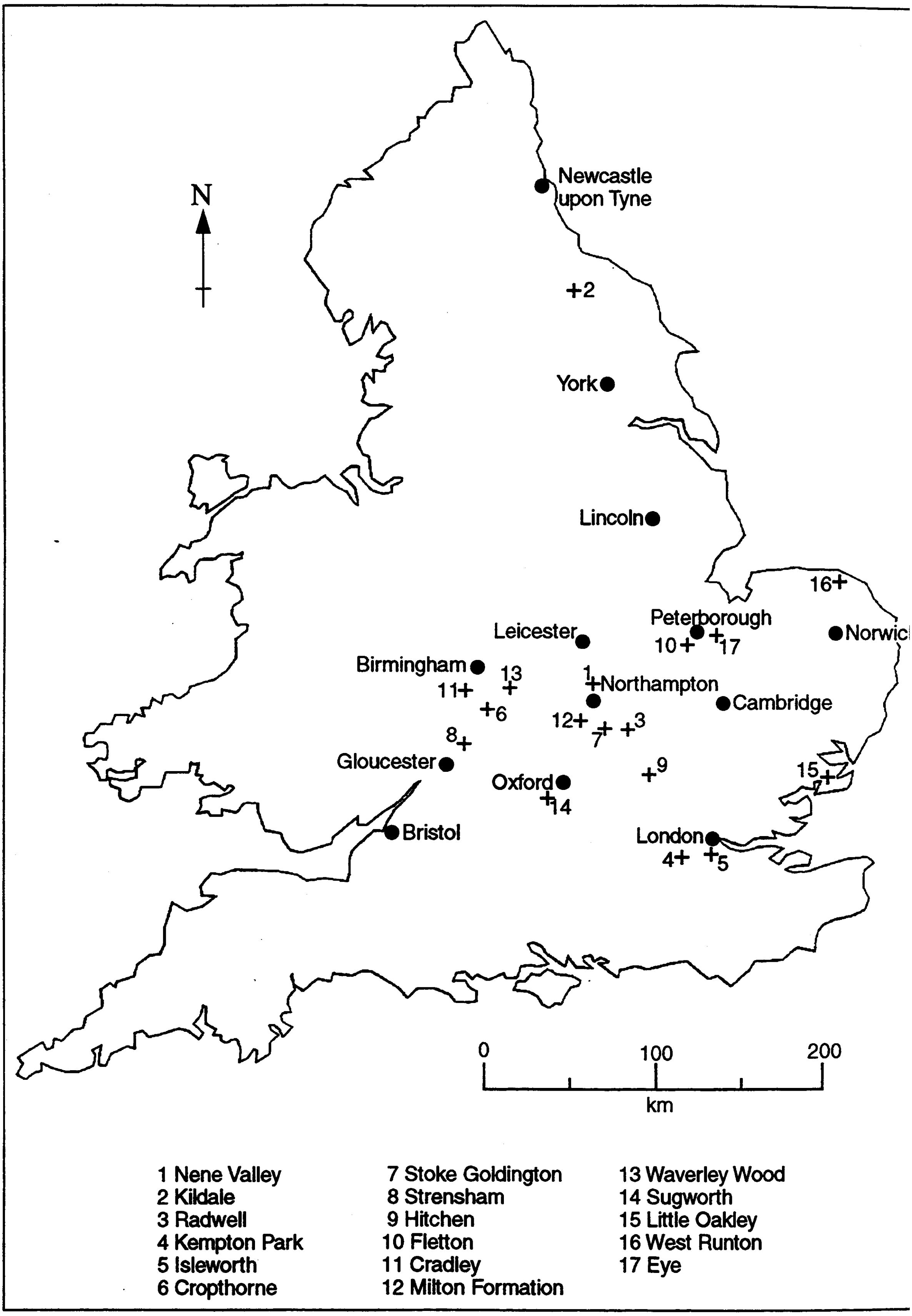
Until the present research no small fossils or microfossils have been recorded from the Milton Formation and, although small fossil remains have been found in the Nene Valley (Figure 1.01.1) ostracods have been largely ignored in the Quaternary sequence. It is hoped that the ostracod data presented here from the Milton Formation and the Nene Valley deposits in general will significantly add to, and reinforce the importance of, the Quaternary evidence collated from the Milton Formation and the Nene Valley Sands and Gravels.

Past research papers that deal with similar fluvial sediments to that of Northamptonshire include work on the English Midlands, East Anglia, and as far north as Yorkshire. Important research includes: the Peterborough area (Lewis *et al.,* 1991), the Midlands (Gibbard *et al.,* 1981; Kemey *et al.,* 1982; Rogerson *et al.,* 1992; Green *et al.,* 1996), the West Midlands (Maddy *et al.,* 1991; De Rouffignac *et al.,* 1995), East Anglia (De Deckker, 1979; Preece, 1990) and Yorkshire (Keen *et al.,* 1984) (Figure 5.01.1).

Of the 26 site reports reviewed, fifteen contain ostracod analyses. These ostracod studies are usually combined with one or more of the following fossil groups: molluscs; pollen, plant macrofossils, beetles and vertebrates. The remaining eleven papers exclude ostracods, but still share similarities to the Milton Formation and the Nene Valley sediments. From the comparison of this past research, with and without ostracod data, it should be possible to reason out if there are benefits to be gained for including the time-consuming collection and analyses of ostracods.

The chapter concludes with tables created from past and present published research. The tables collate ostracod data (applicable to any current research), in order to highlight the importance of ostracod analyses within the environmental and chronological framework of the Quaternary period. Such tables have not been put together before and will be applied to the ostracod analyses of the Milton Formation and Nene Valley (Chapters 7 & 8).

Figure 5.01.1 Location map for most of the sites reviewed in Chapter 5.



5.01.1. A general description of freshwater ostracods.

Freshwater Ostracoda are a subclass of the class Crustacea. Highly specialised arthropods, they are small, 0.3 to 2.5 mm long when adult, and are enclosed within a protective bivalved, hinged calcareous carapace into which the appendages may be retracted (Holmes, 1992). As ostracods mature they outgrow and shed the valves, each moult representing the end of a growth stage or instar. There are usually eight moult stages (instars) between the egg and the adult (Holmes, 1992). The calcareous valves, made of low magnesium calcite, are readily preserved as fossils.

A fossil ostracod valve and carapace assemblage recovered from aquatic sediment, if it includes a series of different sized instars, is considered to be the remains of that of a once living, *in situ,* fauna (West *et al.,* 1994). Furthermore, the presence or absence, and the number of individuals of a species, particularly if the species is reasonably habitat specific, will provide a valuable source of palaeoenvironmental information. The number and diversity of genera found (an assemblage) may do the same. The condition of the ostracod valves, whether they are holed or broken, will indicate whether predation and/or transport has taken place (Robinson, pers. comm.).

"Ostracods show clear habitat preferences. The substrate, habitat permanence, flow rate, dissolved solids, temperature and predator pressure are major factors influencing their distribution" (Henderson, 1990). As the freshwater habitats of lowland Britain, are affected by numerous climatic, physical and chemical factors (Moss, 1980; Selby, 1985; Vandenberghe, 1995), most ostracod species have become specialised to occupy one or two particular habitats, including damp earth and grass. Nevertheless, and despite specialization, very few species can survive in actively flowing water (De Deckker and Forester, 1988). Ostracod species that are habitat specific are soon unsettled when their habitats change and, in any assemblage, some will die out, these being replaced by others more suitably adapted to the new conditions.

Ostracods generally fulfill the following criteria. They are, with very few exceptions, habitat specific (Delorme, 1969; Forester, 1987). They have gone through very little evolutionary change and very few species have become extinct during the Quaternary

(Robinson, pers. comm.). They preserve well in organic sediments collecting in fresh water. They shed their calcareous valves up to eight times during growth to adult size, which makes them, therefore, invaluable environmental indicators (Henderson, 1990; Robinson, 1990). In sediment, the types and number of species present and the number of individuals of each species, can indicate the viability of the community and suitability of the habitat. The valves are fragile and rarely survive reworking in active gravel fluvial environments; thus an assemblage found in such an environment is more than likely to be indigenous to its surroundings. Ostracods are able to colonise niches within a gravel environment where they can survive and multiply. Some individuals are washed in from the wider environment, consequently giving useful data related to the habitats along the floodplain and valley-sides within the area investigated.

Ostracods specific to the following present day habitats may be found in association with braided river environments: a) hardwater springs; b) lime crust deposits; c) slow-moving streams; d) open water of ponds and lakes; e) vegetated areas of ponds; lakes and streams; f) sand-bedded streams; g) damp leaf litter; h) temporary pools (winter species and spring species both resting as dormant eggs in the opposite season); i) Quiet areas of the main river (Figure 1.01.3).

5.02. Summary of ostracod analyses of 16 Quaternary sites and comparison with 10 similar sites which have no ostracod analyses.

The following 26 sites were chosen for their possible palaeoenvironmental similarities to the Milton River deposits and the Nene Valley deposits. The discussion is in two parts:

Part A examines the ostracod data from the 16 sites from which such data was collected.

Part B examines the remaining sites, and considers the advantage gained by including data from other fossil groups.

The full name, also shown in the species list of each site, and the author of each ostracod species is listed in Appendix A.

5.02.1. Part A: Ostracod analyses from sites with similarities to the sites of this research (Tables 5.02.1 - 5.02.4).

HOLOCENE AND DEVENSIAN (Table 5.02.1)

Site 2: Kildale, Yorkshire (Keen *et al.*, 1984) (Table 5.02.1).

Five species were recovered: *Candona candida*, *Pseudocandona (Candona) marchica, Potamocypris arcuata (maculata), Cypridopsis vidua*, *Cyclocypris laevis*, (Table 5.03.1, see Appendix A for authors).

Changes in the ostracod species and assemblages throughout the sediments recovered from Kildale indicated that the palaeoenvironment was one of a cold water body which fluctuated in depth. At first, as the majority of the fauna preferred still water, it was concluded that an organic-rich lake or pond was present. The cold water indicator ostracod species, *P.* cf. *diebeli,* was present early on and, as this species increased in number upwards through the lower sediments, the temperature must have decreased over time. The number of species and population size also indicate a decrease in the size of the water body. Eventually, as the temperature began to increase, the water body first became larger and then dried out. The low faunal diversity contrasts with the twenty or so species that might be expected in the present day British temperate conditions. No open water or active swimming ostracod species were present. No extinct species were recovered from the sediments.

Site 7: Radwell, Bedfordshire (Rogerson *et al.*, 1992) (Table 5.02.1).

Six species of ostracods were recovered: *Candona candida*, *Candona neglecta*, *Darwinula stevensoni, Ilyocypris inermis, Ilyocypris gibba, Prionocypris serrata.*

The analyses showed that the palaeoenvironment was one of slow-flowing to relatively still water with a soft muddy substrate. The species present indicate a cool but not extremely cold climate. No extinct species were recovered from the sediments.

Author & Date	Formation & County	Member	Geochronology	Fossils.	Significant Species.	Environmental Interpretation.	
					Quercus (P)	Cold stage sands and gravels	Holocene
Site 1	Fluvial sands, gravels and	Nene	Iron Age	Molluscs	*Chenopodium album (P)* ,	overlain by interglacial oxbow	overlying
Holyoak &	oxbow lake infill,	Valley	Pottery in	Pollen	*Stellaria media (P)*	lake.	Late
Seddon,	alluvial plain.	Sands &	floodplain	Plant macro			Devensian
1984	Orton Longueville,	Gravels.	silts.				
	Northamptonshire.		500-600 B.C.				
	S.P. 790600						
Site 2	Fossiliferous silted kettlehole	Kildale	Rc. date	Molluscs	(B) Cyperaceae (P)	An impoverished lake system at	(B) Early
Keen	in glacial sands and gravels.	shelly marl,	10,3350+-	Pollen	*Artemisia (P)*	the base of a kettlehole.	Holocene.
et al.,	Kildale,	lake infill	200 B.P.	Plant macro	*(A) Betula (P) Salix (P)*	Climatic warming (Windermere	(A) Late
1984	North East Yorkshire.		1,6713+	Ostracods	*Filipendula (P) Vallonia*	Interstadial) open woodland	Devensian
	N. Z.609097.		340 B. P.		*costata (M) Oxyloma*	followed by the Loch Lomond	1-3.
					pfeifferi (M) Trichia	stadial, then Early Holocene fen	
					hispida (M)	and dry land.	
					Candona marchica (O)		
					Paralimnocythere diebeli (O)		
Site 3	Fossiliferous silty channels	Nene		Molluscs	*Ranunculus (P)*	Open and treeless vegetation	Late
Holyoak &	within fluvial gravels.	Valley		Pollen	Cyperaceae (P)	with marshy pools beside a	Devensian.
Seddon,	Titchmarsh,	Sands &		Plant macro	*Armiger crista (M)*	moving water channel.	
1984	Northamptonshire.	Gravels.			*Vallonia costata (M)*		
	T.L. 010808.				*Punctum pygnaeum (M)*		
					Pisidium milium (M)		
					Pupilla muscorum (M)		
Site 4	Fluvial sands and gravels	River Nene		Vertebrates	*Coelodonta antiquitatis (V)*	Cold stage fauna suggests	Middle
Chancellor &	with fossiliferous silty	First			*Rangifer tarandus (V)*	possible Arctic tundra environ-	Devensian.
Langford,	channel-fill at base.	Terrace			*Bos (V) Bison (V)*	ment.	
1992	Peterborough,	Gravels.					
	Northamptonshire.						
		Rc: Radiocarbon, P: pollen, M: mollusc, O: ostracod, V: vertebrate.					

Table 5.02.1 Stages of Early Holocene and Devensian period: details of selected sites.

Author &	Formation &	Member	Geochron-	Fossils	Significant Species	Environmental interpretation	O.I. Stage
Year	County		ology				
Site 5	Fossiliferous channel-fill	Nene	Rc. date	Molluscs	*Thalictrum alpinus (P)*	Cold Arctic tundra with small	Middle
Morgan,	within fluvial sands and	Valley	28,225+-	Pollen	*Scorpidum scorpoides (P)*	shallow pools. Permafrost 6' C.	Devensian
1969	gravels.	Sands &	330 B.P.	Plant macro	*Planorbis leucostoma (M)*	average annual temperature.	
	Great Billing,	Gravels.		Coleoptera	*Succinea spp. (M)*	July - 10' C. (lower Alpine of	
	Northamptonshire.			Vertebrates	*Helophorus spp. (M)*	today). The pools had a sandy	
	S.P. 617826.				*H. obscurellus (C)*	gravel substrate.	
					H. glacilis (C)		
					Rangifer tarandus (V)		
					Coelodonta antiquitatis (V)		
Site 6	Fossiliferous channel-fills in	Nene		Molluscs	Cyperaceae (P)	Cold northern climate.	Middle
Holyoak &	fluvial sands and gravels.	Valley		Pollen	*Arenaria ciliata (P) Salix cf.*	Permafrost conditions similar to	Devensian
Seddon,	Little Houghton,	Sands &		Plant macro	*poleris (P) Salix (P)*	Great Billing (5, above). Ice-	
1984	Northamptonshire.	Gravels.		Vertebrates	*Pisidium vincentianum (M)*	wedge cast indicates tundra with	
	T.Q. 7960.				*Pupilla muscorum (M)*	polygonal formations.	
					Mammuthus primigenius (V)		
					Coelodontus antiquitatis (V)		
Site 7	Fossiliferous channel-fill	River Great		Molluscs	*Abies (P) Armeria maritima*	The silty infill represented	Middle
Rogerson	within sands.	Ouse Lower		Pollen	*(P) Groenlandia densa (P)*	sediments of a sparsely	Devensian
et al.,	Radwell,	Terrace		Plant macro	*Columella columella (M)*	vegetated pool in a braidplain	
1992	Bedfordshire.	Gravels		Ostracods	*Vertigo genesii (M)*	surrounded by a treeless	
	T. L. 006586			Coleoptera	*Anodonta anatina (M)*	tundra grassland.	
					Pisidium henslowanum (M)		
					Eucypris zenkeri (O)		
					Ilyocypris inermis (O)		
					Diacheila polita (C)		
					Aphidius holderi (C)		
		Rc: Radiocarbon, C: Coleoptera, P: pollen, M: mollusc, O: ostracod, V: vertebrate.					

Table 5.02.1 Stages of Early Holocene and Devensian period: details of selected sites (continued).

Author &	Formation &	Member	Geochron-	Fossils	Significant Species	Environmental interpretation	O.I. Stage
Year	County		ology				
Site 8	Fossiferous silty lenses	River	Rc. date	Molluscs	*Salix herbacea (P) Arenaria*	A clean, well vegetated, slow	Middle
Gibbard,	in current-bedded sands	Thames	35,230+-	Pollen	*ciliata (P) Linum perenne (P)*	flowing channel surrounded by	Devensian
et al.,	and gravels.	Kempton	185 B. P.	Plant macro	*Silene maritima/vulgaris (P)*	a treeless, sparsely vegetated	
1981	Kempton Park,	Park		Ostracods	*Groelandia densa (P)*	meadowland which was, initially,	
	Sunbury.	Gravels		Coleoptera	*Pupilla muscorum (M)*	warm, but cooled, as indicated	
	T. Q. 118703				*Candona lozeki (O)*	by changes in flora and fauna.	
					Limnocythere inopinata (O)		
					Diacheila polita (C)		
					Anotylus gibbulus (C)		
Site 9	Fossiliferous channel-fill	River		Molluscs	*Groelandia densa (p)*	The lower sediments	Middle
Kerney,	below sands and gravels.	Thames		Pollen	*Linium perenne (p)*	represented a clean, slow	Devensian
et al.	Isleworth, London.	Upper		Plant Macro	*Plantago (p)*	flowing channel which	substage
1982	T.Q. 158746	Floodplain		Ostracods	*Pupilla muscorum (M)*	periodically flooded the	
		Terrace			*Anodonta anatina (M)*	Surrounding treeless grass-	
		Gravels and			*Pisidium henslowanum (M)*	land. The flora was typical	
		Silts			*Prionocypris zenkeri (O)*	of trampled ground.	
					Linocythere inopinata (O)		
		Rc: Radiocarbon, C: Coleoptera, P: pollen, M: mollusc, O: ostracod, V: vertebrate.					

Table 5.02.1 Stages of Early Holocene and Devensian period: details of selected sites (continued.)

Site 8: Kempton Park, Sunbury (Gibbard *et al.*, 1981) (Table 5.02.1).

Thirteen species were recovered: *Candona candida, Candona* cf. *lozeki, Fabaeformiscandona (Candona) protzi, Cyclocypris laevis, Cypria ophthalmica, Eucypris pigra, Herpetocypris reptans, Ilyocypris bradyi, Ilyocypris gibba, Psychrodromus (Ilyodromus) olivaceus, Limnocythere inopinata, Nannocandona faba, Potamocypris wolfi* (Table 5.03.1, see Appendix A for authors).

The analyses showed that the palaeoenvironment gradually changed from flowing open water with little or no vegetation to a still water vegetated lake. The presence of all instars to adult stage valves indicate that the assemblages were indigenous. The change in species throughout the sediment suggest that the climate deteriorated from an initially warm to a later cold period. No extinct species were recovered from the sediments.

Site 9: Isleworth, London (Kerney *et al.*, 1982) (Table 5.02.1).

Seven ostracod species were recovered: *Candona neglecta, Cyclocypris serena, Cypridopsis vidua, Ilyocypris bradyi, Limnocythere inopinata, Prionocypris zenkeri, Ilyocypris* sp. (unidentified).(Table 5.03.1, see Appendix A for authors).

All moult stages are represented which suggests the species were living *in situ* at the time of deposition. The ostracod fauna is dominated by *P. zenkeri*, together with *C. serena* and *C. vidua*. These species are found in clear water with a slow to modest flow, rich in aquatic plants. The deposition of the sediments probably occurred in a short, warm period with treeless grassland and an abundance of plants of disturbed ground.

IPSWICHIAN: (Table 5.02.2)

Site 10: March Gravels, Eye, Cambridgeshire (Keen *et al.*, 1990) (Table 5.02.2).

Some 28 species of ostracod were recovered from the March Gravel sediments; of these, 11 species were of fresh water, 3 of brackish water and 14 of marine origin.

Freshwater species recovered from this site include: *Darwinula stevensoni, Leucocythere baltica, Limnocythere inopinata, Cytherissa lacustris, Metacypris cordata, Candona neglecta,* *Pseudocandona marchica, Cyclocypris laevis, Ilyocypris gibba, Paralimnocythere compressa, Candona* sp. (Table 5.03.1, see Appendix A for authors).

The freshwater fauna appeared to be reworked, many of the valves being broken, and juvenile valves rare. The brackish fauna were intact and contained all moult stages, suggesting that the brackish water fauna were indigenous to the palaeoenvironment.

P. compressa, a freshwater ostracod, was formerly associated only with the middle Pleistocene deposits of West Runton (De Deckker, 1979) and Little Oakley, Essex (Robinson,1990), but more recently has been found in sediments of Stage 7, 9 or 11 at Tottenhill, Norfolk (Gibbard *et al.*, 1992) and in Late-Glacial and Holocene deposits (Griffiths, 1995).

The remainder of the freshwater ostracods were valves transported from ponds or lakes into the brackish water estuarine deposits. The faunal assemblages represented an environment with temperatures similar to today. There were no clear indications as to the age of the deposit, but it is most likely to be of an Ipswichian 5e or Stage 7 date.

Site 14: New Inn, Cropthorne, Warwickshire (Maddy *et al.*, 1991) (Table 5.02.2).

Two species of ostracods were recovered from the New Inn sediments: 1 valve of *Herpetocypris* sp., and 29 valves of *Candona rawsoni* (Table 5.03.1, see Appendix A for authors). This is the first and only British record of the latter species. The environment it represents is debatable because, although it is most commonly found in cold tundra-like conditions similar to those of Siberia or Canada (Delorme & Donald, 1969), it has also been found within interglacial deposits in Canada (Poplawski and Karrow, 1981).

Author &	Formation &	Member	Geochron-	Fossils.	Significant Species.	Environmental interpret
Date	County		ology			
Site 10	Sparsely fossiliferous gravel	March		Molluscs	*Hydrobia (M) Corbicula*	Littoral or marine gravels
Keen	ridges that predate Nene First	Gravels		Pollen	*fluminalis (M)*	temporate stage. Shallow
et al.,	Terrace gravel.			Plant macro	*Paralymnocythere*	with a low salinity.
1990	Eye, Cambridgeshire			Foraminifera	*compressa (O)*	
	TF. 23030364				*Cyprideus torosa (O)*	
					Carpinus (P), Pinus (P)	
					Haynesina germanica (F)	
Site 11	Fossiliferous silts	River Nene		Molluscs	*Ancylus fluviatalis (M)*	Temperate climate depos
Langford,	interbedded with sands and	Second		Vertebrates	*Megaloceros gigantus (V)*	followed by cooling climat
1992	gravels.	Terrace			*Cervas elephas (V)*	deposition and sands and
	Sutton Cross,	Gravels				
	Nr. Peterborough.					
	TF. 108989					
Site 12	Fossiliferous silts filling	Pondfill	Earlier than	Molluscs	*Lymnaea stagnalis (M)*	Temperate water hole us
Smith,	depression in bedrock below	Nene Valley	RC	Pollen	*Bithynia tentaculata (M)*	large vetebrates. Grassla
1995	sand and gravel.	Sands and	38,000 B.P	Plant macro	*Trichia plebia (M)*	some trees nearby.
	Little Houghton,	Gravels.			*Pupilla muscorum (M)*	Followed by cooling clima
	Northamptonshire.				*Palaeoloxodon antiquus (V)*	
	SP 793597				roots and wood (PM)	
Site 13	Fossiliferous channel-fill	Marsworth		Vertebrates	*Hippotamus amphibus (V)*	Temperate channel cuttin
Green	cutting through chalky muds	channel-fill			*Arvicula terrestris (V)*	through coombe rock
et al.,	above earliar channel	and coombe			*Dicerorhinus*	(chalky colluvium)
1984	sediments.	deposits			*hermiloechus (V)*	
	Marsworth, Worcestershire.					

Rc. Radiocarbon, F: forams, P: pollen, PM: plant macro, O: ostracods, M: molluscs, V: vertebrate.

Table 5.02.2: Ipswichian Stage 5e: details of selected sites.

Author & Date	Formation & County	Member	Geochron-ology	Fossils.	Significant Species.	Environmental interpret
Site 14	Fossiliferous silts	New Inn		Molluscs	*Discus rotundus (M)*	A large temperate river w
Maddy	interbedded with sands and	fossil bed		Ostracods	*Belgrandia marginata (M)*	unshaded and damp, sha
et al.,	gravels.	River Avon			*Ancylus fluviatalis (M)*	habitats nearby.
1991	Cropthorne, New Inn site.	Sands and			*Pupilla muscorum (M)*	
	Warwickshire.	Gravels			*Anisus vorticulus (M)*	
					Candona rawsoni (O)	
					Hippotamus amphibus (V)	
					(found earlier at Cropthorne)	
Site 15a	Upper channel	River Great	A.A.R. of	Molluscs	*Pinus (P) Picea (P) Abies (P)*	The upper channel cut int
Green	Fossiliferous channel-fill	Ouse Terrace	*Bithynia*	Pollen	*Polygonum viviparum (P)*	middle gravels. It was infil
et al.,	within fluvial terrace sand and	Sand and	*tenticulata*	Plant macro	*Pisidum lapponicum (M)*	hill wash and colluvial dep
1996	gravels.	Gravels	0.1.5e	Ostracods	*Pisidum hibernicum (M)*	during a cool period no la
	Stoke Goldington,			Coleoptera	*Candona candida (O)*	O.I.S. 5e. The ostracod s
	Bedfordshire.			Vertebrates	*Ilyocypris biplicata (O)*	were indicative of small te
		A.A.R. Amino Acid Ratio.				
		P: pollen	O: ostracods	M: molluscs	V: vertebrate, Rc: Radiocarbon.	

Table 5.02.2: Ipswichian Stage 5e: details of selected sites (continued).

OXYGEN ISOTOPE STAGES 7-11: (Table 5.02.3)

Site 15: Stoke Goldington, Bedfordshire (Green *et al.*, 1996) (Table 5.02.3).

Species recovered from this site: *Darwinula stevensoni, Candona candida, Candona neglecta, Cyclocypris serena, Heterocypris salina, Herpetocypris reptans, Ilyocypris gibba, Ilyocypris biplicata, Cypridopsis vidua, Cypris ophthalmica* and *Cyclocypris laevis, Ilyocypris* sp. A (Table 5.03.1, see Appendix A for authors).

Fossiliferous material was recovered from two channels at Stoke Goldington. The 11 species found in the lower sediments represent a typical river channel. It was inhabited by several ostracod assemblages which were dominated either by *Herpetocypris* or *Candona* species. The majority of the species indicate that there were temperate pond-like or sluggish stream environments present. *H. reptans, I. gibba, C. vidua, C. ophthalmica* and *C. laevis*, being almost all active swimmers, verify the presence of open water with vegetation in limited areas. *H. salina*, present in parts of the sediment, indicates that the water occasionally evaporated to a state of mild salinity. *Ilyocypris* sp. A had not, at that time (see results, Chapter 8, of this research), been found in deposits as recent as Ipswichian 5e.

The fauna of the lower channel at Stoke Goldington, is similar to that found at Stanton Harcourt, Marsworth and Aveley and may be of Oxygen Isotope Stage 7 age.

The small ostracod fauna recovered from the upper channel was consistent with cooler conditions (*I. biplicata, C. candida* and *C. neglecta*) and may have been a cool period during the Ipswichian, Stage 5e age.

Site 16: Upper Strensham, Worcestershire (De Rouffignac *et al.*, 1995) (Table 5.02.3).

Species recovered from this site: *Ilyocypris* cf. *decipiens, Candona angulata, Candona candida, Candona neglecta, Herpetocypris reptans, Heterocypris salina, Pseudocandona zenkeri* (Table 5.03.1, see Appendix A for authors).

The species recovered indicate a warm climate. The eggs of *H. salina* do not hatch below $5^{O}C$ (Henderson,1990) and, in the present day, *P. zenkeri* is found in England, but not

Author & Year	Formation & County	Member	Geochron-ology	Fossils	Significant Species	Environmental interpre
Site 15b	Fossiliferous channel-fill	River Great	U.S	Molluscs	*Pinus (P) Picea (P)*	The lower channel cut int
Green	within fluvial terrace sand	Ouse Terrace	170KA TO	Pollen	*Abies (P) Corylus(P)*	lowest gravels and infilled
et al.,	and gravels.	Sand and	167.5 KA	Plant macro	*Nymphoides pehata (P)*	a flood plain pond in temp
1996	Stoke Goldington,	Gravels.	A.A.R of	Ostracods	*Anodonta anatina (M)*	conditions. The coniferou
	Bedfordshire.		*Bithynia*	Coleoptera	*Pisidium moitessierianum (M)*	pollen indicated a cooler
			tentaculata	Vertebrates	*Corbicula fluminalis (M)*	the start or end of a full
			0.1.7.		*Heterocypris salina (O)*	interglacial period.
					Cypridopsis vidua (O)	
					Oxytelus gibbulus (C)	
					Stomodes gryosicollis (C)	
Site 16	Fossiliferous pool, oxbow	Strensham	A.A.R of	Molluscs	*Rumex (P) Artemisia (P)*	A temperate shallow pool
De Rouffignac	lake deposits overlain by	Member.	*Bithynia*	Pollen	*Sagittaria sagitifolia (P)*	marshland with restricted
et al.,	fluvial sand and gravels.	Clays, Avon	*tenticulata*	Plant macro	*Caltha palustris (P)*	and species rich grasslan
1995	Upper Strensham,	Valley Sands	0.1.7.	Ostracods	*Bithynia tentaculata (M)*	
	Worcestershire.	and Gravels.		Coleoptera	*Discus ruderatus (M)*	
				Vertebrates	*Eucypris zenkeri (O)*	
					Heterocypris salinus (O)	
					Oxytelus gibbulus (C)	
Site 17	Fossiliferous interbedded	Ailstone	A.A.R. of	Molluscs	*Ancylus fluviatalis (M)*	Bedload sedimentation a
Maddy	sands, gravels and clays.	member.	*Valvata*		*Pisidium*	floodplain deposits of
et al.,	Ailstone, Warwickshire.	Avon Sands.	*piscinalis*		*moitessierianum (M)*	temperate well-oxygenat
1991	SP 211512	and Gravels	0.1.7		*Corbicula fluminalis (M)*	
Site 18	Fossiliferous channel-fill in	Marsworth	U.S Dates	Molluscs	*Quercus (P) Ulmus (P)*	A shallow spring fed strea
Green	lower sequence of chalky	Lower	171+28-24 k	Pollen	*Alnus (P) Salix (P)*	backwater slacks, marshl
et al.,	muds and sandy gravels.	Tempererate	years.	Plant macro	*Prionocypris serrata (O)*	grassland nearby. This w
1984	Marsworth, Oxfordshire.	Deposits		Ostracods	*Potamocypris spp (O)*	replaced by a Carex dom
				Coleoptera	Mammoth-horse association	depression. Temperate.
				Vertebrates	*Panthera leo (V) Canus lupus (V)*	
					Oxytelus gibbulus (C)	
					Anotylus gibbulus (C)	
		A.A.R: Amino Acid Ratio, U.S: Uranium series, C: Coloptera, P: pollen, M: molluscs, O: ostracods,				

Table 5.02.3: Oxygen Istope Stages 7-11: details of selected sites.

Author & Year	Formation & County	Member	Geochron-ology	Fossils	Significant Species	Environmental interpre
Site 19	Fossiliferous lake deposits	Hitchen		Pollen	*Quercus (P) Alnus (P)*	The upper marl layers of
Boreham	in a former kettle-hole.	Lake Bed.		Plant macro	*Corylus (P) Salix (P)*	deposit represent develo
& Gibbard	Hitchen,	(Overlies and		Ostracods	*Rumex (P) Artemisia (P)*	thermophilous woodland
1995	Hertfordshire.	is constrai-		Vertebrates	*Stachys palustris (P)*	interglacial. The basin wa
		ned by the			*Mentha aquatica (P)*	a stream. The brick earth
		Anglian			*Palaeoloxodon antiquus (V)*	formed under a return to
		Lowestoft till)			*Dicerorhinus sp (V)*	conditons.
					Scotta browniana (O)	
Site 20	Fossiliferous marine	Woodston		Molluscs	*Ulmus (P) Quercus (P)*	The sediments were dep
Horton	transgression sediments	Beds of Fen		Pollen	*Alnus (P) Tilia (P) Acer (P)*	the upper reaches of a la
et al.,	underlain and overlain by	Basin.		Plant macro	*Azolla filiculoides (P)*	estuary. The basal sedim
1991	fluviatile gravels.			Ostracods	Type X (P)	represent fluvial conditio
	Fletton. Peterborough,			Coleoptera	*Valvata piscialis (M)*	rising sea-level turned th
	Northamptonshire.			Vertebrates	*Ancylus fluviatilis (M)*	environment into a brack
	TL. 18999564				*Pisidium*	habitat. Fully temperate.
					moitessierianum (M)	
					Herpetocypris reptans (O)	
					Ilyocypris cf. decipiens (O)	
Site 21	Fossiliferous silts overlain	Cradley	A.A.R. of	Pollen	*Salix (P) Quercus (P)*	In the late Anglian, a slug
Barclay	by the Colwall Gelliflluctate.	Silts	*Valvata*	Plant macro	*Ulmus (P)*	river developed, bordere
et al.,	Colwall, Hereford and	(Lacustrine	*piscinalis*	Ostracods	*Valvata piscinalis (M)*	marshland. This change
1992	Worcester,	silts)	stage 7	Vertebrates	*Valvata cristata (M)*	fully temperate woodlan
	Malvern Hills				*Oxyloma pfeifferi (M)*	water body silted up and
	SO. 73814000				*Vallonia costata (M)*	marshland.
					Candona leveranderi (O)	
					Ilyocypris papillata (O)	
			A.A.R: Amino Acid Ratio, P: pollen, M: molluscs, O: ostracods, V: vertebrates.			

Table 5.02.3: Oxygen Istope Stages 7-11: details of selected sites (continued).

in Scotland or Scandinavia. *C. angulata* and *H. reptans* are found both in Europe and North Africa. The Upper Strensham deposits were likely those of a temperate, low energy fluvial environment with marsh close to the floodplain. The fossil species recovered were similar to Marsworth, Stoke Goldington and Stanton Harcourt and represent an intermediate age between Ipswichian and Stage 9 interglacials. No extinct species were recovered from the sediments.

Site 18: Marsworth, Oxfordshire (Green *et al.*,1984) (Table 5.02.3).

Species recovered from the lower channel: *Ilyocypris bradyi, Candona neglecta, Candona lactea, Candona pubescens, Cyclocypris globosa, Prionocypris serrata, Eucypris virens, Potamocypris* sp. (Table 5.03.1, see Appendix A for authors).

At Marsworth two organic sediments were separated by periglacial deposits, and it seemed the lower channel represented an earlier interglacial than the upper channel from which no ostracods were recovered (Table 5.02.2, Site 13). The ostracods recovered were dominated by *P. serrata.* The indications were of a shallow spring fed stream with backwater slacks within a local context of marshy grassland. The stream was replaced by a *Carex* dominated swamp depression which was finally infilled with colluvial debris. The ostracods do not indicate a particular time period, but G. R. Coope says, in this paper, that the beetle, *Anotylus gibbulus*, which is not found in firmly established Stages 11 or 9 or the Ipswichian time periods, is also common at Marsworth, Stoke Goldington in the Great Ouse Valley, Aveley in the Lower Thames Valley, and Stanton Harcourt in the Upper Thames Valley (from previously unpublished data). He suggests that, although this species is found rarely in Devensian sites (such as Kempton Park, Sunbury - Site 8, Table 5.02.1), these sites may have a Stage 7 episode in common.

Site 19: Hitchin, Hertfordshire (Boreham and Gibbard, 1995) (Table 5.02.3).

Species recovered from this site: *Darwinula stevensoni, Limnocythere inopinata, Cyclocypris laevis, Cyclocypris globosa, Eucypris virens, Herpetocypris reptans, Cypridopsis* *vidua, Ilyocypris gibba, Ilyocypris bradyi, Candona candida, Candona lactea, Candona pubescens, Scottia browniana, Candona* spp. (Table 5.03.1, see Appendix A for authors).

The ostracods were collected and recorded by Chapman in 1903. It represents a species assemblage from a still, freshwater pool or lake filled by a slow flowing stream. The species also suggest the lake was partially overgrown around its shores. The indicator species, *S. browniana* points to a pre-Ipswichian age (Griffith,1995).

Site: 20 Fletton, Peterborough, Northamptonshire (Horton *et al.,* 1991) (Table 5.02.3).

Species recovered from this site: *Herpetocypris reptans, Prionocypris serrata* and *Candona* spp. (Table 5.03.1, see Appendix A for authors).

The ostracod remains recovered were few in number and the fauna was of low species diversity. Their abraded condition suggested they were washed in from further upstream. The presence of two brackish water species (*C. torosa* and *I.* cf. *decipiens*) confirmed there was at least one marine incursion into the freshwater environment. The species present indicate a possible palaeoestuarine environment. Fossil evidence other than the ostracods suggests a Stage 7, 9 or 11 age for this site.

Site 21: Colwall, Hereford and Worcester (Barclay *et al.,*1992) (Table 5.02.3).

Species recovered from this site: *Candona leverandi, Herpetocypris reptans, Ilyocypris bradyi, Ilyocypris gibba, Cypridopsis vidua* and *Ilyocypris papillata* (Table 5.03.1, see Appendix A for authors).

The Cradley Silts are found, at 116 m O.D., in the valley of the Cradley Brook which is approximately 2 km south of Colwall, Hereford and Worcester. They rest on White House Silts (of Anglian age) and are overlain by the Colwall Gelifluctate (described in this paper under review).

The ostracod assemblages in the Cradley Silts were of low species diversity. This indicates the waterbody was probably stagnant and had a soft muddy base colonised by *C. leverand.* The water above was inhabitated by *H. reptans, I. bradyi, I. gibba, C. vidua* and *Ilyocypris papillata*. Any ostracod species requiring dense vegetation are absent from the species list, suggesting the presence of an open water habitat. Nowadays one would expect to find 12-15 species in a similar pond or lake deposit.

As *I. papillata* has not been found in Pleistocene, or later, sediments Robinson gave the deposits an early to middle Pleistocene date (pre-Ipswichian). It is suggested by Barclay *et al.*, (1992) that the sediments were laid down soon after the Anglian glaciation and during a period of climatic warming.

CROMERIAN III B.- BEESTONIAN: (Table 5.02.4)

Site 23: Waverley Wood, Warwickshire (Shotton *et al.*, 1993) (Table 5.02.4).

Species recovered from this site: *Ilyocypris quinculminata*, *Candona tricicatricosa*, *Candona weltrieri obtusa*, *Cyclocypris serena*, *Candona leverandi*, *Ilyocypris decipiens*, *Ilyocypris gibba*, *Ilyocypris monstrifica*, *Notodromas monacha*, *Cypris marginata*, *C. pubera*, *Eucypris dulcifrons*, *Trajancypris clavata* (Table 5.03.1, see Appendix A for authors).

The ostracod species from the Waverley Wood organic muds indicate a low energy environment in a late phase of a temperate climate. The sediments, interpreted as small ponds or slow flowing water channels, contained 3 biozones:-

(1) The base muds were those of quiet waters inhabited by *H. reptans* and *C. weltneri obtusa*.

(2) The middle biozone was a muddy substrate with considerable weed growth and periodic open water inhabited by *I. quinculminata* and *C. weltneri obtusa*.

(3) The uppermost biozone was different in that it was dominated by *I. quinculminata* and *C. leverandi*, the presence of which indicates either that climatic cooling was taking place or there was a fresh influx of cold spring fed water entering the water basins.

The majority of the ostracod species from these sediments were non-swimmers and lived on, or in, the mud sediments. The fauna, suggested by the extinct species *C. tricicatricosa* and *I. quinculminata* (extinct), is of Middle Pleistocene age. The absence of *S. browniana* and the presence of *C. leverandi* suggests cooling was taking place.

Author & Year	Formation & County	Member	Geochron-ology	Fossils	Significant Species	Environmental interpreta
Site 22	Milton Formation, sand.	Milton:-		Vertebrates	*Equus (tibia)*	A wide river depositing fluv
Castleden,	Sites near Northampton,	Sands			*Mammuthus or*	sand with some local ironst
1980a	Northamptonshire.				*Palaeoloxodon (tusk)*	gravel.
Site 23	Fossiliferous channel-fills	Waverley	A.A.R of	Molluscs	*Betula (P) Pinus (P)*	Deposition occurred in a lat
Shotton	below the Bagington-	Wood	*Bithynia*	Pollen	*Picea (P)*	phase of a temporate clima
et al.,	Lillington Sands and Gravels.	organic	*troscheli*	Plant macro	*Rumex maritimus (P)*	A slow river and still water
1993	Waverley Wood,	muds	*Trichia*	Ostracods	*P. moitessieranum (M)*	fluctuated as climate fluctu
	Warwickshire.		*hispida*	Vertebrates	*Unio crassus (M)*	Marsh, grassland and borea
	SP. 45132007		0.1/ 15	Coleoptera	*Bithynia troscheli (M)*	woodland thrived on the riv
					Eucypris dulcifrons (O)	banks and nearby.
					Schlerocypris clavata	
					prisca (O)	
					Candona leverandi (O)	
					Pletobuis vittatus (C)	
					Arvicola cantiana (V)	
Site 24	Fossiliferous channel-fills	Sugworth		Molluscs	*Nematurella runtoniana (M)*	Proto-Thames. A large wel
Shotton	beneath glacial drift.	Bench		Pollen	*Unio crassus (M)*	oxgenated river fringed with
et al.,	Sugworth,	Deposits		Plant macro	*Pisidium*	marsh and flowing through
1979	Nr Oxford			Ostracods	*moitessierianum (M)*	temperate woodland.
	Oxfordshire.			Vertebrates	*Scottia browniana (O)*	
	SP. 45132007				*Eucypris dulcifrons (O)*	
					Candona triciatrisa (O)	
					Metacypris cordata (O)	
					Sorex cf. savini (V)	
					Mimomys savini (V)	
					Dicerorhinus etrascus (V)	
		A.A.R: Amino Acid Ratio, C: Coleoptera, P: pollen, M: mollusc, O: ostracod, V: vertebrate.				

Table 5.02.4: Stages throughout Pre-Anglian, Cromerian and Beestonian period: details of selected sites.

Author & Year	Formation & County	Member	Geochron-ology	Fossils	Significant Species	Environmental interpreta
Site 25	Fossiliferous silty sandy,	Little Oakley	Palaeo	Molluscs	*Ulmus (P) Picea (P)*	Large, wide river of
Preece	poorly bedded channel.	silts and	Magnetism	Pollen	*Ouercus (P) Tilia (P)*	temperate climate. Open
(editor),	Little Oakley,	sands	730 KA	Plant macro	*Corylus (P)*	grassland which, in part, be
1990	Essex		A.A.R.	Ostracods	*Unio crassus (M)*	deciduous forest.
			Valvata	Vertebrates	*Bithynia trocheli (M)*	
			piscinalis		*Scottia browniana (O)*	
			Valvata		*Candona tricicatricosa (O)*	
			naticana		*Ilyocypris quinculminata (O)*	
			Cromerian		*Scherocypris clavata*	
			11b		*prisca (O)*	
					Megoloceros verticornia (V)	
					Mimomys savini (V)	
Site 26	Fossiliferous sediments.	Cromer		Ostracods	*Scottia browniana (O)*	A period of climatic change
De Deckker,	Goss's Gap,	Forest Bed			*Candona leverandi (O)*	Initally cold, the evidence is
1979	West Runton.	Formation.			*Eucypris dulcifrons (O)*	warming upwards through t
						sediments. Cold standing p
						increased in size during the
						temperate zone.
		A.A.R: Amino Acid Ratio, P: pollen, M: molluscs, O: ostracods, V: vertebrates.				

Table 5.02.4: Stages throughout Pre-Anglian, Cromerian and Beestonian period: details of selected sites (co

The Waverley Wood site has been interpreted as similar to that of the Sugworth Bench deposits, but with a boreal forest cover which would make it a later and cooler environment than that of Sugworth.

Site 24: Sugworth, Oxfordshire (Shotton *et al.*, 1979) (Table 5.02.4).

Species recovered from this site: *Darwinula stevensoni, Candona neglecta, Candona tricicatricosa, Candona compressa, Pseudocandona marchica, Cyclocypris ovum, Ilyocypris bradyi, Potamocypris wolfi, Metacypris cordata, Eucypris* cf. *dulcifrons, Eucypris pigra, Scottia browniana, Herpetocypris reptans* (Table 5.03.1, see Appendix A for authors).

The Sugworth Bench ostracods species are associated with a sluggish stream which tended to stagnate and become overgrown with weed. Intermittent flooding would have reworked loose ostracod valves from pools into the river where they became mixed with river sediments. All the ostracod species are found in temperate climates and an early interglacial date was considered the most likely. The presence of *S. browniana* indicates, at least, a Middle Pleistocene age. *Eucypris* cf. *dulcifrons* and *C. tricicatricosa* are both found in the late Beestonian fauna in Norfolk.

The environment postulated for the Sugworth Bench Deposits are very similar to those of both the West Runton and Little Oakley Cromerian IIb period. However, the ostracod assemblages differed in having additional species including *E. pigra,* (an ostracod found in streams), and *H. reptans* (an ostracod of vegetated temporary and permanent pools). *E. pigra* was probably washed into the main body of water from valley side springs. The temporary pool species present in the assemblage indicated that the floodplain was regularly inundated with flood water.

As these deposits, found in the Midlands of England, are notably different from the East Anglian sites, the local geology and climate must have a strong influence on the kind of ostracod species present at any site.

Site 25: Little Oakley, Essex (Robinson, 1990) (Table 5.02.4).

Species recovered from this site: *Darwinula stevensoni, Limnocythere* cf. *usenensis* Karmischina, *Candona tricicatricosa, Paralimnocythere compressa, Pseudocandona marchica, Ilyocypris quinculminata, Ilyocypris papillata, Ilyocypris lacustris, Ilyocypris schwarzbachi, Cypridopsis vidua, H, reptans, Cyclocypris laevis, Heterocypris salina, Potamocypris fulva, Trajancypris clavata, Scottia browniana, Heterocypris. salina* (Table 5.03.1, see Appendix A for authors).

The Little Oakley environmental interpretation differs from that of West Runton (described below). The aquatic environment at West Runton (De Dekker, 1979) was vegetation-rich with still waters dominated by *S. browniana.* This species is rare at Little Oakley, most probably because of the lack of vegetation. The dominant ostracods are of the *Ilyocypris* group. *I. quinculminata, I. papillata, I. lacustris*, and *I. schwarzbachi* are all extinct in Great Britain (Griffiths 1995).

P. fulva, a species of springs and streams, would have been inwashed from the valley side. The other species represent a large river with a slow, silt-depositing flow regime.

The species *C. tricicatricosa* and *P. compressa* are extinct and suggests a Mid-Pleistocene (pre-Anglian) age for the ostracod fauna.

Site 26: West Runton, Norfolk (De Deckker, 1979) (Table 5.02.4).

Species recovered from this site: *Darwinula stevensoni, Candona candida, Candona angulata, Candona parallela, Paralimnocythere compressa, Candona neglecta, Pseudocandona compressa, Ilyocypris bradyi, Cyclocypris laevis, Cyclocypris ovum, Scottia tumida, Scottia browniana, Fabaeformiscandona fabaeformis, Candona leverandi, Eucypris dulcifrons, Potamocypris zschokkei* (Table 5.03.1, see Appendix A for authors).

The West Runton ostracod fauna indicate a climatic change from cold to warm. Initially, the few ostracods species present were of low population density which inferred there were either small ponds and/or an intermittent stream. The species *S. browniana* indicates shallow water bodies that frequently dried up, but these were alternating with river sediments, as indicated by an increase in black cherty pebbles within the sediment. The presence of *C. candida, P. compressa* and *I. bradyi* indicates the water may have been stagnant at times. As the climate slowly warmed a small lake, pond or swamp developed. The ostracod species indicate a marshy, vegetated and possibly eutrophicated environment. There was possibly an episode in which evaporation was occurring at a high rate: ostracods *C. angulata, P. compressa, C. neglecta* and *I. bradyi,* as an assemblage, can tolerate some salinity in their environment (brackish water). As the climatic warming continued fen and reed swamp developed. This may have been at a time of transition in the Cromerian. At this time, the burrowing *Candona* species would have been at their most abundant, particularly *C. parallela.* A small shallow lake must have developed with fairly abundant aquatic vegetation with fen and swamp vegetation around the shoreline. The presence of *I. gibba* suggests a temperate climate. *S. browniana* (also, a temperate climate indicator species) was abundant. The supply of sand and vegetation debris was high and the lake productive. As warm temperate forest developed, so the water-body became shallower. The lake continued to silt up; the sand and vegetation debris causing *S. browniana* to decrease in number.

If the age of the West Runton final stage (Cromerian 111b) is correct and it correlates with the age of Little Oakley, then the wide diversity of the ostracod species found shows that, at that time, the environment of the east coast of England varied quite considerably and provided a large variation in the habitats available for colonisation by these animals. The variations in the environment, as indicated by the changes in the West Runton habitat, may have been caused by oscillations in the climate. The oscillations may not have affected, greatly, the much larger, slow-flowing river 4 km to the east, in the Cromer area.

The literature concerning the Quaternary of the Lowland Midlands of England has few records of ostracod analyses and these are meagre compared with sites in East Anglia, such as Little Oakley (Robinson, 1990) and Goss's Gap, West Runton, Norfolk (De Deckker, 1979). The advantage of a large number of samples, such as De Deckker's 62 samples collected from Goss's Gap, is that it can be demonstrated, with conviction, that ostracods species were reliable indicators of changing and fluctuating environments.

5.02.2.Part B: Sites without ostracod data (Tables 5.02.1 - 5.02.4).

Site 1: Orton Longueville, Northamptonshire (Holyoak and Seddon, 1984) (Table 5.02.1).

Site 3: Titchmarsh, Northamptonshire (Holyoak and Seddon, 1984) (Table 5.02.1).

Site 4: Peterborough, Northamptonshire (Chancellor and Langford, 1992) (Table 5.02.1).

Site 5: Great Billing, Northamptonshire (Morgan, 1969) (Table 5.02.1).

Site 6: Little Houghton, Northamptonshire (Holyoak and Seddon, 1984) (Table 5.02.1).

Site 11: Sutton Cross, Peterborough (Langford, 1992) (Table 5.0.2.2).

Site 12: Little Houghton, Northamptonshire (Smith, 1995) (Table 5.0.2.2).

Site 13: Marsworth, Worcestershire (Green *et al.,* 1984) (Table 5.0.2.2).

Site 17: Ailstone, Warwickshire (Maddy *et al.,* 1991) (Table 5.0.2.3).

Site 22: Milton Formation, Sites near Northampton, Northamptonshire (Castleden, 1980a) (Table 5.0.2.4).

These sites have been included for their similarities to the sites from which the ostracod data was collected and to those of this research. All the deposits are associated with finer grained fossiliferous sediments within or beneath coarse sediments in a freshwater, usually fluvial, environment. All of these sites are within the time range of those chosen for ostracod analyses. They also have many molluscan and mammalian species in common with the other sites.

From the data for these sites (Tables 5.02.1, 5.02.2, 5.02.3 and 5.02.4) it is apparent that the more fossil groups analysed (Coleoptera, Foraminifera, pollen, plant macrofossils, molluscs, ostracods and vertebrates) the more skillfully the environment can be interpreted.

For instance, the Sites 1, 3 and 6, Nene Valley Sands and Gravels (Holyoak and Seddon, 1984), cold stage sediments were compared with the earlier Site 5, Nene Valley Sands and Gravels (Morgan, 1969), and depended on the similarity of the data to the latter site for much of the interpretation and dating (cold stage deposits of the Middle and Late Devensian periods). Either any ostracods present in the sediments were not processed (sites of this age do yield ostracod fossils, see Chapters 7 & 8), or the environment was unsuitable ostracods. The same could be said for Sites 10-13, 17 and 22. Site 4, River Nene First Terrace Gravels (Chancellor and Langford, 1992) were still under investigation at the time the report was published.

Having compared the fifteen papers with ostracod data against the eleven papers without (Tables 5.02.1-4), it can be appreciated that, despite the dearth of information in this particular field, ostracod data are likely to add fine detail to understanding of Quaternary fluvial environments that may be missed by the other fossil groups. Ostracod analyses on their own, as used by De Deckker (1979) at West Runton (Site 26), can give clear indications of climatic change (as interpreted by changes in the ostracod species present and their particular environmental needs). When combined with other fossil group data (as in the other papers reviewed) they can be utilized to indicate environments as varied as pools within a cold treeless, tundra landscape (Rogerson *et al.*, 1992), fully temperate lakes (Boreham and Gibbard, 1995), estuaries (Lewis *et al.*, 1991) and rivers with grassland and temperate woodland nearby (Shotton *et al.*, 1979).

5.03. Collation.

5.03.1 Ostracods, signals of timescale and climatic change in the Quaternary.

Ostracod analysis, in association with other data, has shown that the time prior to the Devensian cold stage and the temperate Ipswichian Stage 5e comprised a sequence of cold (Stages 10, 8, 6) and warm (Stages 11, 9, 7) stages. In this work, the Hoxnian will be taken as Stage 11 following Bridgland *et al.* (1991).

On occasion, unusual ostracod assemblages can help correlate sediments from site to site, such as in the case of Marsworth (Green *et al.*, 1984), Upper Strensham (De Rouffignac *et al.*; 1995) and Stoke Goldington (Green *et al.*, 1996). Together, these sites have a strikingly different ostracod and *Coleoptera* fauna from those of the Stages 11 and 9 sites, and probably belong to a later stage, referred to in the literature as the Stage 7 Interglacial. It must not be forgotten, however, that, in any study, the local geology and climate must have an affect on the kind of ostracod species present at any site.

Extinction of biota has occurred throughout the Early and Middle Pleistocene and it is possible for extinct ostracod species to give a minimum age for British sediments, for instance, *I. papillata* appears to have become extinct during Stages 11 or 9, and *S. browniana* is not found in sediments younger than Stage 9. Ostracod data, world-wide, however, are continuing to change and it is as well to check the most recent records before committing a species to a certain time period.

Extinctions occurred during the Beestonian-Cromerian IIIb stage. It was a long period in which extreme climatic changes occurred, at first cold, then warm and subsequently cool again, ending with the Anglian glaciation. During this time, the ostracod species present coped with changing habitats, increasing and decreasing in numbers according to the suitability of the available habitats. These environmental changes resulted in (as indicated by each author) some ostracod species, common during the earlier Cromerian period, becoming extinct towards the end of the Cromerian interglacial and the beginning of the glaciation. Similar climatic oscillations occurred in later time periods. This could account for the distinct change in the ostracod assemblages of Stage 7 (Sites 15 - 18), when compared with those of Stage 9 and 11 (Sites 19 - 21).

5.03.2 Chronostratigraphic order of ostracods from the literature review.

A table of the ostracod species named in the review have been drawn up, placing the sites in apparent chronostratigraphic order (see Table 5.03.1). The compilation of this table suggests that ostracods might be used in a more specific way than has been realised formerly and that conclusions can be reached beyond those of the original authors.

The data in Table 5.03.1 indicate that some ostracod species provide distinct 'time signals', for example, the species *S. browniana* and *C. leverandi* appear to have become extinct in England within, or at the end of, the earliest Stage 7, 9 or 11 stages (*C. leverandi* is still extant in Europe). This makes it unlikely that either species would be found in many Stage 7 sediments, other than by reworking, which, due to the fragile nature of freshwater ostracod valves, is extremely rare (Horne, pers. comm.).

CHRONOLCGICAL STAGE,	BEESTONIAN					CROMERIAN				ANGL'N			HOXNIAN								IPSW'N		DEVENSIAN					HOLOCENE						
POLLEN ZONE OR O.I. STAGE	A	B	1A	1B	IIA	IIB		IIIB		LATE			11	11	9	7	7	7	7				5e	5d	5c	5c		EARLY	PRESENT					
LITHOLOGICAL UNIT OR MEMBER	West Runton	West Runton	West Runton	West Runton	West Runton	West Runton	Little Oakley	Sugworth	Waverley Wood	GLACIAL	Cradley Silts	Hitchen Lake Beds	Cradley Silts	Hitchen Lake Beds	Woodston Beds	March Gravels	Ailstone	Strensham	Stoke Goldington	WOLSTONIAN EVENT			Cropthorne	Isleworth	Kempton Park	Radwell	Kildale	Kildale		1990.	& Henderson	Griffiths,1995	Taken from	
OSTRACOD SPECIES																																		
Darwinula stevensoni		○					◀	○						√		○			○							○				√	√			
Leucocythere baltica																○														E	E			
Limnocythere inopinata														√		●								○	◀					√	√			
Limnocythere cf. *usenensis*							□																							E	E			
Paralimnocythere compressa	○	●					□									○														√	√			
Paralimnocythere cf. *diebeli*																											○			E	E			
Metacypris cordata							○	●								○														√	√			
Cytherissa lacustris																●														√	√			
Candona angulata		●			●													○												√	√			
Candona candida	○													√				◁	○						□	○	■	◁		√	√			
Candona lactea														√																?	?			
Candona rawsoni																							◁							√	E			
Candona levanderi									●				□																	E	E			
Candona lozeki																									■					√	E			
Candona neglecta		●						○								◁		□	□					◁		□				√	√			
Candona parallela		□	◀	◀	◁	○																								√	√			
Candona pubescens														√																?	E			
Candona tricicatricosa							◀	○	◀																					?	?			
Candona weltneri obtusa									◁																					√	√			
Fabaeformiscandona protzi																									●					?	√			
Fabaeformiscandona fabaeformis		○																												√	√			
Pseudocandona compressa	○	●			○																									√	√			
Pseudocandona marchica							●	○								●											□	○		√	√			
Nannacandona faba																									○					√	√			
Cyclocypris globosa														√																√	√			
Cyclocypris laevis		□	●	●	○		○							√		○			○						◁		○			√	√			
Cyclocypris ovum		■	●	○				○																						√	√			
Cyclocypris serena									○															◀						√	√			
Cypris ophthalmica																			○						○					√	√			

Frequency (as indicated by the individual authors).

Rare ○ ● ◁ ◀ □ ■ Abundant

√ Frequency unknown

E Extinct in Britain or worldwide

? Presence in Britain unknown

Table 5.03.1. Chronological order of ostracod data from papers of the literature review.

CHRONOLOGICAL STAGE,	BEESTONIAN					CROMERIAN				ANGL'N			HOXNIAN								IPSW'N			DEVENSIAN				HOLOCENE						
POLLEN ZONE OR O.I. STAGE	A	B	1A	1B	IIA	IIB		IIIB		LATE			11	11	9	7	7	7	7				5e	5d	5c	5c		EARLY		PRESENT				
LITHOLOGICAL UNIT OR MEMBER	West Runton	West Runton	West Runton	West Runton	West Runton	West Runton	Little Oakley	Sugworth	Waverley Wood	CLACIAL	Cradley Silts	Hitchen Lake Beds	Cradley Silts	Hitchen Lake Beds	Woodston Beds	March Gravels	Allstone	Strensham	Stoke Goldington	WOLSTONIAN EVENT			Cropthorne	Isleworth	Kempton Park	Radwell	Kildale	Kildale		1990.	& Henderson	Griffiths, 1995	Taken from	
OSTRACOD SPECIES																																		
Ilyocypris bradyi	O	O	O					O					O	√										◀	◀					√	√			
Ilyocypris biplicata																			√															
Ilyocypris decipiens									O						√			◀												√	√			
Ilyocypris gibba					O				◀				◁	√		●			O						O	●				√	√			
Ilyocypris inermis																										◀				√	√			
Ilyocypris lacustris							□																							E	E			
Ilyocypris monstrifica									O																					√	√			
Ilyocypris papillata							□						O																	E	E			
Ilyocypris quinculminata							◁		O																					E	E			
Ilyocypris schwarzbachi							◀																							E	E			
Ilyocypris sp. A Stoke Goldington																			O											E	E			
Notodromas monacha									O																					√	√			
Cypris marginata									O																					√	√			
Cypris pubera									O																					√	√			
Eucypris dulcifrons		O						●	●																					?	E			
Eucypris pigra								O																	□					√	√			
Eucypris virens														√																√	√			
Prionocypris serrata															√											◀				√	√			
Prionocypris zenkeri																		O						■						√	√			
Tranjancypris clavata							O		O																					√	√			
Herpetocypris reptans							O	O	◀				●	√	√			□	●				O		□		O			√	√			
Psychrodromus olivaceus							●	O																	◀					√	√			
Scottia browniana		□	◀	●	■	●	O	■						√																E	E			
Scottia tumida					O	O																								E	E			
Heterccypris salina							●									●		O	O											√	√			
Cypridopsis vidua		●	●				●						◁	√					O					◀			O			√	√			
Potamocypris fulva							O																							√	√			
Potamocypris arcuata																											◁			√	?			
Potamocypris zschokkei	O																								◁					√	√			

Frequency (as indicated by the individual authors).

Rare O ● ◁ ◀ □ ■ Abundant

√ Frequency unknown

E Extinct in Britain or worldwide

? Presence in Britain unknown

Table 5.03.1. **Chronological order of ostracod data from papers of the literature review.** continued.

The species *I. lacustris, I. quinculminata, E. dulcifrons*, and *S. tumida*, appear to have become extinct during the Anglian cold stage, and hence may occur only in Cromerian or earlier sediments.

Certain other ostracod species, such as *P. zenkeri, I. inermis, C. lozeki, C. rawsoni,* and *L. inopinata* appear to have arrived in England after the Anglian glaciation, giving a marker for post-Anglian organic deposits.

Some ostracod species are found throughout the Quaternary period and are present in Great Britain today, for instance *Cypridopsis vidua, I. bradyi, Cyclocypris laevis* and *D. stevensoni.*

It is anticipated that the current research will provide new information to add to this table.

5.04.1 Application of past research to present ostracod analysis.

Several factors, drawn from the past research and the environmental requirements of different ostracod species, can be used for the analyses of the present research. The following are the most useful:

1) Correlations can be drawn between the number and type of ostracod species, the population size of each species, and the type of organic sediment present to give a reasonably accurate idea of what the fluvial environment was like at the time of deposition. For example:

A **cool** environment is represented by the presence of one or more of the following species: *L. sanctipatricii, C. lacustris, C. globosa, B. fuscatus, P. olivaceous.*

A **temperate** environment is represented by the presence of one or more of the following species: *L. inopinata, P. marchica, I. gibba, Prionocypris serrata, P. arcuata, P. similis.*

A **vegetated** aquatic environment is represented by the presence of one or more of the following species: *L. inopinata, P. marchica. C laevis, I. bradyi, E. virens, B. fuscatus, H. reptans, H. incongruens, C. vidua.*

An environment with **open water** is represented by the presence of one or more of the following species: *C. globosa, C. laevis, Prionocypris serrata, H. Incongruens, C. vidua.*

An environment of **flowing water** is represented by the presence of one or more of the following species: *P olivaceus, E. pigra, Ilyocypris* spp.

An environment with **fine muds and silts** is represented by the presence of one or more of the following species: *D. stevensoni, C. lacustris, Candona* spp., *H. reptans*.

An assemblage of ostracod species may consist of any number of the above species, but where an assemblage is weighted towards any one of the above groups by its number of species of that group, or has high population figures of one or more species of that group, then the assemblage is giving good environmental signals in its composition. Frequently, an assemblage is weighted towards two or more of the above groups, indicating, perhaps, temperate, vegetated, still water with an influx of cooler, flowing water from a spring. Often, however, the sample of ostracods is small, or there are few strong environmental indicator species associated with it. This is where an understanding of the origins of the sediment / matrix (from which the ostracod valves were removed) is beneficial. Deduction from the presence of features such as fine muds and silts, copious sand or fragmented vegetation, should contribute towards establishing the larger picture. Good examples of this kind of evidence is seen in the review of past research, for example:

a) Site 7: Radwell, Bedfordshire (Rogerson *et al.*, 1992) (Table 5.02.1).

b) Site 19: Hitchin, Hertfordshire (Boreham and Gibbard, 1995) (Table 5.02.3).

c) Site 24: Sugworth, Oxfordshire (Shotton *et al.*, 1979) (Table 5.02.4).

2) A sediment containing ostracod valves of all or most instars of each species represents an autochthonous - life - assemblage: that is, the sediment is unlikely to have been reworked. The following two sites amply illustrate this point:

a) Site 9: Isleworth, London (Kerney *et al.*, 1982) (Table 5.02.1).

Seven ostracod species were recovered of which all the moult stages of each species were represented. This, suggested the authors, is sufficient evidence to believe that all the species were likely to be living *in situ,* that is, they were a autochthonous life-assemblage, the time of deposition.

b) Site 10: March Gravels, Eye, Cambridgeshire (Keen *et al.,* 1990) (Table 5.02.2).

Some 28 species of ostracod were recovered from the March Gravel sediments; of these, 11 species were of fresh water, 3 of brackish water and 14 of marine origin. Many of the valves of the freshwater fauna were broken, and juvenile valves rare. The freshwater remains were interpreted as valves washed from ponds or lakes into the brackish water of the estuary. The brackish fauna were intact and contained all moult stages, suggesting that the brackish water fauna were indigenous to the environment.

3) Ostracod valves are fragile and frequent reworking in a coarse environment will break them up. It is, then, more likely, if there are few ostracod valves recovered from a sediment, that the conditions were either unfavourable for the ostracods' survival, or insufficient time had passed for them to become established, rather than for them to have been reworked (confirmed by Horne, pers. comm.).

Site 21: Colwall, Hereford and Worcester (Barclay *et al.*,1992) (Table 5.02.3) is a good example of an environment unsuitable for most freshwater ostracod species.

From three samples of sediment, six species of ostracod were recovered from the Cradley silts. This low diversity ostracod fauna indicates that the waterbody was stagnant. The mud was colonised by *C. leveranderi* and the open water above by *H. reptans, I. bradyi, I. gibba, Cypridopsis vidua* and *I. papillata.* Ostracod species requiring dense vegetation were absent from the species list, suggesting the presence of an open water habitat. Nowadays one would expect to find 12-15 species in a similar pond or lake (Robinson, pers. comm.).

4) Any reworked sediment likely to be encountered in the Midlands is likely to be of local derivation, and probably is a result of flooding and seasonal increases in river discharge. The organic sediment is usually moved over short distances in a fairly short span of time. The river basins encountered in the English Midlands today have low-angled slopes, and, although the Quaternary climatic changes caused some change in the topography (it eroded some surfaces and raised others with deposits of till) there seems little evidence, in the research reviewed, for high-angled valley slopes in the past. Besides, all the evidence seems to point to the fact that no ostracod species would inhabit streams and rivers with no respite from fast flowing water (see section 5.01.1 above). Most reworking

occurs when intermittent flooding washes valves of spring and temporary pool species from the floodplain into the river channel. This was proved to have occurred in the past at Sugworth, Oxfordshire (Shotton *et al.*, 1979) (Site 24) (Table 5.02.4).

5) In the literature the size of the samples collected and analysed varied from site to site which makes comparative analyses between them and the new data difficult to assess. To overcome the problem in this new research samples of sediment of equal weight, about 1000 grammes in all, were collected. Half the sample was stored, whilst the other was processed. In the case of temperate ponds or lakes this would have been too much material, but earlier sampling of the Nene Valley Gravels had shown less material would not have yielded enough ostracod valves for analyses. To simplify comparative analyses of coarse sediments in the future, it is recommended to collect and analyze similar amounts of sediment to that used in this research.

6) Ostracods are usually ignored when freshwater and terrestrial molluscs are available, and this is probably through lack of expertise in the subject area. Besides, ostracods do not appear to be as commonly found as molluscs. Out of 200 fossiliferous samples collected for this research, only 42 samples contained ostracods. As this research has been conducted on coarse sediments this should not be surprising. Most coarse sediments are laid down in cold conditions. There would be few microhabitats available in which ostracods could survive (Figure 1.01.3). Ostracod species that are successful must be tenacious and hardy. However, in temperate phases, for example Site 8, Kempton Park, Sunbury (Gibbard *et al.,* 1981) (Table 5.02.1), and interglacials, such as Site 24, Sugworth, Oxfordshire (Shotton *et al.,* 1979) (Table 5.02.4), ostracods are extremely successful. Unfortunately these sediments are mostly washed away in the next cold phase, leaving only remnants for the researcher to find and analyze.

5.05.1. Ostracod Habits and Habitat.

From the data gathered from the literature reviewed, Henderson, (1990), Griffiths (1995), Griffiths (pers. comm.),. Horne (pers. comm.), and Robinson (pers. comm.) Table

Ostracod species	Springs		Slow rivers		Streams		Temporary pools and intermittent streams		Ponds and lakes		Calc-tufa	Aquatic vegetation	Burrows in benthos	Surface of benthos	Open water above benthos	Water surface
	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold		Additional habitat requirements				
Darwinula stevensoni									X	X		p	X	X		
Limnocythere falcata	Extinct											p				
Limnocythere inopinata									X			X		X		
Limnocythere sanctipatricii										X		p		X		
Cytherissa lacustris										X		p	X	X		
Candona candida	X	X	X	X	X	X	X	X	X	X		p	X	X		
Candona neglecta			X	X	X	X	X	X	X	X		p	X			
Candona rawsoni / lactea	Extinct											p				
Fabaeformiscandona fabaeformis							X	X	X	X		p		X		
Pseudocandona marchica			X						X			X		X		
Cyclocypris globosa								X				p			X	
Cyclocypris laevis										X		X			X	
Ilyocypris biplicata					X	X	X	X	X	X		p		X		
Ilyocypris bradyi	X	X	X	X	X	X	X	X	X	X		X		X		
Ilyocypris gibba	X		X		X		X		X			p		X		
Ilyocypris papillata	Extinct											p				
Ilyocypris schwarzbachi	Extinct											p				
Ilyocypris sp. A.	Extinct											p				

Table 5.05.1. **The habitat requirements of freshwater ostracod species recovered from the Milton Formation and the Nene Valley gravels.**
p : vegetation for protective cover.

Ostracod species	Springs		Slow rivers		Streams		Temporary pools and intermittent streams		Ponds and lakes		Calc-tufa	Aquatic vegetation	Burrows in benthos	Surface of benthos	Open water above benthos	Water surface
	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold		Additional habitat requirements				
Eucypris dulcifrons	Extinct											p				
Eucypris pigra	X	X	X	X	X	X			X	X		p		X		
Eucypris virens							X	X				X				
Prionocypris serrata							X					p			X	
Trajancypris clavata							X	X	X	X		p		X		
Bradleystrandesia fuscatus								X				X		X		
Herpetocypris reptans	X						X	X	X	X		X	X	X		
Psychrodromus olivaceus				X		X		X			X	X	X			
Heterocypris incongruens							X	X				X			X	
Cypridopsis vidua							X	X	X	X		X			X	
Potamocypris arcuata									X			p		X		
Potamocypris similis									X			p		X		
Amplocypris tonnensis	Extinct											p				

Table 5.05.1. (continued). The habitat requirements of freshwater ostracod species recovered from the Milton Formation and the Nene Valley gravels.
p : vegetation for protective cover.

5.05.1 has been compiled. The data provided in the table determines the dominant characteristics of the ostracod habitats represented by the species recovered from the sediments of the palaeo-Milton and Nene Rivers (see Chapters 7 & 8). It includes such information as the climate the ostracods may represent (temperate, cold or both), the character of the freshwater (still or moving), and the zone preferred (open water for swimming, vegetation or benthos for crawling, or benthos for burrowing into).

A brief up-to-date summary of the habitats and Quaternary records of each of the ostracod species recovered from the sediments of the Pleistocene Milton Formation and Nene Valley sediments is given in Appendix C. Characteristics such as appearance, diet, and breeding habits are discussed only where the characteristic is relevant to this research. Further information is obtainable from Henderson (1990) and Griffiths (1995).

It is important to note that recent work with ostracods has extended the range of some species and improved the information available on individual species. For instance, it is now known that *Limnocythere* species cannot swim. In fact they are slow crawlers and burrowers (Horne, pers. comm.). There are also no pelagic (open water) species. All ostracod species, including those that swim, seek sheltered places such as on or around littoral macrophytes: otherwise they would be "*picked off*" by fish (Horne, pers. comm.).

Studies comparable with the present one are included in the fossil analyses at Little Oakley (Robinson, 1990, 5.01.1); Radwell, Bedfordshire (Rogerson *et al.,* 1992); Isleworth, West London (Kerney *et al.*, 1992); Kildale, north-east Yorkshire (Keen *et al.,* 1984); Eye, Cambridgeshire (Keen *et al.,* 1990) and Upper Strensham, Worcestershire (De Rouffignac *et al.,* 1995).

Further useful information was gathered from the following:

Pleistocene fluvial environments: Jones and Keen (1993), Lowe and Walker (1984).

Braided river formation: Reinfelds and Nanson (1993).

Glacial rivers: Milner and Petts (1994), Scrimgeour *et al.* (1994)

Freshwater ecology: Lock and Dudley Williams (1981), Petts (1983), Winterbourne and Townsend (1980).

Ostracod data: Preece and Robinson (1984), Sohn (1985).

5.06.1. Reworking of sediments.

The past research has shown that, within a fluvial environment, the possibility that some of the sediments may be reworked has to be taken into consideration. The processes of reworking and their effect on fossil assemblages have been discussed by authors such as Briggs *et al.* (1990) and West *et al.* (1994).

From the literature, the following are the most likely types of reworking to be met in the field:-

(a) Reworking may occur as the result of fluvial processes such as downcutting of river terraces and the erosion of abandoned pools in braided stream environments (Gibbard *et al.*, 1992; Whiteman, 1991; Hoey and Sutherland, 1991; Ballantyne and Harris, 1994), and the erosion of riverside and estuarine marshland (West *et al.*, 1994).

(b) In cold stages, seasonal snow melt may give rise to back-wearing through fossil-rich sediments. This results in the development of thaw lakes and outflow channels which may develop into fen containing reworked fossil material among the living fauna (West, 1991).

(c) Aeolian removal and deposition of sediments occurs wherever vegetation cover is sparse or absent in dry periods (Ballantyne and Harris, 1994). It occurs in both interglacial and periglacial environments and can be responsible for the windblown dispersal of the fossil valves and live eggs of ostracods along with remains of other flora and fauna.

(d) Periglacial, open-country environments are effected by solifluction and gelifluxion which move slope material downhill causing aggradation in the valleys. Slope slip-off and accretion may also occur in any tidal channel or estuary, periglacial or interglacial (West *et al.*, 1994). The slope material may contain fresh, or fossil, ostracods of springs, temporary pools or tributaries. These, if they survive transport, will be washed into the main river, resulting in intermixing of two or more separate assemblages, including those of the river itself (Bryant *et al.*, 1983; West *et al.*, 1994).

(e) Valley bulging may also occur at times of periglaciation. This may displace aquatic deposits which will be reworked (Brandon and Sumbler, 1991).

(f) Reworking of aquatic sediments due to ground upheaval may occur as a result of subglacial glaciotectonic deformation in cold stages (Hart, 1995), and formation of ground ice in permafrost zones (Ballantyne and Harris, 1994).

5.06.2. Ostracods and reworking.

Because ostracod valves are so thin and fragile any of the above instances of reworking would damage and virtually remove them from any fossil assemblage found (Horne, pers. comm.). Transport over short distances quickly damage ostracod valves, and even a modest flow may separate the two valves of a decaying ostracod. In fact, the presence of intact carapaces and their ratio to single valves is used as evidence for the rate of deposition and sedimentary flow (West *et al.*, 1994).

5.06.3. How ostracod analysis differs from that of molluscs.

Briggs *et al.* (1990) have suggested that a molluscan (sub)fossil assemblage from a braided river deposit may be placed into any one of six groups; namely autochthonous, residual, allochthonous, mixed, faunal concentration or transported habitat; according to the taphonomy of the fossil life and death assemblage. Difficulties arise, however, when this analysis is applied to the freshwater ostracods.

The molluscan species range contains both terrestrial and aquatic species and a (sub)fossil aquatic molluscan life fauna may also have within it shells of dead (drowned) terrestrial molluscs. However, although some species of ostracod are almost terrestrial, in that they live among permanently wet mosses where springs bubble to the surface, they are all aquatic species (Robinson, pers. comm.).

Ostracod analysis has a subtle advantage over molluscs in that the molluscan species retain and add annual growth to their shells (that is, apart from bivalved molluscs) and, therefore, one shell equals one animal. Ostracods, however, have two valves which they shed up to seven times during their growth to maturity. This means, therefore, that if the sum total of ostracod valve instars recovered from (sub)fossil material outnumbers the number of adult valves then the ostracod assemblage represents a once thriving colony.

This indicates a relatively stable period of time may have passed in which the colony became established; molluscan analysis cannot give such detail.

5.07.1. The braided stream environment.

The permanent channels of a braided stream environment, usually sand-, gravel-, or sand and gravel bedded streams and rivers, are too active to provide habitats for molluscs (Briggs *et al.*, 1990), or ostracod species (Robinson, pers. comm.). The movement of the gravel may crush small invertebrates attempting to colonise it and bury algae attached to it (Hynes, 1970; Moss, 1980). Within these fluvial systems, however, there are sheltered backwater areas and temporary pools, namely, channels within the bar-terrace zone, back-channels to the semi-stable bar-zone, and abandoned pools and channels in the semi-stable bar zone, which may maintain a varied aquatic fauna, including molluscs and ostracods (Figure 1.01.3) (Briggs *et al.*, 1990; Rogerson *et al.,* 1992; Green *et al.,* 1996). In these areas, sheltered from the main stream, the loose pebbles at the base of old and newly formed gravel-based pools or abandoned channels provide shelter for small invertebrates. An algal covering on the clasts forms the foundation for a rapidly expanding food chain (Holmes, 1965). Generally the larger the stones, the more diverse is the invertebrate fauna. Sand has fewer ostracod species, and silt or mud, although possibly rich in biomass, has an even more limited number of ostracod species (Hynes, 1970). However, according to the species adaptation, ostracods are generally found in the water just above the benthos, either crawling on vegetation or swimming within the vicinity of it. Some species, particularly of *Candona*, do, however, inhabit muddy substrates; very few species inhabit sandy substrates (Robinson, pers. comm.).

Frequently, the aquatic fauna and flora are disturbed as a result of drought or, more commonly, flooding. New habitats are created, and old habitats modified or destroyed, during peaks of snowmelt and rainfall. These discharge peaks coincide with a time when slope-wash and soil erosion are most active and the eroded material (such as the components of sand and gravel) entering the braided river system often becomes trapped in slow-flowing channels (Kerney *et al.,* 1982). The channels may then become cut off from the main stream and form shallow still-water bodies which, as discussed earlier, are progressively inhabited by pond dwelling flora and fauna (from which the fossiliferous organic deposit accumulates). Meanwhile, as the river discharge increases, old abandoned channels may no longer be isolated from the main body of flowing water. Some of the accumulated still-water deposit from these channels may be eroded and, along with the fauna, washed downstream.

The extent of colonisation and re-colonisation of these new pools and abandoned channels depends on factors such as temperature, changes in water chemistry, turbidity and available light. However, the new conditions should be immediately suitable for occupation by at least one or two ostracod species (Robinson, pers. comm.).

Finally, close to the braided streams, on the river banks, smaller and shallower temporary or permanent pools may be colonised by different ostracod assemblages. The remains of these are frequently washed into the main river and may represent the derived (in-washed) faunal content of recovered fossil material (a mixed assemblage). They provide information about the adjacent environment (De Deckker, 1979; Briggs *et al.*, 1990).

In a gravel deposit, the fossiliferous organic material is usually found in sediments of these former backwater deposits and abandoned channel fills, but, as mentioned above, some material may have been transported downstream, particularly as frozen deposits (De Deckker, 1979; Selby, 1985). If no intermixing of the sediments occurs, the transported fauna, the allochthonous assemblage, may be found separate from the local, autochthonous fauna, but, more usually the sediments are intermingled, giving rise to a mixed assemblage (Briggs *et al.*, 1990).

CHAPTER 6: APPROACHES TO THE RESEARCH: FIELD, AND LABORATORY METHODS AND TECHNIQUES.

6.01. Introduction.

The methods employed within this study were designed to collect and analyse the data needed to research the environmental and faunal change exhibited by the Quaternary sediments of Central Northamptonshire. Thereby, the aim was to produce to produce a chronological sequence to the events and enlarge the pool of knowledge on environmental and faunal changes in Northamptonshire within the last two million years.

Stratigraphical, lithological, sedimentological and faunal (particularly ostracod) data was obtained from fluvial sediments of the pre-glacial Milton Formation, and the sands and gravels of the Nene Valley. To a lesser degree, the sands and gravels at Yardley Hastings and the glacial tills were also examined. To discern the relationship between all of the sediments it was necessary to do considerable field and laboratory research, not all of which is recorded here.

Permission was obtained from the gravel companies to visit the open sections in quarries. Whilst in the field, a range of field measurements were made, photographs taken and samples collected for laboratory analysis.

3.01.1. The aims of the fieldwork were:

1) To measure and draw the bedding and structures to an accuracy of at least 0.05 m.

2) To look for and record sedimentary structures and structures that indicate reworking may have taken place (e.g. tree holes, bioturbation, mud slides).

3) To carry out lithological and stratigraphical analysis of the tills.

4) To determine sediment colours, using the Munsell colour notation.

5) To determine the topographic position of the sediments within the river valleys.

6) To take samples for laboratory analysis.

In the laboratory the following analyses were undertaken as appropriate.

7) Stone counts for 4-8 mm, 8-16 mm, 16-32 mm, 32-64 mm and 64-128 mm for gravels and tills.

8) Particle size analyses.

9a) Ostracod recovery and identification of ostracods.

9b) Ostracod analyses for the determination of the aquatic and, if possible, the wider environment of the river valleys.

6.02. How the aims were met.

1) Stratigraphy.

Section drawing in the field was accomplished using 25 m tapes and 2 m measuring rods. These were placed in grid form along the face of each section and major structures were drawn in, noting the position, to within 0.05 m, where they crossed the tapes. The drawings were then finished freehand. The drawing was completed on graph paper - the scale varying to accommodate the width of each section. The measurements are clearly marked on each completed drawing.

Both the length and thickness of each section was measured and a log drawn of the sediments from surface to base. All features were included in the drawing and notes were made of their sedimentology, lithology and colour. The orientation of the sediments at Clifford Hill West Field, Little Houghton, were recorded using a compass-clinometer (Suunto Co.). A photographic record was made of all significant phenomena in the field.

The organic samples of the Milton Formation at Courteenhall were collected from the lowest 4.50 m of the sediments exposed for drainage purposes. A request was made to Sandspinners, and granted, for a hole to be excavated down to the pine- and spruce-rich gravels at the base of the quarry.

A section was examined and a sample of gravel collected from the now disused Yardley Hastings Quarry.

2) Sediment colours.

The colour of the fluvial deposits and the upper and lower till was determined using the Munsell soil colour notation, on fresh moist samples.

3) Sedimentary and other structures and reworking.

Besides primary structures, deformation structures (such as ice wedge casts) were included in the section drawings.

Deformation structures are equally valuable in determining palaeoenvironments, and are particularly important when sampling for small fossils like ostracods. Disruptions, such as tree holes, also may indicate reworking in fluvial sediments. Any such seen in the field were recorded in both the field note book and in the section drawings.

4) Sediment Sampling.

a) Vertical sections were cleared and every unit sampled for stone counts and particle size analyses. Some data was reserved for a later paper as it was not needed for this thesis.

b) The tills were sampled at least 1.5 m below the ground surface to avoid possible pedogenesis and cryoturbation.

5) Sample size.

Minimum samples, wherever possible, were collected to allow for at least 300 clasts for stone counting in each of the appropriate size ranges (Krumbein and Pettijohn, 1938).

6)Till lithology and stratigraphy.

For this study, on fluvial sediments, reliance has been placed more on the desk study discussed below and past research for analyses of the tills. However, the upper till was sampled for stone counts and colour analyses of both the upper and lower till was made using the Munsell Colour Chart. The lower till contained few clasts at the site sampled. however, it was possible to confirm that there are two tills, an upper and a lower till, present in parts of Northamptonshire. The stone count of the upper till was also compared with the stone counts of the Nene Valley Gravels.

7) Topographic position.

The topographic position of the sedimentary units were estimated from contour maps of the Landranger 1.50 000 series, numbers 141, 142, 151, 152,and 153, and the Pathfinder 1: 25 000 series, numbers 957, 958, 959, 977, 978, 979, 1000 and 1001.

The position of the sediments within the landscape was also worked out from geological maps Sheet 202: Towcester, Geological Survey, 1969, Sheet 185: Northampton, Geological Survey, 1960 and Sheet 186: Wellingborough, Geological Survey, 1974.

8) Lithology

In order to gain the fullest possible database on clast lithological composition, the standard practice of combining size of 4-8mm, 8-16 mm, 16-32 mm, was extended to 32-64 mm and 64-128 mm. The largest sizes were counted on site.

Standard methods were used for the lithological analyses (Bridgland, 1986). The purposes of this technique were as follows: a) establishing lithological content of the deposits, b) differentiation between deposits, c) identifying the source area(s) of the deposit, d) determination of the number of specific input events.

As some sandy gravels were too fine for a large particle size count, to ensure a count of 300-500 clasts for every gravel sample, the 4.0-8.0 mm was counted in all the samples collected. As it was, the varied particle-size stone count ensured differential breakdown of the rock types into different size ranges was allowed for also in the final analyses.

Where identification of rock-type was uncertain second opinions were sought from Prof. J. Rose, Dr. D.R. Bridgland and Dr. G. K. Gillmore.

9) Particle size analyses.

Particle size analyses were carried out according to the British Standards Institutions (1975). This was most useful in distinguishing units of sediments from each other; that is, in establishing whether a sample of sediment was dominantly a silty clay, silt, sandy silt, silty sand, sandy gravel or gravel.

10) Field and laboratory methods for recording ostracod data.

a) Where available, approximately two kilogram of organic sediment were collected for analysis at each site. The sample was split and the second kilogram being reserved in case the first sample was damaged in any way.

b) The following method used for fossil recovery is similar to that described by West (1977). About one kilogram of each organic sample collected was processed for ostracod analysis. Loosely bonded sandy sediments were air dried and disaggregated in a bowl of hand-hot water. Clays were soaked in a solution of 10% hydrogen peroxide for one to three hours. This usually proved to be enough time for the clays to disaggregate. Each sample of sandy sediment and disaggregated clay was then washed through a 63 micron sieve (240 mesh). The sediments were then oven-dried at 40^{o}C. Each sample was then placed in a bowl of tepid water. The sediments were agitated gently and, using a fine nylon tea strainer, snails and plant macrofossils were skimmed off as they rose to the surface. This greatly reduces the amount of hand-sorting later on in the process. The sediments were, once more, dried at 40^{o}C. The sediments were then passed through a 1.4 mm sieve, the large fraction being reserved for molluscan analysis. The fine fraction was finally shaken through sieves of mesh sizes 500, 250 and 125 micron. Using a binocular microscope, the ostracod valves were lifted from the sediment with the tip of a moistened, fine paintbrush and fixed to a squared cardboard slide.

The disadvantage of this method is that some of the more delicate ostracod valves may be broken or lost. This is an unavoidable problem met in ostracod research (Horne pers. comm.).

c) Other work in the laboratory included:

Making a photographic record of both the mammal remains and microfossils.

Identification of the ostracod remains, with assistance from Dr H. I. Griffiths (University of Wales Cardiff), Dr. D. Horne (Greenwich University) and Dr. J. E. Robinson (University College, London).

11) Radiocarbon dating.

A radiocarbon date was requested for organic matter found at the base of a channel eroded into the sub-alluvial gravels. The organic material was sent to the East Kilbride Laboratories in 1992. A date was given of 36,840 +455/-430 years B.P.

6.03 Further comments on site visits and analyses.

The sites between Northampton and Wellingborough were monitored on a regular weekly and, frequently, bi-weekly, basis. On each of these visits samples of gravel and organic material were collected and new sections measured and recorded as graphic logs. The Milton Formation sites were visited less frequently fossiliferous material was obtainable on two occasions only. The methods used were, where possible, the same as for the Nene valley.

In the Nene Valley, over 120 visits took place and 500 samples of gravel, clays, colluvium, sub- and topsoils were collected. Where available, approximately two kilogrammes of organic sediment were collected for analysis at each site. Molluscs, beetle fragments, plant macrofossils, fossil teeth and bones of small and large mammals were collected from most sites and put aside for identification.

Finally, the sedimentological, stratigraphical and lithological and ostracod data were synthesized with that of the desk-top studies.

6.04. Using ostracods as a tool for this Quaternary palaeoenvironmental research.

The review of past Quaternary research (Chapter 5) has shown there has been little work done on ostracods in fine sediments found in coarse fluvial environments. In view of this, the ostracod information from the Milton Formation and Nene Valley sites are potentially of considerable significance to the Quaternary record.

To add to the current ostracod data available the identification and numeric information on the ostracods from the Milton Formation and Nene Valley sites (Appendices B, C and D) has had to be combined with the environmental information from Chapter 5. This has then applied to the stratigraphy, sedimentology and lithology of the Milton Formation and the Nene Valley Gravels with the expectation that the total data may contribute to an understanding of the following:

a) The environment at the time of deposition.

b) The age of the deposit.

The environmental and chronological information for each ostracod species, summarised here, is based on the discussions in Chapter 5 and Appendix C.

In the process of analysis, where the Quaternary assemblages found are similar to those in past research, some analogies may be drawn. Where new records occur, then the contribution to the Quaternary record is novel and is of considerable stratigraphic and environmental value.

6.04.1. Use of data from ostracod assemblages.

As the number of ostracod valves from both the Milton Formation and Nene Valley Gravels varied widely from sample to sample, i.e. 1 minimum to 225 maximum, the following factors were used to assess the assemblages: i) size of population, ii) number of species in the assemblage recovered, iii) the number (expressed as percentage of population) of juvenile moult valves in the assemblage. The following group dimensions were considered suitable for this analyses. However, it was realised that they were only suitable for this work and could not be applied to other completed research.

i) Size of population: maximum number of valves: 225.

small 1 -75 medium 76 - 125 large 126 - 225

ii) Number of species in the assemblage (species diversity): maximum number 12

low 1 -4 average 5 - 8 high 9 - 12

i) The percentage of juvenile moult valves in the assemblage:

low 1 - 33%   average 34 - 66%   high 67 - 100%

6.04.3. Environmentally specific ostracods applicable to interpretation.

The following lists place the ostracod species present in the Milton Formation and Nene Valley sediments according to their most conspicuous environmental requirements. Some of the ostracods palaoenvironmental needs have been disputed in the past and, where considered necessary, this is discussed in the text below (see Chapter 5 and Appendix C for detailed discussion on individual species).

a) Aquatic or marginal vegetation indicator species: Most ostracods would soon be picked off by fish or other predators if they were in open water. Thus, wherever ostracods are found, it can be inferred there was likely to be some aquatic vegetation, however sparse it might be (Horne, pers. comm.).

b) Temperate water indicator species: *Limnocythere falcata* (extinct), *Limnocythere inopinata*, *Pseudocandona marchica*, *Ilyocypris gibba*, *Prionocypris serrata*, *Potamocypris arcuata*, *Potamocypris similis*, *Eucypris virens.*

c) Cool water temperature indicator species: (winter species and stenothermal forms): *Limnocythere sanctipatricii* (stenothermal), *Cytherissa lacustris* (stenothermal), *Fabaeformiscandona fabaeformis* (winter - spring), *Cyclocypris globosa* (winter - spring), *Ilyocypris biplicata*, *Trajancypris clavata* (winter - spring) (debated), *Bradleystrandesia fuscatus* (winter - spring), *Psychrodromus olivaceus* (stenothermal).

d) Slow flowing water indicator species: *F. fabaeformis* (debated), *P. marchica*, *I. biplicata*, *Eucypris pigra*, *P. olivaceus.*

e) Temporary pools, intermittent streams indicator species*:* *C. globosa*, *P. serrata*, *T. clavata*, *B. fuscatus*, *E. virens.*

f) Permanent ponds and lakes indicator species: *Darwinula stevensoni*, *L. inopinata*, *C. lacustris*, *P. marchica*, *Cypridopsis vidua.*

g) Species common to many different environments: *Candona candida*, *Candona neglecta*, *Cyclocypris laevis*, *Ilyocypris bradyi*, *Herpetocypris reptans*, *Heterocypris incongruens*.

h) Species for which little is known: *Candona rawsoni* and/or *lactea*, *Ilyocypris papillata* (extinct), *Ilyocypris schwarzbachi* (extinct), *Ilyocypris* sp. A (extinct), *Amplocypris tonnensis*.

i) Species common to 5 or more sites out of the 9 sites investigated: *C. candida*, *C. neglecta*, *P. marchica*, *C. laevis*, *I. bradyi*, *I. gibba*, *E. pigra*, *H. reptans*, *P. arcuata*.

6.04.5. Other considerations important to ostracod analysis.

1) An increase in the number of juvenile valves present may be due to improved preservation in a soft muddy sediment rather than a spurt of growth in the population.

2) Some ostracod valves may have been destroyed during sample preparation and ostracod extraction. This was particularly applicable to the fragile valves of *Limnocythere falcata*, a species found in the Milton Formation samples.

CHAPTER 7: SITE DESCRIPTIONS, ANALYSES AND INTERPRETATION OF THE MILTON FORMATION AT COURTEENHALL, NORTHAMPTON.

7.01. Introduction.

This chapter describes the sites at Courteenhall Grange Farm from which the Milton Formation sediments were collected. It also discusses the significance of the ostracod species for the sediments examined and describes the Milton Formation sediments in which no ostracods were seen, but which contained numerous spruce and pine cones were extracted. The sites are mapped on Figure 7.01.1.

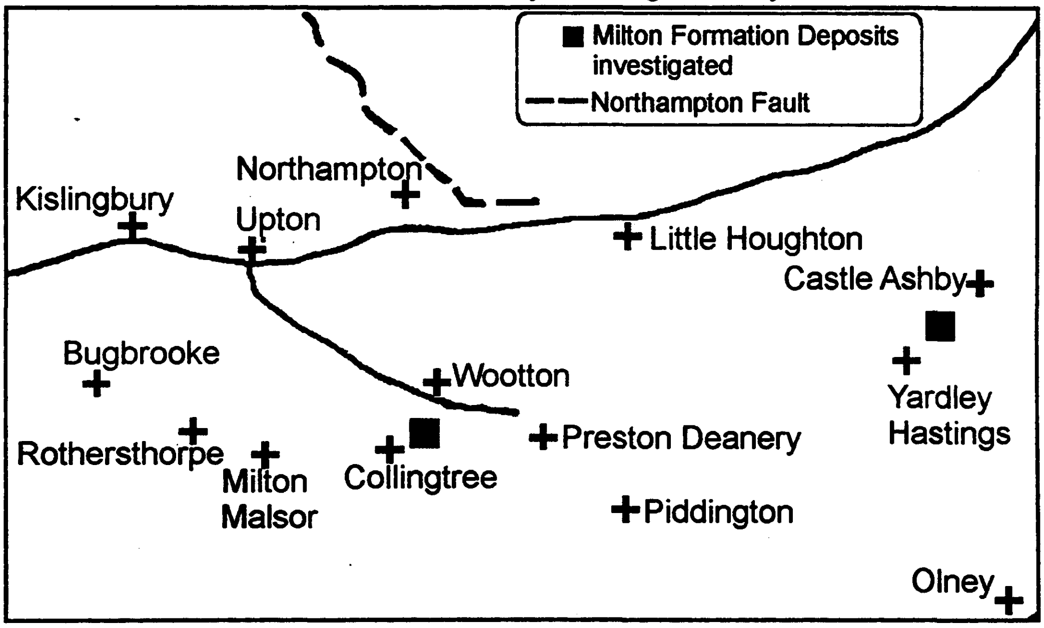
The results show that the number of ostracod species (16) in the Milton Formation compare well with other pre-Anglian (Beestonian and Cromerian) ostracod sites here reviewed: Little Oakley, 18 species; Waverley Wood, 14; Sugworth, 13; West Runton, 7 Cromerian, 15 Beestonian, (Robinson, 1990; Shotton *et al.,* 1993; Robinson, 1979; De Deckker, 1979). In total, 37 species have been recorded from these sites, but obviously all are not present at each site.

The Milton Formation has 12 extant species. Seven, recognised as temperate species found in Britain today, were also noted from the Beestonian and Cromerian sites (see Table 5.03.1). These seven species are *C. neglecta, F. fabaeformis, P. marchica, C. laevis, I. gibba, E. pigra* and *H. reptans*. The remaining five extant species, also found in Britain today, are: *L. sanctipatricii* (rare), and *H. incongruens, E. virens, B. fuscatus* and *P. arcuata* (the last two species are not previously recorded in the British Pleistocene). It is suggested that they are present in the Milton Formation because the environment was that of a braided river with more habitats of a temporary nature than the sites examined in the past. There may have been more 'run-off' from the surrounding floodplain.

The absence of *Scottia browniana* (a species found in the temperate deposits of Little Oakley, Sugworth and West Runton) from the Milton Formation suggests that, as in the case of the Waverley Wood site (Shotton *et al.,* 1993), there were cooling conditions. Cooling temperatures were indicated also in sample S5.MS of Milton Formation by the presence of *L. sanctipatricii,* a cold stenothermal species. This is the first time *L. sanctipatricii* has been recorded in Pre-Anglian sediments in Great Britain (Griffiths, 1995).

The geographic position and its associated inland environmental differences may explain why the ostracod species assemblage from the pre-glacial Milton Formation bears little resemblance to the aforementioned assemblages allocated to the pre-Anglian period (Chapter 5, Section 5.02). However, the ostracod assemblage may also represent a different time period within the Cromerian Complex.

7.07.1 Location of Site A and Yardley Hastings Quarry.



7.02. SITE A1 Courteenhall Grange Farm Quarry, near Collingtree, Northampton (SP758555), Map: Figure 7.01.1, Section: Figure 7.02.1.

7.02. Introduction.

The Courteenhall exposure of the Milton Formation lies 5 km due south of Northampton, immediately east of the A508, about 1 km north of its junction with the M1 (Junction 15), occupying an area of at least 20 ha (Figure 1.01.4). A succession of gravels, sands and occasional muds overlie beds of Lower Jurassic Upper Lias Mudstone bedrock and are capped by chalky till at 86 m O.D. (Section: A of Figure 4.03.2).

No stone counts or particle size analyses are available for this site (A1).

The ostracods were recovered from organic deposits within sediments marked as fluvio-glacial gravel deposits on the geological map (Sheet 202: Towcester, Geological Survey, 1969). Clarke and Moczarski (1982) describes them as *"deposits of fine and medium grained sand, previously mapped as fluvio-glacial gravel, in the area around Milton [which] appear to represent a deeply dissected, continuous spread of early Pleistocene fluvial material"* and that *"the Milton Sand deposits pre-date the main glacial events in the area"*.

7.02.1. Site description and analyses of Site A1: Sediments, Map: Figure 7.01.1; Section: Figure 7.02.2 (Key: Figure 7.02.1).

OSTRACOD SAMPLES: S1.MS - S6.MS.

The lithology of the clasts in Units A, B, and C was composed entirely of local Jurassic sandstones, Ironstones, limestones and fossils such as *Gryphea* and *Belemnites*. The sand grains were sub-rounded to rounded iron-stained quartz and Ironstone. The muds contained considerable quantities of silt-sized mica fragments derived mainly from the Lias Clays and Northamptonshire Sandstones. The till consisted of clasts of far-travelled and local rock in a sandy, silty, clay.

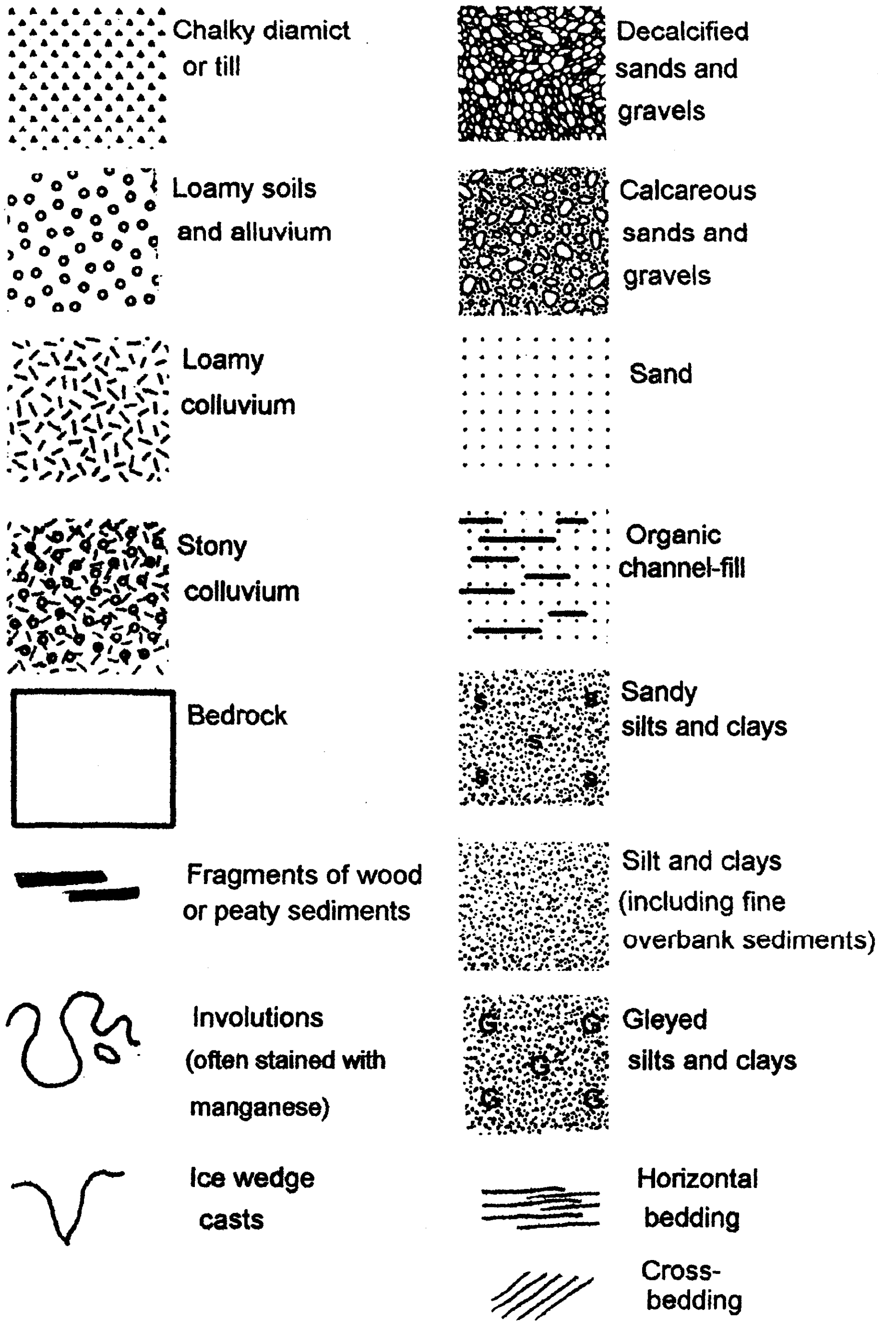


Figure 7.02.1. Key to site sections discussed in Chapter 6.

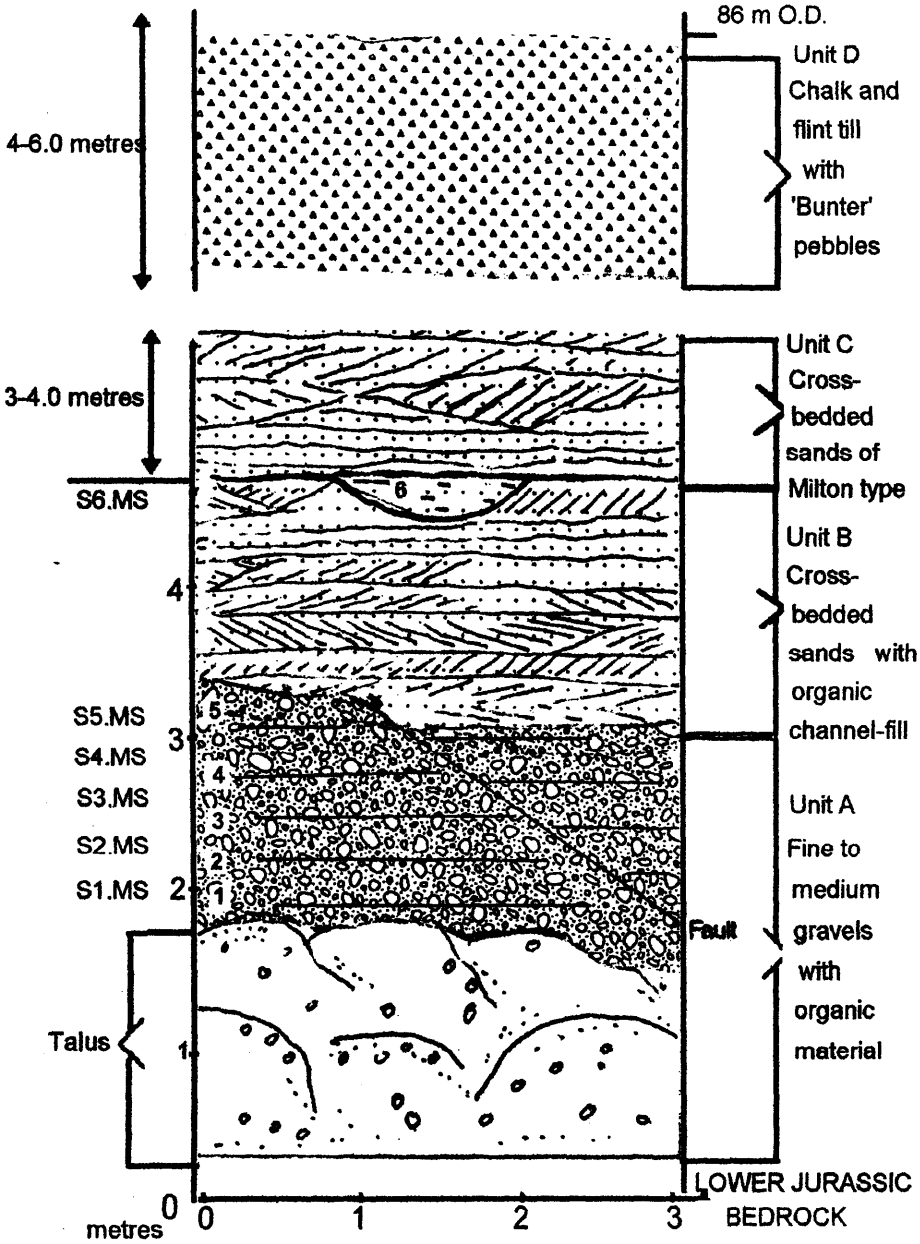


Figure 7.02.2. Site A1: Section recorded at the Milton Formation sand quarry at Courteenhall, Northampton (SP7555). Ostracod samples S1.MS - S6.MS. Key: Figure 7.02.1.

7.02.2. Sediments of Site A1

Unit	Description	Maximum observed thickness.
	(Surface -youngest material: 86 m O.D.)	
D	Chalky diamicton with pebbles of flint and Bunter Quartzite.	6.0 m
C	Trough cross-bedded and horizontally bedded sands.	4.0 m
B	Planar and trough cross-bedded sand with channel on upper surface infilled with organic silts.	1.5 m
A	Horizontally bedded fine to medium gravels with thin horizontal beds of organic silts and clays	3.0 m (the lower 1.5 m obscured by talus).
	(Unit A was oldest and lowest material)	

Unit A. (Unit A was oldest and lowest material)

Unit A was exposed in the floor of the pit in 1992 as a result of drainage and preparation for landfill. The material (Unit A), from which samples S1.MS - S5.MS were collected, stood 2 m proud of the quarry face thus forming a buttress 3 m high. This was the most readily available material. The unit was seen to extend across the exposed quarry face at this point. It comprised apparently muddy, matrix-supported gravels, interbedded with thin beds of silty clay and sands. The silty clay beds were sampled for ostracods (S1-S5.MS). A low-angled fault cut from the bottom of the east corner of the buttress to near the top of the south-west intersection with the side of the pit. Movement appears to have been from NNE to SSW causing about 0.80 m of downthrow (Figure 7.02.2). Similar faults were observed throughout the deposit at other points in the quarry. All the faults caused only minor disruption of the sediments and appeared to have occurred as a result of settlement of the deposits over time.

Fragments of wood, bone and a complete tooth of *Palaeoloxodon antiquus* were recovered from the gravel beneath the lowest Sediments comprising ostracods (S1.MS).

Unit A: Sediments comprising ostracods (Figure 7.02.2):

S1.MS: The sediments consisted of blue/grey silts and clays with a few small clasts of local rock, 90% of which were Ironstone. The organic portion was poorly preserved and most of the ostracod and mollusc remains were fragmented.

S2.MS: The sediments consisted of blue/grey silts and clays with a few small clasts of local rock, 90% of which were Ironstone. The organic material was well preserved and most of the ostracod and mollusc remains were intact. Among the remains there were also seeds, fragments of charcoal and beetle wings.

S3.MS: The sediments consisted of blue/grey silts and clays with a few small clasts of local rock, 90% of which were Ironstone. The organic portion was fairly well preserved and most of the ostracod and mollusc remains were intact. Among the remains there were also seeds, fragments of wood and bone, and beetle wings. There was no charcoal present.

S4.MS: The deposit was more sandy than the previous sample. It consisted of blue/grey sandy silts and clays with a few small clasts of local rock, 90% of which were Ironstone. The organic portion was smaller. Most of the ostracod and mollusc remains were intact. Other organics were few in number the most notable being fragments of wood.

S5.MS: The sediments consisted of blue/grey sandy silts and clays with a few clasts of local origin. The organic portion included oogonia of *Chara* species.

Unit B.

On site, Unit B, between 3 and 4.5 m above the bedrock and stratigraphically above Unit A, was above the level of the buttress from which Unit A was sampled. Thus, it was set 2 m further back than Unit A and was in the actual face of the quarry (Figure 7.02.2).

Unit A was overlain, either erosively or gradationally, by 1.5 m of planar and trough-bedded, fine to medium sands. The top of this sand unit was eroded by a channel structure with a silty organic rich infill (S6.MS).

Unit B: Sediments comprising ostracods (Figure 7.02.2):

S6.MS. The sediment was of a stiff muddy consistency and the organic content was low.

Unit C.

A further erosive contact separated Unit B from the sedimentologically similar Unit C. These sands were of the Milton Formation type and of a light brown to yellowish brown colour. They were described by Kendrick (1993) as "*a sequence of well-bedded pale brown fine and medium grained quartz sands, which in places are heavily ironstained. Milton Sand [Formation] deposits typically have a composition of 80% sand and less than 10% gravel, the gravel pebbles deriving mainly from local Ironstone*". Davey (1991a) described gravel stringers and lenses comprising almost all locally derived Ironstone within cross-bedded Milton Formation deposits at Kislingbury, Northampton.

Unit D (Youngest material)

The upper surface of Unit C was possibly truncated before the deposition of the overlying grey, chalky diamicton of Unit D.

7.03. Interpretation of the environmental using ostracod data.

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E. (Tables 5.04.1, & 7.03.1, and Appendices B-D).

The organic sediments (described above) were collected from Units A and B. The remainder of the sediments appeared to be non-fossiliferous. The ostracod valves were recovered from organic silty clay horizons within the sand and gravels. Most of the valves were well preserved, most samples containing a mixture of both adult and juvenile instars (moult stage valves).

S1.MS contained a small assemblage of ostracods (total 73 valves) of low species diversity (3) with a low percentage of juvenile moult valves present (20.4%).

The assemblage was dominated by the temperate lake species *Limnocythere falcata* and *Ilyocypris* sp. A (Robinson, pers comms.). Both these species are extinct. *L. falcata* was recovered from interglacial sediments at Mark Tey and Cromer (Robinson, 1978).

MILTON FORMATION, COURTEENHALL						
Sample number	**1**	**2**	**3**	**4**	**5**	**6**
OSTRACOD SPECIES						
Limnocythere falcata	26	4	16	50		
Limnocythere sanctipatricii					27	
Candona candida					10	
Candona neglecta	1				23	
Candona spp.		4			7	
Fabaeformiscandona fabaeformis				1		
Pseudocandona marchica					21	
Cyclocypris laevis					36	
Ilyocypris gibba			2			
Ilyocypris papillata				1		
Ilyocypris sp. A	46	16	18	58		
Eucypris pigra					21	4
Eucypris virens		10			7	
Bradlystrandesia fuscatus				7	7	
Herpetocypris reptans				6		11
Heterocypris incongruens				3		
Potamocypris arcuata					20	
Total	73	34	36	126	179	15

Table 7.03.1. The number of valves recovered of each ostracod species extracted from the lower sediments of the Milton Formation, Courteenhall.

Ilyocypris sp. A was recovered from temperate (Oxygen Isotope Stage 7) sediments of the River Great Ouse at Stoke Goldington, Bedfordshire, but not from the cool (Oxygen Isotope Stage 5 or younger) sediments of the upper channel of the same succession (Green *et al.*, 1996). Thus, the environment supporting these ostracod species at Courteenhall may have been a warm, shallow lacustrine-like setting with aquatic vegetation, possibly an abandoned channel in a braided gravel stream. As the burrowing species *Candona neglecta* is rare and others absent it probably had a sandy benthos. From the low numbers and the environmental data, it is considered that the ostracods were becoming established in an environment that was also newly established. Perhaps the channel had only recently been abandoned and was now part of a temperate, slow flowing river system.

S2.MS contained a small assemblage of ostracods (total 34 valves) of low species diversity (4) with a high number of juvenile moult valves present (65.8%).

Compared with the lower sediment (S1.MS) there is a decrease in the number of ostracod valves and a decrease in the number of species present.

The assemblage consists of the temperate species, *L. falcata,* together with *Candona* spp., *Ilyocypris* sp. A and *Eucypris pigra*. *E. virens*, a temporary pool species, may have been inwashed into the environment or there was a reduction in the water depth making it more of a temporary habitat for ostracods. Again, burrowing species are rare, there was a sandy benthos.

It is likely that the lacustrine environment has become increasingly shallow (due to sedimentation and, possibly, low precipitation). The assemblage was, as earlier, dominated by *Ilyocypris* sp. A, indicating that little change had taken place in the habitat. Importantly, the presence of *E. virens,* a winter species, shows that the winters at that time were wet, providing temporary pools on the floodplain, and the absence of summer temporary pool species suggests that the summers were dry.

S3.MS contained a small assemblage of ostracods (total 36 valves) of low species diversity (3) with a high number of juvenile moult valves present (96.4%).

The assemblage was dominated by species *Ilyocypris* sp. A and *Ilyocypris gibba*, indicating either slow moving or still permanent waters. It has 2 temperate species, *L. falcata* and *I. gibba* and 1 species, *I. gibba*.. Again, there are no typical burrowing species present.

The absence of *E. virens* and the increased number of *L. falcata* shows a return to more stable conditions. The presence of so many juvenile moult valves suggests that the ostracods, now in favourable conditions, were becoming established with the possibility of developing into a large population. The channel was still cut off from the mainstream. The existence of the extant ostracod, *I. gibba,* indicates the climate was temperate.

S4.MS contained a large assemblage of ostracods (total 126 valves) of average species diversity (7) with a low number of juvenile moult valves present (19.8%).

The assemblage contains a number of new species and, although low in number, indicates changes in the environment. It has 2 species found usually in winter and spring, *Bradleystrandesia fuscatus* and *Fabaeformiscandona fabaeformis*. It is still dominated by *L. falcata* and *Ilyocypris* sp. A. The new species to the environment, *Herpetocypris reptans*, is a hardy, adaptable species which often crawls on water-weed, or burrows in the soft substrates of permanent and temporary freshwater pools and even large lakes. *Ilyocypris papillata* is extinct.

Both temporary and permanent habitat species are present suggesting a time when an established colony of ostracods is declining and others are moving into the environment to take their place. It is likely that the abandoned channel had, over time, become increasingly productive. There are small numbers of winter/spring ostracod species of temporary pools and yet no temporary pool species of summer. This suggests that the winters continued to be wet and the summers dry. Fragments of charcoal and singed beetle wings found within the sediments suggest that wildfire may have occurred periodically.

S5.MS contained a large assemblage of ostracods (total 179 valves) of high species diversity (10) with a low number of juvenile moult valves present (11.2%).

The assemblage has seen major changes since the deposition of sediment S4.MS. The temperate species *L. falcata* has been replaced by *Limnocythere sanctipatricii*, a cold stenothermal species. Like its predecessor, it lives in permanent water bodies such as lakes and ponds. There are still 2 temperate species present, *E. virens,* and, new to the environment, *Pseudocandona marchica*, a species that prefers thickly vegetated habitats with muddy sediments. *Cyclocypris laevis*, new to the environment, also indicates there was an increase in aquatic vegetation. The muddy benthos was inhabited by *C. candida* and *C. neglecta*.

Danielopol *et al.,* (1985) suggested that, in lake assemblages, some form of depth partitioning takes place between *C. candida* and *C. neglecta, C. candida* occurring mostly in shallow waters. However, it is unlikely for the water in an abandoned channel to be of sufficient depth for depth partitioning to be of relevance.

B. fuscatus has, again been washed into the abandoned channel, as has *Eucypris pigra*; *Potamocypris arcuata,* a temperate species, may have inhabited it

Both temporary habitat and permanent habitat species are present in the assemblage. This suggests a time of change when an established colony of ostracods is slowing down and others are moving into the environment to take their place. The, now well vegetated, abandoned channel continued to be cut off from flowing water. However, the climate was cooling, as indicated by the species *L. sanctipatricii*, but was still warm enough to support the temperate species *P. arcuata, C. laevis* and *P. marchica*. As in the lower sediments, the temporary pool species suggest that there were wet winters and long dry summers. The floodplain and channel, as indicated by the presence of *E. pigra,* were fed by springs and streams from the valley sides.

S6.MS contained a small assemblage of ostracods (total 15 valves) of low species diversity (2) with an average number of juvenile moult valves present (41.6%).

The assemblage was recovered from a channel-fill situated in sands 1.5 m above S5.MS. The two species recovered were *E. pigra* and *H. reptans*. The *H. reptans* valves were large and thin. The *E. pigra* valves were probably washed into a permanent or temporary muddy pool inhabited by the species *H. reptans*.

The presence of *L. sanctipatricii* in sample S5.MS suggests that the climate was already cooling, but it is likely that it has further deteriorated. Also, since the deposition of sediment S5.MS, a deposit of sand, 1.5 m thick (Figure 7.02.2), has been laid down. This sand is fossil free, probably due to continual aggradation of the deposit (Rose, pers. comm). With continual aggradation and increasingly cold temperatures most of the ostracod species have disappeared. The ostracod species, sedimentology and stratigraphic evidence show that a distinct change has taken place in the environment.

This event was, probably, a long cold period of deposition followed by a time in which the small channel (S6.MS) was downcut and infilled with organic sediments. This was followed by either further deposition and then a period of erosion followed by the deposition of the type Milton Formation sands, or the deposition of the type Milton Formation sands.

7.04. SITE A2. Milton Formation, Courteenhall (SP758553) (from which spruce and pine remains were extracted), Map: Figure 7.01.1, Section: Figure 7.04.1.

7.04. Introduction

In 1995 a newly opened section (SP758553) at Courteenhall quarry revealed a channel deposit which cut down and into the 'Blue' Lias bedrock. The stratigraphy in this part of the pit at Courteenhall showed that the ostracod-rich fluvial sediments seen at Site A1, Courteenhall, which had been laid down on a wide base cut into the Lower Jurassic bedrock, had been bisected by a channel which had cut more deeply into the bedrock. The contents of the younger channel sedimentary infill differed from that of the older sediments. These younger sediments were up to 7.0 m thick and were overlain by up to 5.0 m of sediments typical of the Milton Formation. The lowest 2.0 m of the channel infill, a fine, sandy gravel, contained numerous cones and fragments of wood of both spruce and pine (Unit A). Probably due to the acidity of the plant material, any calcareous material that had

Plate 1. The lower sediments of the Milton Formation at Courteenhall Quarry. The lowest metre, the dark sediment, comprised remains of spruce and pine (see Section 7.04.1. Site A2).

Plate 2. The spruce and pine cones from the Milton Formation were well preserved (see Section 7.04.1. Site A2).

been in the lower channel, including the gravel, had dissolved and, thus, the sediments were decalcified. Above this sediment the channel infill consisted of fine sediments lacking anything other than finely comminuted plant material (Units B and C). These sediments were covered by the type Milton Formation (Stage D) and then overlain by Anglian till (Unit E). It was not clear if an unconformity existed between the two (Figure 7.02.2).

7.04.1. Sediments of A2.

Unit	Description	Maximum observed thickness.
	(Youngest material: 86 m O.D.)	
G	Chalky diamicton with pebbles of flint and Bunter quartzite.	6.0 m
F	Trough cross bedded and horizontally bedded sands.	4.0 m
E	Ripple bedded laminated sands, silt and clays	0.3 m
D	Sandy silts and clays	0.3 m
C	Sandy silts and clays	0.25 m
B	Sands, silts and clays	1.10m
A	Horizontally bedded fine to medium gravels with thin Horizontal beds of organic silts and clays (fining upwards)(Unit A was oldest and lowest material)	2.0 m (the lower 0.5 m obscured by water).

The sediments sampled for lithology and particle size were collected from a section cut expressly for this purpose by the Sandspinners company. The analyses show that the lithology of the clasts was composed entirely of local Jurassic sandstones, Ironstones, limestones and fossils such as *Gryphea* and *Belemnites*. The sand grains were sub-rounded to rounded iron-stained quartz and Ironstone. The muds contained considerable quantities of silt-sized mica fragments derived mainly from the Lias Clays and Northamptonshire Sandstones. There were too few clasts for comparable stone count analyses, but the particle size distribution is shown in Table 7.04.1.

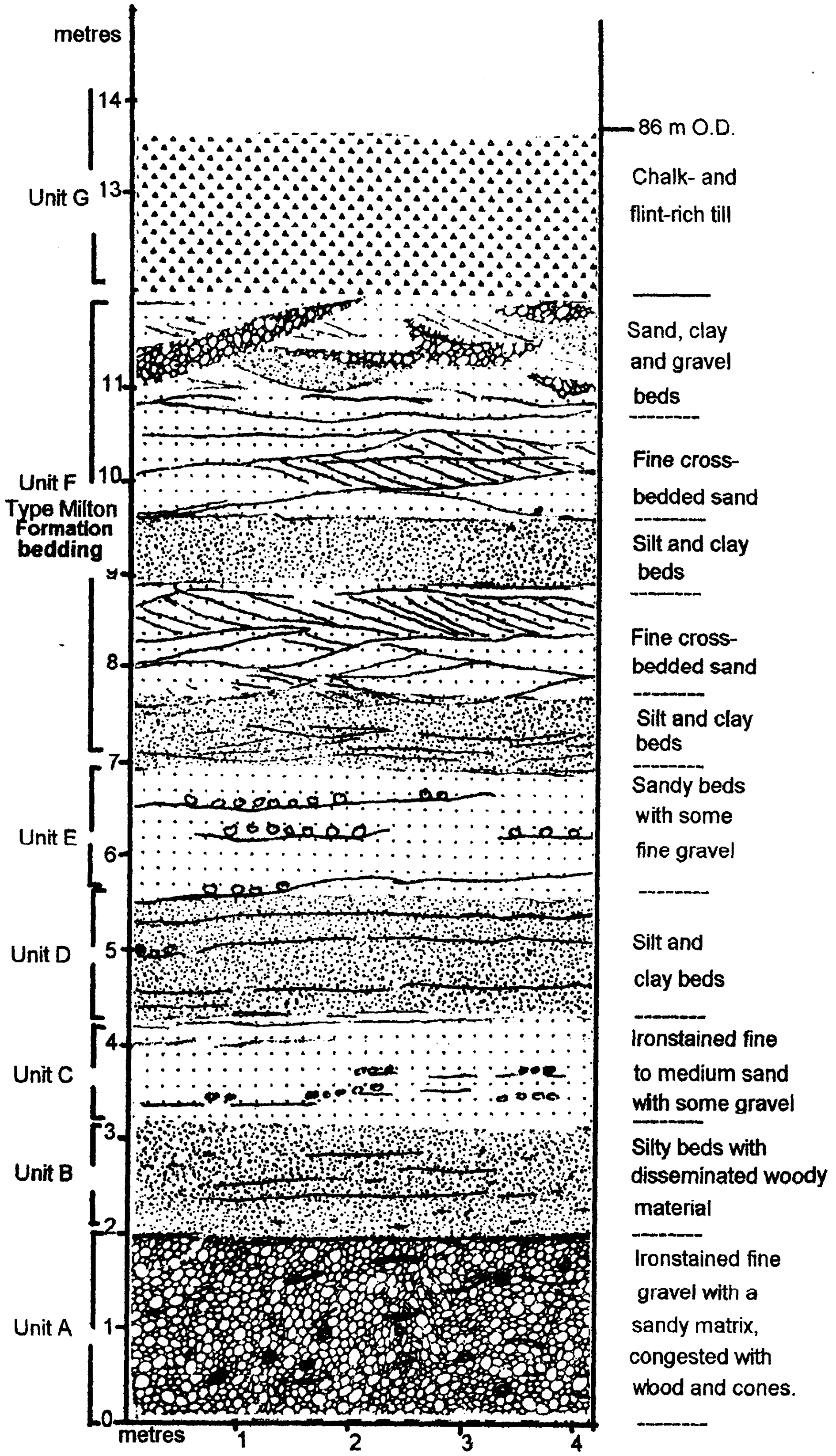


Figure 7.04.1. Site A2: section recorded at the Milton Formation quarry, Courteenhall, Northampton (SP758553). Key: Figure 7.02.1

Unit A. (Unit A was oldest and lowest material)

Unit A comprised laterally extensive horizontally bedded, muddy, matrix-supported gravels, interbedded with thin beds of clay, silt and sand. The analyses shows that the bedding of the unit graded downwards to coarser sizes throughout the deposit (samples A1-A3, Table 7.4.01). The finest sediments were mica rich.

The ironstained, dark brown, 10YR 3/3, lower gravels, (sample A1) contained wood, cones and also nodules of iron-panned clasts from a previously iron-panned bed.

The remainder of the gravels of Unit A (including samples A2 and 3) were dark grey to olive grey (5Y 3/1 - 5Y 6/3). They also contained many woody fragments and cones of spruce and fewer pine. The sand from this part of the unit, when washed, was almost white (10YR 8/1) as if derived from the white sands of the Northamptonshire Sand Formation.

Unit B

Unit A was overlain, probably gradationally, by sandy silts and clays of grey (5Y 5/1) to pale olive (5Y 6/4) coloring (Unit B). To the west of the area Unit B was partially eroded, by a channel infilled with clays and silts. These were darkened to black (5Y 2.5/1) by fine disseminated plant remains which had a strong organic smell. All the sediments at this level were flecked with vivianite which, although white, soon turned brilliant blue when exposed to the air. The bedding, although disturbed by the quarry machinery, showed some laminations. Particle size analyses indicates that there was a continuation in the fining upwards of the sediments - samples B4 and 5 of Table 7.04.1.

Unit C

Unit C appeared to grade upwards from Unit B and contained enough clasts to give it the appearance of fine gravel. Nevertheless, the particle size analyses (sample C6) shows that 57% of the sediment was smaller than 63 microns (< 4 phi). The colour was grey brown (2.5Y 2/4) and it had a strong organic smell.

Unit D

The sediments of Unit D (sample A7) showed some cross-bedding and were much finer, at almost 100% silts and clays, than those of Unit B. They were of a colour varying between olive grey (5Y 4/2) and brownish yellow (10YR 6/8).

	particle size.........	>-4 phi	-3	-2	-1	0	1	2	3	4	<4 phi	0%		
	Field description												**Analyses**	
UNIT E	A8) rippled sand	0	0	0.1	0.1	0.3	0.3	25.3	40.5	3.8	29.6	100	silty sands	youngest
UNIT D	A7) sands/silts	0	0	0	0	0.1	0.3	0.8	3.7	2.8	92.3	100	silts and clays	
UNIT C	A6) pebbly sand	0	0.3	0.9	1.6	1.5	1.8	8.4	15.5	13.1	56.9	100	sandy " " "	
UNIT B	A5) sands/silts	0	0	0	0	0.1	0.4	8.7	17.9	11.3	61.6	100	sandy silts and clays	
"	A4) sands and silts	0	0	0	0.2	0.1	0.4	11.6	15.5	9.1	63.1	100	sandy silts and clays	
UNIT A	A3) pebbly sand	0	0.7	1.3	1.5	2.1	6.6	30.1	16.6	6.4	34.7	100	silty, gravelly sands	
"	A2) gravels	0	6.3	6.3	5.6	3.6	6.9	8.3	5.4	1.5	56.1	100	silty, sandy gravels	
"	A1) basal gravels	6.4	5.4	7.1	17.4	12.5	21.2	23.7	5.9	2.4	4.4	100	sandy gravels	oldest
Above:	Site A2: Courteenhall Milton Formation deposits containing remains of spruce cones													
		5.2	10.4	23.7	22.4	8.1	11.7	15.5	2.4	0.3	0.3	100	sandy gravel	
Above:	Sand and gravel from Yardley Hastings.													

Table 7.04.1: **The particle size and description of the lower Milton Formation at Courteenhall Grange Farm and Yardley Hastings, Northampton.**

Unit E

Unit E (sample A8) comprised ripple-bedded, sandy silts and clays of a similar colour to Unit B.

Unit F

Unit E was overlain by 4-7.0 m of planar and trough cross-bedded, fine to medium sands of the Milton Formation type. These sands were light brown to yellowish brown and follow the same description as Unit C in the previous section - Site A, Courteenhall pit.

Unit G (Youngest material)

The upper surface of Unit F was possibly truncated before the deposition of the overlying grey, chalky diamicton of Unit G.

7.02.2. Discussion of Site A2 sediments.

As most of the sediment samples were of too fine a particle size for clast analyses no stone count tables were drawn up for this site. However, an examination of the clasts available proved that only local rock was present, over 90% was ironstone; the remainder being sandstone.

The particle size analyses show two episodes of declining river discharge and a consequent fining upwards of the sediments: 1) within Unit A and 2) between Units B through to D with a short period of higher discharge when Unit C was laid down. However, Unit E, the highest sediment sampled for particle size, shows a large increase in the 2 and 3 phi range and a consequent drop in the silts and clays (Table 7.04.1). In fact, the lowest gravel and the uppermost, finest deposit of Unit A have a similar percentage of 2 phi particles (24 % and 30 %) to the rippled sand of Unit E (25%) and Unit E is modal at 3 phi (40%).

It is generally accepted that sediments of the type Milton Formation, those deposited in the upper deposit of this site and not analysed (Unit F of Figure 7.04.1), are strongly modal at 2 phi (250 microns) and are made up from the local bedrock (Belshaw, 1989). As discussed in Chapter 2, section 2.02.1, it is said that the local bedrock of the Variable Beds and Northampton Sands (the Northampton Sand Formation) has a smaller modal size at 3 to 4 phi (Belshaw, 1989).

As the deposit examined here is all from local rock, the evidence here is that the modal size of the deposit may vary according to the type of bedrock being eroded rather than the amount of river discharge available. The Variable Beds are just that, ranging from Ironstone, Red Freestone, Limestone to white sands (as found in Unit A above) and the Ironstone Beds of the Northampton Sands vary in thickness from between 0 to 10.0 m over very short distances (Thompson, 1902). Add to this, the underlying Upper, Middle and Lower Lias Clays (mudrocks) and the overlying limestones (Figure 2.01.1) and it can be seen that the Milton River sediments must vary in their modal size according to the bedrock it is eroding through, as well as the amount of runoff and consequent river discharge. If the largest material gets into the system early, it would be available for reworking at a later date.

Considering the bedrock from which the mass of Milton Formation is derived, much of it is friable and would be readily eroded by a large river. There would have been heavy sediment loads available from which, as the river widened, bars could grow to form braided channels. A combination of variable discharge and growth of the bars by deposition of more bedload material would give rise to lateral bank erosion and consequently further deposition. That this is the case for the Milton River, especially in its early, temperate stage, is reflected in its complex pattern of bars and channels. Later, as the climate cooled, both erosion and discharge in the braided river environment and its tributaries would increase, giving rise to almost continuous aggradation; hence the lack of fossils in the upper sediments.

7.05. Age and environmental factors of the Milton Formation Sites A1 and A2.

The ostracod species assemblage from Site A has one possible pre-Anglian species, *I. papillata*, and one 'Hoxnian' species, *L. falcata* (Table 7.02.1).

As the latter species and 7 other species found (all of which are extant) have been recorded as found in sediments from a warm period, the ostracods indicate temperate, sometimes dry summers. With time the summers became cooler as shown by the assemblage in Unit B. It has no temperate ostracod species and, therefore, must have been laid down in colder conditions.

As the sediments are buried beneath Anglian and, in places, possibly older till (Chapter 4) it would be expected that there would be more Pre-Anglian indicator species than there are. However, the ostracod assemblage bears little resemblance to any comparable assemblage in the pre- Anglian period. A likely reason for this is that there are differences in the geographic position, the morphology, the geology and the local climate of Northamptonshire to that of each of the sites reviewed for this research. More importantly, this is a new record for this period of time in the Quaternary and may well represent a previously unrecorded period of time

At Courteenhall, at the site sampled, 4.5 m above bedrock, there is an unconformity between the sediments of S6.MS and the sediments (Milton Formation) above them. It is suggested by the author that the sediments represented by S6.MS were deposited just before a period of increased discharge and downcutting. This was followed by a time in which the river flowed through boreal woodland and the newly cut river channel was infilled with sands and gravels containing wood and cones of spruce and pine. There followed a periglacial period, before the earlier glaciation that deposited the lower till, in which the river sediments were buried and the valley infilled to a higher level by the Milton Formation type sands and gravels. The sands and gravels were then subjected to glacial conditions in which they were overlain by the lower glacial till which was later largely eroded. This erosive period was then followed by the deposition of the Anglian till.

7.06. Yardley Hastings: abandoned quarry (SP874581).

This site was visited once to confirm the pre-glacial nature of this gravel; that is, that it comprises only local lithologies.

The gravel (surface approximately 73 m O.D.) was stripped of any till and its base was concealed by talus. The section (Figure 7.06.1) showed sand and fine to medium gravels of local Ironstone and Limestone lithologies. The particle size distribution (Table 7.04.1) shows the gravel is courser than that at Courteenhall and it is suggested that this is because of the change in the surrounding geology of the valley (Figure 4.01.6).

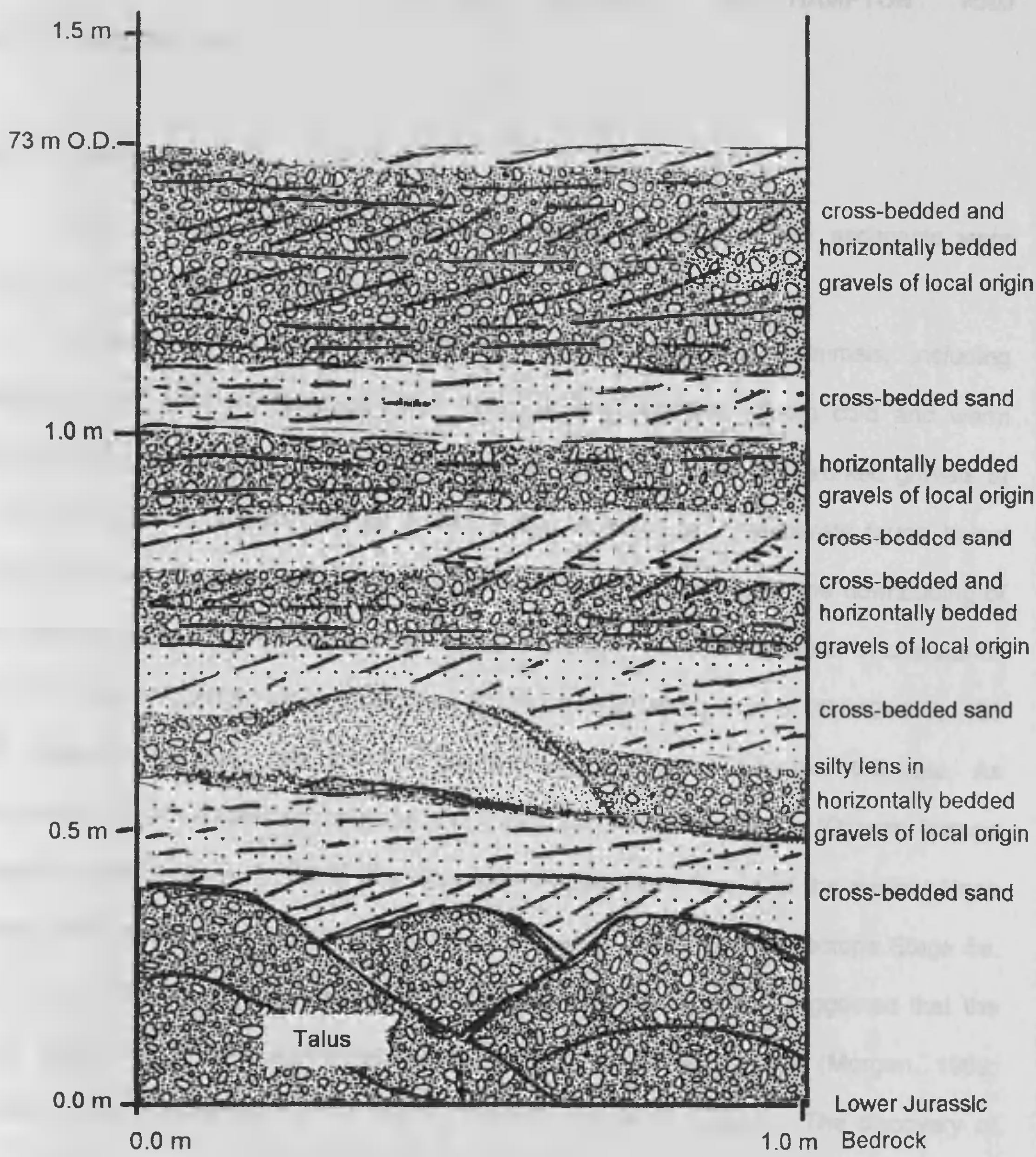


Figure 7.05.1. Section drawn at Yardley Hastings abandoned quarry (SP874581). Key Figure 7.02.1.

CHAPTER 8: SITE DESCRIPTIONS, ANALYSES AND INTERPRETATION OF THE NENE VALLEY SANDS AND GRAVELS BETWEEN NORTHAMPTON AND WELLINGBOROUGH.

8.01. Introduction.

This chapter describes the sites from which the Nene Valley sediments were recovered. The sites are mapped on Figure 8.01.1.

Between 1992 and 1994, remains of extinct temperate mammals, including straight-tusked elephant (*Palaeoloxodon antiquus*) and species of both cold and warm climate bison, were found in silts deposited in a depression beneath reworked gravels at Clifford Hill, Little Houghton (Smith, 1995). The presence of a temperate fauna below reworked gravels at this site indicates that a warm stage occurred after the downcutting of the older gravels and before the deposition of the younger, reworked gravels. A channel-fill (Site F of this discussion) incising the latter yielded a radiocarbon date of 26,840+455, -430 B.P. (East Kilbride, 1992) and, therefore the reworked gravels are older than this date. As the straight-tusked elephant became extinct during the earlier Ipswichian (Oxygen Isotope Stage 5e) period (Currant, 1989), this fact alone verifies that the time of the earliest Nene Valley gravel deposition was during and, most probably, before Oxygen Isotope Stage 5e. This contradicts the available literature of the time (Chapter 2) which suggested that the Nene Valley Gravels of Northamptonshire were all of Devensian age (Morgan, 1969; Shotton, 1973; Castleden, 1976 & 1980b; Holyoak and Seddon,1984). The discovery of these fossils led to a further investigation of the Nene Valley Gravels of Northamptonshire (Chapter 4 of this research and the following analyses of the ostracods recovered from the Nene Valley sediments).

At the southern edge of the valley, now decalcified gravel was found to form an early terrace of the River Nene. The decalcified gravel (previously unrecorded) was non-fossiliferous and showed a fining-up sequence of sediments from medium gravel to fine silts at 2.8 m above bedrock. This early gravel was deposited before the period of incision and infilling of the tunnel valley at Northampton.

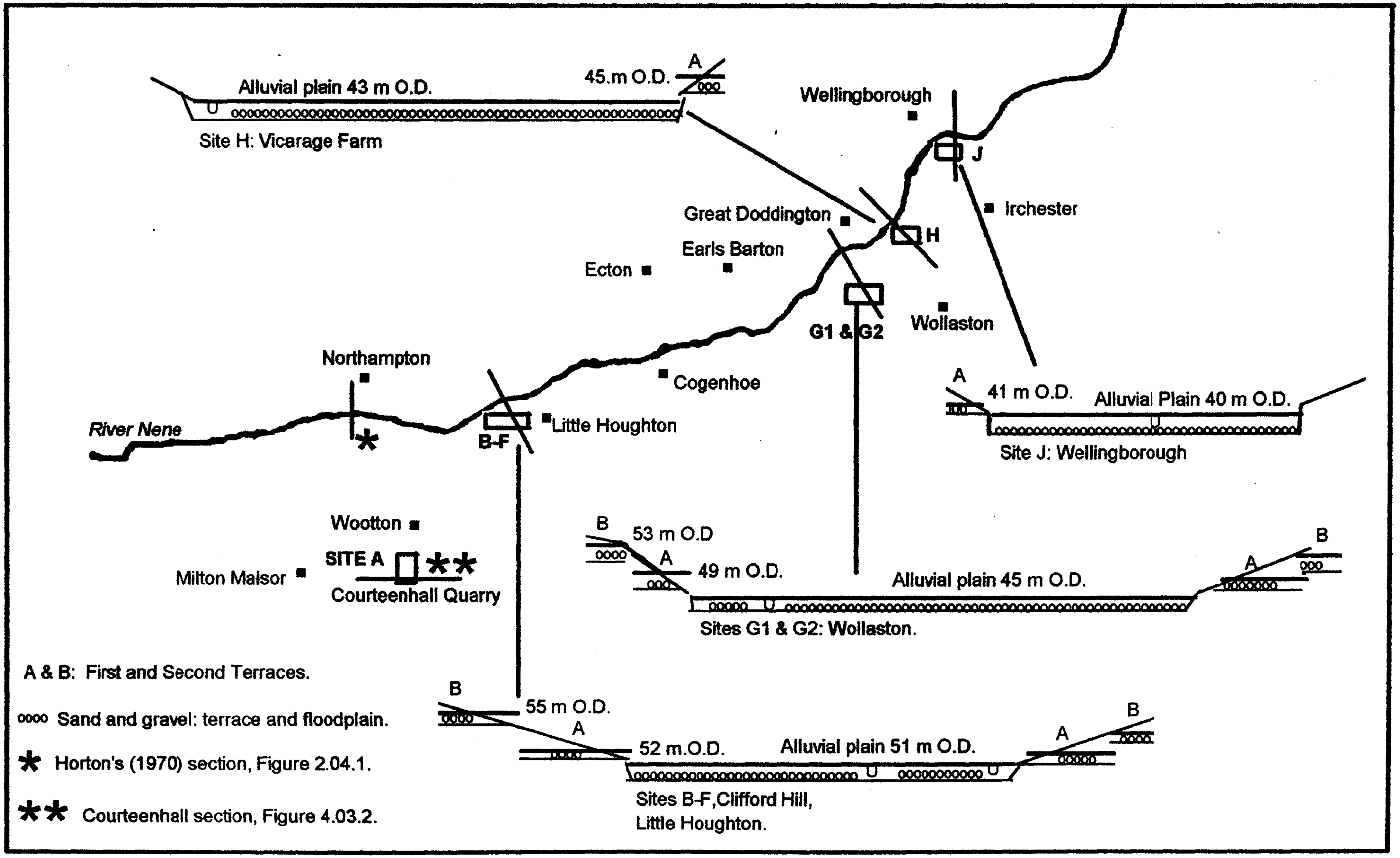


Figure 8.01.1: Map and sections of Nene Valley deposits between Northampton and Wellingborough.

At Clifford Hill there was much reworked sand washed down from the pre-glacial sediments beneath this decalcified gravel sampled at Little Houghton. The sands contained no far-travelled lithologies and could have been mistaken for *in situ* Milton Formation. This gives evidence for the existence of the Nene Valley before any glaciation occurred.

Much of the earlier valley gravels (those remnants that are now decalcified) were eroded down to bedrock by either a high energy river, or the waters of the tunnel valley. After the Anglian deglaciation there were repeated episodes of down- and lateral-cutting followed by infilling with gravels. After one downcutting period a depression in the bedrock was infilled with temperate pond sediments (Smith, 1995). These sediments and the surrounding bedrock were then overlain by horizontally bedded gravel. Nearly all the quarry sections showed evidence of cryoturbation, but the position of the features within the sediments varied from site to site. The lithology and bedding of the gravels also varied. Downstream, at Cringle Farm, Vicarage Farm and Wellingborough the lowest gravel contained between 20% and 50% calcareous material and showed crossbedding, whereas, upstream, the gravels, apart from the decalcified gravel mentioned, contained 8-15% calcareous material (limestones and chalk) and were, for the most part, horizontally bedded.

The ostracods were recovered from black silty organic sediments within and below the gravels and from the finer sediments above the gravels. Several important ostracod species were recovered from the Nene Valley sediments. The following species were the most notable; *Candona rawsoni* and/or *Candona lactea*. These two may be one and the same species (Griffiths, pers. comm.). The first, *C. rawsoni,* is extant, but not found in Britain today, the second has only ever been reported from the British fossil record. The ostracod *Ilyocypris biplicata,* found at Clifford Hill, tolerates cold water conditions, but is, also, not found in Britain today. *Potamocypris similis*, another species found only at Clifford Hill, inhabits one site in Britain today (Griffiths, 1995) It has never been recorded in the British Pleistocene which suggests that this may be the first finding of *P. similis* in British Pleistocene sediments. *Ilyocypris schwarzbachi* and *Ilyocypris* sp. A are both extinct species, but, in this research, the fossil record for *Ilyocypris* sp. A is has been brought forward to the Mid-Devensian period. This means that it cannot, safely, be used to define sediments as being pre- Oxygen Isotope Stage 6 in age. The rare *Ilyocypris schwarzbachi,* previously recorded only in Cromerian sediments in Britain (Robinson, 1990), has also been found in Mid-Pleistocene material in the Netherlands and Germany (Kemph, 1967 & 1975). *Bradleystrandesia fuscatus* is a first record for the British Pleistocene, except during the present study where it has been found in the Milton Formation.

Candona candida is absent from the assemblages in Clifford Hill West Field. It is, according to Griffiths (1995), very common and is recorded from over 30 sites in Britain from the late Beestonian onwards. Its absence cannot be explained, but the whole species list is unusual in having the species *I. biplicata, I. schwarzbachi* and *C. rawsoni/lactea* which have neither been found in the Milton Formation nor anywhere else in the Nene Valley sediments.

8.02 CLIFFORD HILL WEST FIELD, OSTRACOD SAMPLES S7.CH - S18.CH

8.02 Introduction.

The gravels of the Nene Valley contain far-travelled erratics, such as chalk, flint and Bunter quartzite pebbles and, therefore, they are post-chalky till in age. The lithology of the gravels does, however, vary from site to site, downstream and across the valley. This is due to the reworking of the river gravels and the fresh inputs from the tributaries in past times of high-energy fluvial activity.

At Clifford Hill, the general orientation of the gravels suggested a north-easterly flow direction (Castleden, 1976). Strong cryoturbation and large ice-wedge casts are notable features in parts of the Nene Valley Gravels and were seen in evidence at Clifford Hill site.

The ostracod valves from the Nene Valley were found in organic rich clay horizons within, and directly beneath, the sand and gravels. Most of the valves were well preserved. Most assemblages contained a mixture of adult and juvenile instars (moult stage valves).

Plate 3. These fine organic sediments, embodied within gravel 2.0 2.20 m thick, were seen at Clifford Hill in West Field (Section 8.02.1. Site B).

Plate 4. Ice wedge casts intruded the gravels in a polygonal pattern throughout West Field (see Sections 8.02.1 & 8.02.2).

8.02.1 SITE B

Site description and analyses: Clifford Hill West Field, Little Houghton (SP788595), Map: Figure 8.01.1; Section: Figure: 8.02.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES S7.CH & S8.CH.

This section was cut through sediments marked as First Terrace deposits on the geological map (Sheet 185: Northampton, Geological Survey, 1960).

8.02.2. Sediments of Site B (Tables 8.02.1 & 2)

Unit	Description	Maximum observed thickness.
	(Youngest material at surface: 52 m O.D.)	
E	Decalcified top soils	0.2 m
D2	Loamy colluvium	0.55 m
D1	Stony colluvium with truncated ice-wedge casts	0.5 m
C	Upper horizontally bedded gravel	1.0 m
B	Involuted, organic, silty channel infill 10.0 m wide	0.6 m
A	Lower horizontally bedded gravel	0.65 m
	(Unit A was oldest and lowest material)	

Unit A. (Unit A was oldest and lowest material)

Unit A (Samples B1 and B2 of Table 8.02.1 & 8.02.2) was a sandy pebbly gravel, colour yellowish brown 10YR 5/4, which fined upwards through the deposit. Analysis also shows that there was a decrease in the local material in the particle size fractions 4-8 & 8-16 mm. This shows, especially, as an increase in the amount of flint and a corresponding drop in the ironstone of the 4-8 mm fraction and an increase in the Bunter (liver quartz and vein quartz) with, again, a corresponding decrease in the local Ironstone, in the 8-16mm fraction (sample B2).

The gravel in contact with the overlying sediments was ironstained (strong brown 7.5YR 5/6)

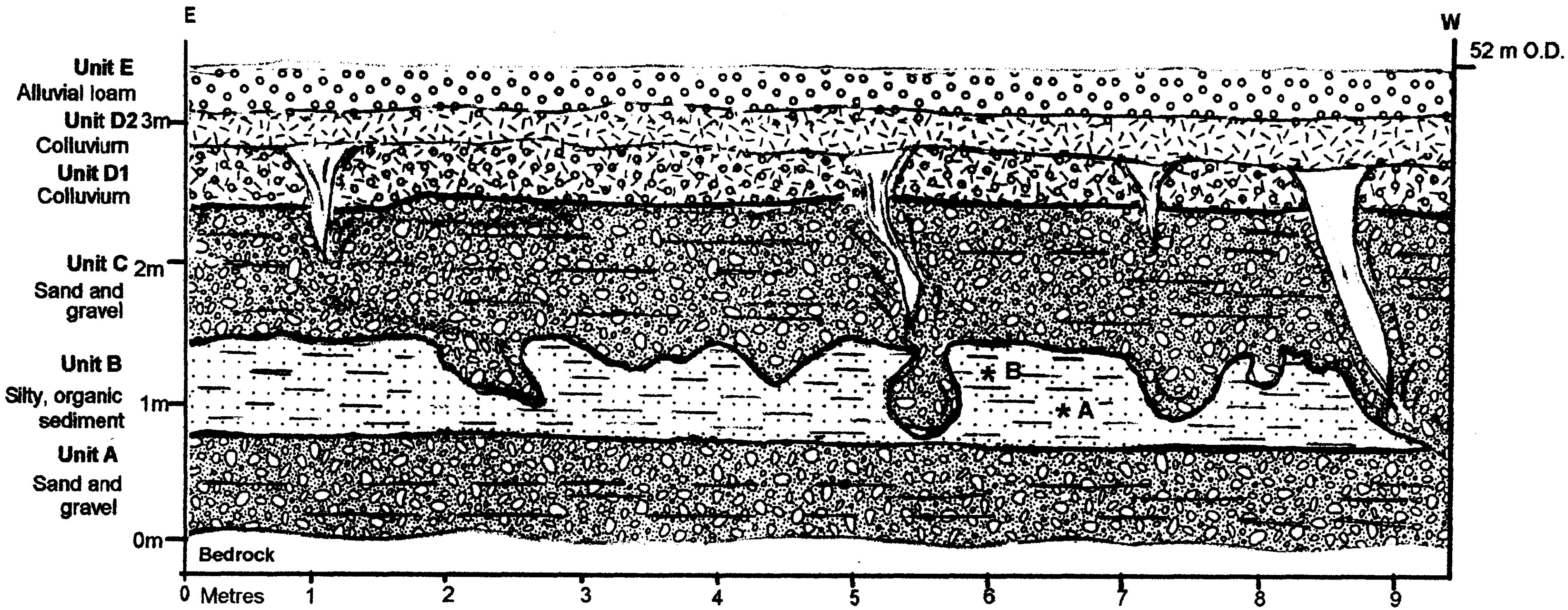


Figure 8.02.1. Site B: Section recorded at West Field, Clifford Hill quarry, Little Houghton (SP785595).

* A & * B: Organic samples S7.CH and S8.CH. Key: Figure 7.02.1.

Unit B

Ostracod samples, S7.CH and S8.CH, were collected from a fossiliferous dark grey/black (5YR 3/1 -2.5/1) silty clay (Unit B of Figure 8.02.1) channel-fill within the gravel.

The fabric of the gravels shows a preferred orientation to the east (Figure 8.02.2) indicating flow to the east.

Unit B: Sediments comprising ostracods (Figure 8.02.1):

S7.CH: The sediments consisted of dark grey silts and clays with a few small clasts of flint and Ironstone. The organic component was well preserved and most of the ostracod and mollusc remains were intact. Among the remains there were also seeds, fragments of fish bones and beetle wings.

S8.CH: The sample was sedimentologically and fossiliferously similar to S7.CH with the addition of *Chara* oogonia.

Unit C

Analysis of Unit C (Samples B3 and B4 of Tables 8.02.1 & 8.02.2) gravels shows the upper gravel (Unit C) had a depositional tendency opposite to those of the lower gravel, The gravels both coarsened and darkened (colour dark yellowish brown 10YR 4/4) upwards towards the surface. The proportion of local to erratic material in the 4-8 and 8-16 mm fractions remained similar to that of sample B2 of Unit A. There was little difference in the lithology between the two units. In the particle size 16-32 mm fraction, Unit C showed a small increase in flint with a decrease in Bunter clasts when compared with Unit A.

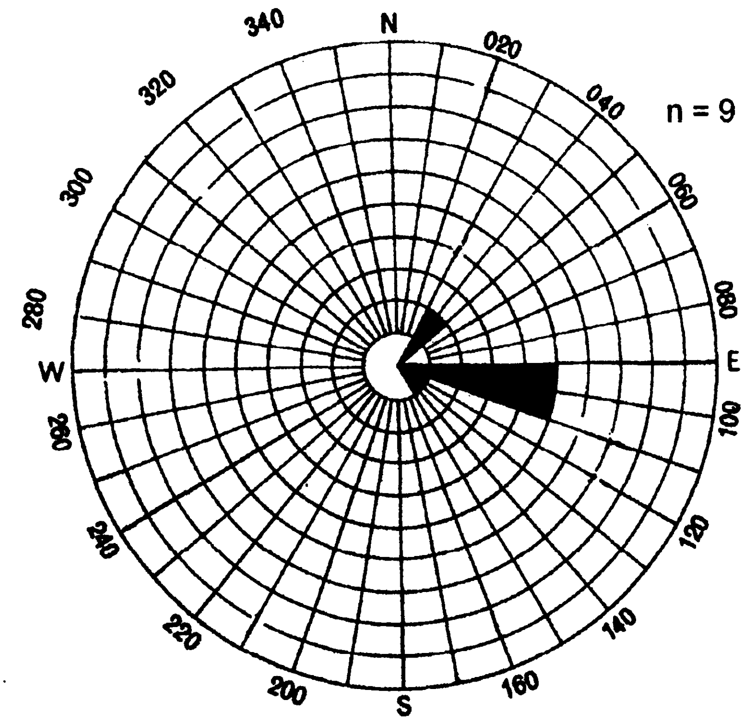
Units D1 and 2.

The gravel deposit was overlain by two units of colluvial material (Unit D1 & 2). The lower unit (sample B.Col.1 of Table 8.02.1) exhibited truncated fossil ice wedge structures which penetrated the upper 1.00 m of gravel beneath the colluvium. The ice-wedge cast's matrix colour was very dark greyish brown 10YR 3/2. The lithological analysis shows that the clast assemblage of the ice-wedge cast, B.IWF, which contained 27% chalk pebbles, was a complete contrast to both colluviums, Units D1 and D2 which contained no chalk and were of colour yellowish brown 10YR 5/6. The two colluviums were shown to have similar stone count analyses for the 8-16 mm fraction, but the 4-mm size range in both shows there

Site B	Clifford Hill West Field																		
	Site B: Clifford Hill West Field																		
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone	J. Fossils	Others.	Total local %
UNIT D:2	B.Col.2:clast size																		
62	8.0-16.0mm	27.4	3.3	9.7	40.4	0	11.3	3.2	0	0	0	0	54.9	41.9	1.6	1.6	0	0.2	45.3
295	4.0 - 8.0mm	10.8	2.4	0.3	13.5	0	0	1.7	0	0	0	0	15.2	78.6	0	6.2	0	0	84.8
I.W. FILL	Site B: Clifford Hill West Field																		
	B.IWF:clast size																		
37	8.0- 16.0mm	low number no analysis																	
424	4.0 - 8.0mm	7.6	6.6	3.5	17.7	0	0.5	1.4	0	0	0	27.8	47.4	35.8	1.4	15.2	0.2	0	52.6
UNIT D:1	B.Col.1: Clast size																		
161	8.0- 16.0mm	18.1	22.3	4.3	44.7	0.6	3.7	5.6	0	0	0	0	54.6	42.9	2.5	0	0	0	45.4
968	4.0 - 8.0mm	12.2	12.3	1.3	25.8	0	0	1.3	0	0	0	0	27.1	71.8	1.1	0	0	0	72.9
	Site B: Clifford Hill West Field gravel samples							B1) upper, B2) upper middle, B3) lower middle, B4) lower gravel											
UNIT C	B3+B4	(16-32 mm sieved on site).																	
255	16-32.0mm	24.7	5.9	8.4	39	0	24.2	6.2	1.6	3.1	0	0	74.1	16.5	9.4	0	0	0	25.9
	B4:clast size																		
478	8.0-16.0mm	31.4	13.4	5.9	50.7	0	5.4	1.5	0	0.6	0	0	58.2	37.4	4.2	0	0	0.2	41.8
691	4.0 - 8.0mm	14.4	8.5	2.9	25.8	0	0.6	2.3	0	0.1	0	0	28.8	69.9	1.3	0	0	0	71.2
	B3: Clast size																		
159	8.0- 16.0mm	24.5	11.9	5.1	41.5	0	6.3	6.3	0	0.6	0	0	54.7	39.6	3.2	2.5	0	0	45.3
786	4.0 - 8.0mm	13.1	8.4	3.4	24.9	0	0.8	2.3	0	0.3	0	0.5	28.8	68.8	1.3	1.1	0	0	71.2
UNIT B	Too fine for stone count.																		
UNIT A	B1+B2	(16-32 mm sieved on site).																	
151	16-32.0mm	30.5	9.3	5.9	45.7	0	19.9	5.9	0.7	1.4	0	0	73.6	15.2	11.2	0	0	0	26.4
	B2: Clast size																		
122	8.0-16.0mm	15.5	9.1	8.2	32.8	0	6.7	4.9	0	1.5	0	0	45.9	50.1	2.4	0.8	0.8	0	54.1
374	4.0 - 8.0mm	9.6	8.8	7.5	25.9	0	1.3	2.2	0	0.5	0	0	29.9	69.3	0.5	0.3	0	0	70.1
	B1: Clast size																		
370	8.0- 16.0mm	23.2	4.1	5.7	33	0.3	0.8	0.3	0	0.5	0	0	34.9	63.2	1.1	0.8	0	0	65.1
775	4.0 - 8.0mm	10.7	1.3	1.4	13.4	0	0.8	1.7	0.4	0.3	0	0.4	17	80.6	1.8	0.5	0.1	0	83
Table 8.02.1.	**Site B: Clifford Hill West Field stone count.**																		

	Sample												
Site B	**particle size..........**	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	**Analyses**
Unit C	**B4) upper gravel**	15.9	24.1	15.6	10.2	7.3	12.2	12.9	1.4	0.4	0	100	**sand and gravel**
"	**B3) upper middle**	8.1	11.3	10.8	8.5	5.9	7.5	16.1	11.3	3.4	17.1	100	**muddy sands & gravels**
Unit A	**B2) lower middle**	10.6	15.7	19.1	14.7	10.3	12.7	14.8	1.2	0.4	0.5	100	**sand and gravel**
"	**B1) lower gravel**	25.4	11.9	15.5	9.4	8.3	17.2	7.9	3.2	1.2	0	100	**sand and gravel**
	Sample												
Site C	**particle size..........**	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	
Unit A	**C4) upper gravel**	25.4	13.5	13.1	11.1	10.8	10.8	10.4	3.8	1.1	0	100	**sand and gravel**
"	**C3) upper middle**	22.4	15.4	12.6	9.6	7.3	12.1	17.6	2.6	0.4	0	100	**sand and gravel**
"	**C2) lower middle**	32.1	15.7	12.9	9.9	7.5	9.1	11.1	1.3	0.4	0	100	**sandy gravel**
"	**C1) lower gravel**	18.3	16.7	14.6	10.4	6.1	7.3	11.4	4.1	1.2	9.9	100	**muddy sands & gravels**
	Sample												
Site D	**particle size..........**	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	
Unit B	**D) mid-lower gravel**	26.6	32.6	17.2	7.4	3.6	3.3	7.5	1.5	0.3	0	100	**sandy gravel**
Site E	**Sample**												
	particle size..........	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	
Unit D	**E6) upper gravel**	42.1	16.5	12.7	5.1	4.1	14.1	4.3	0.9	0.2	0	100	**sandy large gravel**
	E5) middle gravel	40.1	16.9	16.1	8.7	5.2	6.4	5.4	1.1	0.1	0	100	**sandy large gravel**
	E4) lower gravel	43.1	18.9	9.4	5.3	3.9	13.1	5.1	0.9	0.3	0	100	**sandy large gravel**
Site E	**Sample**												
Unit A	**E) mean of samples**	13.1	20.1	23.1	16.1	8.2	6.7	10.5	1.9	0.3	0	100	**sandy gravel**
	E1-E3												
Site F	**Sample**												
	particle size..........	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	
Unit A	**F) gravels in which**	20.3	14.1	10.8	7.6	15.8	26.6	2.9	1.4	0.5	0	100	**sand and gravel**
	channel rests.												

Table 8.02.2. Particle size of Clifford Hill gravels, Little Houghton.



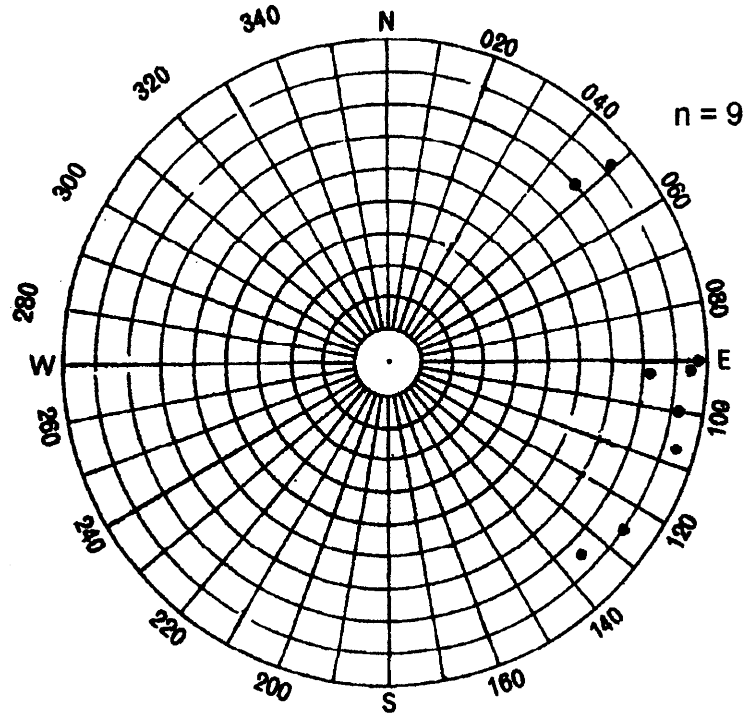


Figure 8.02.2.

Macro fabric diagrams from Clifford Hill, Site B, Unit B gravels. They show a preferred orientation of east, while the mean dip of clasts is relatively low at 10° from horizontal.

was a decrease in flint and a corresponding increase in local Ironstone clasts relative to the larger size fraction.

Not illustrated at this section, but seen nearby in other sections of the pit (for example, Site C), larger ice-wedge casts were seen to cut through the gravels from the surface to a depth of 2.0 m or more.

Unit E (Youngest material)

The whole section was covered by a decalcified loamy soil (Unit E), colour dark brown 10YR 3/3.

8.02.3. Discussion: Site B sediments.

Unit A, 0.65 m of horizontally bedded sandy gravel, rested on the Blue Lias bedrock. The gravels were first laid down at a time of high discharge, but this decreased as evidenced by the fining up of the sediments and the deposition of the fine sediments of Unit B.

The sediments of Unit B (Figure 8.02.1), from which the ostracods were recovered, was a brown/black silty clay channel-fill. As these sediments were not continuous along the site it seems that they were part of an abandoned channel infill, the abandonment possibly resulting from a lowering of precipitation and reduced surface run-off.

The silting up of the channel was followed by an increase in the river discharge. This resulted in the aggradation of a further 1.0 m of horizontally bedded gravel (Unit C). As this gravel coarsens upwards it is likely that the river discharge continued to increase. Meanwhile, the silty organic sediments of Unit B were then, or later, deformed by load structures due to the weight of the sediments above.

It is not clear if there is then an unconformity between the gravels and the colluvium of Unit D1. However, the succeeding gravel deposit (Unit C) was then, or later, overlain by a unit of colluvium 0.5 m thick (Unit D1). This was followed by a period of permafrost in which this unit, the gravel of Unit C and the deformed material of the channel-fill (Unit B) were penetrated by fossil ice wedge structures. The ice-wedge casts were infilled with small chalk pebbles, black silts and sands. The ice-wedge casts were planed off at the surface before a second unit of colluvium (Unit D2) was deposited on top. This suggests that the ice-wedged tundra deposits were eroded away before the upper colluvial material (Unit D2) was laid down.

The whole section was covered in 0.75 m of loamy soil (Unit E) of which the top 0.25 m was decalcified.

8.02.4: Site B:- Environmental interpretation from ostracod data (Table 8.02.3).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.

For ostracod species and numbers recovered, see Appendix D and Table 8.02.3.

S7.CH contained a small assemblage of ostracods (total 16 valves) of low species diversity (3) with a low number of juvenile moult valves present (12.5%).

Of the assemblage, all 3 species, *C. neglecta*, *C. laevis*, and *H. reptans*, are commonly found in many different environments.

The abandoned channel was vegetated with either permanent or temporary water. The ostracod assemblage was probably just becoming established as certain criteria, mostly concerning length of time and reasonably warm temperatures, were not ideal.

S8.CH contained a small assemblage of ostracods (total 17 valves, 8 carapaces) of low species diversity (3) with an average number of juvenile moult valves present (60.6%).

The assemblage contains *Ilyocypris biplicata*, a species of cool vegetated running water, pools and ponds and 2 commonly found species, *C. neglecta and H. reptans. H. reptans,* and *C. neglecta* are found in vegetated waters with a muddy benthos and are common to many different environments.

The ostracod assemblage was finding it difficult to get established before the channel either a) started to dry out, or, b) returned to flowing water conditions. The presence of *I. biplicta* implies the latter. The small number of species present implies that the channel may have been filling with sediment fairly rapidly.

WEST FIELD, CLIFFORD HILL.												
Sample number	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
OSTRACOD SPECIES												
Candona neglecta	2	13	23			28	6			2	35	
Candona rawsoni/lactea			9		15	18	5			5	18	
Candona spp.			11		8		8	2		8	7	4
Pseudocandona marchica							4					
Cyclocypris laevis	4		5	2	15							
Ilyocypris biplicata		19		6					9	3		
Ilyocypris bradyi				15	5	7	14	2			14	
Ilyocypris gibba						3	3					
Ilyocypris schwarzbachi					2	8						
Ilyocypris sp. A					3							
Eucypris pigra									3			
Prionocypris serrata			12		35	7						
Prionocypris sp.					10							
Bradlystrandesia fuscatus						6						
Herpetocypris reptans	10											
Herpetocypris sp.		1										
Cypridopsis vidua						9				18		
Potamocypris arcuata						7						
Total	16	33	60	27	126	112	40	4	12	36	74	4

Table 8.02.3. The number of valves recovered of each ostracod species extracted from the sediments of West Field, Clifford Hill, Little Houghton.

8.02.5: Site B:- Age and environmental factors of the sediments from Clifford Hill.

I. biplicata is not found in Britain today and there may have been only a few isolated communities in the past. It has been found in Hoxnian (Oxygen Isotope Stage 11) and Holocene sediments in Britain (Griffiths, 1995). The presence of this species suggests that there was a warm period of time but, as the ostracod data has indicated a relatively poor environment, it may not have existed for very long. The remaining ostracods were not age specific indicators (Appendix E).

The stratigraphy, clast and macrofabric analyses shows that the suite of sediments infilling the channel bed were subject to a fluctuating river regime perhaps due to first decreasing and then increasing precipitation. This was followed by a period of permafrost and eventually a return to a warmer climate. The channel was seen to have incised the gravels examined at Site C.

8.03. SITE C

Site description and analyses: Clifford Hill West Field (SP788594), Map: Figure 8.01.1: Section: Figure: 8.03.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES S9.CH - S18.CH.

This section, 18.0 m in width, was cut across the valley and faced east. These sediments are marked as First Terrace deposits on the geological map (Sheet 185: Northampton, Geological Survey, 1960).

Ostracod samples S9.CH to S16.CH were collected from the lower 1.0 m of a section of sandy gravel (Unit A, Figure 8.03.1, gravel samples C1-C4, Tables 8.02.2 & 8.03.1). Ostracod samples S11.CH and S12.CH were collected from the remains of fossiliferous channel-fills in the lower gravels above bedrock (Sample C1). The ostracod samples S9.CH, S10.CH, S11.CH and S14.CH were collected from organic silty lenses within the lower middle gravels (sample C2).

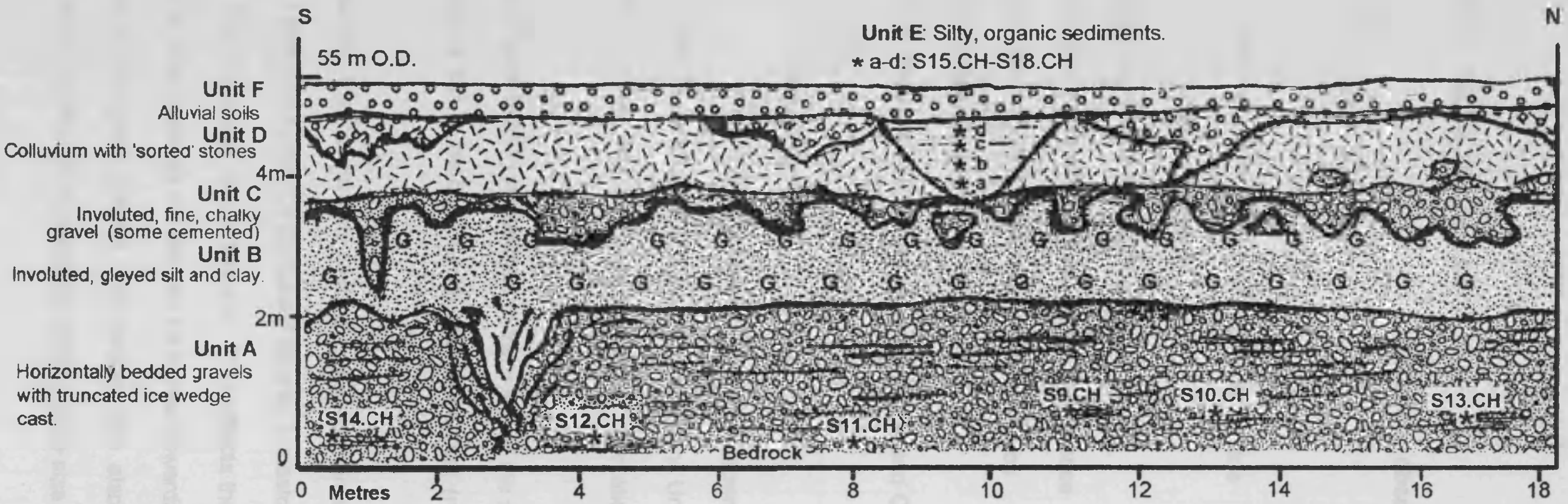


Figure 8.03.1. Site C: Section recorded at West Field, Clifford Hill quarry, Little Houghton (SP785594).
* Organic samples: S9.CH-S18.CH. Key: Figure 7.02.1.

8.03.1. Sediments of Site C. (Tables 8.02.2 & 8.03.1)

Unit	Description	Maximum observed thickness.
	(Youngest material at surface: 55 m O.D.)	
F	Decalcified top soils	0.3-0.5 m
E	Organic, silty, channel infill, 1.5 m wide, cryoturbated at surface	1.2 m
D	Clayey colluvium (showing stone-sorting?)	0.75 m
C	Involuted fine gravels penetrated by small ice-wedge casts	0.5 m
B	Involuted clay sediments continuous from ice wedge infill at base	1.5 m
A	Horizontally bedded gravel unit with ice-wedge casts at surface	2.0 m
	(Unit A was oldest and lowest material)	

The sandy gravels in the upper part of Unit A, samples C3 and C4 of Table 8.02.3, did not appear to contain fossils.

Unit A (Unit A was oldest and lowest material)

The colour was a general mix of the clasts, overall a yellowish brown, stained to dark yellowish brown 10YR 4/6 where in contact with the ice-wedge cast and Unit B. The fabric of the gravels shows, similarly to Site B, that there was a preferred orientation to the east and east-north-east (Figure 8.03.2).

The section drawn (Figure 8.03.1) shows that, to the south of the section, the gravel unit was intruded into from its top to its base by an ice-wedge cast (near sample point S12.CH).

The clast analyses from this horizontally bedded gravel are similar throughout the unit and samples, C1-4 of Table 8.03.1, may be discussed as one. Limestone, present in the lower gravels, was absent from the upper part of the unit. This reflects the general trend of an increase in erratic against local rocks as the deposit thickened upwards. Apart from the addition of silts and clays in the lower gravels, the particle size also tended towards uniformity, but they had a larger percentage of pebble to small cobble size clasts than those of Unit B (Table 8.02.2).

Site C	Clifford Hill West Field									C.Col:1 upper colluvium, C.Col:2 lower colluvium (see lo						
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone
UNIT E	Too fine for stone count.															
Sub-unit D1	clast size															
590	8.0-16.0mm	0.8	1.5	0.8	3.1	0	0	0.3	0	0	0	0	3.4	29.5	0	66.6
623	8.0-16.0mm	2.1	2.9	1.9	6.9	0	0	0	0	0	0	0	6.9	36.1	0.2	56.8
UNIT D fine	Too fine for stone count.															
UNIT C	C.Col.2:clast size															
350	8.0-16.0mm	2.3	2.3	0.9	5.5	0	0.3	0.6	0	0	0	0	6.4	26.5	1.3	65.5
587(25%)	4.0 - 8.0mm	1.3	2.1	0.3	3.7	0	0.2	0	0	0.3	0	0.9	5.1	36.3	0	58.6
	C.Col.1: Clast size															
96	8.0- 16.0mm	2.1	1.1	2.1	5.3	0	2.1	0	0	0	0	0	7.4	26.1	0	57.6
474	4.0 - 8.0mm	3.2	5.1	3.2	11.5	0	0	0.2	0	0	0	0	11.7	48.9	0	38.7
UNIT B	Too fine for stone count.															
UNIT A	C3+C4	(16-32 mm sieved on site).														
196	16-32.0mm	27.4	5.6	11.2	44.3	0	20.4	5.6	0	1.1	0	0	71.4	20.4	8.2	0
	C4: Clast size															
223	8.0-16.0mm	21.5	12.1	7.6	41.2	0	4.9	1.8	0.4	1.8	0	0	50.1	44.4	5.5	0
1108	4.0 - 8.0mm	9.8	6.9	2.2	18.9	0	2.5	1.8	0	0	0	0	23.2	73.6	3.2	0
	C3: Clast size															
120	8.0- 16.0mm	25	5.7	5.1	35.8	0	4.2	4.2	0.8	1.6	0	0	46.6	50.3	2.4	0
523	4.0 - 8.0mm	12.8	6.6	1.9	21.3	0	1.1	1.1	0	1.1	0	0	24.6	73.6	1.8	0
	C1+C2	(16-32 mm sieved on site).														
268	16-32.0mm	21.6	10.4	11.6	43.6	0	17.9	11.2	0.4	0.4	0	0	73.5	14.2	8.9	3.4
	C2: Clast size															
183	8.0-16.0mm	25.1	8.2	4.4	37.7	0	5.5	3.3	0	0.5	0	0	47	50.3	2.7	0
811	4.0 - 8.0mm	12.6	5.8	2.7	21.1	0	0.9	2.5	0	0.1	0	0.1	24.7	73.4	1.6	0.2
	C1: Clast size															
138	8.0- 16.0mm	21.7	4.3	2.9	28.9	0	0.7	10.9	0	0	0	2.2	42.7	54.4	2.2	0.7
361	4.0 - 8.0mm	10.8	6.1	1.4	18.3	0	0.8	2.8	1.3	0	0	1.3	24.5	74.1	0.6	0.8

Table 8.03.1. Site C: Clifford Hill West Field stone count.

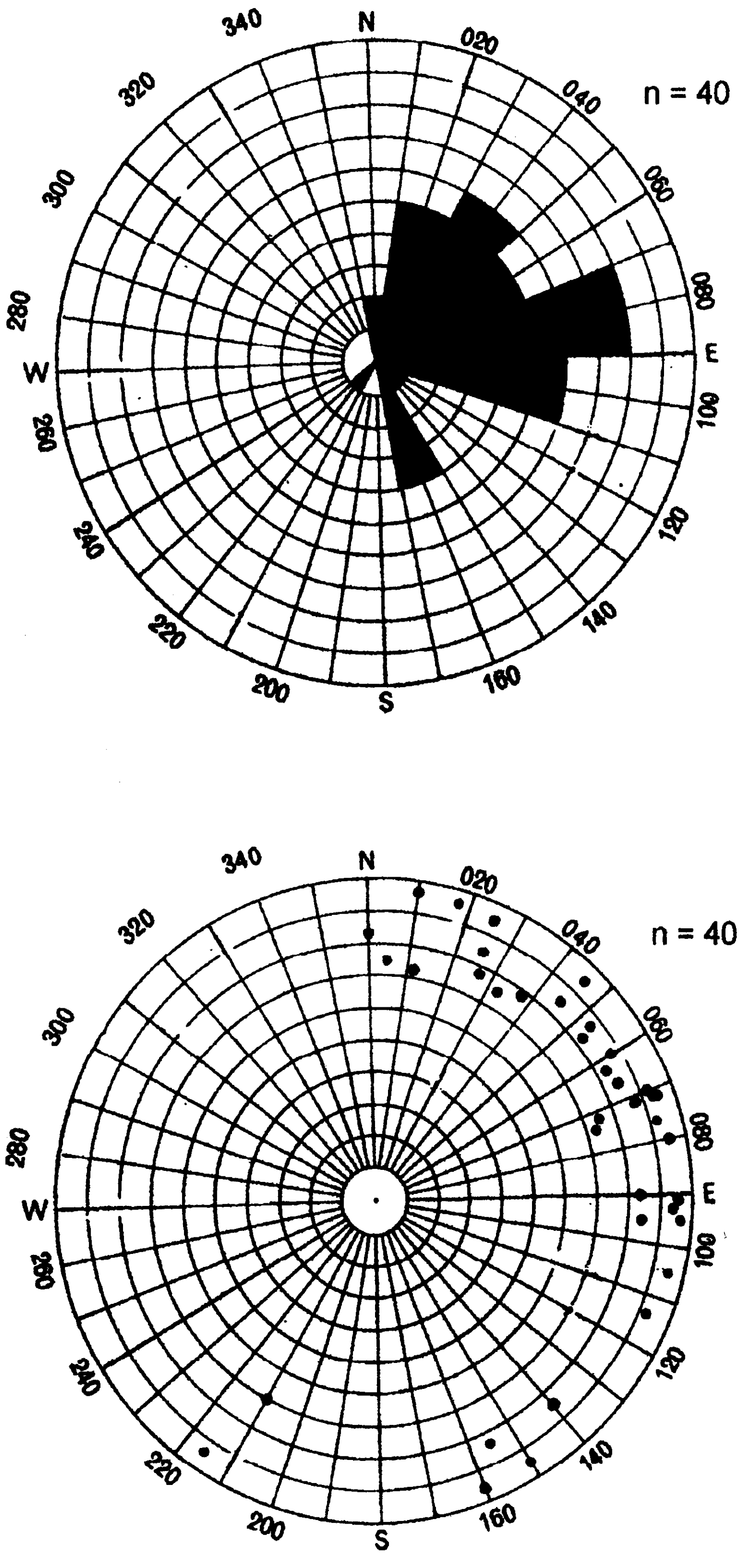


Figure 8.03.2.

Macrofabric diagrams from Clifford Hill, Site C, Unit A gravels. They show a preferred orientation of east, north-east, while the mean dip of clasts is relatively low at 9º.

Unit A: Sediments comprising ostracods (Figure 8.03.1).

S11.CH and S12.CH These sediments were fine sands and silt washed up against small sand bars on the surface of the 'Blue' Lias bedrock. There was little plant material, the fossils being mainly shells of molluscs and ostracods. They were part of, but overlain by, the gravel unit.

Unit A: Sediments comprising ostracods (Figure 8.03.1).

S9.CH, S10.CH, S13.CH, S14.CH, S15.CH, and S16.CH These sediments were within the gravel unit. They consisted of fine sands, silts and clays, dark grey to black in colour and encompassed a high percentage of disseminated plant remains which gave them a peaty consistancy. The fossil content included molluscs, ostracods, small mammal and fish remains and beetle wings.

Unit B

The gravel unit, Unit A, was overlain by involuted sandy clays (Unit B of Figure 8.0?????3b.1). They appeared to be continuous with the infill of the ice-wedge cast that penetrated the gravels. The sediments included fine sands, silts and clays with a scattering of small clasts. The general colour was dark yellowish brown 10YR 4/4 and 4/6 with dark grey to light grey mottling (5Y 4/1 to 6/1) where the clays were gleyed.

Unit C

The gleyed sediments were overlain by a highly involuted unit of fine gravels or, possibly, colluvium (samples C.Col.1 and 2 Table 8.03.1). There were also ice-wedge casts, up to 1.0 m in depth, penetrating this unit. Much of the fine gravel was bound together with calcareous cement of a light grey colour (10YR 6/1 and 6/2). The loose material sampled for clast analyses shows that there was an increase, of up to 65%, of limestones when compared with the lower gravels. The limestones and Ironstone clasts were small, usually 4-8 mm and rounded.

Unit D

The overlying yellowish brown (10YR 5/6), loamy sands, silts and clays of Unit D showed evidence of what might be stone-sorting along its surface. The analyses of the stony elements show they contained a high proportion of local rock, particularly limestone.

In contrast to the limestones of Unit C, these were tabulate and oblate or bladed in shape (after Zingg, 1935).

Unit E

Bisecting Unit D, down to its base, there was a fossiliferous silty channel-fill (Unit E) 2.20 m wide. The basal sediment of the channel was of a whitish colour (2.5YR 8/2) and contained numerous semi-dissolved and broken mollusc shells. The remainder of the deposit was brown 10YR 5/3. The upper 0.7 m of sediment appeared cryoturbated. The channel trended west to east across the Nene Valley. Samples S15.CH - S18.CH were extracted from this channel-fill.

Unit E: Sediments comprising ostracods (Figure 8.03.1).

S15.CH-S18.CH These samples were sedimentologically similar, consisting of fine sands, silts and clays. Their colour changed from whitish grey at the base to brown at the surface. The fossil elements were chiefly molluscs and a few ostracods. There were no plant remains.

Unit F (Youngest material)

The whole section was covered by alluvial soils (Unit F), coloured dark brown 10YR 3/3.

8.03.2 Discussion: Site C sediments.

The lowest 1.0 m of a section of horizontally bedded gravel (Unit A), resting on Blue Lias bedrock, contained lenses of finer sands, silts and clays. From these ostracods were recovered. The stratigraphy suggests that the basal lenses of organic material (Figure 8.03.1) may have been remains of a single channel-fill 18.0 m wide or a series of smaller abandoned channel-fills. Either way, the fine sediments are intimately associated with the gravels above and so are recorded as part of the same unit. This is much the same for the fossiliferous lenses found slightly higher in the gravels. The gravel unit is remarkably uniform in both bedding and lithology but has a larger clast size, generally, than those seen at Site B.

The gravels were intruded into from surface to base by an ice-wedge cast filled with material similar to that of the unit of sands, silts and clays above, Unit B of Figure 8.03.1. Unit B was gleyed and involuted. Gleying is a soil-forming process in water-logged soils (Trudgill, 1989), which implies that these sediments may have been overbank sediments deposited when the current channel was abandoned as the river migrated to a different part of the valley (Reinfelds and Nanson, 1993).

This period of deposition was followed by a further migration of the river and the return of a channel to this area. The channel was infilled with a fine, highly calcareous gravel (Unit C). This deposition was associated with, or followed immediately by, a period of permafrost. The channel infill and much of the clays of Unit B below were cryoturbated and penetrated by ice wedges. The ice wedge infill is similar to that of the ice-wedge casts penetrating the units seen at Site B. Much of the fine involuted gravel was bonded together with calcareous cement but it was not clear when this process may have occurred.

After the period of seasonal freezing or permafrost the river again migrated to a different part of the valley and the exposed valley surface received a second covering of overbank alluvial sediments, this time 1.5 m in thickness (Unit D). This unit, however, also exhibits the effects of seasonal freezing or permafrost. There is evidence of stone-sorting at its surface and this is associated with large ice-wedge casts that penetrate the sediments from the surface of Unit D to the Blue Lias bedrock. These ice-wedge casts could be followed across the whole of Clifford Hill West Field and formed polygonal patterns in the landscape. The presence of these polygons may be indicative of former mean ground temperatures of -2 to -10 degrees C (Washburn,1975).

Unit D was incised by a fossiliferous silty channel-fill (Unit E) 1.2 m thick by 2.2 m wide. The channel, which trended west to east across the Nene Valley, must have incised Unit D at a much later date as its fill does not conform in colour or sediment size to that of Unit D. The basal sediment of the channel was of a whitish colour and this was due to numerous semi-dissolved and broken mollusc shells. The sediments decreased in fossiliferous content upwards through the deposit.

The whole section was covered by 0.3-0.5 m of alluvial soils (Unit F).

The stratigraphy of Site C was complex and gave evidence for at least three cold stages. The uppermost channel, was, apparently, of a warm stage.

8.03.3. Site C:- Environmental interpretation of ostracod data: Samples S11.CH and S12.CH (Table 8.02.3).

Samples S11.CH and S12.CH were collected from the lowest sediments of this site Figure 8.03.1) and will, therefore, be considered before S9 & S10.CH.

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.
For ostracod species and numbers recovered, see Appendix D and Table 8.02.3.

S11.CH contained a large assemblage of ostracods (total 114 valves, 6 carapaces) of average species diversity (8) with a low number of juvenile moult valves present (29.3%).

The assemblage contains 2 temperate species, *Ilyocypris schwarzbachi* (extinct, but most probably temperate) and *P. serrata,* a species of temporary pools and intermittent streams. It also has 3 commonly found species, *C. neglecta*, *C. laevis* and *I. bradyi.* As *C. neglecta* is relatively abundant there would have been a muddy benthos within the habitat. The presence of *C. rawsoni* (Maddy *et al.,* 1991) or */ lactea* (Boreham and Gibbard, 1995) is worthy of note, but, as it is extinct in Britain, it does not tell much about the environment. *Ilyocypris* sp. A, first found at Stoke Goldington, Bedfordshire, (Green *et al.,* 1996) is an extinct species.

Although the ostracods were well established in the environment, the low number of juvenile moult valves infers their numbers were growing, but slowly.
S12.CH contained an average assemblage of ostracods (total 106 valves, 3 carapaces) of high species diversity (9) with an average number of juvenile moult valves present (50.8%).

The assemblage contains 3 temperate species: *I. gibba, P. serrata* and *P. arcuata.* It also has 3 commonly found species, *C. neglecta*, *I. bradyi,* and *I. gibba*. *P. arcuata* is rare in Britain (Griffiths, 1995). *B. fuscatus* (a winter/spring species) and *C. vidua* (permanent pond or lake species) are present in low in numbers.

The three species, *I. gibba, P. serrata* and *P. arcuata,* indicate the sediments were of temperate vegetated channels (abandoned). The channels were possibly cut off from their water supply at the onset of warmer and drier conditions.

Later, the climate probably cooled considerably and the rate of gravel deposition increased, eroding much of the muddy sediment, and burying the remainder.

8.03.4. SITE C:- Environmental interpretation of Unit A from ostracod data: S9.CH, S10.CH, S13.CH and S14.CH (Table 8.02.3).

Samples S9.CH, S10.CH, S13.CH and S14.CH were situated in the gravels directly above, but to the left and right of the two channel-fills (Figure 8.03.1).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.
For ostracod species and numbers recovered, see Appendix D and Table 8.02.3.

S9.CH contained a small assemblage of ostracods (total 58 valves, 1 carapace) of average species diversity (5) with a low number of juvenile moult valves present (23.4%).

The assemblage contains 1 temperate species: *P. serrata,* a species of temporary pools and intermittent streams. It has 2 commonly found species, *C. neglecta* and *C. laevis.* The presence of *C. rawsoni / lactea* does not tell much about the environment (see S.11 and S12 CH for further discussion).

The habitat was likely to have been a vegetated, permanent or temporary pool with a muddy benthos. There was probably a cool temperate climate.

S10.CH contained a small assemblage of ostracods (total 27 valves) of low species diversity (3) with a low number of juvenile moult valves present (22.2%).

The assemblage contains *I. biplicata*, a species that inhabits permanent, cool and, possibly, flowing water. It also has commonly found 3 species, *C. neglecta*, *C. laevis*, and *I. bradyi*.

From the presence of the *Ilyocypris* species this habitat may have been one of slow flowing, vegetated water. The rarity of *Candona* species suggests a sandy benthos and, as this was an organic lens within gravel, this may reflect the supporting gravel environment. A low number of juvenile moult valves probably means that a) there was inwashing, or b) dissolution of the valves, or c) there was not a biocoenosis.

S13.CH contained a small assemblage of ostracods (total 40 valves) of average species diversity (6) with an average number of juvenile moult valves present (50.0%).

The assemblage has 4 commonly found species, *C. neglecta*, *P. marchica*, *I. bradyi*, and *I. gibba*. There are two temperate species, *P. marchica and I. gibba*. *C. rawsoni / lactea* is present (see S11 and S12.CH for further discussion).

The climate was either temperate or cool temperate. The habitat was possibly diverse, vegetated with a muddy benthos. It is likely that the small, but growing, population was establishing itself.

This assemblage, like that of S9.CH, was more in keeping with the sediment it was extracted from than that of S10.CH or S14.CH below. It is possible that these sediments represent a series of small channels at different stages of development within the wider braided river environment.

S14.CH contained a small assemblage of ostracods (total 4 valves) of low species diversity (2) with no juvenile moult valves present.

The 1 species, *I. bradyi*, is found in many different habitats.

From the absence of other ostracod species it can be assumed that ostracods had a poor chance of survival in this habitat. It was probably a channel with a sandy benthos and very little vegetation.

8.03.5. SITE C:- Age and environmental factors of the sediments (Unit A) from Clifford Hill, Site C.

I. schwarzbachi has been recovered from Cromerian temperate and cold stage deposits (Robinson, 1990). This is confirmed by Griffiths (1995) who states that it is known only from Middle Pleistocene deposits.

As *I. schwarzbachi* has been found in the post-Anglian sediments of the Nene Valley this raises a question about the time of extinction for this species. It can be argued that, as *I. schwarzbachi* was not found in the Milton Formation, these specimens have not been reworked from Cromerian, or, indeed, any earlier sediments from the older parts of the Nene Valley. These are decalcified (Chapter 4) and would not be fossiliferous anyway. This points to the ostracods having been alive at the time the sediment was laid down at Clifford Hill. As the Clifford Hill sediments are known to be post-Anglian in age this puts the ostracod valves of *I. schwarzbachi* in the same age range.

Ilyocypris sp. A has been estimated to have become extinct at the end of the Oxygen Isotope Stage 7 (part of the Hoxnian debate of 3 stages 7, 9, & 11 (Robinson, pers. comm.; Green *et al.*, 1996).

The presence of *C. rawsoni/lactea* suggests a possible Ipswichian (Oxygen Isotope Stage 5e) or Stage 7, 9 or 11 deposit. *I. biplicata* is recorded once in Hoxnian (Oxygen Isotope Stage 11) deposits (Morgan, 1973), once in Ipswichian (Oxygen Isotope Stage 5e) deposits (Green *et al.*, 1996) and in Holocene sediments (Griffiths, 1995).

P. arcuata is recorded as found only in Devensian or younger sediments, but in this study it has been found in both the pre-glacial Milton Formation and the Nene Valley Gravels. This places the species in a new position in the Pleistocene record. As it is extremely rare in Britain today this makes it an important new addition to the record.

B. fuscatus has been found in these sediments and those of the Milton Formation, but has not been recorded in the British Pleistocene before now (Griffiths, 1995).

Because of the small numbers of each ostracod species present, it could be argued that the sediments of the two channel-fills contain reworked fossils. However, this is highly unlikely, because ostracod valves are so fragile (Horne, pers. comm.), so this must be an indigenous assemblage.

The low numbers of ostracods are probably an indication of a cooling climate at the end of an interstadial or interglacial period. That this could be so is indicated also by the stratigraphic position of the channel-fills, which are in the lowest 0.3 m of gravel.

8.03.6. SITE C:- Age and environmental factors of the sediments (Unit A) from Clifford Hill., Site C.

The presence of *C. rawsoni/lactea* suggests a possible Ipswichian (Oxygen Isotope Stage 5e) or stage 7, 9 or 11 deposit.

I. biplicata is recorded once in Hoxnian (Oxygen Isotope Stage 11) deposits (Morgan, 1973) and in the Oxygen Isotope Stage 7 or, possibly Ipswichian sediments of the River Ouse, Stoke Goldington (Green *et al.*,1996). None of the other species recovered were age specific indicators (Appendix E).

The ostracod species indicate reasons other than just a change in temperature for the difference in the assemblages found in Clifford Hill West Field gravels. The whole environment has altered from one of warm pond-like conditions of sediments S11.CH and S12.CH to a cool temperate one later in the deposition of the gravels. It is likely that a decrease in water depth and a change to slow-moving water accounts as well for the change in the ostracod species present.

See below S15 - S18.CH for detailed stratigraphic comments.

8.03.7. SITE C:- Environmental interpretation of Unit E from ostracod data: S15.CH, S16.CH, S17.CH and S18.CH (Table 8.02.3).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.
For ostracod species and numbers recovered, see Appendix D and Table 8.02.3.

S15.CH contained a small assemblage of ostracods (total 10 valves, 1 carapace) of low species diversity (2) of which all were juvenile valves.

The assemblage contains *I. biplicata*, a species found in cold, often running water, and 1 commonly found species, *E.pigra,* usually found in cool springs.

From the data and the absence of temperate climate indicators and burrowing species such as *Candona*, this channel may, in the beginning, have been similar to a small spring or stream.

S16.CH contained a small assemblage of ostracods (total 34 valves, 1 carapace) of average species diversity (5) with a high number of juvenile moult valves present (88.8%).

The assemblage contains *Cypridopsis vidua*, a species of permanent ponds and lakes, *C. rawsoni / lactea* and *I. biplicata* (both extinct in Britain). *C. rawsoni / lactea* is also present (see S11 and S12.CH for further discussion). It has only 1commonly found species, *C. neglecta.*

The presence of *C. vidua* suggests there was a pond-like habitat established. *I. biplicata* has reduced in number and it is not found in sediment sampled from the deposit higher up in the channel (S17. & S18.CH) (Figure 8.03.1). *Candona*, being few in number, suggests a sandy benthos. The high number of juvenile moult valves shows the population of ostracods was establishing itself well and that these were quiet waters.

S17.CH contained a small assemblage of ostracods (total 74 valves) of low species diversity (4) with an average number of juvenile moult valves present (52.7%).

The assemblage has increased numbers of *Candona* species, both *C. neglecta* and *C. rawsoni / lactea*, an indication of possible silting up of the water-body. It has 2 commonly species, *C. neglecta* and *I. bradyi.*

It is likely that a permanent, vegetated slow-moving to still water-body with a muddy benthos existed and it supported a small but growing population of ostracods.

S18.CH contained one species, *Candona*, (total 4 valves) of which all were juvenile valves.

As there are no fen or bog species of ostracods in these upper channel sediments, it seems the water-body silted up and dried out.

8.03.8. SITE C:- Age and environmental factors of the sediments (Unit E) from Clifford Hill, Site C.

C. rawsoni/lactea may indicate an Ipswichian (Oxygen Isotope Stage 5e) age or older (Appendix E). *I. biplicata* is recorded once in Hoxnian (Oxygen Isotope Stage 11) deposits (Morgan, 1973) and Ipswichian deposits (Green *et al.*, 1996). The remaining ostracods were not age specific indicators (Appendix E).

The ostracod data indicates that after the lower organic sediments (S11.& 12.CH) were deposited there was a change in the environment from temperate to cool conditions as successive gravels were laid down. The temperate and cool stenothermal species present in the ostracod assemblages recovered from these sediments represent a cool temperate phase during the deposition of the gravels. There appears to have then been a long interval of time before the incision and deposition of the upper channel sediments (Unit B of Figure 8.03.1) dated as no younger than 5e. The infilling of the channel was followed by periglaciation.

8.03.9. SITES B and C:- The sedimentological and stratigraphic record of Clifford Hill West Field (S9.-S18.CH).

The evidence for this section of the Nene Valley is that gravel deposition occurred in a typical braided river environment (Petts, 1983). The river was subject to lateral migration (Bristow, 1993). At such times it incised earlier gravels and deposited overbank sediments in the area of former position. This resulted in the following succession of events as illustrated at Sites B and C.

After the initial deposition of gravel, Unit A of Site C, and a possible permafrost event, as indicated by the lower ice-wedge cast, the gravels were incised by a channel which infilled during a changing environment (Units A, B, and C of Site B). Overbank sediments were deposited on the surface of the Unit A gravels. This was followed by a general widening of the braided river to include Site C and then deposition of a fine highly calcareous gravel. A cold period began and seasonal or permanent permafrost caused the development of ice wedges and cryoturbation of the landscape.

In Section B planing off of the fine gravels and the upper surface of the ice wedges indicates a period of erosion. This did not occur at Site C where, due to a thicker amount of sediment, Units A, B, and C formed a bank side to the braided channels.

At some stage later this was followed by migration of the river bed and the covering of these sediments with stony hillwash and/or alluvial sands, silts and clays. The stones were moved through the sediments to the surface during a further period of permafrost associated with large ice wedges and deformation by cryoturbation (see Figure 8.03.1, site C for appearance and spacing of sorted-stones).

The climate warmed and, possibly much later, during a warm period as seen at Site C, a small channel incised the valley sediments and infilled with fossiliferous sediments (Figure 8.03.1). The channel-fill was also cryoturbated in the upper region of the sediments. This cryoturbation would have occurred during the Devensian periglacial stage.

The whole section was later covered in modern alluvial deposits.

8.04. CLIFFORD HILL MIDDLE FIELD OSTRACOD SAMPLES S19.CH - S36.CH.

8.04. Introduction.

The following samples were collected from gravels approximately 350 m further downstream from Clifford Hill West Field. The lithology was similar to that of the West Field. Cryoturbation was also a strong feature of these gravels.

The ostracod valves were found in organic rich clay horizons beneath and within the sand and gravels. Most of the valves were well preserved. Most ostracod assemblages contained a mixture of adult and juvenile instars (moult stage valves).

Plate 5. These sediments were decalcified from surface to base and are considered to be of early Anglian age (Section 8.05.1, Site E, Middle Field, Clifford Hill).

Plate 6. First terrace gravels at Clifford Hill in Middle Field (Section 8.04.1, Site D).

8.04. SITE D

Site description and analyses: Clifford Hill Middle Field (SP793596), Map: Figure 8.01.1: Section: Figure: 8.04.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES S19.CH - S22.CH.

The gravels and other sediments are marked as floodplain deposits on the geological map (Sheet 185: Northampton, Geological Survey, 1960).

8.04.1. Sediments of Site D. (Tables 8.02.2 & 8.04.1)

Unit	Description	Maximum observed thickness.
(Youngest material at surface: 57 m O.D.)		
E	Decalcified top soils	0.5 m
D	Cryoturbated colluvium	0.5 m
C	Sandy channel infill	1.0 m
B	Horizontally bedded gravels	2.0 m
A	Fine silts and clays	0.3-0.8 m
(Unit A was oldest and lowest material)		

Unit A (Unit A was oldest and lowest material)

Sample S19.CH was from fine organic sediments (Unit A) filling a depression in the 'Blue' Lias bedrock (Smith, 1995). The sediments consisted of weathered, micaceous, dark grey, 5YR 4/1, 'Blue' Lias Clay mudrock with a few scattered clasts of local ironstone, sandstone, local Blisworth Limestone, limestone and fossils derived from the 'Blue' Lias.

Unit A: Sediments comprising ostracods (Figure 8.04.1):

S19.CH These sediments yielded ostracods and also contained small Jurassic fossils, molluscs, beetle wings, ostracods, seeds, fragments of wood and disseminated plant remains.

Unit B

Unit A was overlain by a unit of clast-supported, horizontally bedded, sandy, pebbly gravel (Unit B of Figure 8.04.1 and Table 8.04.1). The colour of the gravel, yellowish brown,

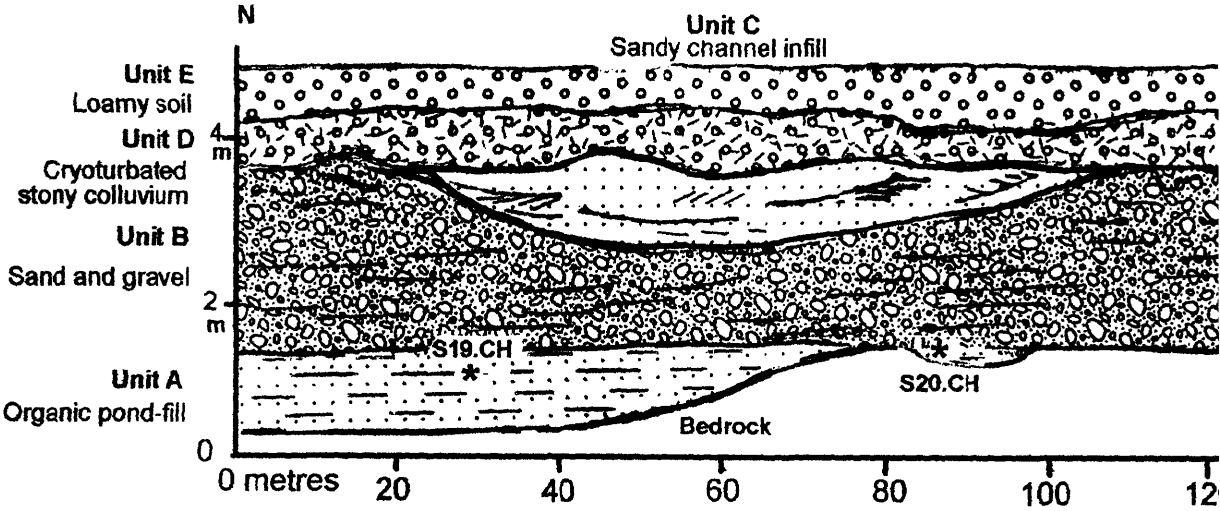


Figure 8.04.1. Site D: Section recorded at Middle Field, Clifford Hill qua

* Ostracod samples S19.CH - S22.CH. Key: Figure 7.02.1

Site D	Clifford Hill Middle Field																		
	D.Col:1 colluvium above gravels																		
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone	J. Fossils	Others.	Total local %
UNIT D	D.Col:1:clast size																		
251	8.0-16.0mm	5.6	7.2	0	12.8	0	4.4	2.1	0	0	0	7.1	26.4	66.9	1.1	5.4	0	0.2	73.6
836	4.0 - 8.0mm	0.7	5.1	0.1	5.9	0	0.7	0.6	0.1	0	0	4.7	12	73.1	0	14.7	0.2	0	88
UNIT C	Too fine for stone count.																		
	Site D: Clifford Hill Middle Field gravel sample.																		
UNIT B	D1: Clast size	(16-32 mm sieved on site).																	
159	16-32.0mm	26.4	15.1	1.3	42.8	24.5	6.3	0.6	0	0	0	0	74.2	12.6	12.6	0	0	0.6	25.8
561	8.0-16.0mm	29.6	11.9	1.6	43.1	0	6.8	4.5	0.5	0.9	0	0.5	56.3	38.9	2.3	2.1	0.4	0	43.7
1735	4.0 - 8.0mm	12.5	8.2	1.2	21.9	0	1.7	1.6	0.2	0.2	0	1.2	26.8	69.8	2.1	1.2	0.1	0	73.2
UNIT A	Too fine for stone count.																		
Table 8.04.1.		Site D: Clifford Hill Middle Field stone count.																	

was derived from the clast content except where ironstained to a dark yellowish brown 10YR 4/6. The lithological analyses shows the gravel was similar to that of site B and C and had similar proportions of local and erratic clasts (Table 8.02.2). Sedimentary samples S20.CH, S21.CH and S22.CH were collected from small depressions in the 'Blue' Lias bedrock which lay beneath the gravels (Unit B). These sediments appeared to be associated with, and thus, part of, the gravel unit above them.

Between bedrock and Unit B: Sediments comprising ostracods (Figure 8.04.1):

S20.CH, S21.CH and S22.CH These sediments consist of fine sands, silts and clays, dark grey to black in colour (grey/black, 5YR 3/1 -2.5/1) and encompass a high percentage of disseminated plant remains giving them a peaty consistency. The fossil content includes molluscs, ostracods, small mammal remains and beetle wings.

Unit C

Unit C was a brownish yellow, 10YR 6/6, coloured, silty, sand-filled channel. Approximately 80.0 m wide, it rested in the upper part of gravel Unit B.

Unit D

A cryoturbated unit of yellowish brown, 10 YR 5/6, stony colluvium (Unit D) covered the gravels. The analyses shows that almost 75% of the 8-16 mm sized clasts was of local origin (sample D.Col.1 of Table 8.04.1).

Unit E (Youngest material)

Unit D was overlain by alluvial soils (Unit E), colour dark brown 10YR 3/3.

8.04.2. Discussion: Site D sediments.

Ostracod valves were recovered from fossiliferous pond sediments (Unit A) filling a depression in the Blue Lias bedrock. These sediments were surrounded by disturbed ground containing many fragmented mammal remains identified as those from an Oxygen Isotope Stage 5e or earlier fauna (Smith, 1995).

These sediments were overlain by 2.0 m of horizontally bedded gravels (Unit B of Figure 8.04.1). Ostracods were recovered from dips in the Blue Lias bedrock beneath the gravels (Unit B). The gravels are of similar lithology, but of a larger particle size than those of Unit C of Section B Clifford Hill, West Field, upstream of this site. However, no ice wedges were seen anywhere in the gravels of Clifford Hill Middle Field.

A silty sand-filled channel (Unit C) incised the upper 1.0 m of the gravels (Unit B). Both the channel-fill and upper 0.5 m of gravel showed evidence of deformation by cryoturbation.

A cryoturbated unit of stony colluvium (Unit D), 0.5 m thick, covered the gravels.

This was overlain by 0.5 m of alluvial soils (Unit E).

For further discussion see Site E.

8.04.3: SITE D:- Environmental interpretation from ostracod data (Table 8.04.2).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.

For ostracod species and numbers recovered, see Appendix D and Table 8.02.3.

S19.CH contained one species of ostracod (total 2 valves) with no juvenile moult valves present.

The pond sediments (Figure 8.04.1) yielded one ostracod species, *Amplocypris tonnensis*. This species is extinct. It was recovered from the surface of pond sediments which were overlain by sands and gravel. This implies that *A. tonnensis* was present just before a time of cooling climatic conditions. According to other fossil evidence, the pond sediments are interglacial (Smith, 1995).

Samples S20.CH, S21.CH and S22.CH, collected from below the base of the gravels but to the south of the pond sediments (Figure 8.04.1), yielded a low number of ostracod valves and there were no juvenile moult stages present.

S20.CH contained a small assemblage of ostracods (total 7 valves) of low species diversity (2) with no juvenile moult valves present.

MIDDLE FIELD, CLIFFORD HILL.																
Sample number	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
OSTRACOD SPECIES																
Limnocythere sanctipatricii						13										
Candona candida				8		17		20	4	8	33	22	23	7	2	3
Candona neglecta		1	1	1		22		5		1	18	12	35	22	5	4
Candona rawsoni/lactea								4								
Candona spp.						6	9			8	5		18			
Pseudocandona marchica						3										
Cyclocypris globosa													14			
Cyclocypris laevis						16		1			28	8	24			
Ilyocypris bradyi			3	9				94		9	27	13	45			
Ilyocypris gibba						1										
Ilyocypris sp. A											9	7	12			4
Eucypris pigra		6	2			8		2			1	1	10			
Eucypris sp.									1			1		1	8	
Prionocypris serrata										54	1	1				
Prionocypris sp.												5				
Trajancypris clavata												2				
Bradlystrandesia fuscatus											2					
Herpetocypris reptans												2		10	22	
Psychrodromus olivaceus													1			
Heterocypris incongruens													8			
Potamocypris arcuata						18		1					4			
Potamocypris similis				9												
Amplocypris tonnensis	2															
Total	2	7	6	27	17	104	9	127	5	80	124	74	82	40	37	11

Table 8.04.2. The number of valves recovered of each ostracod species extracted from the sediments of Middle Field, Clifford Hill, Little Houghton.

Both species, *C. neglecta*, and *E. pigra,* are commonly found in many different environments, but from the absence of other ostracod species it can be assumed that the habitat was poor, or, indeed, these valves may have been washed in.

S21.CH contained a small assemblage of ostracods (total 6 valves) of low species diversity (3) with no juvenile moult valves present.

The 3 species, *C. neglecta*, *I. bradyi,* and *E. pigra* are commonly found. *E. pigra* is a temperate species.

The environment was possibly cool, lightly vegetated and had a sandy benthos, if, again, the valves had not been just washed into the area.

S22.CH contained a small assemblage of ostracods (total 27 valves) of low species diversity (4) with no juvenile moult valves present.

The assemblage contains 1 temperate species, *Potamocypris similis*, and 3 commonly found species, *C. candida*, *C. neglecta*, and *I. bradyi.*

It seems there was a poor chance of survival for the ostracods, although there are more valves found in this sediment including the rare *P. similis*. The environment was possibly cool, lightly vegetated and had a sandy benthos.

Like *E. pigra, P. similis*, a species of lakes and large ponds, may have entered the river system as part of hill wash material from the valley sides or from the floodplain.

8.04.4: SITE D:- Age and environmental factors of the sediments from Clifford Hill.

A. tonnensis has been recorded from one other site, that is, in the Early Devensian sediments of Fisherton, near Salisbury, Wiltshire (Green *et al.*, 1983). In the current research the species was recovered from material of an Ipswichian (Oxygen Isotope Stage 5e), or earlier, age. None of the other species are age significant (Appendix E).

P. similis is found at one site in Britain (Griffiths, 1995). It has not been recorded in the British Pleistocene and so this may be the first record of *P. similis* to enter the record.

8.05 SITE E

Site description and analyses: Clifford Hill Middle Field (SP795594), Map: Figure 8.01.1: Section: Figure: 8.05.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES S23.CH - S28.CH.

These sediments are marked as First Terrace and floodplain deposits on the geological map (Sheet 185: Northampton, Geological Survey, 1960).

8.05.1. Sediments from Site E. (Tables 8.02.2, 8.05.1, 8.05.2 & 8.05.3).

Unit	**Description**	**Maximum observed thickness.**
(Youngest material)		
F	Decalcified top soils	0.6 m
E	Colluvium	1.2 m
D	Horizontally bedded gravels with fine cryoturbated colluvium at surface (subdivided into Units D1 & 2)	1.8 m

(Unit D was the lowest and oldest of a suite younger than those listed below but older than Units E & F listed above, see Figure 8.05.1).

C	Horizontally bedded gravels	2.0 m

(Unit C was the lowest and oldest of a suite younger than that below but older than that listed above, see Figure 8.05.1).

Sediments listed above were adjacent to, and not above A and B below.

B	Cryoturbated fine sediments with ice-wedge casts at surface (subdivided into Units B1-3)	1.5.m
A	Horizontally bedded gravels	1.8m

(Unit A was the oldest and lowest material, see Figure 8.05.1).

As shown in the section drawing (Figure 8.05.1), Units A, C and D, although of different ages, were the lowest of their suite and alongside each other.

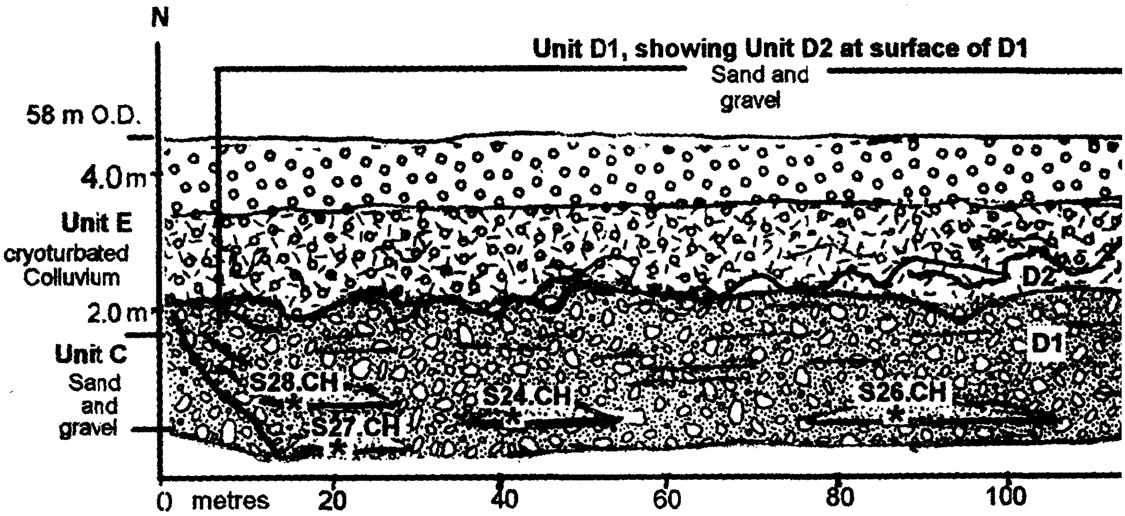


Figure 8.05.1. Site E: Section recorded at Middle Field, Clifford Hill
* Samples S23.CH-S28.CH Key: Figure 7.02.1

Silts and clays.

Figure 8.05.1 shows a complex sequence of events and as a consequence it was decided to collect sediment samples and record six graphic logs at 25.0 m intervals across the section from base to surface (particle size distribution: sections A-E of Table 8.05.1).

The particle size analyses showed that, from the amount of silts and clays washed out, it was possible to differentiate between the two major masses of sedimentation. The gravel units at the southern edge of the valley were separated by a unit of finer sediment, unlike the younger units towards the middle and northern edge of the section examined (Figure 8.05.1).

Unit A (Unit A was oldest and lowest material)

Unit A was situated at the southern end of the section (Figure 8.05.1). The analyses show that Unit A consisted of horizontally bedded, decalcified, clast supported, sandy gravel (samples E1-E3 of Tables 8.02.2 & 8.04.2) with a similar proportion of erratic /local clasts to those seen in the previous samples. The gravels were a greyish brown (2.5Y 5/2) except where ironstained to dark yellowish brown (10YR 4/6).

Unit B1

Unit A appeared to have been overlain gradationally by decalcified river or lake clays and overbank sediments (Units B1 and 2). They were highly involuted in the upper part of the unit. They graded in colour from very dark greyish brown, 2.5Y 3/2, dark grey, 10YR 4/1, very dark grey, 7.5YR N3/, to dark grey 5Y 4/1. The analyses show that Unit B1 sediments were 79-88% silts and clays (Section F of Table 8.05.1).

Unit B2

Unit B2 was a dark brown, 7.5YR 3/2, decalcified colluvium (sample E.Col.1 of Table 8.05.2), the clasts of which were almost 100% Ironstone. The colluvium showed two sets of involutions which were intruded by a narrow ice-wedge cast (B3) infilled with stony sands.

Unit B3

The ice-wedge cast contained some limestones and calcareous sandstones and formed younger units within B2; however, they are not labelled separately here.

Particle size	<0.0625mm	(<+4 Phi)										
Sample no.	Section A	Morphology A	Section B	Morphology B	Section C	Morphology C	Section D	Morphology D	Section E	Morphology E	Section F	Morphology F
									Surface		Surface	
37									23.2	soils	42.9	soils
36					soils removed on sections C, and D.				15.3	"	**48.4**	"
35									11.4	"	40.8	stony soils
34	Surface		Surface						**54.3**	"	11.5	consolidated
33	Section A		Section B						16.9	"	10.3	colluvium
32	**56.7**		**74.8**	soils					19.1	"	12.3	"
31	**70.9**		**85.1**	"					1.8	unconsolidated	19.8	"
30	**60.6**	soils	**52.8**	"					3.3	colluvium	**53.2**	"
29	**67.4**	"	**69.1**	"					2.9	"	**48.9**	"
28	**67.7**	"	**75.6**	overbank seds.					2.2	"	**75.4**	silts and clays
27	**60.8**	"	**70.8**	"					2.9	"	**89.2**	(water laid)
26	**69.1**	overbank seds	**77.3**	"					3.8	"	**74.4**	"
25	**68.7**	"	**72.1**	"					1.3	"	**66.6**	"
24	**61.4**	"	**53.3**	colluvium	13.9	colluvium			0.9	"	**79.2**	"
23	**70.5**	"	48.5	"	13.2	"			2.1	"	**84.3**	"
22	30.2	"	**51.4**	"	9.1	"			1.7	"	**88.2**	"
21	23.2	"	48.9	"	7.9	"			1.1		**85.5**	"
20	7.9	colluvium	70.5	"	4.2	"			1.6	"	**86.6**	"
19	2.7	"	14.4	gravel	5.1	gravels	4.3	gravels	3.8	decalc.gravel	**85.5**	"
18	11.1	gravels	12.6	"	4.3	"	5.1	"	6.1	"	2.8	decalc.gravel
17	2.4	"	**62.4**	"	3.2	"	4.1	"	5.5	"	0.3	
16	15.9	"	26.7	muddy gravels	4.6	"	2.1	"	1.8	"	0.9	
15	2.2	"	12.4	"	2.3	"	2.3	"	8.8	"	0.9	
14	3.6	"	20.7	"	30.5	muddy gravels	2.2	"	2.5	"	0.8	
13	4.2	"	33.9	"	26.1	"	3.1	"	4.2	"	3.2	
12	2.2	"	23.4	"	1.5	gravels	4.2	"	4.5	"	8.3	
11	5.6	"	27.9	"	2.1	"	29.5	muddy gravels	3.7	"	3.1	
10	1.6	"	12.2	sandy gravels	1.4	"	3.6	gravels	1.4	"	1.1	
9	2.1	"	10.6	"	1.3	"	2.7	"	3.1	"	2.4	
8	1.3	"	9.5	"	2.3	"	3.1	"	2.2	"	2.8	
7	0.3	"	10.5	"	5.6	"	5.1	"	1.6	"	1.6	
6	0.2	"	17.1	"	1.6	"	7.4	"	1.3	"	1.3	
5	1.4	"	21.2	"	2.7	"	7.2	"	3.7	"	4.2	
4	41.3	muddy gravels	15.1	"	2.4	"	1.9	"	16.8	"	5.2	
3	10.1	"	24.9	"	2.2	"	1.1	"	3.6	"	17.1	
2	bedrock	Blue Lias	10.4	"	1.5	"	4.1	"	3.7	"	2.7	
1	"	"	**67.3**	muddy gravels	1.1	"	12.7	"	6.3	"	5.4	
									Bold figures > than 50%			

Table 8.05.1. **Percentage silt and clay particles in six closely sampled (every 0.10-0.15 m) logged sections across Clifford Hill Middle Field.**

Unit C

Unit C gravels appeared to be of the same suite as those above the bedrock and fine sediments of Site D. The gravels of Unit C extended northwards a further 200 m (at the edge of the quarry), but probably extended even further across the Nene Valley. Originally, before later erosion and reworking of the gravel to the south of the valley, they would also have abutted against the decalcified gravel in the south of the section. The colour of the gravel, yellowish brown, was derived from the clast content except where ironstained to a dark yellowish brown 10YR 4/6.

Unit D

For descriptive purposes Unit D has two sub-units, Unit D1 and D2.

Unit D1

The sandy, large pebbly gravels of Unit D1 (samples E4-E6 of Tables 8.02.2 & 8.05.3) rested in a palaeochannel, 127 m wide, which downcut through Unit C and abutted Unit A to the south of the section. The analyses show that these gravels, clast supported, contained both a higher proportion of calcareous material and local material and a larger proportion of pebble/cobble sized gravel than any of the previous gravels examined. The colour of the gravel, light yellowish brown,10YR 6/4, was derived from its clast content except where ironstained to a dark yellowish brown 10YR 4/6.

Unit D1: Sediments comprising ostracods (Figure 8.05.1):

The samples of organic material came from Unit D1 (Figure 8.05.1). Sample S23.CH was from the channel-fill (Unit D1) 1.50m above the channel base. S24-S27.CH were from remains of organic lenses and sand bars found within the lowest 1.00 m of the gravels (Unit D1).

<u>S24.CH-S27.CH</u> The sediments consisted of yellowish brown, 10YR 5/4, fine sands silts and clays. The fossil content included molluscs, ostracods, small mammal remains and beetle wings.

<u>S23.CH</u> The sediment was a dark grey/black (5YR 3/1 -2.5/1), highly fossiliferous organic silt within which was a skull of the Norway lemming *Lemmus lemmus* (identified by A.

SITE E	UNIT B:	Clifford Hill Middle Field samples collected from above decalcified gravels														
UNIT B2	E.Col:1: Clast size			Too fine for stone count.												
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron- stone	J. Sand- stone	J. Lime- stone
UNIT B1																
122	8.0- 16.0mm	0.8	4.1	0	4.9	0	0	0	0	0	0	0	4.9	95.1	2.5	[illegible]
629	4.0 - 8.0mm	1.4	3.1	1.8	6.3	0	0.3	0.2	0	0.2	0	0	7	92.5	0.5	[illegible]
UNIT A	Site E: Clifford Hill Middle Field samples collected from decalcified gravels															
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron- stone	J. Sand- stone	J. Lime- stone
	E1+E2+E3	(16-32 mm sieved on site).														
270	16-32.0mm	32.9	12.6	2.6	48.1	0	17.5	4.4	0.8	0	0	0	70.8	20.3	8.5	[illegible]
	E3: Clast size															
572	8.0-16.0mm	25.8	14.5	3.8	44.1	0	7.1	5.5	0.3	0	0	0	57	39.5	3.5	[illegible]
379	4.0 - 8.0mm	16.1	8.2	0.5	24.8	0	4.2	2.4	0	0.8	0	0	32.2	66.5	1.3	[illegible]
	E2: Clast size															
593	8.0- 16.0mm	18.1	16.3	2.6	37	0	7.5	4.2	0.7	0.6	0	0	50	46.4	3.6	[illegible]
689	4.0 - 8.0mm	13.5	10.4	2.2	26.1	0	4.2	2.6	0	0.4	0	0	33.3	63.6	3.1	[illegible]
	E1 Clast size															
492	8.0-16.0mm	19.7	16.7	3.9	40.3	0.6	6.1	4.8	0.2	0.4	0	0	52.4	43.7	3.9	[illegible]
391	4.0 - 8.0mm	14.6	10.5	2.5	27.6	0.3	4.1	1.5	0	0.8	0	0	34.3	62.9	2.8	[illegible]
Table 8.05.2.		Site E: Clifford Hill Middle Field stone count.														

Site E	Clifford Hill Middle Field															
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone
UNIT E	**E.Col:3: Clast size**															
217	8.0-16.0mm	1.8	6.9	3.2	11.9	0.5	0.5	1.4	0	1.8	0	5.1	21.2	57.6	0	21.2
978	4.0 - 8.0mm	2.4	2.8	0.9	6.1	0	0	0.9	0.2	0	0	10.2	17.4	58.4	0.2	23.7
UNIT D2	**E.Col:2: Clast size**															
147	8.0- 16.0mm	4.8	7.5	4.1	16.4	0	2.7	1.4	0	0	0	10.8	31.3	32.7	8.2	23.7
646	4.0 - 8.0mm	1.3	3.7	2.2	7.2	0	0	1.6	0	0	0	12.1	20.9	41.8	0.9	36.4
UNIT D1	**E6: Clast size**		(16-32 mm sieved on site).													
220	16-32.0mm	21.6	3.1	4	28.7	0.4	18.9	2.2	6.2	0.9	0	0.9	58.2	27.3	5.2	6.2
976	8.0-16.0mm	10.9	6.1	1.3	18.3	0	4.3	3.1	0.2	0.5	0	2.9	29.3	64.1	2.2	3.6
543	4.0 - 8.0mm	7.9	2.1	0.8	10.8	0.2	2.2	2.6	0	0.4	0	2.2	18.4	78.5	1.1	1.8
	E5: Clast size		(16-32 mm sieved on site).													
664	16-32.0mm	26.1	12.1	1.6	39.8	0	13.7	11.1	1.2	0.9	0	1.5	68.2	24.2	2.9	3.3
1216	8.0- 16.0mm	15.4	7.7	1.1	24.2	0.2	4.9	2.6	0.6	0.3	0	3.5	36.3	57.3	2.4	3.9
916	4.0 - 8.0mm	8.5	5.5	1.6	15.6	0	1.5	1.1	0.1	0.2	0	3.2	21.7	72.6	0.7	4.7
	E4: Clast size		(16-32 mm sieved on site).													
374	16-32.0mm	23.5	0.3	4.3	28.1	0.3	18.1	7.8	1.9	1.1	0	5.6	62.9	22.7	2.9	7.8
413	8.0-16.0mm	16.2	6.3	1.1	23.6	0	0.7	5.7	1.1	0.2	0	8.8	40.1	47.9	2.2	8.8
705	4.0 - 8.0mm	8.5	2.7	0.6	11.8	0	1.1	1.6	0	1.7	0	2.4	18.6	75.7	0.3	5.1
UNIT C		Gravel as Unit B of Site D														
Table 8.05.3.		**Site E: Clifford Hill Middle Field stone count**														

Currant, 1991, pers. comm.). The fossil content also included seeds, molluscs, ostracods, small mammal remains and beetle wings.

Unit D2

Unit D1 was overlain by a yellowish brown, 10YR 4/4, unconsolidated calcareous colluvium, Unit D2 (sample E.Col. 2 of Table 8.05.3). It appeared to be cryoturbated.

Unit E

A further light yellowish brown, 10YR 5/6, stony, calcareous colluvium (Unit E, sample E.Col.3 of Table 8.05.2) covered the whole of the deposits of Units C, D1, and D2 and abutted Unit B above the decalcified Unit A. There appeared to be an unconformity between Unit D2 and Unit E. This was more obvious in the field than the clast analyses would indicate (although there was up to 10% more local rock in the upper colluvium, Unit E). Both Units D2 and E showed involution and/or cryoturbation in the field.

Unit F (Youngest material)

The whole section was covered in decalcified alluvial soils (Unit F), colour dark brown 10YR 3/3.

8.05.2. Discussion: Site E sediments.

The earliest gravels, Unit A are decalcified and are considered by the author, to have been deposited before the incision and formation of the tunnel valley (Chapter 4, sections 4.10 & 4.11.1). The tunnel valley formation is outside of the scope of this chapter but is discussed in Chapter 4, section 4.11.

At Clifford Hill gravel pit, Little Houghton, the sediments along the southern edge of the site, including the gravels, were completely decalcified from bedrock to surface (unit A, Figure 8.05.1). The decalcified sediments, as described below, were up to 5.50 m thick. These sediments were seen to have been cut through by a later erosive event thought to be associated with the tunnel valley. At Clifford Hill, the tunnel valley incised the northern edge of the valley, leaving the proglacial gravels to the south of the valley intact. During the infilling of the tunnel valley with glacial clays, a period of time of up to, or longer than, 1,000 years (Early, 1956) some erosion of the decalcified material (unit A of Figure 8.05.1), must have occurred because what appear to be calcareous lake clays (unit B of Figure 8.05.1) sediments were highly calcareous this is another indication that the earlier gravels were either already decalcified or did not contain calcareous material, it being unlikely that decalcification could occur under such material.

The earliest (lower till) quartz and quartzite-rich gravels from the 'Milton' Nene River sediment were then reworked with chalk and flint-rich gravels from what is now known to be the Anglian ice sheet (Perrin *et al.*, 1979). They are notably higher in quartz and quartzite clasts. The clasts, of size range 16-32 mm, collected from the Clifford Hill gravel pit, Little Houghton, have a higher ratio of quartz and quartzite to flint than the gravel samples analysed from sites further downstream (Table 8.05.4) The oldest gravels and other sediments at Clifford Hill are also devoid of calcareous clasts. Any decalcified sandstones crumble to sand when handled in the field. The absence of chalk (and any soft limestones) may be due to decalcification or, more likely, abrasion with distance of transport. It is believed, by the author, that these gravels were laid down as pro-glacial sediments before the over-riding of the ice sheet and the formation of the tunnel valley.

were resting on the lowered deposits of the decalcified gravels (unit A) where erosion had previously occurred. It seems that after the tunnel valley was filled with glacial lake deposits sedimentation may have continued and the valley filled to a higher level, over-riding the lowest gravels present to the south of the tunnel valley. The silt and clays above the decalcified gravel (see also the section on lithology) shown in Figure 8.05.1 were devoid of fossiliferous material other than highly disseminated plant remains.

The decalcified gravel was non-fossiliferous and showed a fining-up sequence of sediments from medium gravel to fine silts at 2.8 m above bedrock. This decalcified gravel did not show any evidence of cryoturbation. It was horizontally bedded and overlain by 1.5 m of silty clay, interpreted as lake sediments (Unit B1) of which 84 - 89% are of silt- or clay-sized grains (Table 8.05.1). The silty clay was involuted or deformed by load structures at its surface and overlain by further sediments (Unit B2).

It is likely, from the evidence at Clifford Hill, Site E, that, after the infilling of the majority of the tunnel valley, a lake formed in the glacial cold conditions.

Apart from the ice wedge infill (formed at a later date), the glacial lake sediments and the sediments (Unit B2) above the silts and clays were all decalcified, and Unit B2, a stony, sandy loam, also showed festooning. This points to the possibility of a considerable amount of time elapsing before the incision of the valley sediments. When it occurred, the channel cut down by 3 or 4 m into the lake clays and older gravels before it began to infill with post-Anglian gravels.

As has already been observed, it is impossible to estimate the age of deposition of one particular suite of gravel without referencing it to other suites within its proximity. This is so with the Unit C gravel. It is present at the previous site, D, the site under discussion (E) and at Site F, but, as considerable reworking may have occurred before its deposition (Bristow and Best, 1993), it is not necessarily the first gravel that was laid down.

Therefore, Units A and B were eventually incised and Unit C gravels, or an earlier gravel, was deposited. This gravel deposit and 0.3-0.5 m of Blue Lias bedrock was then incised and the resulting channel filled with the gravels of Unit D1 (from which the ostracods were recovered). These gravels, which were of a larger particle size and contained a fresh input of clasts, including chalk and limestone, from the valley interfluves, may reflect a new sediment pulse rather than reworking. The channel (Unit D of Figure 8.05.1) was up to 127.0 m wide. An organic lens in the channel-fill gravels (Unit D), 1.5 m above the channel base, yielded a skull of the Norway lemming *Lemmus lemmus* (identified by Currant, pers. comm.).

The channel-fill (Unit D1) was overlain by stony, calcareous colluvium (Unit D2) Some of the colluvium was eroded during a period of cryoturbation. Both the remainder of Unit D2 and the exposed gravels show cryoturbation for a depth of 0.5 m plus. After the cryoturbation a second unit of calcareous stony colluvium (Unit E), up to 1.2 m thick, was laid

Clast lithological ratios of local till and Nene Valley sediments, clasts size 16-32 mm.								
number	sample name	ironst.	sandst.	limest.	chalk	quartz.	flint	description
1	CH WEST 1	0.5	0.2	0	0	0.6	**1**	decalc.gravel
2	CH WEST 2	0.3	0.2	0.07	0	0.7	**1**	gravel
3	CH WEST 3	0.5	0.2	0	0	**0.8**	**1**	decalc.gravel
4	CH WEST A 1-5	0.5	0.2	0.06	0.01	**0.8**	**1**	gravel
5	CH WEST WR 6-8	0.3	0.2	0	0	0.6	**1**	decalc.gravel
6	CH WEST WR 1-3	0.4	0.2	0	0	**0.8**	**1**	decalc.gravel
7	CH MID 1	0.5	0.2	0.1	0.02	0.6	**1**	gravel
8	CH MID 2	0.3	0.3	0	0	0.7	**1**	decalc.gravel
9	CH MID E1	**1**	0.2	0.2	0.03	**1**	**1**	gravel
10	CH MID E2	0.6	0.7	0.08	0.03	0.7	**1**	gravel
11	CH MID E3	**0.8**	0.1	0.3	0.2	**1**	**1**	gravel
12	CH MID E4-6	0.4	0.2	0	0	0.5	**1**	decalc.gravel
13	CH MID E4&5	0.2	0.05	0	0	0.2	**1**	decalc.gravel
14	CH MID F	0.7	0.09	0	0	0.4	**1**	decalc.gravel
15	CH EAST OF MID	0.6	0.5	0	0	**1**	**1**	decalc.gravel
16	CH POND FIELD.	0.7	0.3	0	0	0.3	**1**	decalc.gravel
17	C FARM 2nd Terr.	0.2	0.1	0.7	0.03	0.4	**1**	gravel
18	C FARM 2nd Terr.	0.2	0.2	**0.9**	0.1	0.3	**1**	gravel
19	C FARM 1st Terr.	0.3	0.4	0.3	0.06	0.7	**1**	gravel
20	C FARM G4&5	0.1	0.1	0.1	0.06	0.3	**1**	gravel
21	C FARM G1	0.1	0.01	0.05	0.02	0.5	**1**	gravel
22	WELLINGBOROUGH.	0.3	0.3	0.7	0.08	0.6	**1**	gravel
23	C FARM TILL	0.2	0.1	1.1	**2.6**	0.2	1	chalky till
24	GT. HOUGHTON Till	0.3	0.06	0.04	0.2	0.2	**1**	chalky till
	bold numbers represent dominant rock type							

Table 8.05.4. Table showing a larger ratio of quartz and quartzite in the older gravels of the Nene Valley.

down. This sediment abutted Unit B (above the decalcified Unit A) and spread across both Unit D and Unit C gravels.

The whole section was covered in decalcified alluvial soils 0.6 m thick (Unit F).

8.05.3. SITE E:- Environmental interpretation from ostracod data (Table 8.04.2).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.
For ostracod species and numbers recovered, see Appendix D and Table 8.04.2.

As Sample S23.CH came from higher in the gravels than the following samples it will be considered last.

S24.CH contained a medium sized assemblage of ostracods (total 70 valves, 17 carapaces) of high species diversity (9) with a low number of juvenile moult valves present (16.4%).

The assemblage contains 3 temperate species, *P. marchica, I. gibba* and *P. arcuata*, and 1 cold stenothermal species, *L. sanctipatricii*. It has 6 commonly found species, *C. candida*, *C. neglecta*, *P. marchica*, *C. laevis*, *I. gibba*, and *E. pigra*. *P. arcuata* is rare in Britain today (Griffiths, 1995). The species represent an indigenous ostracod assemblage and is a fairly stagnant pool pond assemblage, as indicated by the presence of the genus *Limnocythere*, which is usually taken to indicate permanent still water (Robinson, pers. comm.). The presence of *C. laevis* and *C. marchica,* suggests that there was a high organic content.

The environment was probably temperate, there being three temperate to one cold species, but the species are not very conclusive of warmth. The river discharge may have diminished causing this channel to be cut off from running water (Figure 1.01.3), thus forming a pond-like habitat with aquatic vegetation. However, as the sediment contains only a few juvenile moult valves, and these are outnumbered by carapaces, it is likely that the habitat was a stressed environment with a high rate of silting up.

Later, the climate became cooler and the rate of gravel deposition increased eroding much of the muddy sediment, but burying the remainder.

S25.CH contained a small population of *Candona* (total 9 valves) of which all were juvenile valves.

Either the environment was unsuitable for ostracods, being only lightly vegetated, or these valves were washed into the area.

S26.CH contained a large assemblage of ostracods (total 93 valves, 17 carapaces) of average species diversity (7) with an average number of juvenile moult valves present (41.7%).

The assemblage was dominated by the ostracod *I. bradyi,* which, according to Henderson (1990), prefers cool moving water but is found occasionally in ponds and marshes. There is one temperate species, *P. arcuata* and 5 commonly found species, *C. candida*, *C. neglecta*, *C. laevis*, *I. bradyi,* and *E. pigra*. *P. arcuata* is rarely found in Britain today (Griffiths, 1995).

There was an indigenous assemblage living in permanent, either slow-flowing, or still water. The water would have been vegetated with a muddy base. *E. pigra* would have been in-washed from cool springs that fed the river environment.

The climate at that time may have been subject to short pulses of cool and temperate periods, as indicated by the presence of both the cold water stenothermal ostracod *L. sanctipatricii* and the temperate species *P. arcuata*.

S27.CH contained a small assemblage of ostracods (total 5 valves) of low species diversity (2) with a low number of juvenile moult valves present (20.0%).

The *Eucypris* valves were juvenile and difficult to identify to species level. *C. candida*, is commonly found, but in this case may have been washed in as the environment appears to have been unsuitable for ostracods.

S28.CH contained an medium sized assemblage of ostracods (total 54 valves) of average species diversity (5) with an average number of juvenile moult valves present (35.0%).

The assemblage was dominated by *Prionocypris serrata*, a temperate species of temporary pools and intermittent streams. It also contains 3 commonly found species *C. candida*, *C. neglecta*, and *I. bradyi*..

The presence of *P. serrata* suggests the habitat was of a temporary nature, a specialised or difficult habitat. If the habitat was in a cool environment then the temperate ostracod species, *P. serrata*, may have survived only because it lived at the northern edge of the channel-fill at this site, where the sampled sediment was collected (Map: Figure 8.01.1). Even at the present time, this part of the valley is notably warmer, as it receives solar radiation for longer periods of time, than that of the southern-most edge of the valley. The southern-most edge was observed to be in shadow much of the early morning and late evening.

S23.CH contained a small population of ostracods (total 17 valves) of one species with no juvenile moult valves present.

The single species, *H. reptans*, *is* commonly found and are not good environmental indicators. From the absence of other ostracod species it seems conditions were poor. The presence of the skull of the Norway lemming, *Lemmus lemmus*, indicates there was a cold climate at the time.

8.05.4. SITE E:- Age and environmental factors of the sediments from Clifford Hill.

There were no age indicator ostracod species (Appendix D) at this site.

However, a skull of the Norway lemming, *Lemmus lemmus,* intact with lower jaw, was recovered from S23.CH. It is rare to find a skull and a lower jaw together unless the animal decayed in still water (Currant, pers. comm.). The ostracods were adult valves of, *H. reptans* which were probably washed in from the flood plain. As this sediment was situated at the edge of the channel-fill it is possibly the remains of cold-stage reed beds or marshland.

Plate 7. The organic sediments at the base of a channel-fill bisecting gravels atClifford Hill in Middle Field (Section 8.06.1, Site F).

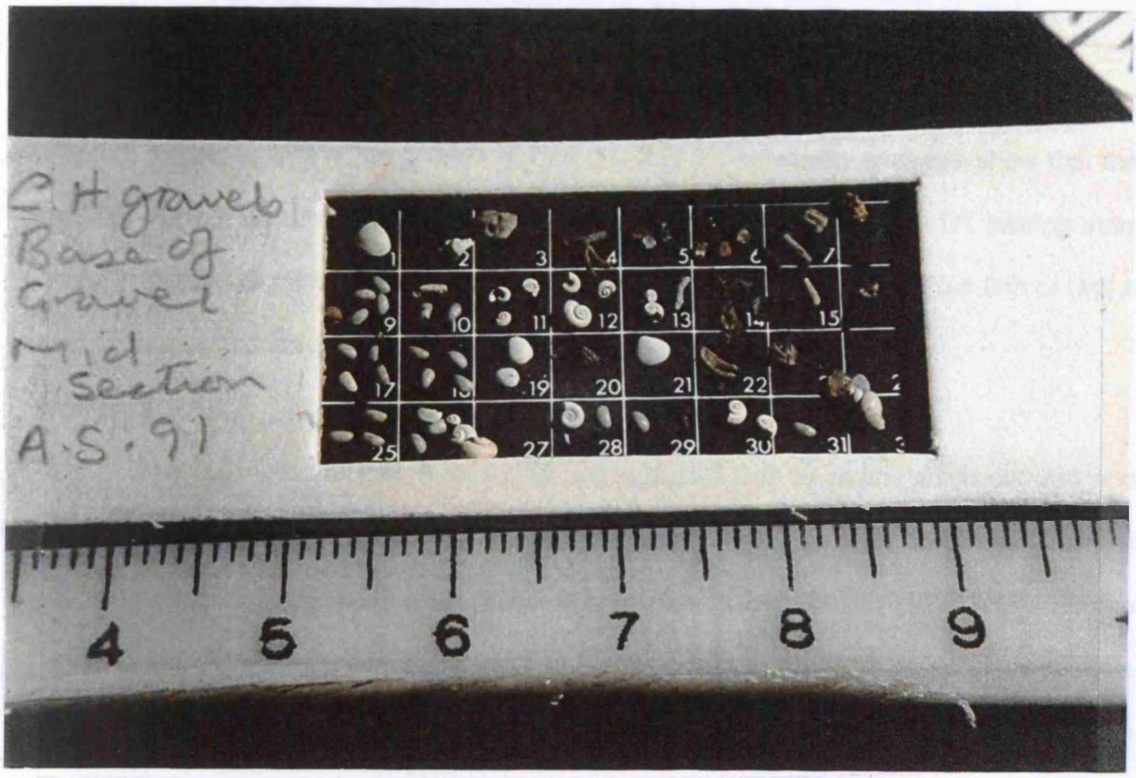


Plate 8. The organic sediments were a rich source of small fossils such as molluscs and ostracods (Section 8.06.1, Site F).

8.06. SITE F

Site description and analyses: Clifford Hill Middle Field (SP795594), Map: Figure 8.01.1: Section: Figure: 8.06.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES S29.CH - 34.CH.

These sediments are marked as First Terrace and floodplain deposits on the geological map (Sheet 185: Northampton, Geological Survey, 1960).

8.06.1. Sediments of Site F. (Tables 8.02.2 & 8.06.1)

Unit	Description	Maximum observed thickness.
(Youngest material at surface: 59m O.D.)		
D	Decalcified top soils	0.5 m
C	Cryoturbated colluvium	0.5-1.0 m
B	Fine to medium, laterally bedded, sandy sediments and sandy channel infill with fine colluvium at surface	2.0 m
A	Horizontally bedded gravels	2.30 m
(Unit A was oldest and lowest material)		

Unit A (Unit A was oldest and lowest material)

The sandy gravels (Unit A, sample F1 of Table 8.06.1) at this site had a colour and lithology similar to that of the gravels of Unit D1, Site E. However, analyses show that the quantity of pebble/cobble sized clasts was less than in the gravels of Unit D1 making them more similar to the gravels of Unit A of Site C (Table 8.02.2). The upper 0.75-1.0 m of Unit A gravel was cryoturbated.

Unit B.

The sediments of Unit B occupied a channel 38.0 m in width, which cut into and almost to the base of the sandy gravels of Unit A (Figure 8.06.1). They consisted of sands, silts and clays, light brownish grey (10YR 6/2) to dark greyish brown (10YR 4/2). To the south of the channel, the sand appeared to be deposited in the form of either large-scale cross-bedding or epsilon beds. Epsilon, or point bar, deposits are normally associated with bends of a meandering river, but are now recognised in braided

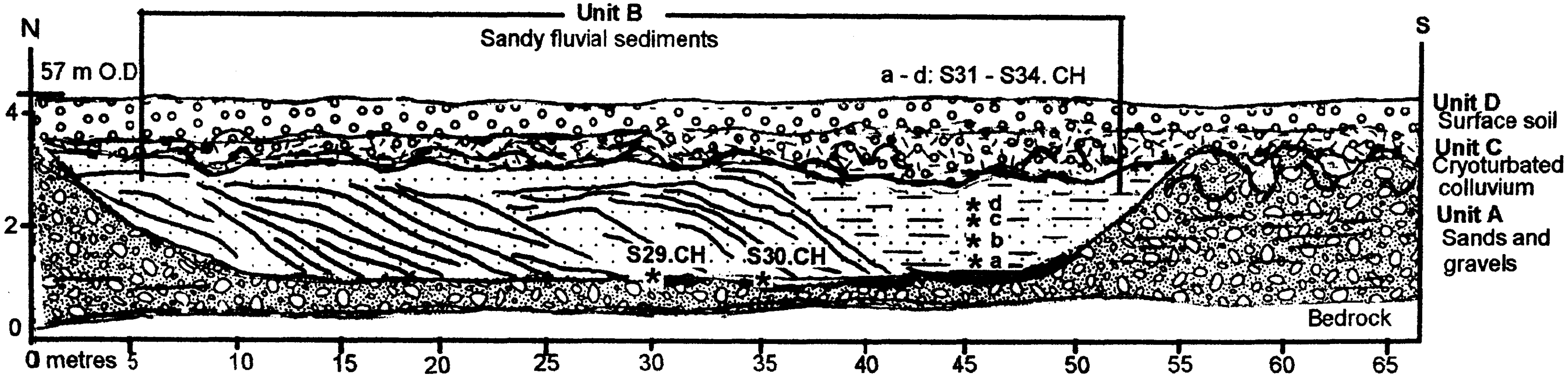


Figure 8.06.1. Site F: Section recorded at Middle Field, Clifford Hill quarry, Little Houghton (SP795594).
* Ostracod samples S29.CH - S34.CH. Key: Figure 7.02.1.

Site F	Clifford Hill Middle Field															
	F.Col:1 colluvium above gravels and channel-fill.															
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lim stone
UNIT C	F.Col:1:clast size															
240	8.0-16.0mm	1.3	7.1	1.3	9.7	0	0.8	0.8	0	0	0	5.4	16.7	58.3	2.5	22
793	4.0 - 8.0mm	2.5	5.3	2.1	9.9	0	0.5	0.6	0	0	0.1	10.1	21.2	49.4	0.6	28
UNIT B	Too fine for stone count.															
	Site F: Clifford Hill Middle Field sample collected from gravels supporting organic channel-fill.															
UNIT A	F1: clast size		(16-32 mm sieved on site).													
111	16-32.0mm	22.5	9.9	8.2	40.6	0	19.8	5.4	0	0.9	0	0.9	67.6	21.6	6.3	4
487(50%)	8.0-16.0mm	15.6	9.1	2.5	27.2	0	3.7	4.6	0.2	0.6	0	2.5	38.8	50.7	2.3	8
1207	4.0 - 8.0mm	6.1	8.6	1.6	16.3	0	0.8	1.2	0	0.2	0	1.6	20.1	77.1	0.9	1
Table 8.06.1.		Site F: Clifford Hill Middle Field stone count.														

river environments as a type of bedding laid down during a period of lateral erosion by the river (Bristow and Best, 1993).

Plant material and small vertebrate and invertebrate remains occurred at the base of these structures.

Unit B: Sediments comprising ostracods (Figure 8.06.1):

S29.CH-S34.CH. There was a high percentage of disseminated plant remains which gave these fine sands, silts and clays an almost grey/black (5YR 3/1 -2.5/1) peaty consistency. The fossil content included seeds, molluscs, ostracods, small mammal and fish remains and beetle wings.

A sample of the organic material was sent, in 1992, to East Kilbride for radiocarbon dating. The resulting radiocarbon date of 26,840+ 455/ -430 B.P (East Kilbride, 1992). placed this deposit in the Middle Devensian period.

The upper 0.5-1.0 m of the channel infill was disturbed by large cryoturbation structures which were seen to be continuous with the structures in the gravels (Unit A).

Unit C

A wedge of light yellowish brown (10YR 5/6) colluvium (Unit C, sample F.Col.1 of Table 8.06.1) covered the pit at this section. It thinned from 2.0 m at the southern end to 0.5 m at the northern end.

The colluvium (lithologically similar to Unit E of Site E) showed evidence of cryoturbation.

Unit D (Youngest material)

The sediments were covered by up to 0.50 m of alluvial soil (Unit D), colour dark brown (10YR 3/3).

8.06.2. Discussion: Site F sediments.

A unit of calcareous gravels (Unit A) was seen to be incised by a channel infilled with sand, silt and clay (Unit B). The channel-fill, 38.0m in wide, did not penetrate the earlier gravels to bedrock, but almost reached the base of the gravels in most sections where seen in the pit. The northern edge of the channel sediments, comprised of fine to coarse sand, accreted in the form of epsilon bedding (usually seen as point bars on the bend of a meandering stream or river) to the south of the channel. These have been formed by lateral erosion of the river bed (Bristow and Best, 1993) and means that there was a measure of landscape stability. Similar epsilon cross-bedding was seen in the Chadbrick Gravels, Somerton, Somerset (Hunt *et al.*, 1984). The upper, fossil-free, sands of the channel-fill were disturbed by large cryoturbation structures.

A wedge of colluvium (Unit C) covers the pit at this section. It thins from 1.5 m in thickness at the southern edge (Unit E of Site E) to 0.5 m at the northern edge of the pit. The colluvium also shows evidence of strong cryoturbation at its junction with the sands and gravels. The colluvium (or gellifluctate) consisted of limestone, ironstone, chalk, flint, quartz and quartzites which was most likely laid down in a cold period.

The sediments were then covered by up to 0.5 m of alluvial soil (Unit D).

The ostracods were recovered from the base of, and in the lower 1.0 m of the sand filled channel (Unit B of Figure 8.06.1). Plant material, bony parts of small fish and mammals, mollusc shells and beetle wings were found in the organic material from the base of these structures. A sample of the organic material was radiocarbon dated as 26,840 +455/-430 B.P. (East Kilbride, 1992) suggesting that deposition occurred during a non-eroding event in the Middle Devensian period.

It is most likely that the channel incised the gravels of Unit A during a period of high discharge and infilled later as the discharge decreased. The latter was a fairly productive stage with a well developed floral and faunal range, which suggests warm conditions. As the organic element disappears near the top of the channel-infill the temperature appears to have cooled rapidly and, indeed, the colluvium and cryoturbation suggest, at least, seasonal freezing set in for a period of time.

8.06.3. SITE F:- Environmental interpretation from ostracod data (Table 8.04.2).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.

For ostracod species and numbers recovered, see Appendix D and Table 8.04.2.

S29.CH contained a medium sized assemblage of ostracods (total 88 valves, 18 carapaces) of high species diversity (9) with an average number of juvenile moult valves present (33.8%).

The assemblage contains 1 temperate species, *P. serrata,* a species of temporary pools and intermittent streams, and 1 winter/spring species, *B. fuscatus.* It also has 5 commonly found species, *C. candida*, *C. neglecta*, *C. laevis*, *I. bradyi,* and *E. pigra.*

At that time there was an established indigenous population in a vegetated, pond-like environment. The presence of carapaces also suggests a still-water habitat with a fairly high rate of sedimentation.

S30.CH contained a small assemblage of ostracods (total 2 valves, 36 carapaces) of high species diversity (11) with a low number of juvenile moult valves present (20.2%).

The assemblage is dominated by *Candona* species, and has a valve of a temperate species, *P. serrata,* a species of temporary pools and intermittent streams. It also has 6 commonly found species, *C. candida*, *C. neglecta*, *C. laevis*, *I. bradyi*, *E. pigra,* and *H. reptans.* There are two valves of the species *Trajancypris clavata,* a rare ostracod of small temporary or permanent ponds. This species usually appears in November and matures throughout the winter months (Griffiths, 1995). It is also reported to be a spring-summer species by Martens (1989). Of the remaining species, *Ilyocypris* sp. A is extinct and the *Eucypris* valves were juvenile and difficult to identify to species level.

Despite the wide diversity of species, the population was growing only slowly. As almost 100% of the valves were linked as carapaces it was likely that the water was still and there was fairly rapid burial taking place. This is a reasonable interpretation, considering the deposit was buried under sand (Figure 8.06.1).

31.CH contained a large sized assemblage of ostracods (total 30 valves, 82 carapaces) of high species diversity (11) with a low number of juvenile moult valves present (17.2%).

The assemblage contains two cold water species, *Psychrodromus olivaceous*, and *Cyclocypris globosa*. *P. olivaceous* lives within the coarse benthic sediments of cold running water, springs and streams (Griffiths, 1995). *C. globosa* (identified, in this case, by Griffiths (pers. comm.)) generally occurs in the early spring months in rain-fed pools and temporary ponds. It is commonly found in such waters in the north of Britain. The assemblage also has 1 temperate species, *P. arcuata*, and 5 commonly found species, *C. candida*, *C. neglecta*, *C. laevis*, *I. bradyi*, and *I. pigra*. *P. arcuata* is rare.

Again, despite the wide diversity of species the population was growing only slowly. Almost 80% of the valves were linked as carapaces which indicates the water was still and there was fairly rapid burial taking place. From the species present in the assemblage it is likely that the climate was that of a cool temperate regime. Both temporary and permanent habitats are represented by the assemblage.

S32.CH contained a small assemblage of ostracods (total 40 valves) of low species diversity (4) with a low number of juvenile moult valves present (22.5%).

The assemblage has 3 commonly found species, *C. candida*, *C. neglecta*, and *H. reptans*.

The environmental conditions seem to have deteriorated and here the assemblage was attempting to establish itself in a muddy benthos with little vegetation.

S33.CH contained a small assemblage of ostracods (total 37 valves) of low species diversity (4) with a low number of juvenile moult valves present (10.8%).

The assemblage has 3 commonly found species, *C. candida*, *C. neglecta*, and *H. reptans*.

The environment was possibly identical to that deduced from the lower material (S32.CH).

S34.CH contained a small assemblage of ostracods (total 11 valves) of low species diversity (4) with a low number of juvenile moult valves present (27.2%).

The assemblage has 2 commonly found species *C. candida*, and *C. neglecta*.

The habitat was silting up and temperatures cooling, as indicated by the presence of *Candona* species only.

8.06.4. SITE F:- Age and environmental factors of the sediments from Clifford Hill.

Griffiths (1995) suggests that *T. clavata* is not recorded in the British Pleistocene. However, *T. clavata* was known as *Sclerocypris clavata*. Then, in 1989, Martens placed the species in a new genus, *Trajancypris*. Thus, *T. clavata* is in the Pleistocene record as *S. clavata* from Cromerian sediments at Little Oakley (Robinson, 1990) and Waverley Wood, Warwickshire (Shotton *et al.*, 1993).

As the radiocarbon date of 26,840 B.P. is close to the limit of resolution, and 26,000 B.P. is recognised as the beginning of the Dimlington Stadial (Rose, 1985), the sediments, which indicate a cool temperate stage, may be older than the date given. This would date the basal sediments nearer in time to the Upton Warren Interstadial date of 42,000 B.P. (Coope *et al.*, 1961).

The overall picture obtained for ostracods recovered from S29-S31.CH is that of a spring fed cool temperate, fairly temporary, still water, abandoned channel, as indicated by the presence of *C. globosa, P. serrata,* and *B. fuscatus*. The basal muds were inhabited by both *C. neglecta* and *C. candida* and two *Ilyocypris* species crawled upon the aquatic vegetation. Of the latter, *I. bradyi* is said to prefer cooler water (Henderson, 1990), while *Ilyocypris* sp. A is now extinct. Summers and winters (unlike the Milton Formation time period) provided rain-fed pools for the two species *B. fuscatus* and *H. incongruens,* both of which are common in Britain today (Griffiths, 1995; Henderson, 1990). *B. fuscatus* is present during the winter and spring and *H. incongruens* extant throughout the summer months.

The ostracod assemblages recovered from samples S.32-S34.CH indicate a rapid decline in the number of ostracod species and valves recovered and an absence of temperate species. This suggests that there was a rapid cooling of the climate after the deposition of the lower sediments (S29-S31.CH).

The climatic implications of the ostracod assemblages is that there was a cool temperate stage at the onset of deposition, but conditions rapidly declined. The absence of organic material in the topmost sediments of the channel fill also indicates cooling conditions.

SECTIONS 8.07.& 8.08. SITES G1 & G2. CRINGLE FARM, WOLLASTON.

8.07. SITE G1 CRINGLE FARM, WOLLASTON: OSTRACOD SAMPLES S35.WOL-S37.WOL.

8.07. Introduction

The gravels at Cringle Farm, Wollaston, have a larger calcareous content than those of Clifford Hill. and there appears to be two suites present: one older, cryoturbated and apparently fossil-free; the other younger, relatively free of cryoturbation and fossiliferous. Ice-wedge casts were seen within the sediments. In places, cryoturbation penetrated the bedrock (not shown in Figure 8.07.1).

Plate 9. The remains of a large tree trunk fell out of the fossiliferous gravels at Cringle Farm (Section 8.07.1, Site G1).

Plate 10. Visitors examine till underlying the gravel in part of the quarry at Cringle Farm (Section 8.08.1, Site G2).

8.07. SITE G1.

Site description and analyses: Cringle Farm, Wollaston (SP885632), Map: Figure 8.01.1: Section: Figure: 8.07.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES S35.WOL-S37.WOL.

These sediments are marked as First Terrace and floodplain deposits on the geological map (Sheet 186: Wellingborough, Geological Survey, 1974). The gravel lithology, although of similar rock types to Clifford Hill West, contains a noticeable increase in chalk and limestone.

8.07.1. Sediments of Site G1. (Tables 8.07.1 & 2)

Unit	**Description**	**Maximum observed thickness.**
(Youngest material at surface: 47 m O.D.)		
G	Decalcified top soils	0.5 m
F	Fine sediments (channel infill)	1.75.m
E	Fine sediments (channel infill)	0.8 m
D	Overbank sediments	1.75 m
C	Cross- and horizontally bedded gravels	0.5-0.6 m
B	Cross-bedded gravels in small parallel channels	1.0 m
A	Cross- and horizontally bedded gravels	2.0 m
(Unit A was oldest and lowest material)		

Unit A (Unit A was oldest and lowest material)

The gravels consisted of two units (Units A and B). The upper 1.0 m of Unit A, the lower gravels, had been eroded by channels which were infilled with gravels of Unit B. The analyses shows that up to 50% of the lower sandy, pebbly gravel of Unit A (samples G1-G3 of Tables 8.07.1 & 2) was of calcareous material (chalk and limestone) which gave the deposit a whitish grey (2.5Y/7) to light brownish grey (2.5Y 6/2) colour. The gravels darkened to dark brown (10YR 3/3) in the middle and upper horizons There were cobbles of limestone, broken cemented ironpan gravel and rounded chalk at the base of the gravels. The calcareous element remained high throughout the unit when compared with the gravels from Clifford Hill. The gravels were both cross- and horizontally bedded and there was some

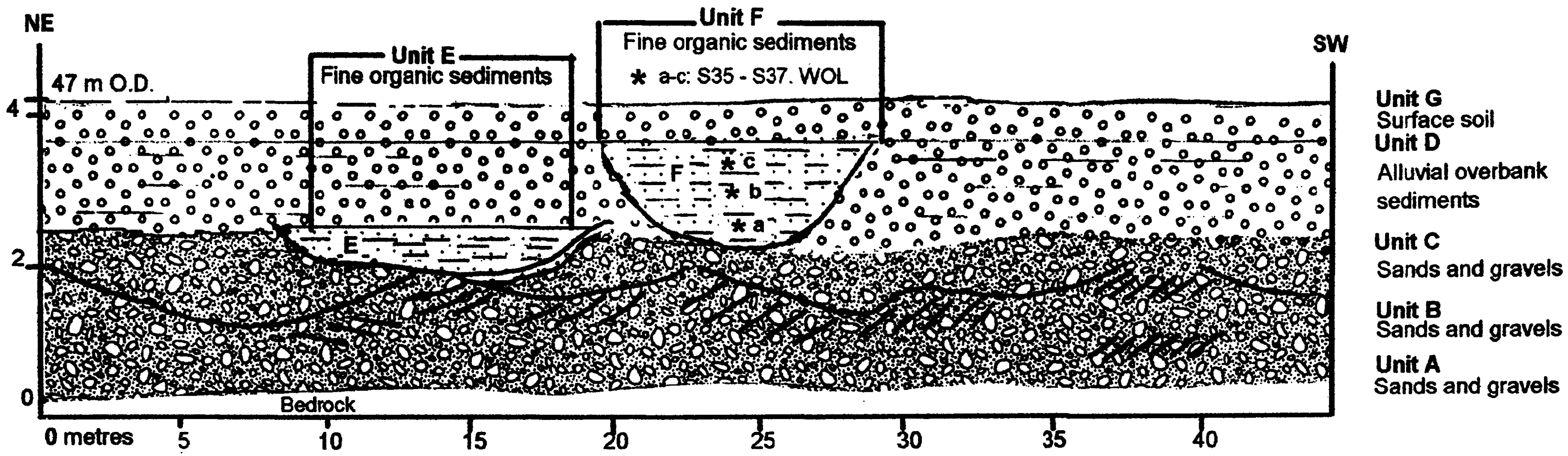


Figure 8.07.1. Site G1: Section recorded at Cringle Farm quarry, Wollaston (SP885632).
* Ostracod samples S38.WOL - S37.WOL. Key: Figure 7.02.1.

No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sandstone	J. Limestone	J. Fossils	O
UNITS D-G		Too fine for stone count.																
UNIT C	**G5: Clast size**																	
226	**8.0-16.0mm**	22.6	21.2	5.8	49.6	0.4	3.5	5.8	0	2.7	0	0	62	34.5	3.5	0	0	
424	**4.0 - 8.0mm**	9.2	13.7	3.8	26.7	0	0.5	2.1	0	0.2	0	0	29.5	70.5	0	0	0	
UNIT B	**G4: Clast size**																	
300	**16.0 - 32.0mm**	(sampled on field)																
		32.5	7.2	12.1	51.8	0	7.2	6.1	0	0	0	0	65.1	4.8	7.2	22.9	0	
	G4: Clast size																	
352	**8.0- 16.0mm**	18.8	6.8	7.6	33.2	0.3	2.3	1.6	0	0.9	0	15.6	53.9	19.3	2	23.9	0.9	
586	**4.0 - 8.0mm**	9.9	6.3	2.6	18.8	0	0	1.4	0	0	0	27.1	47.3	30.3	0	22.2	0.2	
UNIT A	G3) upper, G2) middle, G1) lower Cringle Farm First Terrace Gravel.																	
	G1-G3																	
300	**16.0 - 32.0mm**	(sampled on field)																
		25.8	5.1	6.2	37.1	0	14.6	9.6	0	0	0	2.2	63.5	9.6	15.1	11.2	0.6	
	G3: Clast size																	
279	**8.0-16.0mm**	19.4	3.2	2.9	25.5	0	4.7	3.9	0	0.4	0	4.2	38.7	46.6	2.9	11.8	0	
649	**4.0 - 8.0mm**	15.8	3.6	1.9	21.3	0	0.5	1.3	0	0	0	6.1	29.2	51.8	0.8	18.2	0	
	G2: Clast size																	
594	**8.0- 16.0mm**	18.1	10.3	3.9	32.3	0	2.7	4.4	0.3	0.3	0	2.1	42.1	41.1	1.1	15.7	0	
401	**4.0 - 8.0mm**	14.1	6.4	4.5	25	0	1.7	2.5	0	0.2	0	6.5	35.9	55.4	2.2	6.5	0	
	G1: Clast size																	
390	**8.0- 16.0mm**	8.5	11.5	7.2	27.2	0	0	1.5	0	0	0.3	21.6	50.6	10.1	7.7	30.1	1.5	
533	**4.0 - 8.0mm**	4.3	7.5	7.9	19.7	0	0.6	0.4	0	0	0	17.1	37.8	8.1	2.9	50.1	1.1	
Table 8.07.1. Site G1, Cringle Farm, Wollaston (samples G1-G5).											**First Terrace stone count.**							

Site G2	Sample		Cringle Farm, Wollaston										
	particle size..........	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	
	C.F. 2nd Suite												
Unit C	G8) upper gravel	0.5	13.3	16.8	15.1	11.1	11.5	15.4	4.4	1.5	10.4	,100	muddy sands & gravels
Unit B	G7) lower gravel	36.9	14.8	8.6	8.9	6.1	7.7	5.9	1.1	0.4	9.6	100	muddy sands & large gravels
	G6) diamict/till	36.6	17.9	12.9	10.2	7.3	6.1	3.4	3.6	1.6	0.4	100	sandy large gravel
Site G1													
	Channel gravels												
Unit C	G5) mid. gravel	25.6	22.4	16.1	7.1	3.4	3.7	15.3	4.7	1.7	0	100	sandy gravel
	Channel gravels												
Unit B	G4) mid. gravel	21.9	30.3	28.1	4.3	3.3	6.2	5.4	0.3	0.2	0	100	sandy gravel
	C.F. 1st Terrace												
Unit A	G3) upper gravel	20.8	18.4	18.3	9.1	6.1	10.4	13.8	2.3	0.8	0	100	sand and gravel
,,	G2) middle gravel	18.1	27.5	19.9	11.3	5.5	6.7	7.6	1.9	1.5	0	100	sandy gravel
,,	G1) lower gravel	7.7	31.3	25.3	16.9	11.1	3.7	1.6	1.6	0.8	0	100	sandy medium gravel

Table 8.07.2. Particle size of Cringle Farm, Wollaston.

cryoturbation in the surface of the gravels. Fragments of reindeer (*Rangifer tarandus*) antlers were found in the lower 1.0 m of gravel.

Unit B

The upper 1.0 m of Unit A was divided by numerous shallow channels filled with organic sands and gravels (Unit B). The gravels were both cross- and horizontally bedded.

The analyses shows the lithology of the gravels remained similar to those of Unit A, but the percentage of local rock dropped by about 10-15% in Unit B. There was also less sand present (sample G4 of Table 8.07.1) in Unit B.

The organic fraction including logs, branches and trunks of trees, acorns, hazel nuts and other woody debris, lent a dark, almost black, 10YR 2/1 colour to the gravels which were normally yellowish brown 10YR 5/8. The channel-fills also contained many mollusc shells, broken antler and bones of red deer (*Cervus elephas*) and remains of ox (*Bos* species). However, no ostracods were found in these sediments. Tree roots penetrated these gravels but were truncated at the gravel surface of Unit C.

Unit C

The woody gravel channels of Unit B were overlain by dark yellowish red (5YR 4/6) iron-panned sandy gravel (Unit C, sample G5) which, in places, formed a solid 'cap' to the gravels below. The upper, 'capped' gravels were decalcified and had a corresponding increase in the ironstone and flint content. The gravel of Unit B exhibited both cross- and horizontally bedding.

Unit D

Unit D, consisted of dark yellowish brown (10YR 4/4) sands, silts and clays which rested on the cross-bedded calcareous gravels of Unit C. An unconformity may have existed between the two. The lower sediments of Unit D contained the remains of a wild boar (*Sus scrofa*) and two ox skulls (*Bos* species). Unit D encompassed two channel-fills (Units E and F).

Unit E

Unit E was a coarse sandy silt channel fill within the lower deposits of Unit D (Figure 8.07.1). There was little fossiliferous material, apart from wood fragments, which suggests the sediments may have been decalcified. They had a strong brown colour (7.5YR 5/8) and appeared to be oxidised.

Unit F

Unit F, like Unit E, was deposited on an erosion surface cut into Unit D, with Unit F being stratigraphically above Unit E, but penetrating to the base of Unit D. The sediments were brown (10YR 5/3) sands, silts and clays. The organic element included disseminated plant remains and molluscs with a few ostracods such as in samples S35.WOL and-S37.WOL.

Unit F: Sediments comprising ostracods (Figure 8.07.1):

S35.WOL-S37.WOL. The sediments of these samples had the texture of a sandy loam. Sample S37.WOL was from just below the surface of Unit F (Figure 8.07.1) and trace fossils of burrowing organisms were seen in abundance in this region.

Unit G (Youngest material)

The channel infill was overlain by 0.50 m of alluvial soil (Unit G), colour dark brown 10YR 3/3.

8.07.2. Discussion: Site G1 sediments.

The gravels consist of three units, the lower, Unit A, being incised by the upper gravels of Unit B and these being in turn overlain by Unit C gravel. The three units are designated First Terrace gravels (Castleden, 1976, 1980b).

The lower 1.0 m of gravel appears to be fossil-free, but has occasional blackened muddy lenses within it which smell organic. There is evidence of cryoturbation and ice-wedge casts penetrating these lower gravels and, in places, the bedrock, but it is difficult to suggest its relationship with those of Clifford Hill.

The upper 1.0 m of the gravels consisted of numerous shallow channels filled with organic sands and gravels (Unit B). The organics included logs, branches and trunks of trees, acorns, hazel nuts and other woody debris. Some of the thicker wood appeared to have been axed, but this is not a definite conclusion.

The channel-fills also contained many mollusc shells, broken antler and bones of red deer and remains of ox. However, no ostracods were found in these sediments. As sediments like these were not found at Clifford Hill, again, it is difficult to decide their relationship with the upstream deposits. As there is no evidence for a cold stage, it is tempting to suggest that these gravels were emplaced at a time of forest clearance between 10Ka to 5ka B.P. (Mannion,1991).

The woody gravel channels were overlain by 0.5-0.6 m of iron-panned gravel (Unit C) in places forming a solid cap to the gravels below.

Unit C was overlain by an unusually thick deposit of loam, again, not comparable with anything seen at Clifford Hill. That they were overbank deposits was clear for they contained many aquatic and terrestrial mollusc shells, but nowhere could be seen any definite evidence of fluvial or pond-like deposition. The loam seems to have been deposited rapidly, and, as before with the wood in the gravels, this suggests the onset of local agriculture (Mannion, 1991).

The upper sandy overbank sediments (Unit D) contained two channel-fills and, most likely, the two channels would have contributed towards the overbank sediments. The lower channel-fill (Unit E) was of a coarse sandy texture and contained few organics. The upper channel-fill, from which the ostracods were recovered, was a 2.0 m thick, fossiliferous sandy silt (Unit F of Figure 8.07.1).

The channel-fill and the surrounding loam was overlain by alluvial soils.

8.07.3. SITE G1:- Environmental interpretation from ostracod data (Table 8.07.3).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.

For ostracod species and numbers recovered, see Appendix D and Table 8.07.3.

S35.WOL contained a small assemblage of ostracods (total 29 valves, 1 carapace) of average species diversity (6) with a high number of juvenile moult valves present (67.7%).

The assemblage contains 1 temperate species, *Limnocythere inopinata*, and 3 commonly found species, *C. candida*, *C. neglecta*, and *I. bradyi*. The assemblage is

	CRINGLE FARM				VIC. FARM		WELLINGBOROUGH			
Sample number	**35**	**36**	**37**		**38**		**39**	**40**	**41**	**42**
OSTRACOD SPECIES										
Darwinula stevensoni	1									
Limnocythere inopinata	1		6		10			27		3
Limnocythere sanctipatricii					11					
Cytherissa lacustris								1		
Candona candida	6				72			14	49	21
Candona neglecta	5				35			18		
Candona spp.	15				11		2	2		
Fabaeformiscandona fabaeformis					6					
Pseudocandona marchica					10					32
Cyclocypris laevis									1	
Ilyocypris bradyi	3		8		14					13
Ilyocypris gibba			3		15					
Ilyocypris sp. A					21					
Eucypris dulcifrons									1	
Eucypris pigra								1		
Prionocypris serrata									1	1
Herpetocypris reptans										11
Cypridopsis vidua					23					28
Potamocypris arcuata			1							
Total	31	0	18		228		2	63	52	109

Table 8.07.3. The number of valves recovered of each ostracod species extracted from the sediments of Cringle Farm, Vicarage Farm and Wellingborough.

dominated by the mud burrowing *Candona* species (85%), indicative of a muddy silt based channel or pond.

L. inopinata and *Darwinula stevensoni* are found, both for the first time, in this sediment. *D. stevensoni* is both eurytopic and eurythermal and is, as is *L. inopinata,* usually found in permanent ponds, lakes and slow-flowing rivers. *D. stevenson* prefers shallow water and this may be because it is a pouch-brooding species (Griffiths, 1995).

Despite the low numbers, there was a thriving ostracod community with, as indicated by the large number of moult valves, a growing population. The water was probably temperate, permanent, vegetated, and with a muddy benthos.

S36.WOL contained no ostracods, but it did contain freshwater molluscs and bivalves similar to the upper and lower sediments of the channel.

S37.WOL contained a small assemblage of ostracods (total 8 valves, 5 carapaces) of low species diversity (4) with a high number of juvenile moult valves present (96.4%).

The assemblage contains 3 temperate species, *L. inopinata, I. gibba* and *P. arcuata.* It also has 2 commonly found species, *I. bradyi*, *I. gibba* and *the* rare *P. arcuata*.

The assemblage represents a temperate environment it can be assumed that, again, despite the low numbers, there was the beginnings of a thriving ostracod community with, as indicated by the large number of moult valves, a growing population. The temperate water was permanent, vegetated, with a sandy benthos.

8.04.1. SITE G1:- Age and environmental factors of the sediments from Cringle Farm, Wollaston.

As all the ostracods are extant in Britain today (Appendix D) there is little to indicate the age of the sediments of Site G1.

Overall, although low in number, the ostracods valves recovered from this site embody a broad diversity of species. The high incidence of juveniles suggests a rapidly changing environment where occasionally the habitat was ideal for establishment of an ostracod population (low discharge). These periods of time were interspersed with periods of high discharge or periods of drying out which either delayed the development of, or destroyed, the ostracod populations.

The uppermost gravels and the lowest alluvial sediment above the gravel contained blackened tree trunks, acorns, hazel nuts, antlers, teeth and bones of red deer, and skulls of oxen and wild pig. Although the gravels were fossiliferous none of the samples collected from them contained ostracods. The mammal remains are most likely to be of Early Holocene age.

The alluvial sediments were unusually thick (2-3.0 m) at this site when compared with the other sites in the Nene Valley. There were no signs of cryoturbation above or in the fossiliferous sediments and so they are probably of Early to Middle Holocene origin and, timewise, may correlate with the upper channel of Titchmarsh further down river (Holyoak and Seddon, 1984) (see Chapter 2 for summary). The ostracods recovered are, therefore, of a more recent age than those examined previously.

8.08. Site G2: the Second Suite, Cringle Farm, Wollaston (SP888632).

8.08. SITE G2.

Site description and analyses: Cringle Farm, Wollaston (SP890632), Map: Figure 8.01.1: Sections: Figure : 8.01.1; Key: Figure 7.02.1. and Figure 8.08. 2; Key: Figure 4.01.3.

The section Site G2 was approximately 400 m to the east of Site G1. The gravel lithology, although of similar rock types to Clifford Hill West, contains a noticeable larger amount of chalk and limestone. These sediments rested on chalky diamicton or till. The sediments are marked as First Terrace and floodplain deposits on the geological map (Sheet 186: Wellingborough, Geological Survey, 1974).

8.08.1. Sediments of Site G2. (Tables 8.07.2 & 8.08.1)

Unit	Description	Maximum observed thickness.
(Youngest material at surface: 50 m O.D.)		
E	Soil	0.25 m
D	Colluvial sediments	0.75 m
C	Horizontally bedded gravels	1.0 m
B	Cross and horizontally bedded gravels	1.0 m
A	Diamicton or till	1.0-2.0 m
(Unit A was oldest and lowest material)		

Unit A (Unit A was oldest and lowest material)

Unit A was a pale greyish brown, (10YR 7/1) diamict or till from which a sandy gravel (see below) was obtained (sample G6 of Table 8.08.1). The analysis shows that the gravel of G6 contained 40% chalk and 38% grey limestone (which was possibly derived from the Lias Clays) and appears to be similar to its source material, the surrounding till (Tables 8.07.2 & 8.08.1).

The deposit rested in a depression in the 'Blue' Lias (for further discussion see Chapter 4, Section 4.10) and was not, therefore, widely distributed across the valley floor. The appearance of the deposit was that of a till cut through and then infilled with chalky sands and gravels. The amount of clay appeared to vary throughout the till deposit and the sample collected from the fluvial channel-fill contained very little fine sediment, thus causing it to come out in analysis as a pebbly gravel (G6 of Table 8.08.1).

Unit B

Deposited above and to all sides of the diamict/till was a suite of gravels 2.0 m thick (samples G7 & 8). They comprised two units, Units B and C. The coarser gravels of Unit B were ironstained to a dark yellowish brown (10YR 4/6) and muddy. Highly cryoturbated, they appeared to have been originally cross- and horizontally bedded. Analyses show that the large pebbly gravels of this unit (sample G7 of Tables 8.07.2 & 8.08.1) had a high chalk and limestone content when compared with those of Clifford Hill. They also had a higher percentage of erratic clasts than the gravels of Unit A (sample G1) Site G, Cringle Farm, but,

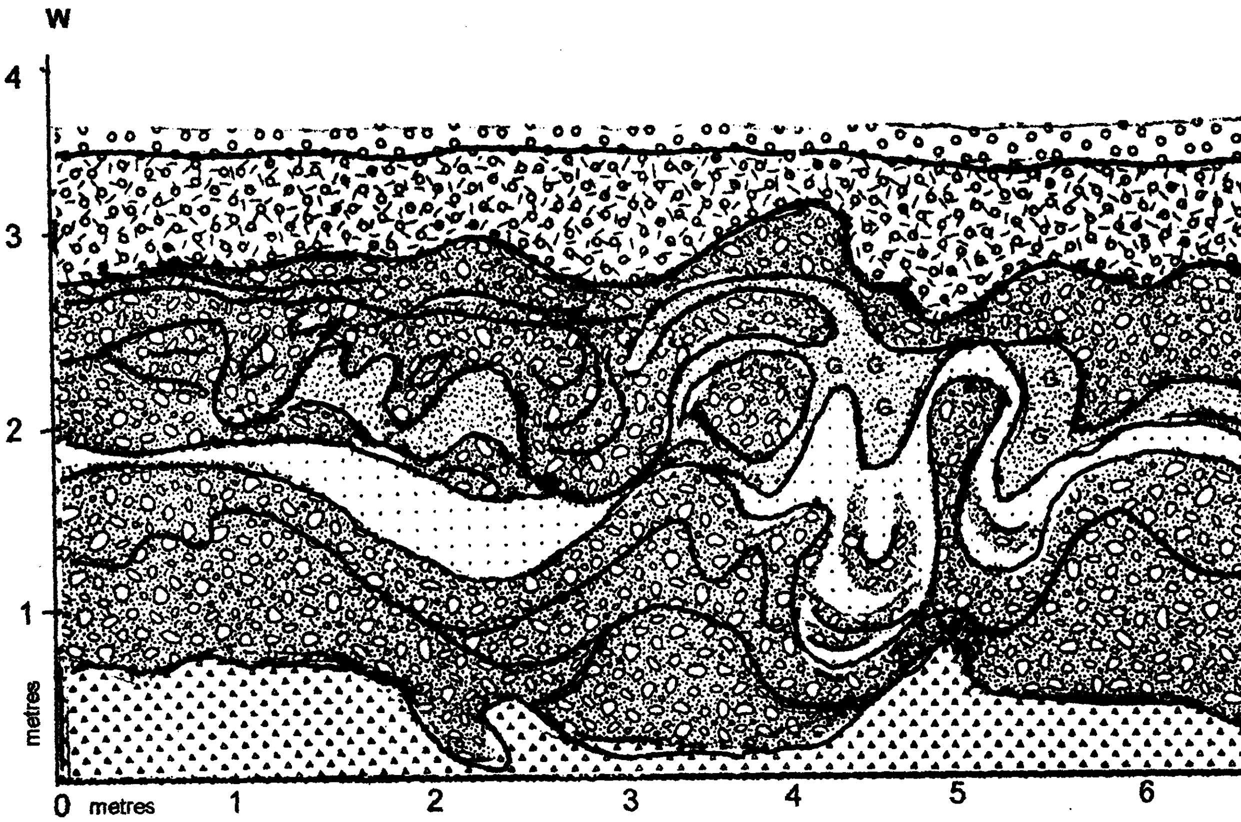


Figure 8.08.1. Site G2, Cringle Farm, Wollaston. Cryoturbated gravels resting on diam

Key: Figure 7.02.1.

Site G																			
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sandstone	J. Limestone	J. Fossils	Others.	Total local %
UNIT D																			
I.W.F.2 G10	Cringle Farm Nene Valley ice wedge (G9 from upper sediments)																		
546	4.0 - 8.0mm	8.1	8.7	1.3	18.1	0	1.1	2.3	0.4	0.4	0	16.5	38.8	45.4	1.3	14.3	0.2	0	61.2
I.W.F.1. G9	Cringle Farm Nene Valley ice wedge (G8 from lower sediments)																		
382	4.0 - 8.0mm	2.2	19.4	1.1	22.7	0	0.3	0.9	0	0.5	0	26.4	50.8	21.2	1.3	26.7	0	0	49.2
	G8) upper, G7) lower Cringle Farm Second Suite of Gravels.																		
UNIT C	G8: Clast size																		
150	8.0-16.0mm	20.7	8	17.3	46	0.7	0	0	0	0	0	12.7	59.4	7.3	0	33.3	0	0	40.6
646	4.0 - 8.0mm	10.8	10.9	1.3	23	0.1	0.3	0.8	0	0	0	22.2	46.4	15.2	1.2	37.2	0	0	53.6
UNIT B	G7:Clast size																		
938	8.0-16.0mm	16.3	21	3.6	40.9	0.2	2.7	2.2	0	0.8	0.1	11.5	58.4	15.8	3.4	22.2	0.2	0	41.6
732 (0.5 sple.)	4.0 - 8.0mm	0.5	14.3	4.6	19.4	0	0.1	0.1	0	0.1	0	15.5	35.2	15.4	0	49.3	0.1	0	64.8
UNIT A	G6: Cringle Farm deposits on bedrock beneath the gravels.																		
DIAMICTON																			
OR TILL	G6:Clast size																		
300	16.0 - 32.0mm	(sampled on field)																	
		1.8	5.4	12.1	19.3	0	0.7	2.4	0	0	3.1	47.7	73.2	0	2.4	22.2	0.7	1.5	26.8
	G6:Clast size																		
132	8.0-16.0mm	2.7	2.9	9.3	14.9	0	0.5	1.2	0	0.1	0.2	40.1	57	2.9	1.1	38.2	0.6	0.2	43
885	4.0 - 8.0mm	1.7	1.7	5.8	9.2	0	0.2	1.1	0.2	0	0.2	42.9	53.8	8.1	0.3	37.1	0.7	0	46.2

Table 8.08.1. Site G2, Cringle Farm, Wollaston (samples G6-G8). Second Suite stone count.

despite the greater proportion of the large pebble to cobble size of Unit B, the lithology was similar to the Unit A of Site G1 (samples G1-G3).

Unit C

Unit B was overlain by highly cryoturbated, horizontally bedded gravels, Unit C (sample G8 of Table 8.08.1). These gravels were pale grey to white (2.5Y/7) and light yellowish brown, 10YR 6/4, in colour. Analyses show that despite the decrease in particle size of these gravels the gravels were still muddy and the lithology remained similar to the lower, Unit B, gravels.

Ice-wedge cast seen in these gravels.

As part of Units B and C but three metres to the west, an ice-wedge cast, not shown on Figure 8.08.1, (Unit D, samples G9 and G10) penetrated the gravels of both Unit B and C and the till below. The ice-wedge cast fill was of calcareous pebbly sands (Table 8.08.1).

Unit D

Consisted of sandy colluvial deposits involuted into the surface of Unit C gravels.

Unit E (Youngest material)

The combined till, gravels, ice-wedge cast(s) and colluvium were overlain by 0.25 m of alluvial soil (Unit E), colour dark brown 10YR 3/3.

8.08.2 Discussion: Site G2 sediments,

The lowest unit, Unit A, was a chalky till deposit (or diamict) incised by a small channel infilled with a sandy gravel derived from the same sediments (from which the clast lithology and particle size analyses were recorded). The till was extremely chalky (45%) and contained far-travelled and local rock. The gravel (Unit B) resting on the till was cut through from its surface by ice-wedge casts and was highly cryoturbated. This and the ice-wedge casts penetrated the till and the Blue Lias bedrock below. The ice-wedge cast(s) used for lithological analyses was at least 3 m deep. As the upper sediments contained up to 30% less chalk and limestone than those lower down in the cast, there may have been two casts stratigraphically superimposed one above the other (Seddon, 1982; Seddon and Holyoak, 1985), although this was not clear on the field.

In places the surface of the gravels had been disturbed by earlier, Victorian gravel extraction, but, where found undisturbed the gravels (as shown in Figure 8.08.1) were overlain by stony, sandy colluvium, topped by modern soil.

8.08.3. Till at Site G2.

A deposit of highly calcareous till found at Cringle Farm, Wollaston (Figure 8.08.2) strengthens the case for a pre-Anglian Nene Valley. The till, at 48 m O.D., suggests the valley was already established down to a low altitude before the deposition of the Anglian chalky till. The till filled a dip in the valley. Hollingworth and Taylor (1946) noticed several of these basin shape structures in the Nene Valley between Wollaston and Ringstead. They suggested they were caused by bulging and erosion of the 'Blue' Lias clay. That the hollow is filled with till at Wollaston indicates the existence of the valley already subject to bulging and/or valley side erosion before the deposition of the Anglian and post-Anglian gravels.

8.04. SITES G1 & G2: Age and environmental factors of the sediments from Cringle Farm, Wollaston.

The ages of the various gravels at Cringle Farm can be determined by comparing sites G1 and G2. The sequence of events established modifies the work of Castleden (1976, 1980b).

At Cringle Farm, the lower gravel (Unit A) of Site G1 (= G1A) although lithologically similar, is of a smaller size, to Units B and C of Site G2 (= G2B, G2C) and has a much lower proportion of flint with a correspondingly higher proportion of chalk and ironstone to G2B and G2C. The larger degree of cryoturbation seen at Site G2 also separates it from Site G2. Unit G1A is seen to infill a channel cut into G2B and G2C, establishing its younger age. It is thought to be derived from gravels reworked from G2C (on the basis of its lithology and pale colour) plus an input of fresh material from the interfluves. In fact, to the east of the section

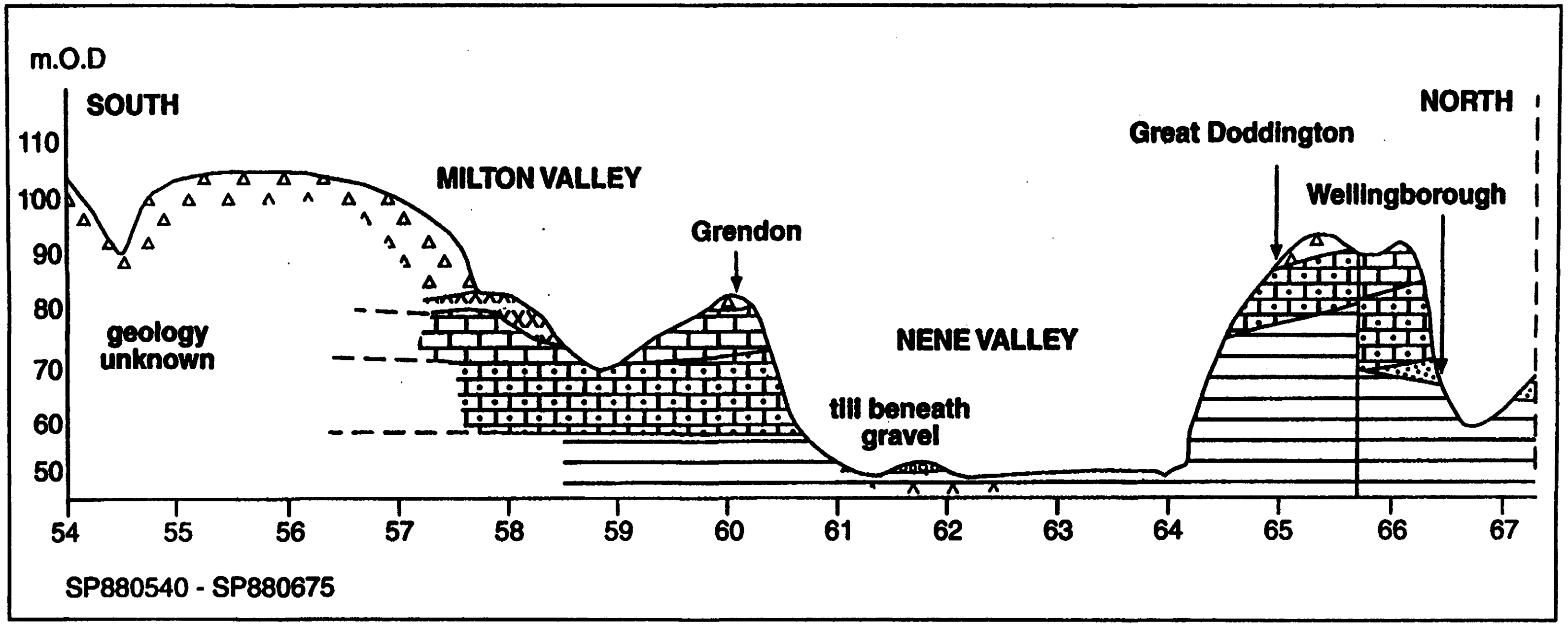


Figure 8.08.2 Section across the Milton and Nene valleys showing till beneath the gravel in the Nene Valley, at the foot of the "Grendon" hill (Cringle Farm, Wollaston). (For legend see Figure 4.01.3)

at Site G1, the channel, infilled with the younger gravel suites of G1, was seen cutting hrough older, cryoturbated gravels similar to, or the same as, those of G2. The channel, 31, up to 2 m deep, was emplaced 1.2 m lower in the bedrock than the older gravels (also 2 m thick) which it incised, causing a step in the bedrock and a lowering of the gravel surface (see below for discussion on the terracing of the Nene Valley).

On the southern and eastern side of the Nene Valley where the tributaries crossed, and are still crossing, the abandoned Milton Valley on their way down to the Nene Valley, the lithology of the gravels, as seen at Wollaston (Sites G1 & 2, Cringle Farm Quarry) (Figure 8.07.1 & 8.08.1) contains large amounts of derived pre-glacial gravels. This is usually in the form of limestone and ironstone pebbles, but sand was in abundance at Clifford Hill (see Chapters 4 & 7 and discussion on terracing below).

8.09. SITE H: Vicarage Farm near Wollaston.

8.09. SITE H.

Site description and analyses: Vicarage Farm near Wollaston (SP894639), Map: Figure 8.01.1: Section: Figure: 8.09.1; Key: Figure 7.02.1.

OSTRACOD SAMPLE S38.VF.

These sediments are marked as First Terrace and floodplain deposits on the geological map (Sheet 186: Wellingborough, Geological Survey, 1974).

Plate 11. First Terrace gravels at Vicarage Farm, Wollaston (Section 8.09.1, Site H).

Plate 12. An organic channel-fill emplaced in one suite of gravels and overlain by a second suite at Vicarage Farm, Wollaston (Section 8.09.1, Site H).

8.09.1. Sediments of Site H. (Tables 8.09.1 & 2)

Unit	Description	Maximum observed thickness.
(Youngest material at surface: 45 m O. D.)		
E	Decalcified top soils	0.2 m
D	Cryoturbated colluvium	0.5 m
C1 & 2	Horizontally bedded gravels	2.0 m
B	Fine to medium organic sediments of channel infill (27.0 m wide)	1.75 m
A	Horizontally bedded gravels showing cryoturbation and ice-wedge casts at surface	1.2 m
(Unit A was oldest and lowest material)		

Unit A (Unit A was oldest and lowest material)

The lower, brown (10YR 5/3) muddy sands and gravels (Unit A of Figure 8.09.1), were deposited across the width of the valley (Sample H1 of Tables 8.09.1 & 2). They showed cryoturbation structures. There were cobbles of limestone, broken cemented ironpan gravel and rounded chalk at the base of the gravels. The analyses show that the limestone and chalk content of the gravels was higher than that of Clifford Hill, but considerably lower than that of Site G, Cringle Farm.

Unit B

The cryoturbated gravels of Unit A were bisected by a dark, almost black (10YR 2/1) organic silty sand channel-fill (Unit B of Figure 8.09.1). The analyses show that it consisted of fine sands, silts and clays, and included a high percentage of disseminated plant remains which gave it a peaty consistency. The fossil content included molluscs, ostracods small mammal and fish remains and beetle wings.

Unit B: Sediments comprising ostracods (Figure 8.09.1):

The sediment of sample S38.VF came from the lower 0.2 m of this organic channel-fill.

Unit C1 & 2

The sands and gravels of Unit C, those above the channel-fill, appeared to be continuous with the channel-fill. The lithological analyses and particle size (C1 of Tables

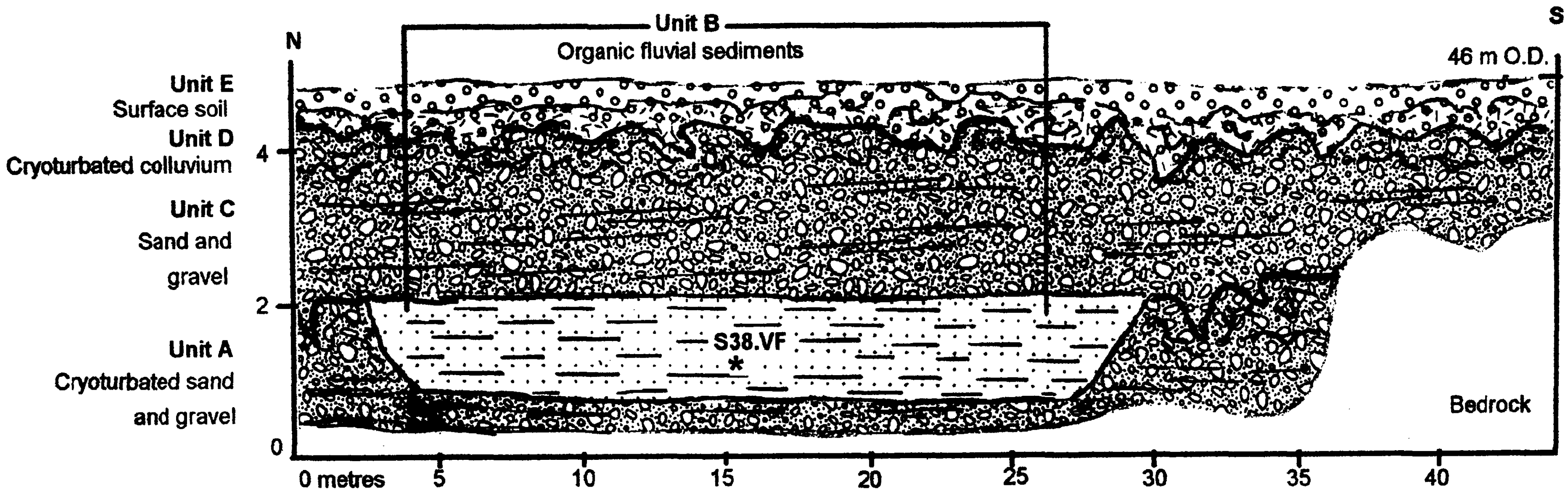


Figure 8.09.1. Site H: Section recorded at Vicarage Farm quarry, near Wollaston (SP894639).
* Ostracod sample S38.VF. Key: Figure 7.02.1.

	Sample name: Site H.																		
	Site H: Vicarage Farm H1) upper gravel H2) lower gravel.																		
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone	J. Fossils	Others.	Total local %
	Site H: Vicarage Farm. Sample H3 collected from 100.0 m downstream to H1 and H2.																		
UNIT C2	**H3 Clast size**																		
260	8.0- 16.0mm	13.6	15.1	5.1	33.6	0	5.1	2.9	4.5	0.4	0.4	7.7	54.6	27.8	0.8	15.8	0.8	0	45.2
403	4.0 - 8.0mm	6.2	9.7	1.5	17.4	0	0.2	1	0	0	0	12.8	31.4	33.6	2.5	31.9	0.5	0	68.5
UNIT C1	**H2: Clast size**																		
312	8.0-16.0mm	3.8	13.5	5.8	23.1	0	2.2	2.6	0.3	0.3	0.3	16.7	45.5	14.1	1.6	36.9	1	0.9	54.5
540	4.0 - 8.0mm	5.4	12.1	0.9	18.4	0	0.4	0.7	0	0	0	15.6	35.1	16.2	0	48.3	0	0.4	64.9
Unit B	Too fine for stone count																		
UNIT A	**H1: Clast size**																		
461	8.0- 16.0mm	12.6	6.5	8.3	27.4	0	8.3	5.2	0.2	0.4	0	3.5	45	35.1	4.1	15.6	0.2	0	55
514	4.0 - 8.0mm	5.9	5.1	2.5	13.5	0	0.8	1.6	0	0	0	7.1	23	62.2	0.8	13.6	0.4	0	77

Table 8.09.1. Site H: Vicarage Farm, Wollaston stone count.

	Sample												
Site H	**particle size..........**	>-4 phi	-3	-2	-1	0	1	2	3	4	< 4	0%	
Unit C2	H3) 100m down-stream	21.2	21.9	12.9	6.8	5.1	9.3	19.6	2.7	0.5	0	100	sand and gravel
Unit C1	H2) upper gravel	27.8	14.5	18.6	13.2	8.4	7.8	7.5	1.9	0.3	0	100	sandy gravel
Unit A	H1) lower gravel	18.7	17.1	13.9	9.1	6.5	10.9	11.5	1.2	0.4	10.7	100	muddy sands & gravels
	Sample												
Site J	**particle size..........**	>-4 phi	-3	-2	-1	0	1	2	3	4		0%	
Unit A4	J4) upper gravel	13.8	23.1	19.6	12.1	7.5	10.6	10.3	1.8	1.2		100	sand and gravel
,, A3	J3) upper mid. gravel	9.8	15.9	24.2	11.6	7.9	15.5	13.6	1.3	0.2		100	sand and gravel
,, A2	J2) lower mid. gravel	3.5	22.1	24.7	18.7	10.8	10.2	9.1	0.8	0.1		100	sand and gravel
,, A1	J1) lower gravel	24.1	20.1	10.8	4.4	4.2	3.5	10.9	6.2	3.1	12.7	100	muddy sands & gravels

Table 8.09.2. Particle size of Vicarage Farm gravels, Wollaston and Wellingborough gravels.

8.09.1 & 2) show that the gravels were similar to First Terrace gravels Unit A, G1-3, of Site G, Cringle Farm. However, the upper gravel unit (sample C2) became sandier with distance downstream (C2 of Tables 8.09.1 & 2) and showed a marked similarity to those of Unit A of this site.

Figure 8.09.1 illustrates how the upper sandy gravels of Unit C1 spread laterally above Unit B as the valley was widened by lateral erosion, overlapping the Terrace of Unit A, and eventually were deposited also on the valley side. The upper 0.5 m of these gravels was cryoturbated.

Unit D

The thin layer of calcareous colluvium (Unit D) above Unit C was involuted and this resulted in the interdigitation of the two units.

Unit E (Youngest material)

The decalcified surface soils, (Unit E) were thin, colour dark brown 10YR 3/3.

8.08.2: Discussion: Site H sediments.

Evidence from the bedrock beneath the gravels shows that the 'Blue' Lias has been subjected to two erosive episodes. The second erosive episode, which was cut a metre lower in altitude than the first, was seen to have cut a narrower channel through the base of the first channel. The first episode left the 'Blue' Lias at the base of the valley cryoturbated and littered with large cobbles to small boulders washed directly from the till. The second erosive episode planed off the central part of the valley (channel) surface and left a smooth-surfaced base with terraces of older cryoturbated 'Blue' Lias to either side. The gravels were light brown, clean and cryoturbated in the lower and upper units.

The section shows at least three units. The lower gravels are 1.2 m thick (Unit A) with cryoturbation structures. These cryoturbated gravels represent a cold episode later than the formation of the heavily cryoturbated gravels of Site G2. Both units of gravel have similar clast lithologies and particle sizes. Because Unit A of Site H is beneath two further sedimentary units, the upper of which is also cryoturbated, they pre-date the downcutting and infilling of the channel and the deposition of the overlying cryoturbated colluvium of Site F.

After the cold period which caused the cryoturbation the gravels of Unit A were bisected and the resultant channel infilled with an organic silty sand (Unit B). The main body of the channel-fill was a dark grey/black silty sediment with numerous fragments of woody plant material. It also contained beetle wings, molluscs and ostracods. The channel was most likely infilled in a period of initially temperate but latterly cooling climate as indicated by the decreasing organic content. The ostracods were recovered from the lower 0.2 m of the organic silty sand channel-fill (Unit B of Figure 8.09.1).

The sands and gravels of Unit C, above the channel-fill, appeared to be continuous with the channel-fill and were 2.0 m thick. The upper gravels (Unit C) spread laterally indicating incision of the river bank and a widening of the terrace on which these gravels rested.

Unit C gravels have a fresh input of calcareous material, probably due to intermixing with fresh colluvium which usually has, as already recorded, a high limestone and, sometimes, chalk content (Units C of Site C, D2 and E of Site E, C of Site F).

The thin layer of colluvium (Unit D) and the upper parts of Unit C gravels are cryoturbated and contain small ice-wedge casts (none shown in illustration, Figure 8.09.1).

The upper gravel deposit spread across the valley and rested on both the channel sediments and the gravel (Unit A) bisected by the channel (Unit B). The deposition was followed by a further periglacial period in which the upper gravels and the colluvium were cryoturbated.

The decalcified surface soils (Unit E) are thin, being less than 0.2 m thick.

8.09.3: SITE H:- Environmental interpretation from ostracod data (Table 8.07.3).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.

For ostracod species and numbers recovered, see Appendix D and Table 8.07.3.

S38.VF contained a large assemblage of ostracods (total 224 valves, 2 carapaces) of high species diversity (11) with an average number of juvenile moult valves present (43.4%).

The assemblage contained 3 temperate species, *L. inopinata, P. marchica*, and *I. gibba*, and one cold stenothermal species, *L. sanctipatricii*. It also has 5 commonly found species, *C. candida*, *C. neglecta*, *P. marchica*, *I. bradyi*, and *I. gibba*. *L. sanctipatricii, L. inopinata*, *P. marchica* and *C. vidua* are species of permanent ponds and lakes. *Ilyocypris* sp. A is extinct. *F. fabaeformis,* is a winter/spring species of temporary pools and here may have been washed into the abandoned channel by flood waters draining off the floodplain.

The assemblage was an indigenous one. The presence of both a cold stenothermal form and temperate forms suggests the climate may have been to short pulses of change. The ostracod species numbered 11 which is typical of an abandoned channel (Robinson in: Green *et al.,* 1996).

8.08.4. SITE H:- Age and environmental factors of the sediments from Vicarage Farm, Wollaston.

Ilyocypris sp. A is the only age indicator species (Appendix D) present. It was found in Oxygen Isotope Stage 7 sediments at Stoke Goldington in Bedfordshire (Green *et al.,* 1996).

The unusual feature of this ostracod assemblage is that it has two species of *Limnocythere* present. It is usual to find only one of these species at any time (Robinson, pers. comm.). This suggests either that the valves of one of the species are reworked fossils from an earlier sediment, or that the assemblage is from a sediment deposited at a time of climatic change, similar to that at Site C, Clifford Hill West Field, where one stenothermal (temperature specific) species is becoming established as the other is dying out *(L. inopinata* and *L. sanctipatricii* are of temperate and cold habitats respectively). The change in climatic conditions may represent one of the short climatic oscillations illustrated by the ice records from the Vostok ice core, Antarctica (Petit *et al.,* 1999).

Plate13. The gravels at Wellingborough showed more cross-bedding than those seen further upstream (Section 8.10.1, (Site J).

Plate 14. The Wellingborough gravels also contained transported peat from an earlier peat bed (Section 8.10.1, Site H).

8.10. SITE J WELLINGBOROUGH: OSTRACOD SAMPLES S39. WEL - S42.WEL

8.10. Site J.

Site description and analyses: Wellingborough (Whitworth Mills) (SP900665), Map: Figure 8.01.1; Section: Figure: 8.10.1; Key: Figure 7.02.1.

OSTRACOD SAMPLES: S39. WEL - S42.WEL.

These sediments are marked as floodplain deposits on the geological map (Sheet 186: Wellingborough, Geological Survey, 1974). The gravels are of a similar lithology to those of Clifford Hill. There is, however, a notable increase in the chalk and limestone elements.

The gravel seen at Wellingborough is usually cross-bedded and interspersed with lumps of peat and sandbars containing peat fragments. The peat may have been transported from a nearby peat bed semi-frozen at that time. The gravel is usually 2.0-3.0 m thick. Unlike further upstream, there does not appear to be any cryoturbation at the surface of the gravels.

8.10.1. Sediments of Site J. (Table 8.10.1)

Unit	Description	Maximum observed thickness.
(Youngest material at surface: 44 m O.D.)		
F	Fine to medium sediments (channel infill)	0.5 m
E	Top soils	0.7 m
D	Fine to medium sediments (channel infill)	0.9 m
C	Fine to medium sediments (channel infill)	1.5 m
B	Overbank sediments	2.0 m
A	Cross-bedded sands and gravels (subdivided into 4 Units)	1.8 m
(Unit A was oldest and lowest material)		

Sample S39.WEL was from a wide shallow channel filled with organic sands and gravels embedded in the surface of the gravel (Unit A). It also contained wood, molluscs and antiers and bones of red deer.

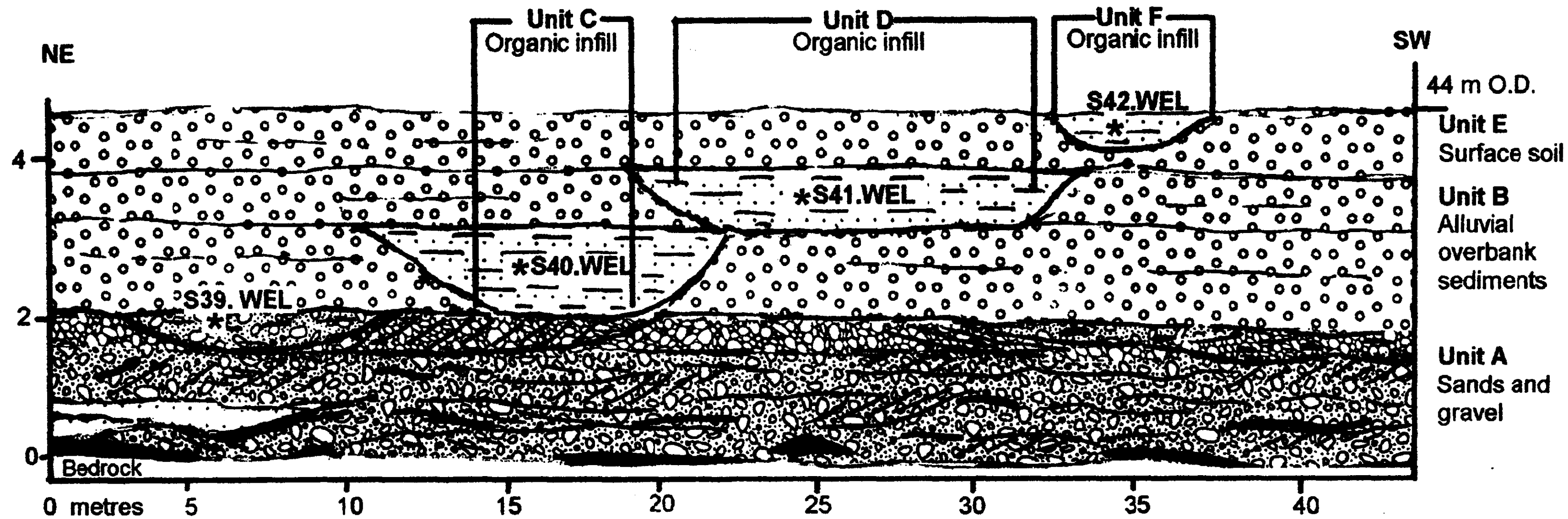


Figure 8.10.1. Site J: Section recorded at Wellingborough (Whitworth Mills) (SP900665).
* Ostracod samples S39.WEL - S42.WEL. Key: Figure 7.02.1.

Unit A (Unit A was oldest and lowest material)

For description, Unit A (Figure 8.10.1) has been divided into sedimentary sub-units A1-A5.

Unit A1 was 1.0 m of trough cross-bedded, calcareous, muddy, cobbly gravel. At its base on the 'Blue' Lias, up to 25% of its particles were large pebbles and cobbles of, chiefly, limestones, Bunter quartzites and flint. The surface of the 'Blue' Lias and the gravel unit was littered with small to medium (up to 0.3 m) chunks of black peat. There were also fragments of black wood, mostly twigs, but some broken, thicker lengths. Analyses show that it also contained 10-15% silts and clays. The organic sediments lent to the gravel a dark greyish brown colour (10YR 4/2).

Unit A2 was a cross-bedded, sandy, pebbly gravel (colour brownish grey 2.5Y6/2). It had ironstained layers (colour yellowish brown 5Y 5/6) in its formation. Analyses show that there was an increase in chalk and limestone in the smaller size fractions (Table 8.10.1). The gravels had fewer fines than those below in Unit A and were of a smaller size fraction (Table 8.09.2).

Unit A3 was similar in deposition and particle size to that of Unit A2 but was lighter in colour due to a visibly significant input of more chalk.

Unit A4 was horizontally bedded, sandy pebbly gravel. It was decalcified and ironstained (colour yellowish brown 5Y 5/6) and of a larger particle size than the lower Units A2 and 3 (Tables 8.09.2 and 8.10.1).

Unit A5 was a small channel incised into Unit A4. Its sandy pebbly gravel included woody fragments and remains of red deer.

Unit A5: Sediments comprising ostracods (Figure 8.10.1):

S39.Wel S39.Wel was from Unit A5. The fossil content included molluscs, ostracods, small mammal remains and beetle wings.

Unit B

Unit B, floodplain deposits, comprised dark brown (10YR 3/3) sands, silts and clays. Two infilled channels, the upper channel (Unit D) being 1 m higher in altitude, and above

	Sample name: Site J.																		
	Site J: Wellingborough gravel samples						J1) upper, J2) upper middle, J3) lower middle, J4) lower gravel												
No. of clasts	Rock Type	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone	J. Fossils	Others.	Total local %
UNIT A4	**J4: Clast size**																		
	8.0-16.0mm	14.7	15.9	3.9	34.5	0	4.3	4.8	0	0	0	0	43.6	50.9	5.5	0	0	0	56.4
	4.0 - 8.0mm	10.1	11.3	1.1	22.5	0	1.4	2.9	0	0	0	0	26.8	71.3	1.9	0	0	0	73.2
UNIT A3	**J3: Clast size**																		
	8.0- 16.0mm	7.7	11.5	9.6	28.8	0	3.8	1.1	0	0	0	10.6	44.3	39.3	4.8	10.5	1.1	0	55.7
	4.0 - 8.0mm	6.3	3.9	6.3	16.5	0	1.1	0.9	0	0	0	12.4	30.9	39.5	0	29.6	0	0	69.1
UNIT A2	**J2: Clast size**																		
	8.0-16.0mm	9.6	12.2	2.7	24.5	0	5.4	5.4	0	1.7	0	5.4	42.4	34.6	0	21.8	1.2	0	57.6
	4.0 - 8.0mm	4.6	3.1	3.3	11	0	1.1	0.4	0	0	0	10.6	23.1	47.7	0	29.2	0	0	76.9
UNIT A1	**J1: Clast size**																		
	8.0- 16.0mm	14.3	6.5	2.9	23.7	0	6.1	7.8	0	0.8	0.4	1.6	40.4	40.4	0.8	17.2	0	1.2	59.6
	4.0 - 8.0mm	10.5	6.8	1.8	19.1	0	1.6	3.7	0	0.4	0	4.3	29.1	52.5	1.2	17.1	0.1	0	70.9

Table 8.10.1. Site J: Wellingborough gravel stone count.

and to the south-west of the other (Unit C), were apparent in the sediments of Unit B (Figure 8.10.1).

Unit C: Sediments comprising ostracods (Figure 8.11.1):

Sample S40.WEL was taken from the lower channel-fill (Unit C) which besides being the most fossiliferous, also contained large fragments of wood. The sediment consisted of fine sands, silts and clays and a high percentage of disseminated plant remains. These gave the sediments a peaty consistency and a dark grey to black colour (5Y 3/1). The fossil content included molluscs, ostracods small mammal and fish remains and beetle wings.

Unit D: Sediments comprising ostracods (Figure 8.11.1):

Sample S41.WEL was taken from the upper channel-fill (Unit D). The infill consisted of fine sands, silts and clays and a high percentage of disseminated plant remains. It had a peaty consistency and a dark grey to black colour (5Y 3/1).

Unit E

Unit E comprised modern alluvial soils (Unit E), colour dark brown (10YR 3/3).

Unit F (Youngest material)

Sample S42.WEL came from a small, dried out, modern channel-fill (Unit F) in the alluvial soils of Unit E. Its fossil content included molluscs, ostracods, fish remains and beetle wings.

8.10.3. Discussion: Site J sediments.

The gravel (Unit A of Figure 8.10.1) at Wellingborough is cross-bedded and is littered with lumps of peat, particularly at the base of the gravel, but the peat is also interspersed as finer grains within the beds of sand. The peat, which was made up of sedge and fine woody remains, but no mosses, may have been transported from a nearby peat bed semi-frozen at the time of its breaking up. It did not appear to be *in situ* even at the base of the gravel unit.

The gravel, Unit A of Site J, has been subdivided into four sub-units.

Unit A1 is a calcareous gravel, dirty and stained in appearance. The gravels of this lower unit were seen resting on a thin layer of blackened twigs and broken down peat on top of Blue Lias bedrock. It has a fair proportion of large gravels and has affinities with the lower unit (Unit A) of gravels at Site H, upstream of Site J. However, if these gravels were cryoturbated at the surface the evidence for it has been eroded away at the time of incision and deposition of the Unit A2 gravel.

Unit A2 gravel has a fresh input of limestone and chalk. It also has a clean, washed appearance when compared with the lower gravel. As the limestone and chalk has been shown to enter the gravel from colluvium, or hill-wash, it is likely that there has been a period of time, resulting in an unconformity, between the deposition of these two gravels; or that, at least, a rapid change took place in the climate at the time of deposition.

Unit A3 gravel shows a decline in the amount of calcareous material, but does not differ too much in appearance or particle size to that of Unit A2.

Unit A4 gravel is decalcified. This may be due partly to comminution, and partly to do with surface decalcification. Gravels near the surface at Site G1 are also decalcified and so are the surface soils of all the sites investigated.

Ostracods were recovered from a wide shallow channel infill of organic sands and gravels embedded in the surface of the gravel (Unit A). The organics included wood, molluscs and antlers and bones of red deer. This channel has affinities to those of Unit B, Site G1.

The remainder of the units (C, D, F) form a series of channel fills within the alluvial loams (Unit B) resting on the gravels.

Ostracods were recovered from the lower channel-fill (Unit C) which, besides being the most fossiliferous, also contained large fragments of wood, the upper channel-fill (Unit D) and a small, dried out, modern channel-fill (Unit F) which rested in the alluvial soils (Unit E) covering the section.

There were no signs of cryoturbation in the upper gravel or above in the fossiliferous sediments. This points to a probable age for the later sediments of Early to Middle Holocene and, timewise, may correlate with the upper channel of Titchmarsh further down river

(Holyoak and Seddon, 1984) (see Chapter 2 for summary). The ostracods recovered are, apart from those of Site G1, of a more recent age than those previously examined.

8.10.4. SITE J:- Environmental interpretation from ostracod data (Table 8.07.3).

Interpretation was made using the stratigraphic and sedimentological data discussed above combined with the evidence from Table 5.04.1 and appendices C, D, and E.

For ostracod species and numbers recovered, see Appendix D and Table 8.07.3.

S39.WEL contained total 2 valves of a *Candona* species neither of which was a juvenile moult valve.

It is likely that the environment was unsuitable for ostracods.

However, other fossils such as wood and antlers of red deer were found at the site in the same stratigraphic position (Figure 8.10.1).

S40.WEL contained a small assemblage of ostracods (total 57 valves, 3 carapaces) of average species diversity (6) with an average number of juvenile moult valves present (36.9%).

The assemblage contains 1 temperate species, *L. inopinata*, and 1 cold stenothermal species, *Cytherissa lacustris* (which may have been reworked from earlier sediments). It also has 3 commonly found species, *C. candida*, *C. neglecta*, and *E. pigra*. *L. inopinata* inhabits temperate ponds and lakes whereas *C. lacustris* is a species of cold ponds and lakes (Robinson, pers. comm.; Griffiths, 1995).

The population was an indigenous one inhabiting a temperate vegetated pond-like habitat with a muddy benthos.

S41.WEL contained a small assemblage of ostracods (total 42 valves, 5 carapaces) of low species diversity (4) with an average number of juvenile moult valves present (55.7%).

The assemblage contained 1 temperate species, *P. serrata* (1valve). It also has 2 commonly found species, *C. candida*, and *C. laevis*. *Eucypris dulcifrons* is a Jurassic species and has been reworked into the younger sediment (Griffiths, pers. comm.).

The environment was not suitable for most ostracod species. It had a muddy benthos inhabited by a thriving *C. candida* population.

S42.WEL contained an medium sized assemblage of ostracods (total 71 valves, 18 carapaces) of average species diversity (7) with an average number of juvenile moult valves present (59.2%).

The assemblage contained 3 temperate species, *L. inopinata, P. marchica* and *P. serrata*. It also has 5 commonly found species, *C. candida, P. marchica, I. bradyi, E. pigra,* and *H. reptans.*

The population was indigenous to the habitat and was well established. The temperate water was vegetated, the dominant species being those of *P. marchica, C. vidua* and *C. candida.*

This indigenous assemblage is similar to the other populations containing *L. inopinata,* such as those of samples S35.WOL, S36.WOL and S38.VF (all collected from further upriver).

8.10.3: SITE J:- Age and environmental factors of the sediments from Wellingborough.

Sample S42.WEL was the youngest ostracod assemblage recovered and is recent (as verified by the *in situ* polythene sheeting). The lower sediments, S40.WEL and S41.WEL were from buried channel-fills (possibly oxbow lakes) within the alluvial deposits of the modern Nene.

Although there are similarities between the assemblages of S38.VF and S42.WEL it is difficult to work out a time scale between the two sedimentary periods. S38.VF was collected from the lowest point sampled, beneath the gravels at Cringle Farm, Wollaston and sample S42.WEL came from within the uppermost alluvial floodplain deposits at Wellingborough. Although the youngest sediment (S42.WEL) is known to be Holocene, the oldest of the two, (S38.VF), is beneath gravels that are, at the surface, cryoturbated. The cryoturbation implies a much older temperate stage for the Vicarage Farm deposits than those of Wellingborough.

Other similar assemblages to these were samples S35.WOL and S36.WOL which were collected from channel-fill deposits within what appears to be early Holocene floodplain deposits 2.0 m in thickness.

8.11. Clast lithological analyses of till and clasts > 32 mm (Table 8.011.1) and < 32 mm (Table 8.11.2-5 plus tables in text for Sites B-J)

8.11.1. Fluvial gravel and till (larger particle size).

A sample of chalky till was collected from Great Houghton Lodge Farm, Great Houghton, Northampton (SP800575) and its lithology compared with that of the till collected from Site G Cringle Farm, Wollaston (sample G6) and the fluvial gravels of Clifford Hill, Cringle Farm, Vicarage Farm and Wellingborough (Table 8.11.1 - 8.11.5).

Analyses show that the two till lithologies were very different in the larger particle sizes (ranging between 32 and 128 mm) (Table 8.11.1). The upper till from Great Houghton contained far less chalk and limestone and, consequently it appeared to contain a larger proportion of ironstone and flint. When comparing both samples of till with the larger gravels (Table 8.11.1), in the >32mm fraction, the uppermost till was seen to contain a greater proportion of local rock than the gravels, except that of Cringle Farm's Second Suite of gravels (G7 and 8) which were closer to the till count. The lowest till, Cringle Farm (G6), has a similar percentage of local rock to that of the gravels (Table 8.11.1). As the upper layers of the chalky till may be decalcified (Davey, 1991b), the two samples of till used for this analyses may not have differed as much as this at the times of original deposition.

Analyses show that the lithological assemblages of both the tills and gravels of larger clast sizes, that is the >32 mm size fraction, had a higher frequency of Bunter quartz and quartzites, only two samples differing in this respect. One was the lowest chalky till, from Cringle Farm, which was dominated by chalk and the other was the second suite of gravels seen at Cringle Farm, Site G2 (samples G7 and 8), which was dominated by limestone (Table 8.11.5).

8.11.2. Fluvial gravel and tills (smaller particle size).

In the Nene Valley Gravels, the lithologies of each of the clast sizes, 4-8 mm, 8-16 mm, and 16-32 mm showed a distinct grouping of the various rock types (Tables 8.11.2-5).

The till below the gravel at Cringle Farm contained, in the clasts less than 16 mm, Jurassic limestone and chalk in equal quantities. The second suite of gravels seen at Cringle Farm, Site G2, samples G7 and 8, which rested directly on the chalky till, contained a high percentage of limestone throughout all the clast size ranges. The clasts in the 4-8 mm size range of the calcareous colluvium samples of Clifford Hill (Sites C, D and E) and the Wellingborough gravels were also dominated by gravels from the local Jurassic Iron- and Limestones.

Interestingly, excluding the lowest chalky till, but not sample G7, gravels from the local Jurassic Sandstone was more abundant in the clasts size range greater than 16 mm, in contrast to clasts of the Northamptonshire Ironstone which increased in frequency as the particle size decreased.

8.11.3. Sands and Gravels of the Milton and Nene Valleys.

Both the particle size and clast lithological analyses of the sands and gravels have proved, generally, of great use in differentiating the gravel suites in the Nene Valley. Less work was done on the Milton Formation but, again, the particle size analyses was useful. It established evidence of the smaller particle size, recognised as coming from the local Northamptonshire bedrocks (Belshaw, pers. comm.), in the lower deposits of the Milton Formation Site G2).

Another important line of evidence from the lithological analyses is that of the large amounts of iron- and limestone clasts in the colluvium. These are smoothed and water-worn and the author suggests that these have been moved from the Milton Valley which is 20 m

Till deposit recovered from 2.00 m below surface, Great Houghton, Northampton.																			
No. of clasts	Sample	Brown Flint	White Flint	Black Flint	Total Flints %	Chert	Liver Quartz	Vein Quartz	Red Vein Quartz	Schorl	Igneous	Chalk	Tot. erratics %	Iron-stone	J. Sand-stone	J. Lime-stone	J. Fossils	Others.	Total local %
TILL	Gt. Hgtn till																		
47	64.0-128.0mm	12.8	14.9	6.4	34.1	0	8.5	4.3	0	0	0	0	46.9	19.1	27.6	6.4	0	0	53.1
46	32.0 - 64.0mm	4.3	0	8.7	13	0	23.9	2.2	2.2	2.2	1.1	9.8	54.4	23.9	8.7	6.5	6.5	0	45.6
94	16.0 - 32.0mm	27.7	17.1	8.4	53.2	6.4	6.4	4.3	1.1	0	0	8.5	79.9	13.9	3.2	2.1	0.9	0	20.1
425	8.0 - 16.0mm	22.2	27.5	18.8	68.5	0	3.3	2.1	0.2	0.2	0.7	0	75	21.7	1.9	1.4	0	0	25
760	4.0 - 8.0mm	13.1	19.9	8.9	41.9	0	1.1	1.6	0	0.5	0	1.3	46.4	52.1	1.1	0.4	0	0	53.6
For comparison with lithology of Gt. Houghton till:- Sample G6: Cringle Farm till. Sample too small to analyse very coarse clasts.																			
TILL	G6:Clast size																		
24	16.0 - 32.0mm	1.8	5.4	12.1	19.3	0	0.7	2.4	0	0	3.1	47.7	73.2	0	2.4	22.2	0.7	1.5	26.8
132	8.0 -16.0mm	2.7	2.9	9.3	14.9	0	0.5	1.2	0	0.1	0.2	40.1	57	2.9	1.1	38.2	0.6	0.2	43
885	4.0 - 8.0mm	1.7	1.7	5.8	9.2	0	0.2	1.1	0.2	0	0.2	42.9	53.8	8.1	0.3	37.1	0.7	0	46.2
FLUVIAL GRAVEL																			
Clifford Hill West Field: Sample 1. Very coarse to small cobble (64-128mm) gravel.																			
438	64.0 - 128mm	20.3	0.2	28.8	49.3	0.2	27.8	1.4	0	0.5	0.2	0	79.4	0	20.1	0.5	0	0	20.6
Clifford Hill West Field:Sample 2. Very coarse (32-50, 50-128mm) gravel.																			
200	50.0-128.0mm	39.5	0	0	39.5	0	48.1	0	0	0	0	0	87.6	0	12.4	0	0	0	12.4
300	32.0 - 50.0mm	36.9	0.8	3.3	41		35.2	4.1	2.5	0.8	0	0	83.6	0.8	15.6	0	0	0	16.4
Cringle Farm Second Suite Gravel.																			
300	32.0 - 64.0mm	16.7	2.1	10.4	29.2	2.1	10.4	2.1	0	4.2	0	8.3	56.3	2.1	12.5	29.1	0	0	43.7
Vicarage Farm: very coarse to small cobble (50-200mm) gravel.																			
300	50.0- 200.0mm	21.7	7.6	6.5	35.8	0.7	33.6	4.9	0.2	0.4	0.9	0	76.5	6.5	15.5	0.9	0.4	0.2	23.5
Wellingborough: Very coarse (32-50) gravel.																			
300	32.0 - 50.0mm	38.3	1.7	5.1	45.1	0	24.5	1.7	0	1.7	0	1.7	74.7	5.1	10.1	10.1	0	0	25.3

Table 8.11.1.

Clast lithological analysis of local till (16mm-200mm) and Nene Valley sediments, clasts size (32 mm - 200 mm).

		Ratios (Flint as 1) of gravels size 4-8mm.												
SITE B	sample	ironst.	limest.	chalk	flint	description		**SITE G1**	sample	ironst.	limest.	chalk	flint	description
Unit D2	BCol.2	**5.8**	0.4	0	1	colluvium		Unit C	G5	**2.6**	0	0	1	decalc.gravel
Unit D1	BCol. 1	**2.8**	0	0	1	colluvium		Unit B	G4	**1.6**	1.2	**1.4**	1	gravel
	BIWF	0.5	0.4	0.1	**1**	cast fill		Unit A	G3	**3**	1	0.4	1	gravel
Unit C	B4	**2.7**	0	0	1	decalc.gravel		,, ,,	G2	0.5	0.1	0.1	1	gravel
,, ,,	B3	**2.8**	0.02	0.01	1	gravel		,, ,,	G1	0.4	**2.5**	0.9	1	gravel
Unit A	B2	**2.7**	0.01	0	1	gravel		**SITE G2**						
,, ,,	B1	**6**	0.03	0.02	1	gravel		Unit D	G10	**2.5**	0.8	0.1	1	cast fill
SITE C								,, ,,	G9	**0.9**	**1.2**	**1.2**	**1**	cast fill
Unit C	CCol.2	**10.6**	**16.5**	0.3	1	colluvium		Unit C	G8	0.6	**1.5**	0.7	1	gravel
,, ,,	CCol. 1	**4.3**	**2.5**	0	1	colluvium		Unit B	G7	0.8	**2.5**	0.8	1	gravel
	CIWF	**3.8**	**2.7**	0.04	1	cast fill		Unit A	G6	0.9	**4.1**	**4.8**	1	C.Farm till
Unit A	C4	**9.9**	0	0	1	decalc.gravel		**SITE H**						
,, ,,	C3	**3.5**	0	0	1	decalc.gravel		Unit C2	H3	0.9	**2.6**	0.8	1	gravel
,, ,,	C2	**3.5**	0.01	0.01	1	gravel		Unit C1	H2	**4.6**	1	0.5	1	gravel
,, ,,	C1	**4.1**	0.04	0.1	1	gravel		Unit A	H1	**1.9**	**1.8**	0.7	1	gravel
SITE D														
Unit D	DCol. 1	**12.5**	**2.5**	0.1	1	colluvium								
Unit B	D1	**3.2**	0.05	0.05	1	gravel								
SITE E								SITE J						
Unit E	ECol. 3	**9.7**	**3.9**	1.7	1	colluvium		Unit A4	J4	**3.2**	0	0	1	decalc.gravel
Unit D2	ECol. 2	**5.9**	**5.2**	1.7	1	colluvium		,, A3	J3	**2.4**	**1.8**	0.8	1	gravel
Unit D1	E6	**7.2**	0.2	0.2	1	gravel		,, A2	J2	**4.3**	**2.6**	1	1	gravel
,, ,,	E5	**4.7**	0.3	0.2	1	gravel		,, A1	J1	**2.8**	0.1	0.2	1	gravel
,, ,,	E4	**6.4**	0.4	0.2	1	gravel								
Unit B1	ECol. 1	**14.6**	0	0	1	decalc.colluvium			Gt. Hgtn. Till	**1.2**	0.01	0.03	**1**	topmost
Unit A	E3	**2.7**	0	0	1	decalc.gravel								
,, ,,	E2	**2.4**	0	0	1	decalc.gravel			C. Farm Till	0.9	**4.1**	**4.8**	1	lowest
,, ,,	E1	**2.3**	0	0	1	decalc.gravel								
SITE F									**bold numbers represent dominant rock type**					
Unit C	FCol. 1	**9.1**	3	1	1	colluvium								
Unit A	F1	**4.5**	0.1	0.1	1	gravel								

Table 8.11.2. Ratios of dominant rock types found in the lithological analyses of tills and Nene valley gravels: 4-8mm clasts.

		Ratios (Flint as 1) of gravels size 8-16mm.												
SITE B	sample	ironst.	limest.	chalk	flint	description		**SITE G1**	sample	ironst.	limest.	chalk	flint	description
Unit D2	BCol. 2	**1**	0.01	0	**1**	colluvium		Unit C	G5	0.7	0	0	**1**	decalc.gravel
Unit D1	BCol.1	**1**	0	0	**1**	colluvium		Unit B	G4	0.6	0.7	0.05	**1**	gravel
	BIWF	**1**	0	0.2	**1**	cast fill		Unit A	G3	**1.8**	0.5	0.2	1	gravel
Unit C	B4	0.5	0	0	**1**	decalc.gravel		" "	G2	**1.3**	0.5	0.06	**1**	gravel
" "	B3	**1**	0.06	0	**1**	gravel		" "	G1	0.4	**1.1**	0.8	**1**	gravel
Unit A	B2	**1.5**	0.01	0	1	gravel		**SITE G2**						
" "	B1	**1.9**	0.02	0	1	gravel		Unit D	G10	**1**	0.5	0.3	**1**	cast fill
SITE C								" "	G9	0.2	0.3	0.2	**1**	cast fill
Unit C	CCol. 2	**4.9**	**11.3**	0.05	1	colluvium		Unit C	G8	0.2	0.7	0.3	**1**	gravel
" "	CCol.1	**5**	**3.4**	0	1	colluvium		Unit B	G7	0.4	**1.5**	0.4	1	gravel
	CIWF	0.5	0.6	0	1	cast fill		Unit A	G6	0.2	**2.6**	**2.7**	1	C.F.till/gravel
Unit A	C4	**1.1**	0	0	**1**	decalc.gravel		**SITE H**						
" "	C3	**1.4**	0	0	1	decalc.gravel		Unit C2	H3	0.6	**1.6**	0.7	1	gravel
" "	C2	**2.1**	0	0	1	gravel		Unit C1	H2	**1.3**	0.6	0.1	**1**	gravel
" "	C1	**1.9**	0.03	0.07	1	gravel		Unit A	H1	**0.9**	0.4	0.2	**1**	gravel
SITE D						gravel								
Unit D	DCol. 1	**5.3**	0.4	0.6	1	colluvium								
Unit B	D1	**0.9**	0.04	0.02	**1**	gravel								
SITE E								SITE J						
Unit E	ECol. 3	**4.8**	**1.8**	0.4	1	colluvium		Unit A4	J4	**1.5**	0	0	1	decalc.gravel
Unit D2	ECol. 2	**2.7**	**2**	**2.3**	1	colluvium		,, A3	J3	**1.4**	0.4	0.4	1	gravel
Unit D1	E6	**3.5**	0.2	0.2	1	gravel		,, A2	J2	**1.4**	0.9	0.2	1	gravel
" "	E5	**2.4**	0.2	0.1	1	gravel		,, A1	J1	**1.7**	0.7	0.06	1	gravel
" "	E4	2	0.4	0.4	1	gravel								
Unit B1	ECol. 1	**19.3**	0	0	1	decalc.colluvium			Gt. Hgtn. Till	0.3	0.02	0.01	**1**	topmost
Unit A	E3	0.9	0	0	1	decalc.gravel								
" "	E2	**1.2**	0	0	**1**	decalc.gravel			C. Farm Till	0.2	**2.6**	**2.7**	1	lowest
" "	E1	**1.1**	0	0	**1**	decalc.gravel								
SITE F														
Unit C	FCol. 1	**6.1**	**2.3**	0.6	1	colluvium								
Unit A	F1	**1.9**	0.3	0.1	1	gravel	**bold numbers represent dominant rock type**							

Table 8.11.3. Ratios of dominant rock types found in the tills and Nene Valley gravels: 8-16 mm clasts.

	Sample & no. of clasts.	Brown Flint	White Flint	Black Flint	Total flints %	Chert	Liver Quartz	Vein Quartz	Red Vn. Qtz.	Schorl	Igneous	Chalk	Tot. erratics %	Ironstone	J. Sandstone	J. Limestone	J. Fossils	Others.	Total local %
Site B																			
Unit C	B3+B4 (255)	24.7	5.9	8.4	**39**	0	24.2	6.2	1.6	3.1	0	0	**74.1**	16.5	9.4	0	0	0	**25.9**
Unit A	B1+B2 (151)	30.5	9.3	5.9	**45.7**	0	19.9	5.9	0.7	1.4	0	0	**73.6**	15.2	11.2	0	0	0	**26.4**
SITE C																			
Unit A	C3+C4 (196)	27.5	5.6	11.2	**44.3**	0	20.4	5.6	0	1.1	0	0	**71.4**	20.4	8.2	0	0	0	**28.6**
,,	C1+C2 (268)	21.6	10.4	11.6	**43.6**	0	17.9	11.2	0.4	0.4	0	0	**73.5**	14.2	8.9	3.4	0	0	**26.5**
SITE D																			
Unit B	D1 (159)	26.4	15.1	1.3	**42.8**	0	24.5	6.3	0.6	0	0	0	**74.2**	12.6	12.6	0	0	0.6	**25.8**
SITE E																			
Unit D	E6 (220)	21.6	3.1	4	**28.7**	0.4	18.9	2.2	6.2	0.9	0	0.9	**58.2**	27.3	5.2	6.2	0.9	2.2	**41.8**
,,	E5 (664)	26.1	12.1	1.6	**39.8**	0	13.7	11.1	1.2	0.9	0	1.5	**68.2**	24.2	2.9	3.3	0.6	0.8	**31.8**
,,	E4 (374)	23.5	0.3	4.3	**28.1**	0.3	18.1	7.8	1.9	1.1	0	5.6	**62.9**	22.7	2.9	7.8	0.8	2.9	**37.1**
Unit A	E1+E2&E3 (270)	32.9	12.6	2.6	**48.1**	0	17.5	4.4	0.8	0	0	0	**70.8**	20.3	8.5	0	0	0.4	**29.2**
SITE F																			
Unit A	F1 (111)	22.5	9.9	8.2	**40.6**	0	19.8	5.4	0	0.9	0	0.9	**67.6**	21.6	6.3	4.5	0	0	**32.4**
SITE G2																			
Unit C	G8 (300)	22.2	12.5	5.1	**39.8**	0	12.9	4.2	0.3	1.1	0	1.3	**59.6**	6.1	5.1	29.2	0	0	**40.4**
UnitB	G7 (300)	21.2	12.2	5.2	**38.6**	0	7.1	4.6	0	0.6	0	4.6	**55.5**	5.8	6.5	32.2	0	0	**44.5**
Unit A	C.Farm till (G6)	1.8	5.4	12	**19.2**	0	0.8	2.4	0.8	0	3	47	**73.2**	0	2.4	22.2	0.7	1.5	**26.8**
SITE G1																			
Unit B	G4 (300)	32.5	7.2	12.1	**51.8**	0	7.2	6.1	0	0	0	0	**65.1**	4.8	7.2	22.9	0	0	**34.9**
Unit A	G1+G2&G3(300)	25.8	5.1	6.2	**37.1**	0	14.6	9.6	0	0	0	2.2	**63.5**	9.6	15.1	11.2	0.6	0	**36.5**
SITE J																			
Unit A1	J1 (300)	16.1	7.1	7.8	**31**	0.8	10.9	8.2	0.4	2.3	0	2.8	**56.4**	8.2	9.3	24.5	1.6	0	**43.6**
TILL	C.Farm till (G6)	1.8	5.4	12	**19.2**	0	0.8	2.4	0.8	0	3	47	**73.2**	0	2.4	22.2	0.7	1.5	**26.8**
,,	Gt.Hgtn. till	27.7	17.1	8.4	**53.2**	6.4	6.4	4.3	1.1	0	0	8.5	**79.9**	13.9	3.2	2.1	0.9	0	**20.1**

Table 8.11.4. **Clast lithological analysis of local till and Nene Valley sediments, clasts size 16 mm -32 mm.**

	Ratios of dominant rock types in 16-32 mm clast samples.							
	sample no.	ironst.	sandst.	limest.	chalk	quartz.	flint	description
Site B								
Unit C	B3+B4	0.4	0.2	0	0	**0.8**	**1**	decalc.gravel
Unit A	B1+B2	0.3	0.2	0	0	0.6	**1**	decalc.gravel
SITE C								
Unit A	C3+C4	0.5	0.2	0	0	0.6	**1**	decalc.gravel
,,	C1+C2	0.3	0.2	0.07	0	0.7	**1**	gravel
SITE D								
Unit B	D1	0.3	0.3	0	0	0.7	**1**	decalc.gravel
SITE E								
Unit D	E6	**1**	0.2	0.2	0.03	**1**	**1**	gravel
,,	E5	0.6	0.7	0.08	0.03	0.7	**1**	gravel
,,	E4	**0.8**	0.1	0.3	0.2	**1**	**1**	gravel
Unit A	E1+E2&E3	0.4	0.2	0	0	0.5	**1**	decalc.gravel
SITE F								
Unit A	F1	0.7	0.09	0	0	0.4	**1**	decalc.gravel
SITE G2								
Unit C	G8	0.2	0.1	0.7	0.03	0.4	**1**	gravel
Unit B	G7	0.2	0.2	**0.9**	0.1	0.3	**1**	gravel
Unit A	G6	0.2	0.1	1.1	**2.6**	0.2	1	chalky till/gravel
SITE G1								
Unit B	G4	0.1	0.1	0.4	0	0.3	**1**	gravel
Unit A	G1+G2&G3	0.3	0.4	0.3	0.06	0.7	**1**	gravel
SITE J								
Unit A1	J1	0.3	0.3	0.7	0.08	0.6	**1**	gravel
TILL	GT. HGHTN Till	0.3	0.06	0.04	0.2	0.2	**1**	chalky till
TILL	C FARM TILL (G6)	0.2	0.1	1.1	**2.6**	0.2	1	chalky till
			bold numbers represent dominant rock type					

Table 8.11.5. Ratios of dominant rock types found in the tills and Nene Valley gravels: 16-32 mm clasts.

higher in the landscape and to the east of the modern Nene Valley (Discussion, Chapter 4, sections 4.02-05).

The Nene Gravels were laid down in a complex braided river system (as in Figure 1.01.3). Channels have incised tunnel valley lake clays and earlier, now decalcified, gravels (Site E). This suite of gravels followed a period when the Nene Valley contained pre-glacial sands and gravels (See Chapter 4) of the Milton Formation type, which are of local origin, indicating deposition occurred before any glacial tills were laid down. That the valley may then not have been as wide, prior to the tunnel valley, is not in dispute, but at some point it was widened to 1 km plus and the river migrated regularly across the valley (Sites B and C). Evidence for two or, possibly, three terraces (Sites G1 and G2) has been considered. Each of the terraces has been subject to freezing conditions for long periods of time (Sites B, C, D, E, F, G). Finally, downstream, where the river valley narrows and reworking is the norm, Late glacial and Holocene material has been recovered and examined (Sites H and J).

8.11..4. Terraces of the Nene Valley.

Castleden (1976) writes, "*The First Terrace and the floodplain are differentiated topographically by a step of about 2 m, [although] the gravels beneath them are continuous and similar in age and character*". In his paper on the Second and Third Terraces (1980b) he writes " *The Second Terrace gravels rest on a valley-side bench whose floor is only 1 m above the top of the first Terrace gravels*". At various points in the Nene Valley between Northampton and Wellingborough Castleden (1980b) found the Second Terrace (his 'Grendon' gravels) to be thicker than those at Grendon (south-west and upstream of Cringle Farm) (SP878617). These occur where there are large tributaries to the Nene which would have deposited gravels, sands and clays. It is proposed that where the additional thicknesses occur there are, in fact, alluvial fans on top of the Second Terrace deposits.

It is possible that at Site G1 Floodplain gravels cut into and overlie First Terrace gravels, as Castleden suggests occurs elsewhere in the valley, and, agreeing again with Castleden, the two suites have a similar character. At Cringle Farm, however, there is a third suite of different character; it is separated by a change in basal level and the amount of disturbance by cryoturbation. The gravel suites of Sites G1 and G2 are very different in appearance. Thus, the river has cut down through the Second Terrace deposits (Site G2) and deposited First Terrace gravels. The First Terrace would then have been partially incised and Floodplain gravels laid down, as seen at Site G1.

If the gravels at Site G2 are Second Terrace (base about 51-52 m O.D.) this would bring the terraces in line with the evidence at Clifford Hill, Site E, and the idea that the oldest gravels (base about 56 m O.D) are those emplaced before the incision of the tunnel valley.

Shotton suggested that the site at Little Billing (Morgan, 1969, Shotton, 1973) was the Nene Second Terrace. However, both Castleden's (1976) and the author's findings disagree with this and find the sediments at Little Billing (Castleden's 'Ecton' gravels) to be Floodplain gravels. considered to be those of the Second Terrace, the gravels of Site G1 thus being those of the First Terrace.

8.12. The significance of the ostracod analyses for the Nene Valley, Central Northamptonshire.

8.12.1 Distribution of the ostracods.

Ostracod valves were found in organic-rich clay horizons beneath and within the sand and gravels. The distribution was uneven, a reflection of changes in the aquatic environment. Most of the valves were well preserved, most sediments containing a mixture of both adult and juvenile instars (moult stage valves) (Table 8.12.1).

The analyses show that the number of ostracods recovered from the 42 samples of sediment varied from 2 to 225 individuals (valves). The number of species per sample ranged from 1 to 11. The average number of valves per species was between 10 and 20.

Of the sites, the Milton Formation contained the highest number of species (16). Of

Sample name	No. of valves	No. of juveniles	% juv.	No. of carapaces
MILTON FORMATION				
SITE A				
S1.MS	73	20	27.4	2
S2.MS	34	25	65.8	0
S3.MS	36	34	96.4	0
S4.MS	126	25	19.8	0
S5.MS	179	20	11.2	0
S6.MS	15	7	41.6	0
NENE VALLEY				
SITE B				
S7.CH	16	2	12.5	0
S8.CH	33	20	60.6	8
SITE C				
S9CH	60	14	23.4	1
S10.CH	27	6	22.2	0
S11.CH	126	37	29.3	6
S12.CH	112	57	50.8	3
S13.CH	40	20	50%	0
S14.CH	4	0	0	0
S15.CH	12	12	100%	1
S16.CH	36	32	88.8	1
S17.CH	74	39	52.7	0
S18.CH	4	4	100%	0
SITE D				
S19.CH	2	0	0	0
S20.CH	7	0	0	0
S21.CH	6	0	0	0
S22.CH	27	0	0	0

Sample name	No. of valves	No. of juveniles	% juv.	No. of carapaces
NENE VALLEY				
SITE E				
S23.CH	17	0	0	0
S24.CH	104	15	16.4	17
S25.CH	9	9	100%	0
S26.CH	127	53	41.7	17
S27.CH	5	1	20%	0
S28.CH	80	8	35%	0
SITE F				
S29.CH	124	42	33.8	18
S30.CH	74	14	20.2	36
S31.CH	194	36	17.2	82
S32.CH	40	9	22.5	0
S33.CH	37	4	10.8	0
S34.CH	11	3	27.2	0
SITE G				
S35.WOL	31	21	67.7	1
S36.WOL	0	0	0	0
S37.WOL	18	17	96.4	5
SITE H				
S38.VF	228	99	43.4	2
SITE J				
S39.WEL	2	0	0	0
S40.WEL	63	22	36.9	3
S41.WEL	52	29	55.7	5
S42.WEL	109	64	59.2	18

Table 8.12.1. The total number, number and percentage of juveniles and number of carapaces recovered from the ostracod assemblages of the Milton Formation and the Nene Valley gravels.

the Nene Valley sediments, site C contained 14 species and site F 13 species; the remaining sites contained fewer species than those referred to here (Table 8.12.2).

8.12.2. Summary: Nene Valley ostracods.

There are five major ostracod assemblages found in the sediments between Northampton and Wellingborough in the Nene Valley; a) Clifford Hill West Field (two assemblages), b) Clifford Hill Middle Field, c) Vicarage Farm and d) Cringle Farm and Whitworth Mills, Wellingborough.

a) Clifford Hill West Field: The assemblages (Table 8.02.3) at this site contain, among others, *C. neglecta, C. rawsoni/lactea, I. bradyi, I. biplicata* and *C. laevis.* The species list suggests stages earlier than the Oxygen Isotope Stage 6, probably Oxygen Isotope Stage 11 or 9. The presence of the extinct species *I. schwarzbachi*, not recorded in Britain except at Cromer (Robinson, 1990), suggests a Middle Pleistocene age for this ostracod.

The upper assemblage, noted for the presence of both species *I. biplicata* and *C. rawsoni/lactea,* neither of which occur in Britain today, when both together, must place the sediments in Oxygen Isotope Stage 5e or earlier.

Of interest to this site, in particular, is the absence of *C. candida* and the presence of *C. rawsoni/lactea.* It is unusual to find a site where *C. candida* is absent. It is, according to Griffiths (1995), recorded from over 30 sites in Britain from the late Beestonian onwards. Its absence cannot be explained, but the whole species list is unusual in having the species *I. biplicata, I. schwarzbachi* and *C. rawsoni/lactea* which have not been found in the Milton Formation or anywhere else in the Nene Valley sediments.

b) Clifford Hill Middle Field: The assemblages (Table 8.04.2) at this site contain, among others, *C. neglecta, C. candida, I. bradyi, Ilyocypris* sp. A, *C. laevis, P. arcuata* and *E. pigra.* Apart from *Ilyocypris* sp. A, the species list suggests a Devensian interstadial stage.

Apart from the second British Pleistocene records of *P. similis* (S22.CH) and *A. tonnensis* (S19.CH) (Griffiths, pers. comm.) this site is remarkable for the presence of *C. candida* and the absence of *C. rawsoni/lactea.*

Site letter	A	B	C	D	E	F	G	H	J	TOTAL
Species										Sites
D. stevensoni							*			1
L. falcata (ex)	*									1
L. inopinata							*	*	*	3
L. santipatricii	*				*			*		3
C. lacustris									*	1
C. candida	*			*	*	*	*	*	*	7
C. neglecta		*	*	*	*	*	*	*	*	8
C. rawsoni/lactea		*	*							2
F. fabaeformis	*							*		2
P. marchica	*		*		*			*	*	5
C. globosa						*				1
C. laevis	*	*	*		*	*			*	6
I. biplicata		*	*							2
I. bradyi			*	*	*	*	*	*	*	7
I. gibba	*		*		*		*	*		5
I. papillata (ex)	*									1
I. schwarzbachi (ex)			*							1
I. sp. A (ex)	*		*			*		*		4
E. dulcifrons (ex)									*	1
E. pigra	*		*	*	*	*		*		6
E. virens	*									1
P. serrata			*		*	*		*		4
T. clavata						*				1
B. fuscatus	*		*							2
H. reptans	*	*	*			*			*	5
P. olivaceus						*				1
H. incongruens	*		*			*				3
C. vidua								*	*	2
P. arcuata	*				*	*	*		*	5
P. similis				*						1
A. tonnensis				*						1
Species	16	5	14	6	10	13	7	12	11	Total

A: Milton Formation

B - J :-

Nene Valley deposits between Northampton and Wellingborough.

ex: extinct

Table 8.12.2.The number of ostracod species recovered from each site and the number of sites from which each species was recovered.

c) Vicarage Farm, near Wellingborough: Apart from *L. sanctipatricii* and *Ilyocypris* sp. A, the assemblage (Table 8.07.3) at this site contains species similar to those in Britain today and it is believed this assemblage is from the last interglacial, Oxygen Isotope Stage 5e. Of special note in this assemblage is the cold stenothermal species *L. sanctipatricii.* At this site it possibly lived in a cool, temperate stage of Oxygen Isotope Stage 5e. The climate, although cool, was warm enough to sustain *P. serrata* (a species also found in sites B and C), which is a species of temperate pools. As previously indicated in the analysis of the Milton Formation, *L. sanctipatricii* has not, up till now been found in material older than the Devensian. This is only the second time *P. serrata* has been recorded in the British Pleistocene (Griffiths, pers. comm.).

d) Cringle Farm, Wollaston and Whitworth Mills, Wellingborough: The assemblages (Table 8.07.3) at this site contain species typical of the Holocene (present interglacial) and contain, among others, *C. neglecta, C. candida, I. bradyi* and *L. inopinata.*

The five assemblages suggest at least five major changes in the environment of deposition in the Nene Valley between Northampton and Wellingborough and, possibly several shorter periods of change within the major ones. As the ostracod assemblages represents only the cool temperate and temperate deposits, it appears Oxygen Isotope Stage 12 and the four long intervening cold stages are represented by deposition of coarse sediments and down-cutting of the valley sediments; these stages also being interrupted by shorter periods of climatic change.

8.13. Model proposed for the early-Anglian to the modern Nene Valley.

Using a combination of the ostracod and sedimentary data from each site a chronological order of deposition can be drawn up (Table 8.13.1).

A model of the Nene Valley based on the data (Table 8.13.1) shows a succession of warm and cold stages from the early Anglian (Oxygen Isotope Stage 12) to the present day (Figure 8.13.1). The findings of this model are discussed further in Chapter 8.

SITE	STRATIGRAPHY	AGE OF SEDIMENTS
Site J, Wellingborough	b) Channel incised alluvium and infilled	**Holocene: ostracods**
,,	with fine sediments (Holocene).	
,,	a) Reworking and deposition of gravels	Devensian/early Holocene
,,	(Floodplain), deposition of alluvium.	
Site G1, Cringle Farm,	b) Channel incised alluvium and infilled	**Holocene: ostracods**
Wollaston.	with fine sediments (Holocene).	
,,	a) Incision of O.I.S. 10 and 8 gravels (2nd T).	Devensian/early Holocene
,,	Deposition of O.I.S. 6 gravels (1st T), and,	
,,	after periglaciation, incision and deposition of	
,,	Devensian and Holocene gravels (Floodplain)	
,,	and alluvium.	
Site F,Clifford Hill Middle Field,	c) Deposition of colluvium, periglaciation.	Devensian
Little Houghton.	b) Incision of lower gravels and infilling	**Middle Devensian:-**
,,	with sands and silts (Floodplain & 1st T).	**26,840 B.P.: ostracods**
,,	a) Deposition of lower gravels followed	O I. S. 6 or earlier
,,	by periglaciation.	
Site E,Clifford Hill Middle Field,	c) Deposition of colluvium, periglaciation.	Devensian
Little Houghton.	b) Incision of older gravels (O.I.S. 6, 1st T)	**Early/Middle Devensian:**
,,	and infilling of channel.	**ostracods**
,,	a) Deposition of lower gravels (1st T)	O I. S. 6
(see Table 7.04.1b)	followed by periglaciation.	
Site H, Vicarage Farm,	c) Upper gravel deposition followed	Devensian
Wollaston.	by periglaciation (Floodplain over 1st T).	
,,	b) Incision of lower gavels (1st T) and infilling	**Late.O.I.S. 5e: ostracods**
,,	of channel.	
,,	a) Deposition of lower gravels followed	O I. S. 6
,,	by periglaciation (1st T).	
Site B, Clifford Hill, West Field,	d) Upper gravel laid down (O.I.S. 8).	
Little Houghton.	C) Incision and infill of fine sediment.	**O.I. S. 8 :ostracods**
,,	b) Infill of lower gravel (O.I.S. 8)	
,,	a) Incision of O.I.S. 10 gravels (2nd T).	O.I. S. 8
Sites B and C, Clifford Hill	Gravels and upper sediments	Pre- Devensian Periglaciation
West Field, Little Houghton.	subjected to permafrost. Large ice	
,,	wedges formed (1st T).	

Table 8.13.1. Summary of incision, deposition and age of each site. This table gives an indication of the chronological order of deposition at each site investigated.

SITE	STRATIGRAPHY	AGE OF SEDIMENTS
Site C, Clifford Hill, West Field,	e & f) Incision and infilling of channel (C2)	**Interstadial or Late**
Little Houghton.	followed by periglaciation.	**O.I.S. 7: ostracods**
,,	g) Fine sediments deposited on O.I.S. 10	O I. S. 8 and 6
,,	overbank sediments. Deposition was	
,,	followed by periods of periglaciation.	
,,	Stone-sorted polygons featured above	
	earlier ice wedge casts.	
,,	f) Incision and deposition (Site B): O.I.S. 8.	O.I.S .8
,,	e) O.I.S. 10 deposition of upper gravels	
,,	d) O.I.S. 10 deposition: organic lower gravels.	**O.I.S. 10: ostracods**
,,	c) Fine sediments beneath lower gravels (C1).	**O.I.S. 11: ostracods**
,,	b) O.I.S. 12 gravels incised.	O.I. S.12
,,	a) Deposition of O.I.S. 12 gravels.	
Site D,Clifford Hill Middle Field,	c) Deposition of gravels followed	O I. S. 6
Little Houghton.	by periglaciation (1st T).	
,,	b) Deposition of fine sediments	deposition of fine sediments
,,	on the bedrock in O.I.S. 7.	**O.I. S. 7: ostracods**
,,	a) End of O.I.S. 8, incision of O.I.S. 8	
,,	gravels (2nd T)	
Site G2, Cringle Farm,	Reworked gravels deposited on bedrock.	O.I. S. 10
Wollaston.	Bedrock and gravels cryoturbated in later	
,,	periglacial periods.	
,,	N.B. O.I.S. !2 gravels removed by reworking	Pre-tunnel valley.
Site E,Clifford Hill Middle Field,	Gravel overlain by fine waterlain sediments	O.I. S. 12, pre-tunnel
Little Houghton.	and overbank sediments, all decalcified.	valley
(see Table 7.04.1a)	After deposition the sediments were	
,,	subjected to more than one episode of	
,,	permafrost. (Sediments: 2nd T).	
See Chapter 4 of thesis.	Milton River enters early Nene Valley and	At some stage before
,,	incises bedrock.	O.I.S. 12
Site A, Milton Formation,	Pre-glacial sands and gravels overlain by	**O. I. S. 13 or earlier:**
Courteenhall	remnants of lower till and upper	**ostracods**
,,	Anglian till.	

Table 8.13.1 (continued). Summary of incision, deposition and age of each site. This table gives an indication of the chronological order of deposition at each site investigated.

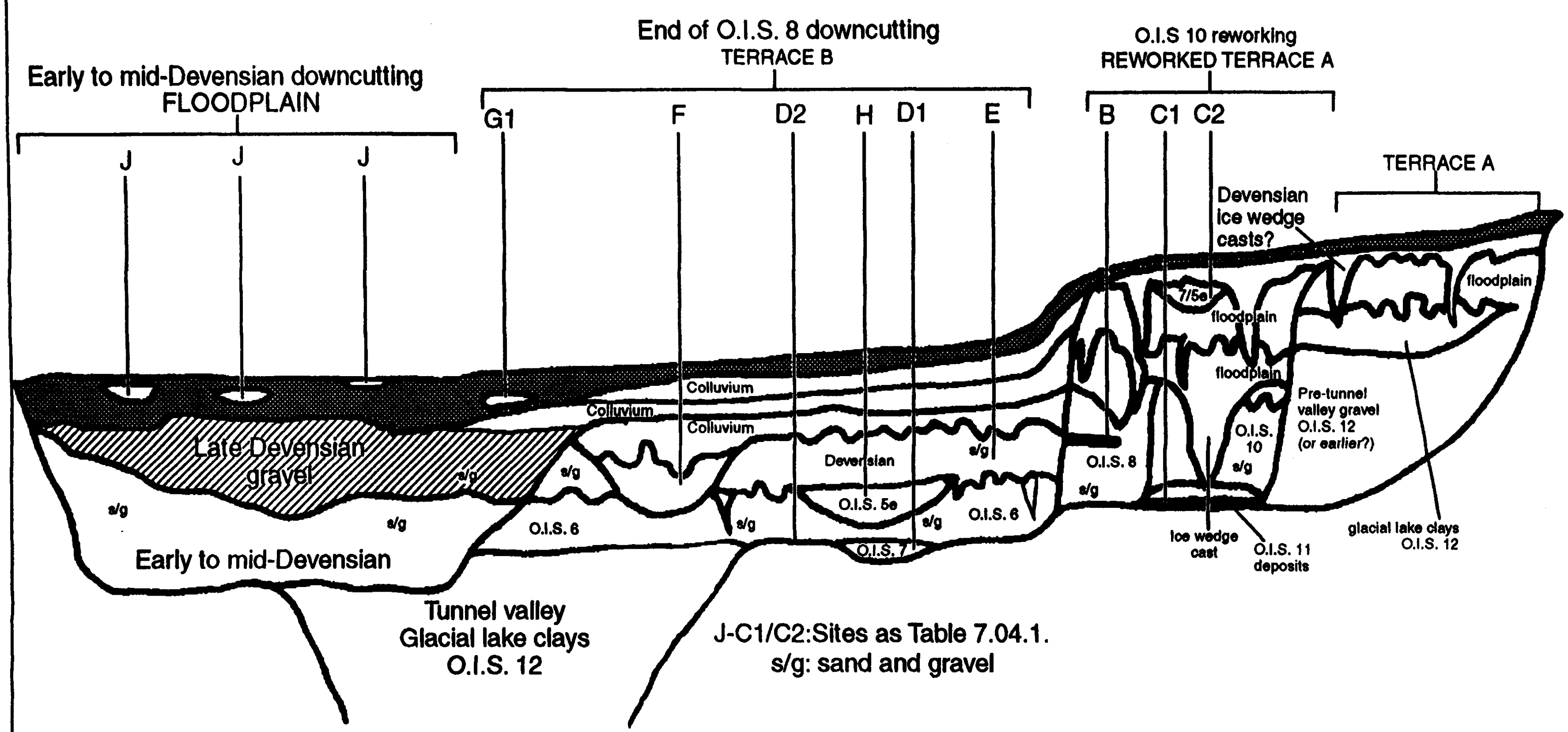
8.14. The status of the 'Wolstonian' in Northamptonshire.

This study confirms the cold Oxygen Isotope Stage 6 at Northampton was a periglacial and not a glacial period as thought by Castleden in 1976. In fact, the Oxygen Isotope Stages 7 and 6 deposits at Northampton, (Figure 8.13.1) may correlate with those found at Stanton Harcourt, Oxfordshire (Briggs *et al.,* 1985) or, turned round, Stanton Harcourt may correlate with sediments in the Nene Valley using the Nene Valley as the standard. At Stanton Harcourt the lower meandering channel-fill is seen to cut through the Oxford clay bedrock. These fossiliferous deposits contain an interglacial fauna similar to that of the proposed Oxygen Isotope Stage 7 remains found beneath gravels at Clifford Hill. The gravels overlying the Stanton Harcourt channel are described as having been subjected to periglaciation and show features very similar to those of the proposed Oxygen Isotope Stage 6 deposits at Clifford Hill quarry, Little Houghton, Northampton. The author suggests that the data of the Nene Valley may be applied to data recorded from the Stanton Harcourt Quarry to see if she is correct in this supposition.

8.15. Other faunal remains.

The 200 samples of organic sediments collected for washing and sorting contained varying amounts of other microfossils (molluscs, beetle remains, plant macrofossils). Only 42 of these contained ostracods. The molluscs, beetle remains and plant macros have been stored for evaluation in the future.

The organic sediments found on site contained varying quantities of other microfossils (molluscs, beetle remains, plant macrofossils) and larger mammal remains (mammoth, woolly rhinoceros, bison, Norway lemmings, straight-tusked elephant, deer and other species). All the larger faunal remains have been preserved and stored for identification and documentation.



10: Holocene deposits above Late Devensian Gravels (J).
9: Holocene deposits above Devensian Gravels (G1).
8: Mid-Devensian interstadial deposits beneath Late Devensian colluvium (F).
7: Early Devensian cool stage gravels (E).
6: Cool temperate stage of O.I.S. 5e beneath Devensian gravels (H).
5: O.I.S. 7 or 5e temperate deposits on earlier floodplain (C2).
4: Downcutting; O.I.S. 7 temperate deposits in channel beneath O.I.S. 6 cold stage gravels (D).
3: Downcutting aggradation of O.I.S. 8 gravels with interstadial organic deposits.
2: O.I.S. 11 temperate deposits beneath O.I.S. 10 cold stage gravels (C1).
1: Downcutting of existing preglacial valley; deposition of cold stage gravels; incision and infilling of O.I.S. 12 tunnel valley.

8.13.1 A stratigraphic model of the Nene Valley at Little Houghton; Based on the stratigraphic, sedimentological and ostracod analyses of this site and downstream to Wellingborough.

CHAPTER 9: SUMMARY AND CONCLUSIONS: THE EVOLUTION OF THE MILTON AND NENE VALLEYS.

9.01 Introduction

The following chapter synthesizes the reconstruction of the earliest Quaternary formations (Chapter 4), the previous work reviewed (Chapter 2) and new field work, including the ostracod data, from Chapters 5, 7 and 8. The chapter will discuss first, the overall change in the fluvial pattern at Northampton and then evolution of the two rivers, the Milton River and the River Nene, in particular using the desk top study of the Milton Formation and field evidence of its sediments at Courteenhall, and of the Nene Valley sediments between Northampton and Wellingborough. The chapter ends with conclusions drawn from the desk top studies of ostracod environments and the distribution of the Milton Formation, and the lithological, sedimentological, stratigraphic and ostracod evidence put together in this thesis.

9.02. Summary to the Anglian glaciation: The overall changes occurring in the fluvial system at Northampton (in chronological order).

a) Reconstruction of the topography to the west of Northampton (Figures 4.01.5 and 4.04.1) shows that the early river system of the Nene is probably the same age as the earliest Milton River. The two rivers, flowing from west to east, were parallel to each other but separated by an interfluve. The River Nene was probably a tributary joining the Milton River to the east of Northampton (Figure 4.01.6). Small outcrops at Sixfields, Northampton, of locally derived sand and gravel at 67-73 m O.D. show that, at that time, the Nene Valley contained pre-glacial sediments similar to the Milton Formation (Chapter 4: Section 4.11).

b) The topography and, consequently, the fluvial systems are to a significant extent fault-bounded at Northampton. The lithological variation of the land surface led to differential erosion of the bedrocks (Figure 4.04.1).

c) The distribution of the Milton Formation and other pre-glacial sands and gravels in a large valley in central Northamptonshire apparently indicates that the early Milton River flowed from the west of the county and to the south of Hunsbury Hill at Northampton (Figure 1.01.4). From Northampton it followed a similar course to that of the modern Nene, but to the south of the Nene Valley. Subsequently it flowed north-eastwards towards Wellingborough and Rushden and then to the south-east from Rushden / Higham Ferrers (Figure 4.01.4). The sub-drift topography shows that the Milton River could not, as suggested by Castleden (1980a), have flowed to the south-east at Northampton.

d) After the deposition of the Milton Formation, but before the onset of glaciation, the continuing process of differential erosion caused a breach of the Ironstone ridge to the west of Hunsbury Hill (Figure 2.01.4 B) (Thompson, 1930a). The Milton River then diverted into the early River Nene, the valley of which, because it formed in the softer, faulted Northamptonshire Ironstone, was probably already incised to a slightly lower level. The Milton Formation was left as a deposit in its old valley. The tributaries entering the Milton Valley from the south would have extended themselves over the Milton Formation deposit as they continued north to enter the Nene Valley.

As the confluent Milton/Nene River incised deeper into its own valley, the Milton Formation was left as an outcrop in the hills (Figure 4.01.6) that form the interfluve between the present Nene and Ouse valleys.

e) The confluent Milton and Nene River may still have crossed the limestone platform towards the south-east at Rushden / Higham Ferrers. However, the early, now buried, river bed to the south-east of Rushden is found at a pre-glacial height above sea level, which is compatible with that of the Milton Formation at Northampton (Chapter 4: Section 4.08). This suggests that the flow of the confluent Milton/Nene River was diverted from the south-east to the north-east at Rushden / Higham Ferrers, as early as the onset of the first glaciation.

f) The Yardley Chase valley (now buried) is younger than the Milton River valley and is not, as believed possible by Castleden (1980a), part of the Milton River system. From past research of Thompson (1930a), Horton (1970) and Castleden (1980a), it is possible to establish that the Yardley Chase valley, at base level of 53 m O.D., incises the Milton Valley (at base level 72 m O.D.) at right angles. Borehole evidence (Table 4.05.1, Figure 4.05.3) shows that the infill of the Yardley Chase valley consists of till and outwash sands and gravels with very little chalk and no flint. These sediments are overlain by chalk- and flint-rich Anglian till (Chapter 4: Sections 4.05 & 6). The sediments and the difference in depth of the two valleys (20 m) indicates that the Yardley Chase valley was cut during or after the earliest glaciation and infilled before the deposition of the flint- and chalk-rich upper till.

g) An early (pre-Anglian?) glaciation deposited till and outwash with clast assemblages, dominated by quartz and quartzites and lacking chalk and flint other than a minute quantity of extremely weathered flint, that indicated movement from the north-west. Most of the till deposited by the early glaciation was eroded before or by the later glaciation. There are, however, some chalk- and flint-free till and gravel deposits recorded at Long Buckby and Yardley Hastings, (Thompson, 1897, 1930a), and at Brigstock, near Kettering (Kellaway and Taylor, 1952).

h) A second ice advance (Anglian) came from the east/north-east, depositing chalk- and flint-rich tills and outwash. The gravel and finer sediments from the earlier glacial event could have been mixed with pro-glacial chalky gravel outwash before actual glaciation at Northampton. These gravels would then have been deposited in the Nene Valley before the tunnel valley formed in the Anglian glacial event (see below).

i) During the later Anglian glaciation a tunnel valley was cut through the early Anglian outwash into the bedrock beneath the Nene Valley. There followed a period in which the valley was infilled with glacial lake clays (Chapter 4: Sections 4.10 and 4.11).

j) The analyses of the ostracod data (Chapter 8) suggests that the fluvial sediments in the Nene Valley are complex and can be assigned to the Oxygen Isotope Stages from the Anglian (Oxygen Isotope Stage. 12) to the present day (Figure 8.13.1). This sequence of events is summarised in Section 8.04.

9.02.1. Milton Formation pine and spruce remains.

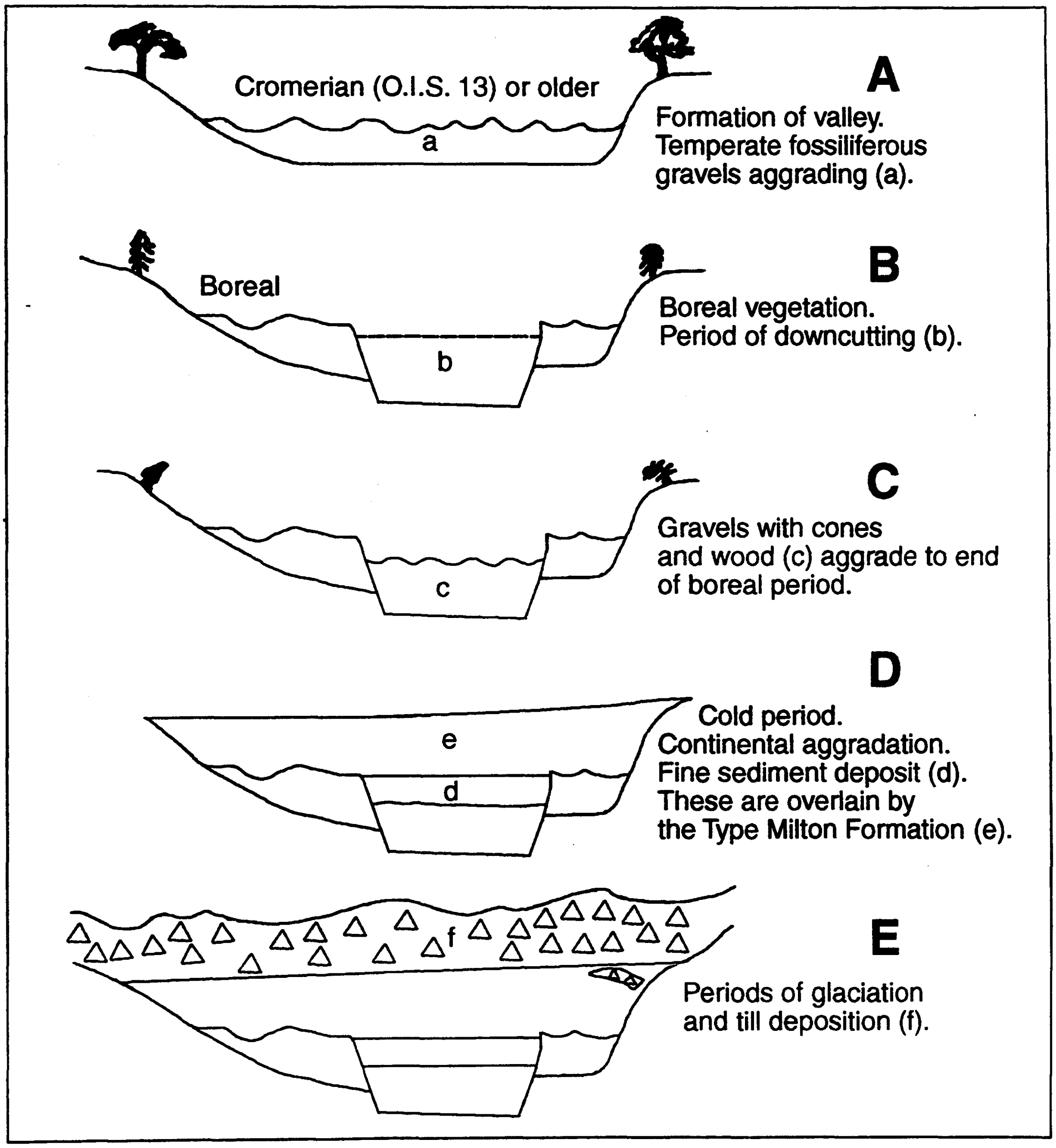
Many of the cones were well preserved, two not being dissimilar from *Pinus sylvestris*, the Scots Pine. The spruce cones (Plates 5.02.1 and 2) appear to be significantly different from the spruce cones previously identified in Britain. Those recovered from a site in Pen-y-Bryn, North Wales were dated as Late Pleistocene and identified as a sub-species of *Picea obvata* Ledeb, the Siberian Spruce (Chambers,1994). Spruce macrofossils recovered from the Chelford site, also Late Pleistocene, were identified as *Picea abies*, the Norway Spruce (Simpson and West, 1958), but were later regarded as a form of *P. obvata* (Whitehead, 1977). The spruce cones from the Milton Formation (Middle Pleistocene) are more similar in appearance to those of *Picea sitchensis*, the Sitka Spruce, or *Picea engelmanii,* the Engelmann Spruce (Mitchell and Wilkinson,1982), but this is not a positive identification. It is possible that this is a new species in the British Quaternary record.

9.03. The evolution of the Milton River at Courteenhall, Northamptonshire.

From the combined sedimentological, stratigraphical and ostracod data of Courteenhall a model of the evolution of the Milton River Valley can be established (Figure 9.03.1). The Milton Formation ostracod evidence compares well with other Cromerian sites reviewed (Table 5.02.4) but its species list differs in having species new to the Pleistocene record and an absence of some species common to other sites (Chapter 5).

The initial ostracod-rich gravel, at Courteenhall, Northampton, was deposited in a wide (0.5 km) channel incised in the Lower Jurassic bedrock (Profile A, Figure 9.03.1). The ostracod species indicate this deposition occurred in a temperate phase with some variations in climate. The assemblages differs from the pre-Anglian sites reviewed in

Figure 9.03.1. The stages in the evolution of the Milton Valley at Courteenhall Grange Farm, Courteenhall, Northampton.



Chapter 5 in that they contain a number of species of temporary habitats. These species, such as *E. virens, B. fuscatus* and *H. incongruens* (Table 7.03.1) were not found at the sites identified in the literature. Their presence in the Milton Formation may be due to the nature of the braided river system, which represents are a frequently changing environment, offering many permanent and temporary habitat types (Figure 1.01.3).

The ostracod analyses show that the warm period was followed by a general cooling of the climate. Towards the end of this period there was a rapid increase in the deposition of sand, as indicated by the sedimentology and stratigraphy recorded at the site (Figure 7.02.2). This stage was followed by the down-cutting of a channel which bisected both the temperate sediments and up to 2.0 m of the bedrock (Profile B, Figure 9.03.1). In 1995, a freshly opened section, south of the earlier section, showed a channel cut down into the bedrock. This was overlain by several metres of fine sediments and type Milton Formation. This lower channel deposit was 2.0 m thick and unlike the type Milton Formation in that it contained little sand within the gravels. The gravels were decalcified and ironstained. They also contained tennis ball sized, iron-cemented nodules of local fine gravels. These nodules would probably have come from a broken ironpan formed in an earlier gravel, most likely the temperate ostracod-rich gravels of Profile A. The gravel also contained numerous cones and fragments of wood of both spruce and pine.

The sediment above the gravel of Profile B consisted of fine sand and silts (Profile C, Figure 9.03.1). It lacked fossils other than finely broken plant material. No fossil-bearing material was seen to overlie these sediments. The fine sediments coarsened upwards into the type Milton Formation deposit (Figure 9.03.1).

The environmental implications are that at the time of, or shortly after, the downcutting of the channel through the temperate gravels into the 'Blue' Lias bedrock, the Milton River flowed through spruce and pine woodland (boreal woodland). The newly cut river channel infilled with sands and gravels into which the wood and cones were washed. There followed a periglacial period, probably with tundra vegetation. This would explain the highly disseminated plant remains seen in the fine silts above the gravel containing cones. The sedimentological evidence also points to a cooling climate.

Following Profile C, both the fine sediments and the terrace deposits were covered by the sediments now known as the Milton Formation (Profile D, Figure 9.03.1). During this phase the valley was widened and was filled, laterally and vertically, to a deeper and wider extent than previously seen. The Milton Formation deposit is 0.66 km wide and 4-6.0 m thick at Courteenhall. The deposit is overlain unconformably by chalky Anglian till (Profile E, Figure 9.03.1). A hiatus is indicated because as the Milton Formation, elsewhere, has been recorded as thicker than 4 - 6.0 m and the lower till is not present.

Indeed, Thompson (1930a) and Harrison (1983) reported finding, in the area between Yardley Hastings and Irchester, Northampton (Figure 4.01.2), the lower till resting on the preglacial gravels of the Milton Formation. This means that, to explain its absence elsewhere, much of the earlier till must have been either eroded before the onset of further glaciation, or cryoplanated by the later glaciation and redeposited as part of the upper, chalky till. This intermixing of the two tills would have concealed any evidence of a lower till. This research has concluded that, firstly, the lower fossil-bearing sediments are not the same type as the Milton Formation and, therefore, should bear a new name (see below) and secondly, that at all sites there is an unconformity between the sand and the chalky till

The ostracod analyses are explicit in suggesting that the ostracod-rich gravel was laid down in a temperate period prior to the Anglian glaciation. Due to the dissimilarities in the assemblage to known (published) sites of East Anglia or elsewhere a more definite conclusion cannot be drawn other than that the ostracods are of a Cromerian, or older age. However, the presence of the tooth of *Palaeoloxodon antiquus* within the sediments suggests a Cromerian stage. The stratigraphic and sedimentological evidence points to a temperate period in which ironpans were formed, followed by a period of cold, possibly periglacial, conditions in which the type Milton Formation was deposited. This periglacial period would have occurred before the onset of glaciation and the deposition of the lower till.

9.04. The evolution of the River Nene between Northampton and Wellingborough.

9.04.1. The Northampton area of the Nene Valley.

This research has shown that towards the end of the Anglian glaciation the Nene Valley, already containing gravels, was incised by a tunnel valley. The valley was then infilled with glacial lake sediments, over a period of time (c. 1,000 years; Early, 1956). The pre-tunnel valley gravels mentioned are now decalcified, leaving no faunal or floral evidence for analysis.

These decalcified sediments may correlate with, or be older than, the oldest terrace of the Thame Valley, the Three Pigeons (Seventh) Terrace, Milton Common, Oxfordshire, 'which are generally more or less decalcified' and are believed to be of Oxygen Isotope Stage 12 origin (Sumbler,1995).

The Nene Valley was then subjected to a series of down-cuttings in which the gravels, containing clasts both locally derived and far-travelled from the till, were reworked several times up to the end of the Pleistocene period. In the Holocene, the reduction in precipitation caused a change from a wide braided river system to the present narrower, meandering river. This, in fact, may have occurred more than once, that is, in each of the warm stages, in the past.

No trace of a third terrace is found in the Nene Valley at Northampton. At Little Houghton, the braided river, instead of cutting down into the bedrock, cut through its own deposits and moved across the valley. This resulted, in this area, in lateral erosion of the bedrock which widened the valley to its present width of 1.5 km. At Wollaston, Wellingborough, downcutting into the bedrock occurred resulting in two terraces being apparent in the valley. However, it is possible a third terrace may exist as a buried feature at Clifford Hill, Little Houghton and at Vicarage Farm, Wollaston.

9.04.2. Summary of the evolution of the Nene Valley at Clifford Hill, Little Houghton: Anglian to the present.

The following order of events is proposed:-

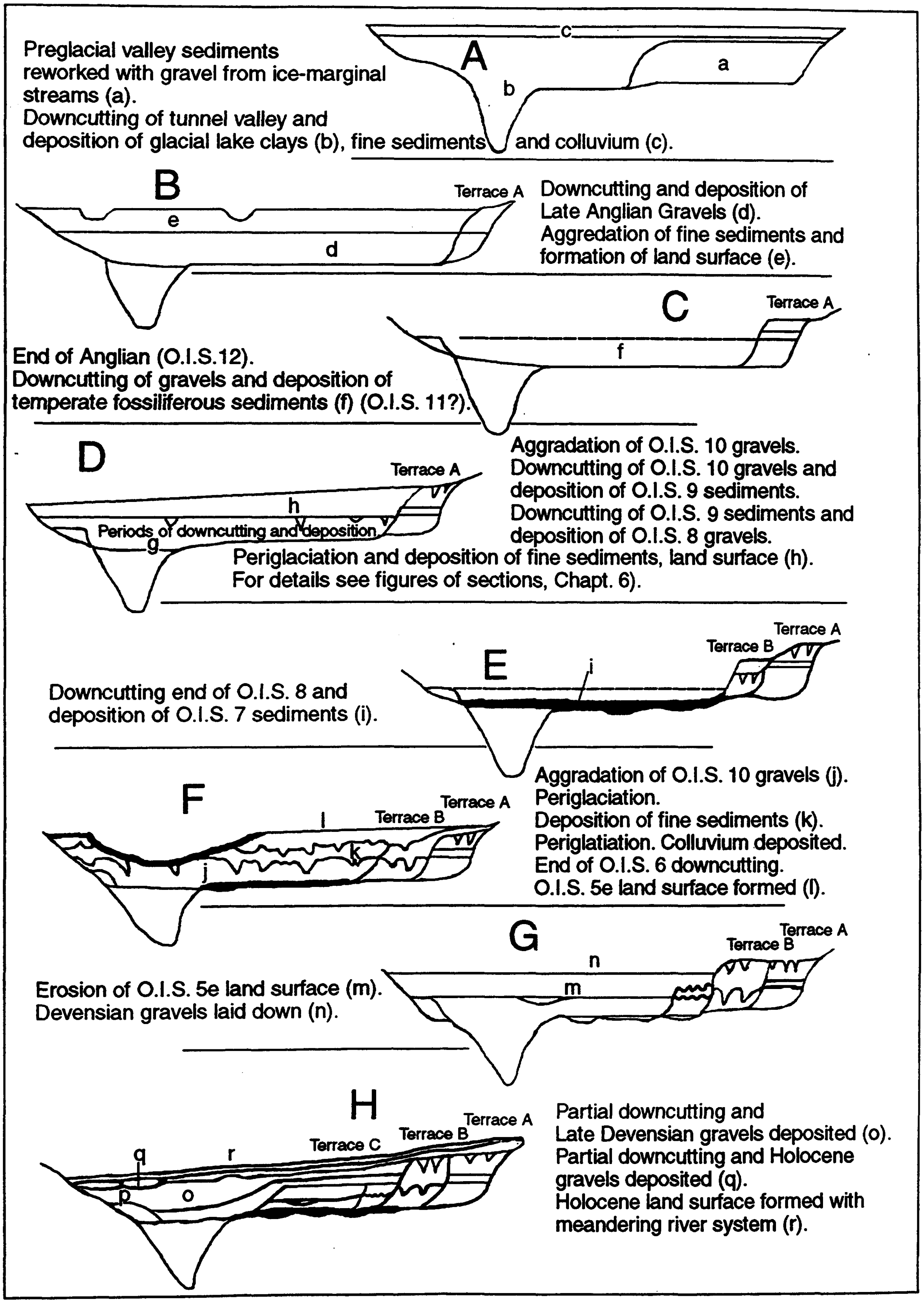
1) Before the over-riding of the ice, chalky, flint-rich fluvial glacial gravels from the last (Anglian) ice sheet were mixed, by reworking, with the gravels associated with the lower till, which already existed as gravel beds in the Nene Valley and elsewhere. These gravels were then incised by a tunnel valley (Figure 4.02.1) between Kislingbury, to the west of Northampton, and Great Doddington to the east. The valley, deepest at Northampton, then filled with glacial lake clays to a height where they overlay the earlier gravels remaining to the south of the tunnel valley incision (Profile A, Figure 9.04.1)

2) Later, downcutting of the upper part of the lake clays occurred. Remnants of the older gravels, with their covering of lake clays, were left *in situ* along the edge of the valley, such as that named Terrace A of Profile B (Figure 9.04.1). Following the incision of the clays Late Anglian gravels were deposited. As this was a wide braided channel, the braid bars would, occasionally, build up and form land surfaces for marginal fauna and flora, as indicated by the presence of the intact skull and lower jaw of the Norway lemming, *Lemmus lemmus* (itself an indicator of cold climatic conditions). As the skull and lower jawbone were intact and together in one place, they are *in situ* or were deposited in still water before disintegration could occur. This means there must have been marshland and pools in the valley some distance from the valley edge (as visualized by Morgan, 1969).

Later, as the discharge decreased, much finer sediments were deposited. A land surface formed on Terrace A and elsewhere (Profile B).

3) Following these early sediments, the valley was down-cut to bedrock again and, in a warm period following the downcutting, the channel began to fill with organic deposits (Profile C, Figure 9.04.1). The channel was inhabited by ostracods such as the extinct species *Ilyocypris* sp. A, and *I. swarzbachi,* and the extant *Prionocypris serrata* and *Candona rawsoni/lactea*, all of which have Ipswichian (Oxygen Isotope Stage 5e), or older, records in Britain (Table 5.03.1). These beds, sampled as Sites B and C, Clifford Hill West, may

Figure 9.04.1. The stages in evolution of the Nene Valley at Clifford Hill, Little Houghton, Northampton.



correlate with the Woodston Beds at Peterborough (Table 5.02.3 and Figure 9.04.2) which Bridgland *et al.* (1991) regard as Oxygen Isotope Stage 11. There is no reason to consider that the ostracods from sites B and C are reworked from the older gravels of Terrace A as they are free of calcareous material.

4) The temperate period was followed by aggradation of the lower gravels (Oxygen Isotope Stage 10) (see g of Profile D, Figure 9.04.1) which were capped by organic deposits (Oxygen Isotope Stage 9). The ostracod assemblage, which included *I. biplicata,* shows the environment had altered from one of warm pond-like conditions at the base of the gravels to a cool temperate one with a decrease in water depth and a change to slow moving water.

5) There was probably a return to cold conditions and aggradation of the gravels resumed (early Oxygen Isotope Stage 8) (see g of Profile D). Finally, the river discharge decreased and the valley was filled with fine sediments to the land surface of Terrace A (Profile D).

6) At the end of Oxygen Isotope Stage 8 downcutting occurred leaving a gravel terrace (Terrace B) (Profile E, Figure 9.04.1). The downcutting was followed by a warm period (Oxygen Isotope Stage 7) During this period fluvial, organic sediments were deposited within pond-like depressions and channels across the valley floor.

The Oxygen Isotope Stage 7 deposits may correlate with deposits found at the base of Pleistocene deposits in the valley of the Great Ouse, at Stoke Goldington, Bedfordshire (Green *et al.,* 1996) and with those of Stanton Harcourt, Oxfordshire (Briggs *et al.,* 1985).

7) At the end of the warm period, gravels, of Oxygen Isotope Stage 6 age, began to aggrade. This cold stage appears to have been, from the degree of cryoturbation of the sediments, a prolonged and intensely cold period during which colluvium was deposited and Terrace B was buried (Profile F, Figure 9.04.1). This periglacial stage may be equivalent to the stage which was once believed to have been associated with the 'Wolstonian' glaciation (Castleden, 1980a).

8) At the end of the periglacial period, partial downcutting of the valley sediments took place and a warm climate (Oxygen Isotope Stage 5e) was, again, established. A temperate land surface developed in which the channel-fills accumulated in the incised channels

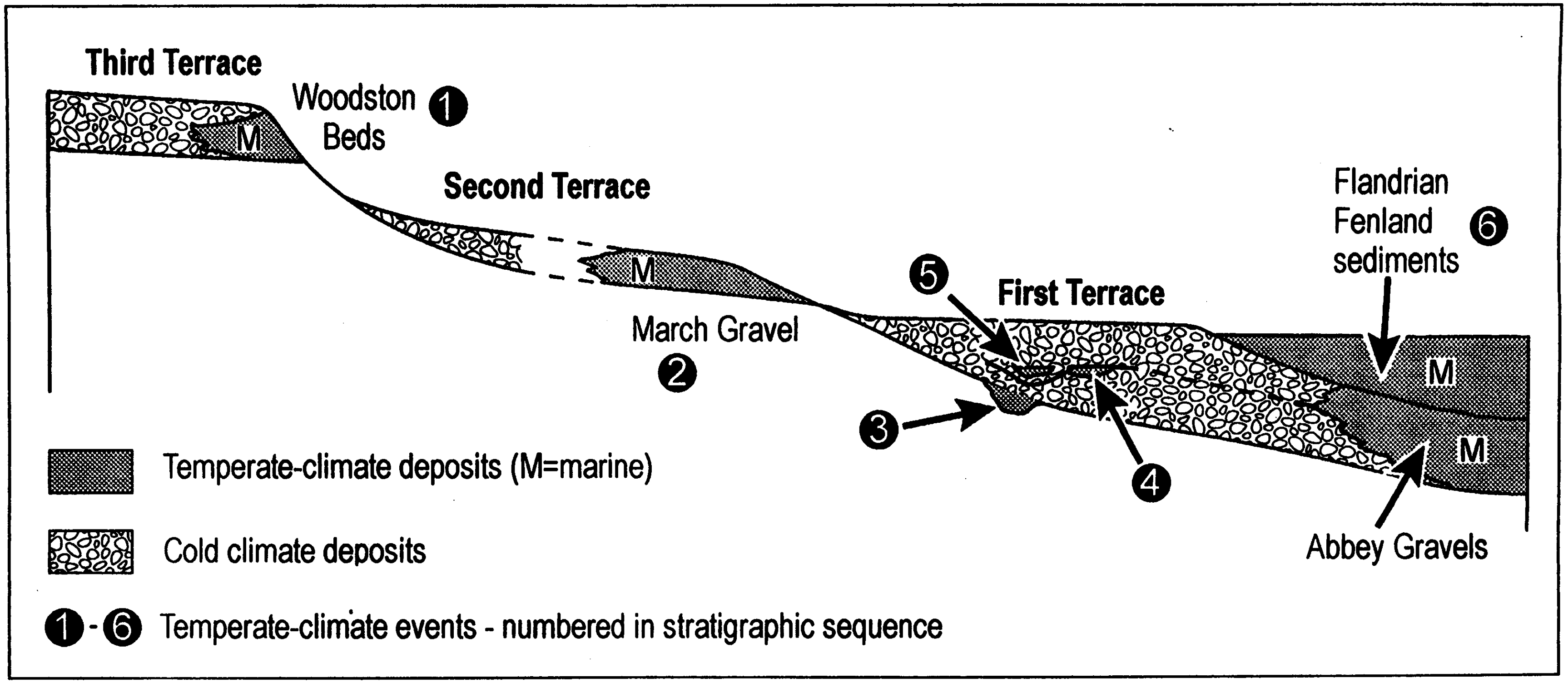


Figure 9.04.2 Schematic section through the fluvial and marine deposits of the Peterborough area.

(Profile F). Two channel-fills of this age were analysed and had temperate ostracod assemblages (Site C, Clifford Hill upper channel and Site G, Vicarage Farm). Site C had species *C. rawsoni/lactea* and *I. biplicata,* both species recognised as Oxygen Isotope Stage 5e or earlier indicator species, within its assemblage. The channel at Site C might correlate with the upper channel found at Stoke Goldington (Green *et al.,* 1996) (K of Figure 9.04.3) which also contained *I. biplicata* and was assigned to a possible cool period within Oxygen Isotope Stage of 5e.

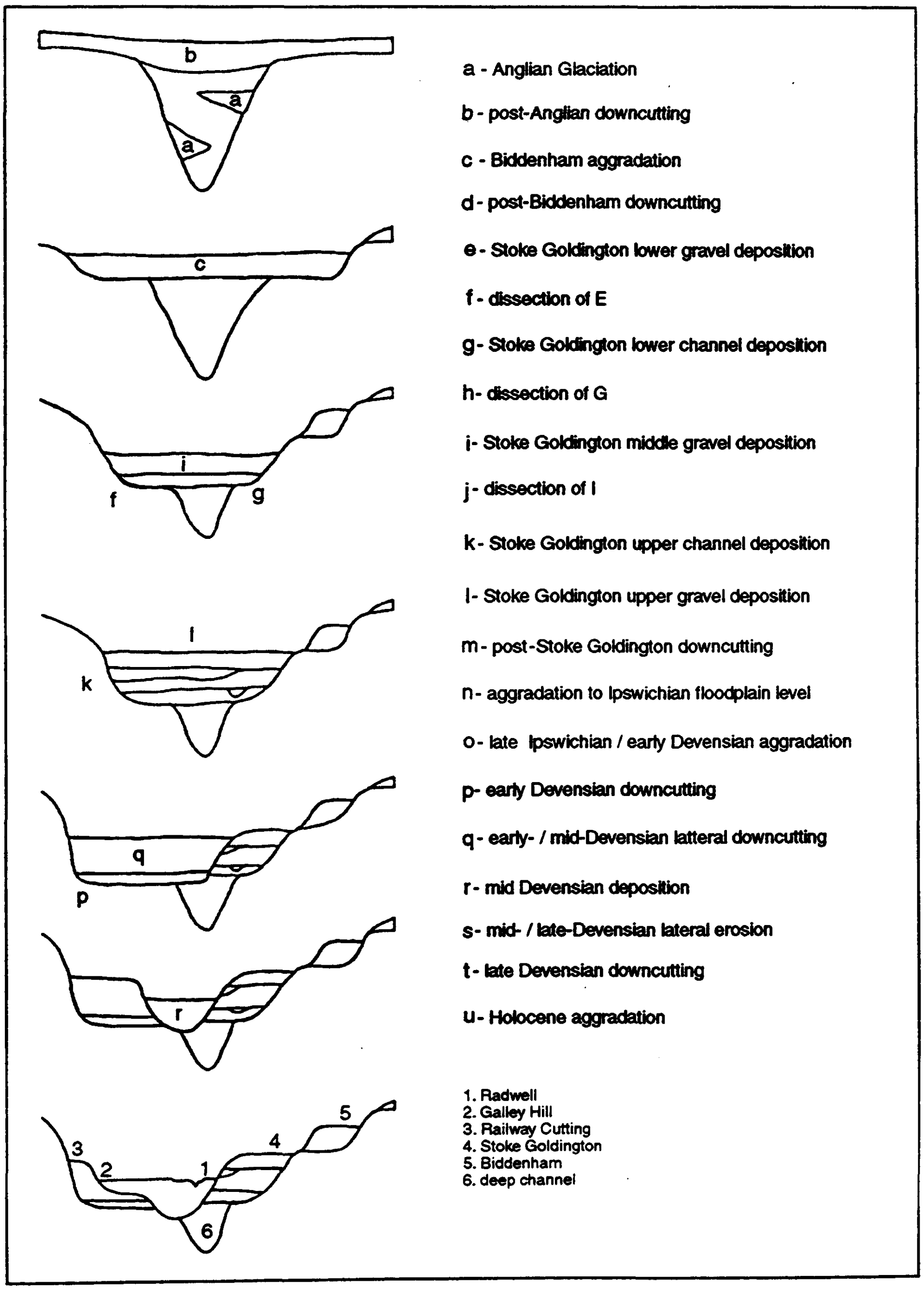
It is more difficult to correlate the deposits with those at Peterborough (Figure 9.04.2) by means of the ostracod data. However, the ostracods from Vicarage Farm were recovered from sediments of a channel cut into gravels marked First Terrace on the geological maps. If these were First Terrace gravels, then the sediments at Site H (Vicarage Farm) may be of a similar age to the Maxey deposits of the River Welland, near Peterborough. There is no ostracod record for these deposits, which are also attributed to the First Terrace, but other fossil evidence and the stratigraphy of the gravels suggest the Maxey deposit ranges from a possible Oxygen Isotope Stage 7 through to Oxygen Isotope Stage 5c (French, 1982; Davies *et al.,* 1991).

9) Following the warm period, at the onset of the Devensian cold stage, downcutting occurred further to the northern side of the valley leaving gravel from Oxygen Isotope Stage 6 exposed on the floor of the valley (Profile G, Figure 9.04.1). In, places, gravels of this stage also overflowed from the downcut channel and spread across the older sediments (as seen at Site H, Vicarage Farm).

10) The downcutting was followed by periods of gravel aggradation and downcutting as the Devensian period became established. Colluvium, usually removed during erosive periods, remains buried in places under the later Holocene alluvium (Profile H, Figure 9.04.1).

11) Ostracods from this last cold stage, radiocarbon dated 26,840, B.P., include *Ilyocypris* sp. A. This was also found in the older gravels at Clifford Hill, Little Houghton and in Oxygen Isotope Stage 7 sediments at Stoke Goldington, Bedfordshire (Green *et al.,* 1996) (Table 5.02.2). This contradicts the currently held belief that this ostracod species became

Figure 9.04.3. A model of the evolution of the River Great Ouse based on the data from Stoke Goldington. From a conference paper after Green *et al.*, (1966).



extinct at the end of Oxygen Isotope Stage 7. Clearly, if the radiocarbon date is correct, *Ilyocypris* sp. A was still extant in the Devensian period. Material from the Nene Valley at Northampton has also been analysed by Morgan (1969) and Holyoak and Seddon (1984) and given a Devensian date (Chapter 2: Section 2.07).

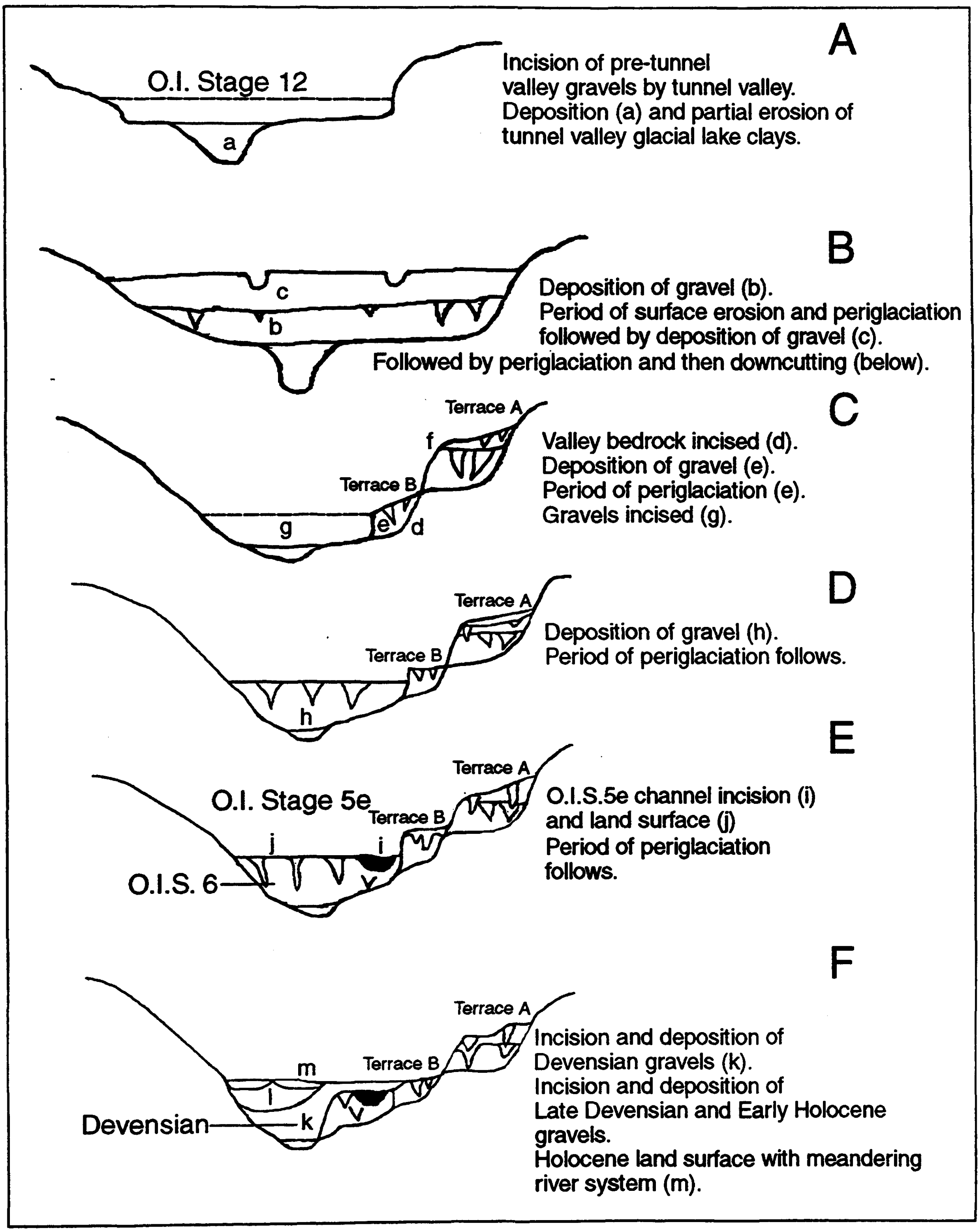
12) The ostracod assemblages from the Holocene sediments of Site G (Cringle Farm) and Site J (Wellingborough), except for assemblage S42.Wel which is modern, appear to be of early Holocene age. The assemblage from the modern channel (S42.Wel) is remarkably similarity to that of Site H (Vicarage Farm) which is lower in the stratigraphy of the gravels and is thought to be Oxygen Isotope Stage 5e in age. This suggests that the local environment of the earlier interglacial may have had similar temperatures, quantities of precipitation and aquatic vegetation to those of today.

9.04.3. Summary of the evolution of the Nene Valley at Wollaston, Wellingborough.

The ancient Nene Valley at Wellingborough is narrower than upstream at Northampton, by about 0.5 km (the modern, meandering River Nene, is an underfit river within the valley of the older, braided river, Castleden, 1976). In the narrower section the braided river responded by downcutting into the bedrock thus leaving raised terraces (Figure 9.04.4).

1) Although glacial lake clays have been reported at Great Doddington, near Wellingborough (Figure 1.01.1) (Castleden, (1980a), no pre-tunnel valley gravels (such as were seen by the present author at Clifford Hill) were seen at the Wellingborough sites of the current investigation. As the valley is narrow they may have been removed through later erosion and deposited downstream as reworked gravel. It seems that where the tunnel valley occurred it was infilled with clays and then the upper layers of the tunnel valley lake clays were eroded away (Profile A, Figure 9.04.4). These were replaced at the end of Oxygen Isotope Stage 12 by two gravel suites, one overlying the other (Site G2, Cringle Farm, Wollaston). Pre-dating and underlying the gravel at Cringle Farm only, is a deposit of

Figure 9.04.4. The stages in the evolution of the Nene Valley at Vicarage Farm, Wollaston, Wellingborough.



chalk- and flint-rich till infilling a depression in the Jurassic bedrock. This suggests that the valley may have been filled with till before the incision of the tunnel valley, an idea first postulated by Castleden (1980a).

2) It is unclear how long the time period was between the two gravels that were deposited following the erosion of the tunnel valley clays. A separate episode of cryoturbation (with associated ice-wedge casts) can be seen in the lower gravels in some places at Cringle Farm, but it is difficult to assess the number of periods of cryoturbation affecting these gravels as the upper gravels are also extremely cryoturbated (Figure 8.08.1). Lithological studies show the lower gravel has a higher proportion of quartz and quartzite when compared with the upper gravel, but the most notable difference is in the larger quantity of limestone against Ironstone in the upper gravels compared with the lower gravels. These limestone clasts appear to be weathered and waterworn, having been washed in by tributaries from the Milton Formation on the interfluve, before entering the Nene Valley. A change in climate, associated with an increase in precipitation, possibly caused the increase in lateral and downward erosion of the valley at this time (Profile B, Figure 9.04.4). The period/s of deposition was/were followed by periglaciation and then downcutting through the gravels into the bedrock (not shown as a separate Profile in Figure 9.04.4). This time the channel was narrower, leaving, in places, remnants of the two, superimposed, gravel units. These now form the River Nene Second Terrace (Terrace A Profile C, Figure 9.04.4). The gravels of Terrace A, although they are calcareous, do not contain any organic material.

The incision was followed by aggradation of gravel in the new channel. A period of periglaciation occurred towards the end of the aggradation (not shown as a separate Profile, but represented by the remnant of gravel, 'e' of Profile C in Figure 9.04.4). These gravels (of which patches of Terrace B are remnants) are fossiliferous and include the remains of the reindeer, *Rangifer tarandus*, indicating there was an established cold-stage fauna at the time of deposition.

3) At the end of the period of periglaciation the valley bedrock was again incised by a similarly narrower channel ('g' of Profile C), leaving remnants of the latest gravel deposit 'e' to the sides of the channel (Terrace B, 'e' of Profile C).

There is no clear indications for the timing of the last event but it ended with a period in which gravel aggraded in the valley bottom ('h' of Profile D). These gravels, like those of Terrace B, are fossiliferous. Remains of the woolly mammoth, *Mammuthus primigenius*, suggests there was an established cold-stage fauna at the time of deposition. Towards the end of this aggradation there followed a period of periglaciation in which the new gravels were cryoturbated.

There is a similarity of the events shown in the stratigraphy and sedimentology to that of Clifford Hill (above), which suggests that Terrace A and B are earlier than Oxygen Isotope Stage 6 and that the down-cutting of Terrace B occurred before or early in Oxygen Isotope Stage 6.

It is believed by the author that these gravels ('h' of Profile D) were aggraded in Oxygen Isotope Stage 6. If this is so, the period of periglaciation which followed the aggradation was long and severe in its extent (as illustrated by these studies, see point 7 of Clifford Hill, above).

4) The aggradation and periglaciation was then followed by an interglacial period; shown by these studies most likely to be Oxygen Isotope Stage 5e (Profile E).

At that time, the upper gravel of Oxygen Isotope Stage 6 unit was incised by one or more relatively shallow channels. After the incision, during the warm period of Oxygen Isotope Stage 5e, a temperate landscape developed. The channels in the gravel surface infilled with temperate deposits.

Again, the sediments are dated by their similarity to the sedimentology and stratigraphy of Clifford Hill. However, the ostracod assemblage from Vicarage Farm (Site H) also points towards a possible date of Oxygen Isotope Stage 5e. The assemblage contained both temperate and cool water ostracod species, however, some species, seen in the pre-Oxygen Isotope Stage 5e sediments at Clifford Hill, are absent in these sediments. In particular, species such as *Candona rawsoni/lactea* and *Ilyocypris biplicata,* are replaced by *Limnocythere inopinata* and *Cypridopsis vidua*. This does not mean these species are present or absent from the record of other rivers, but they seem to set a standard for the Nene Valley sediments in the Midlands.

Overall, the species in the assemblage give some indication of the age of the sediments in that the assemblage is unlikely to be older than Ipswichian (O.I.S 5e). It was probably a cool period at the end of, rather than the beginning of, the Oxygen Isotope Stage 5e. . However, one species, the cold stenothermal ostracod, *Limnocythere sanctipatricii,* is usually recognised as a Devensian species in Great Britain (Griffiths, 1995). Notwithstanding, this research has now put on record the first specimens of *L. sanctipatricii* found in Pre-Anglian temperate sediments, at Courteenhall, beneath Milton Formation.

6) There followed a period of partial downcutting in which a remnant of Oxygen Isotope Stage 6 gravels and 5e sediments were left as a buried terrace (Profile E, Figure 9.04.4).

7) The downcutting, as seen at Clifford Hill, was followed by periods of gravel aggradation and downcutting as the Devensian period became established (Profile F, Figure 9.04.4).

8) During the Devensian and early Holocene the gravels were downcut and redeposited several times. Finally, they were covered with Holocene alluvial deposits in which the much reduced River Nene now meanders. The remains of oxbow lakes and Holocene channels were found in the alluvial sediments. Of these, the lower channel fills (Sites G, H and J) contain ostracods species that are commonly found in assemblages from fluvial sediments of the Oxygen Isotope Stage 5e, Devensian and Holocene.

9.05. Conclusions and specific contributions of this study.

This work has made specific contributions to Quaternary studies and the results are significant for past and future Quaternary stratigraphic and palaeoenvironmental research.

The ostracod analyses have made particular contributions to palaeoenvironmental reconstruction and the stratigraphic range of some species extended and shown to follow a different course and be of a different age than previously thought. The evolution of the Nene itself has been shown to be more complex and extend over a longer time period than previously thought.

9.05.1. Ostracod analyses and their implications for other Quaternary fluvial systems.

A) The reconstruction of the Quaternary fluvial system, including its environment, was based upon the interpretation of lithological, sedimentological and stratigraphical evidence and the presence and frequency or absence of ostracod species, the number of valves per species, and the species habitat requirements.

B) Analysis of the ostracod data, using information already published, was hampered by the fact that information on ostracod fauna from coarse braided river environments was not readily available in the literature.

With this in mind, Chapter 5 was written with the intent to collate and synthesize data from earlier research and up-to-date ecology. The chapter includes information from textbooks on ostracod identification, such as Henderson (1990), and Griffiths (1995), and from discussions with Drs D. Horne, H. Griffiths and E. Robinson.

C) By utilizing the stratigraphy, lithology and particle size of the sediments from the Milton Formation and the Nene Valley, the ostracod assemblages were placed in chronological order. The ostracod evidence was analysed using the collated material discussed in (B) above. The analyses revealed that a pattern of cool and temperate stages was occurring within the sediments of both the Milton Formation at Courteenhall and the Nene Valley deposits. Some ostracod species also suggested the antiquity of the particular sediment from which they derived. With this information, it has been possible to confirm that the Milton Formation was deposited earlier than the Nene Valley gravels. Furthermore, it was also possible to determine that in the Nene Valley the deposition of the earliest fossiliferous sediment was probably as early as Oxygen Isotope Stage 11 and that several cold and warm stage sediments have been deposited since.

D) Ostracods previously used for environmental evidence in other research, have now been recovered from the Milton Formation and the Nene Valley. Taking into account new data encountered in this research the following asssessments were made. The presence of the single specimen of *Ilyocypris papillata* gave a Pre-Anglian age for the Milton River deposits (although the sedimentological and stratigraphic data gave a much stronger case for this date). The absence of *I. papillata* and other species that are generally known to have become extinct or absent in England after the Anglian glaciation (Table 5.03.1) supports a post-Anglian age for the Nene Valley deposits. The presence in the Nene Valley gravels of the pre-Ipswichian ostracod, *Ilyocypris schwarzbachi*, confirmed that not all the Nene Valley deposits are Devensian, as suggested by Castleden (1980b). It appears that there had not been a Wolstonian ice advance in the Northampton area as indicated by the current research, and that of Perrin *et al.* (1979).

Evidence of a post-Anglian age for the Nene Valley was also confirmed by the presence of *Limnocythere inopinata*. This species does not appear in Pre-Anglian records of the English Midlands and it is suggested that *L. inopinata* be recorded as an indicator species for English post-Anglian sediments.

The possibility of *Ilyocypris* sp. A being a post-Anglian indicator species has now been discounted as it was recovered from the Milton Formation at Courteenhall, Northampton.

E) Particular ostracod species recovered from the Milton Formation and Nene Valley Gravels were unexpected and have considerable import for current, past and future research. These included ostracod species found in the Milton Formation and Nene Valley Gravels, which are found living in Britain today, but are new to the Pleistocene record. Species *Bradleystrandesia fuscatus* and *Eucypris virens* prefer temporary pools and *Potamocypris arcuata* is found in sun warmed ponds and ditches (Griffiths,1995); they would, therefore, have been washed into the river sediments examined in this thesis. These species may also be new to the record because most published ostracod data to date has been collected from meandering river, pond and lake deposits which may have less runoff from the local land surface. That this new data cannot be totally explained indicates that there is still some way to go before the ostracod record of the British Quaternary is complete.

F) In the case of the Milton Formation and the Nene Valley, finding ostracods has allowed, for the first time, a detailed chronological sequence to be established that relates to the Oxygen Isotope Stage pattern already established for lowland England from the Cromerian Complex Oxygen Isotope Stage 13 to the present day (Figure 7.04.1). However, the ostracod assemblages of the Milton Formation and Nene Valley Gravels have few affinities with those of East Anglia, and the ostracod assemblage of the Milton Formation has no similarities to that of Waverley Wood, Warwickshire (Shotton *et al.,* 1993). As they all have sedimentological similarities (see below) it is suggested the differences in the assemblages must reflect a difference in one or more of the following: vegetation, temperature, water chemistry, or time period, as well as a difference in their geographical positions.

In the Nene Valley Gravels the changes through time in the ostracod assemblages, supported by sedimentary and stratigraphic evidence, compared well with, and showed similar changes to, the Quaternary deposits of the Great River Ouse at Stoke Goldington (Green *et al*:, 1996) and the River Nene and River Welland at Peterborough (Bridgland, Davey and Keen, 1991; Bridgland *et al.*, 1991; Davey *et al.*, 1991; Horton *et al.*, 1991).

Other sites where coarse sediments were analysed represented a shorter time span than those researched in the Milton Formation and the Nene Valley Gravels.

G) This study has produced new evidence of environmental change, with previously unrecorded species to add to the Quaternary ostracod record. The pattern of ostracod appearances and extinctions through the British Pleistocene has been extended. In fossil analyses, the extinction of species is frequently used to indicate a time scale, and, although there are fewer extinctions within the freshwater ostracods of the Quaternary period than in earlier times there are sufficient to enable dating by this method, for example, *Limnocythere falcata, Ilyocypris* species A., *I. biplicata, I. papillatus* and *I. schwarbachi* are all extinct. However, after examining the evidence from the past research, it can be seen that the new evidence from the Milton Formation and the Nene Valley does not always match with that of the old. This has resulted in some ostracod records being either pushed back or brought forward, or, as in the case of *Ilyocypris* sp. A, both backwards and forwards, in time. For instance *Ilyocypris* sp. A now covers a longer time span as it has been moved back from, but still includes, Oxygen Isotope Stage 7 to Oxygen Isotope Stage 9 and also forward to Oxygen Isotope Stage 5e.

When tabulated, as discussed in Chapter 5, the ostracod data from previous research of the Quaternary sediments of central and northern England show patterns of change in ostracod assemblages from the Beestonian to the present day.

H) This analysis has advanced the evidence already available. Nevertheless, as this research has shown, it is likely to be some time yet before there is a complete record for the Quaternary ostracods.

Generally, from the results of this research, it is clear that ostracods can be used in a wider context than previously recognised. This study has shown that, despite the low number of extinctions, when added to highly detailed stratigraphic data, the number and type of ostracod species and of individuals of each species in an ostracod assemblage are sufficiently informative to act as sources of both environmental and chronological information.

It is hoped that the ostracod data collected in this thesis, from fluvial sediments of central Northamptonshire, will be as valuable to Quaternary science as that of the east coast (West Runton and Little Oakley) where some of what is recorded as the 'best' Quaternary ostracod data comes from. The present study has recovered a larger number of ostracod species than either of the two sites mentioned above and contributes a significant and new extension to the ostracod data base.

J) It is recommended, for the future, that the ostracod data of the Milton and Nene Rivers be used for comparison with data from other British Midlands pre-and post-Anglian Quaternary sites. Any future evidence can then be amalgamated with that of the Nene and Milton Rivers to form a data base for Quaternary ostracods of the English Midlands.

9.05.2. The evolution of the Milton and Nene Rivers and its implications for other Quaternary fluvial systems.

The stratigraphic, lithological and sedimentological data has given a clearer understanding of Quaternary river development in central Northamptonshire. This data, combined with the ostracod data, has shown that both the Milton and Nene Rivers evolved through an extended period of time which covered at least one temperate episode, then a periglacial period in which the Milton River became confluent with the Nene Valley. The area was then subjected to two, or more, periods of glaciation. Evidence for the age of the older glacial episode is inconclusive. It may have been followed by a sequence of temperate and periglacial periods or it may be of early Oxygen Isotope Stage 12. It is definite that the younger glaciation of Oxygen Isotope Stage 12 (the Anglian Glaciation) was followed by a sequence of temperate and periglacial periods (Oxygen Isotope Stage 11 to the present day).

Prior to the current research three theories of river development in central Northamptonshire had been postulated. The earliest (Thompson, 1930a, 1930b) was that the pre-glacial Milton River, flowing in a north-easterly direction, changed to a south-easterly one across a presupposed valley in the area of Yardley Chase, Northampton, to join the River Ouse, in Bedfordshire. The channel was then blocked at the onset of glaciation and the river redirected into the Nene Valley area. Castleden (1980a) added to this theory and produced convincing evidence that a buried valley crossed Yardley Chase. Furthermore, he suggested that the Milton River was blocked during the Wolstonian period and not the earlier Anglian glaciation. Horton (1970) reassessed the evidence from the position of the local bedrock and suggested that as the limestone ridge to the east was too high, the Milton River had always flowed north-eastwards along the Nene Valley.

This research clarifies the situation, tracing the river development of central Northamptonshire by combining the previous work with new evidence. If this hypothesis for the Quaternary river development is correct, then central Northamptonshire is unique in having a nearly continuous, stratigraphic, lithological and sedimentological record of change in the fluvial system that includes pre-Anglian interglacial, glacial and post-Anglian glacial material.

The extensive desk study has provided confirmation of a large valley parallel and to the east of the Nene Valley between Northampton and Rushden / Higham Ferrers. This valley, elevated 20 m above the present Nene Valley, contains frequent outcrops of locally derived sand and gravel rich in limestone, older than and glacial episode of the area, and similar in composition to that of the Milton Formation (Thompson, 1930a; Harrisson, 1983).

These sands and gravels are overlain in parts by the lower flint-free till. Much of the valley is concealed by an infill of chalky till which overlies the older sediments and is frequently proud of the valley sides.

The evidence suggests that the River Milton flowed north-eastwards along this valley and changed direction to flow south-eastwards at Rushden / Higham Ferrers (where similar patches of pre-glacial sand and gravels have been found extending towards the south-east, see Chapter 4).

Changes in the stratigraphic, lithological and sedimentological data suggests that, prior to glaciation, differential erosion of the bedrock in the faulted area of Northampton caused a breach in the bedrock forcing the Milton River to enter the early Nene Valley, the River Nene probably being a tributary flowing parallel to the Milton River at that time.

What occurred to make the combined Milton / Nene River to change its direction of flow from the south-east to the north-east at Rushden / Higham Ferrers is more conjectural. The fact that there is lower till resting on the pre-glacial sands and gravel in the higher valley between Northampton and Wellingborough suggests that the redirection occurred before the lower till was laid down. It may be that as the modern Nene follows the edge of the softer, more friable Ironstone Beds differential erosion occurred here, as did at Northampton, or that the Milton valley was clogged by the first till and this caused the river to move to the Nene route. However, as the lower till was laid down by ice approaching from the north to north-west (West and Donner, 1956) and the upper till from the north-east (Perrin *et al.*, 1979) this would, during those occurrences, prevent flow in a northerly direction, thus making the latter hypothesis the least likely.

The preglacial Milton River (Figure 4.04.1) appears to have evolved in a stable environment. It experienced little lithological or sedimentological change over its lifetime. The Milton River, from lithological analyses, was flowing through a Pre-Anglian landscape of Jurassic limestones, sandstones and clays. A climatic change was signaled as the vegetation changed from temperate to boreal woodland. Finally, upon the approach of stadial conditions, the drastic deterioration in the climate destroyed the forests. The effect of the following erosion of the land surface and the deposition of the tills is reflected in the depositional and lithological nature of the glacial and post-Anglian glacial Nene Valley sediments.

The post-Anglian confluent Milton and Nene Valley (now containing the River Nene) was left with massive beds of till on its valley sides. The tills contributed a much larger particle size gravel to the river bedload.

The Nene River appears to have been less stable than the preglacial Milton River: This may be for several reasons, among which are suggested the following:

a) as indicated by the oxygen isotope curve, climatic oscillations have been more marked since the Anglian glaciation, with downcutting occurring towards the end of the cold periods (as indicated by warm stage organic sediments at the base of the gravels, Figure 7.04.1);

b) the clay surface of the tills may be more impervious than the local bedrock causing more surface run-off and localized downcutting;

c) downcutting may have occurred when energy discharge exceeded the bedload demand.

Although the exposures investigated in this research were reasonably 'comprehensive', there may still have been zones of sediments and fauna missing due to the erosion and reworking of sediments.

9.06. Formal naming of the Milton and Nene Valley sediments.

9.06.1. The newly found sediments beneath Milton Formation at Courteenhall.

The fossiliferous beds investigated at Courteenhall are new to the Quaternary record and should be named in recognition of their worth to future research.

Bed 1 & 2: Units A and B, Site A1: Temperate to cool temperate fossiliferous deposits:-

Grange Farm Member of the Milton Formation.

Beds 3 & 4: Units A-E, Site A2: Cool temperate (fossiliferous) to cold deposits:-

Courteenhall Member of the Milton Formation.

9.06.2. Proposed naming of the Nene Valley sediments of Central Northamptonshire.

Floodplain:	Cringle Farm, Wollaston.	Organic rich gravel	Great Doddington Member
Late Devensian:	Wellingborough.	Gravel	Victoria Mills Member
Mid Devensian:	Clifford Hill, Little Houghton	Gravel	Ecton Member
O.I.S. 5e:	Vicarage Farm, Wollaston	Organic sediments	Vicarage Farm Member
O.I.S. 6:	Vicarage Farm, Wollaston	gravel	Ryeholmes Member
O.I.S. 7	Clifford Hill, Little Houghton	Organic sediments	Hardingstone Dyke Member
O.I.S. 8:	Clifford Hill, Little Houghton	Gravel	Bedford Road Member
O.I.S. 10:	Clifford Hill, Little Houghton	gravel	Great Houghton Member
O.I.S.11:	Clifford Hill, Little Houghton	Organic sediments	Martin's Farm Member
O.I.S. 12:	Vicarage Farm, Wollaston	gravel	Grendon Member
O.I.S. 12:	Clifford Hill, Little Houghton	Tunnel Valley Clays	Cattle Market Member
O.I.S. 12:	Clifford Hill, Little Houghton	Gravel	Clifford Hill Member
Pre-O.I.S. 12:	Clifford Hill, Little Houghton	Sand	Little Houghton Member

9.07. Application and future work.

The knowledge of fluvial palaeogeology of Midlands prior to the Anglian glaciation is limited at the moment. Not many of the palaeo-river systems have been as well preserved as that in central Northamptonshire. However comparisons can be made between the fluvial history of Northamptonshire and other palaeo-river systems. Although limited, these comparisons indicate where there is scope for future work.

The Courteenhall Cromerian terrace sequence appears to be the oldest sediment examined in this thesis. The fossil assemblage from Gayton / Milton Malsor, Northampton, (Baker, 1836) contains mastodon remains which, if correctly identified, would indicate a pre-Cromerian age, as this species became extinct in the Pastonian (Sutcliffe, 1985). However, the remaining species identified, elephant, hippopotamus, ox, elk and deer, are more likely to be an assemblage from the Cromerian Complex (Sutcliffe, 1985). The most convincing evidence for a Cromerian age came from the Courteenhall sediments themselves, that is, a tooth of the straight tusked elephant, *Palaeoloxodon antiquus*, found in the ostracod rich material (Unit A, Chapter 7). This species appeared during the Cromerian Complex and was extinct by the end of the Ipswichian Interglacial (Sutcliffe, 1985). It is important, therefore, to find and re-identify the fossils recorded by Baker (1836) as the possibility of bones from mastodon being reworked into material of Cromerian age suggests that the Quaternary history of the area may be more complex than indicated by the current research.

Although the lower courses of the Milton and Brigstock Rivers cannot yet be determined, both the Milton River and the Brigstock River have similar preglacial sediments and a flow towards the east-south-east (Chapter 4). It seems that, providing the age of the Milton River is correct and the Brigstock river the same age, they both may have been tributaries of the Bytham River, as discussed below.

The quartz and quartzite-rich gravels of the Bytham River can be traced from the West Midlands through Coventry, Leicester, Stamford, Grantham and Kings Lynn (Rose, 1989a, 1989b, 1992; Hamblin and Moorlock, 1995, Lewis *et al.,* 1999). From Kings Lynn the river flowed southwards towards High Lodge near Newmarket before changing direction to the north-east and the coast (Rose, 1992). At High Lodge, in the Breckland area of Suffolk (TL 739754), excavations between 19 and 35 m O.D. exposed a pre-glacial gravel underlying the chalky till of East Anglia, characterised by quartz and quartzite pebbles and palaeocurrent measurements indicating the river flowed towards the south-east. A pre-Anglian age is indicated, the river being destroyed by the Anglian glaciation (Rose 1992). A similar deposit, to the east, also believed to be of the River Bytham system, is found at an elevation of 25 m O. D. at Knettishall, Suffolk (TL 951798) (Lewis *et al.,* 1999). The Milton River is at an elevation of 72 m O.D. at Northampton, and flowed in a east-south-easterly direction from Higham Ferrers / Rushden, Northamptonshire (Chapter 4). If the Milton River maintained an almost easterly direction, its age and elevation makes it a possible tributary of the River Bytham at, or near, High Lodge. Alternatively, in the case of the Milton River maintaining a more south-easterly course over a longer distance overland, it may have reached the east coast at a similar elevation to that of the pre-Anglian River Thames (Whiteman, 1992); the elevation of the 'Cromerian' Thames River being 19 m O.D. at Little Oakley, Essex (Bridgland, Gibbard and Preece, 1990).

The Letchworth Gravel (TL 2045 3535) (Smith and Rose, 1997), at 68 m O.D., is at too high an elevation for the Milton River to have entered the proposed Letchworth River.

Deposits of Cromerian age are rare in Britain. The Sugworth Channel deposit, near Abington, Oxfordshire (SP 513007), appears to be of similar Cromerian age (Shotton *et al.*, 1979; Robinson, 1979) to that of the Milton Formation at Courteenhall. The Sugworth deposit is considered one of the oldest sediments of the Upper Thames (Bridgland, 1994). Although there is unlikely to be a physical connection between the Milton and Thames Rivers it should be noted that the Sugworth channel deposit is overlain by a quartz and quartzite rich clayey gravel. This gravel is derived from the Northern Drift found in that area, itself now believed to be degraded deposits of an earlier river (Hey, 1986, Bridgland, 1994).

The Milton River (and possibly the early confluent Milton / Nene River) flowed towards the south-east before the deposition of the lower till in Northamptonshire. In the future, a search should be made for further deposits of the Milton Formation in the high land between Yieldon, near Rushden, to the River Great Ouse at St. Neots and beyond.

In the area between the Malverns and East Anglia the number of tills and their ages are not clear cut and there is much debate as to which Oxygen Isotope Stage should be allotted to each of the tills if there is, indeed, more than one. There is much confusion as to whether the Anglian Glaciation consists of one or, possibly, two ice advances within Oxygen Isotope Stage 12, or, in fact, whether there were two ice advances with an interglacial period between the two. The second argument spreads the Anglian over the three Oxygen Isotope Stages, 12, 11, and 10 (Sumbler, 1995).

There are sites which suggest that two tills, and their related outwash gravels, do exist. The two glacial events giving rise to the tills and outwash gravels are believed to be, by the various authors, of an age no younger than Oxygen Isotope Stage 10. These sites include the Malvern Hills (Barclay *et al.,* 1992); the Thame and Thames Terraces close to the Goring Gap, Oxfordshire (Sumbler, 1995); and the Frog Hall Pit, Stretton-on-Dunsmore, Warwickshire (Keen *et al.,* 1997). The authors, in general, favour two ice advances, one ascribed to Oxygen Isotope Stage 12, followed by an interglacial, then the second ice advance to that of Oxygen Isotope Stage 10. Sumbler (1995) placed sediments which were previously ascribed to the 'Wolston Series' and possibly also the Lowestoft Till of the Anglian stratotype in Oxygen Isotope Stage 10. Keen *et al.* (1997) after the investigation at Frog Hall Pit, gave a minimum age of Oxygen Isotope Stage 10 to the youngest till at that site. Barclay *et al.,* (1992) suggested that the sediments examined from the west side of the Malvern Hills indicated either that an ice sheet, arriving from the north-west, was followed by a warm period before the Anglian Glaciation occurred, or that the lower till was derived from an ice sheet arriving from the north-west, but possibly retreating before the Anglian ice sheet arrived. If the second case is correct, the authors say, both ice sheets belong to the same glacial episode, which was most probably Oxygen Isotope Stage 12.

To advance this argument more work is needed to be done on the lower till of the Midlands, a suitable exposure being that at Brigstock Country Park, Kettering, Northampton (Chapter 2). It is suggested that, in the near future, the site at Brigstock should be given the status of an S.S.S.I.

Published work, other than that of Smith (1995), suggests that the River Nene Gravels between Northampton and Wellingborough are of Devensian age (Morgan, 1969; Castleden, 1976, 1980b; Holyoak and Seddon, 1984). The current work shows that downcutting and lateral migration of the valley has, in fact, preserved sedimentary deposits from several climatic stages, from early in the Anglian cold stage to the present day. The sediments show evidence for at least five warm stages, not necessarily fully interglacial, divided by cold periglacial stages, Oxygen Isotope Stages 10 and/or 8, 6, and 4. This is in line with, although not always in agreement with, the model of downcutting postulated for the River Thames (Bridgland, 1994). The River Nene at Peterborough has been shown to have experienced 5 temperate stages (not necessarily fully interglacial) (Bridgland *et al.*, 1991). These temperate stages may correlate with Oxygen Isotope Stages 11, 9, 7, 5e and 5c as discussed by Jones and Keen (1993).

There is increasing evidence that Oxygen Isotope Stage 7 may be particularly well represented with good fauna, and biostratigraphic correlation between sites. These sites include: Stanton Harcourt (River Thames), Oxfordshire (Briggs *et al.,* 1985); Maxey Gravel Pit (River Welland), near Peterborough (Davey *et al.,* 1991); Ailstone (River Avon), Warwickshire (Maddy *et al.,* 1991): Marsworth (River Thame), Buckinghamshire (Green *et al.,* 1984); Upper Strensham (River Avon), Worcestershire (De Rouffignac, *et al.,* 1995); Stoke Goldington (River Great Ouse), Buckinghamshire (Green *et al.,* 1996), and recent work at Aveley, Essex (Allen, pers. comm.).

Other features of the Nene Valley worth investigating further include decalcification of the sediments and periglacial structures. These features could be compared with the Devensian gravels showing evidence of permafrost at Stanton Harcourt (Seddon and Holyoak, 1985) and Cassington, near Oxford (Maddy *et al.,* 1998) and the older decalcified material at Frog Hall Pit, Stretton-on-Dunsmore, Warwickshire (Keen *et al.,* 1997).

Several ostracod species encountered in this research warrant further investigation. The species *Ilyocypris schwarzbachi,* found at Clifford Hill (Chapter 8), and in Cromerian deposits at Little Oakley, Essex (Robinson, 1990). There is a paucity of records throughout Europe for this species (Griffiths, 1995), it being currently known only in Mid-Pleistocene deposits from Germany and The Netherlands (Kemph, 1967, 1975). It has not been found in the Cromerian deposits of the Milton Formation at Courteenhall, but, as it is a species found in sediments deposited in both warm and cold climates (Robinson, 1990), it may have been present in the Nene Valley in the latter part of Oxygen Isotope Stage 12. However, the stratigraphy and sedimentology of the valley seems to indicate a more likely age of Hoxnian Oxygen Isotope Stage 11 (Chapters 7 & 8).

Of the three species new to the British record, *Cyclocypris globosa* has a Late Pleistocene record in Europe and *Bradleystrandesia fuscatus* is not recorded elsewhere worldwide and is already a designated British species (Griffiths, 1995). The third species, *Potamocypris similis,* a living ostracod, has been found in Mid- (Furhmann and Pietrzeniuk, 1990) to Late Pleistocene (Diebel & Pietrzeniuk, 1984) deposits in Europe (Griffiths, 1985).

The fossil ostracod assemblage in the Milton Formation differs enough from any recorded British Cromerian assemblage (Chapter 5) for it to be, possibly, a different stage in the Cromerian Complex from those investigated previously. Again, due to the paucity of records, it is difficult to confirm this point. It is important to publish all the stratigraphic and ostracod data from both the Milton Formation and the Nene Valley Sands and Gravels, to stimulate others to compare their data and, perhaps, to bring to light unpublished data relevant to the current research. The ostracod data is also to be added to the database being put together by Dr David Horne at the University of Greenwich.

A limitation of the new ostracod data from the Milton Formation at Courteenhall is that similar fossilliferous sediments have not been recognised at other sites in the Milton Valley. However this does not discredit the value of the data gathered. It is comprehensive enough to be used as a criterion in freshwater ostracod research.

For a more complete picture of the fluvial deposits of Northamptonshire it is imperative to examine the molluscs currently in store at University College Northampton. Almost all of these were collected by the author from the sites mentioned in this thesis, and therefore in most cases have accompanying sedimentological and ostracod data. This data bank should allow even stronger and more accurate palaeoenvironmental reconstructions of the area and its stratigraphic setting. The molluscs also have a potentially larger data bank for comparative analyses with other sites than those of the ostracods. To a lesser extent, this also applies to the vertebrate remains. Pollen and plant macrofossils may also be examined in the near future.

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Northampton Nene Park Sixfields (Geotechnics, 1991).

Cattle Market area (Engineering Services Laboratory, 1993, 1995).

Appendix A

Species of freshwater ostracods identified in previous research (Chapter 5).

Darwinula stevensoni (Brady and Norman, 1870)

*Leucocythere baltica** (Diebel, 1965)

Limnocythere inopinata (Baird, 1968)

Limnocythere cf. usenensis Karmischina, 1966

Paralimnocythere compressa (Brady and Norman, 1889)

Paralimnocythere cf. *diebeli* (Diebel and Piertrzenuik, 1978)

Metacypris cordata Brady and Robertson, 1890

Cytherissa lacustris (Sars, 1863)

Candona angulata (G. W. Muller, 1900)

Candona candida (O. F. Muller, 1776)

Candona lactea, Baird, 1850

Candona rawsoni Tressler, 1957

Candona leverandi Hirschmann, 1912

Candona cf. *lozeki* Absolon, 1973

Candona neglecta Sars, 1877

Candona parallela (G.W. Muller, 1900)

Candona pubescens (Koch, 1873)

Candona tricicatricosa Diebel and Piertrzenuik, 1969

Candona weltneri obtusa (Hartwig, 1898)

Fabaeformiscandona (Candona) protzi Hartwig, 1898

Fabaeformiscandona fabaeformis (Fischer, 1851)

Pseudocandona (Candona) compressa (Koch, 1839)

Pseudocandona (Candona) marchica Hartwig, 1899

Nannocandona faba Ekman, 1914

Cyclocypris globosa (Sars, 1863)

Cyclocypris laevis (O.F. Muller, 1776)

Cyclocypris ovum (Jurine, 1820)

Cyclocypris serena (Koch, 1838)

Cypris ophthalmica (Jurine, 1820)

Ilyocypris Bradyi Sars, 1890

Ilyocypris biplicata (Koch, 1838)

Ilyocypris cf. *decipiens* Masi, 1905

Ilyocypris gibba, (Ramdohr, 1808)

Ilyocypris inermis Kaufmann, 1900

Ilyocypris lacustris Kaufmann, 1900

*Ilyocypris monstrifica** (Norman, 1862)

*Ilyocypris papillata** Robinson, 1990

Ilyocypris quinculminata Sylvester-Bradley, 1973

Ilyocypris schwarzbachi Kemph, 1967

Ilyocypris sp. A

Notodromas monacha (O. F. Muller, 1776)

Cypris marginata (Straus, 1821)

Cypris pubera (O. F. Muller, 1776)

Eucypris dulcifrons Diebel and Pietrzeniuk, 1969

Eucypris pigra (Fischer, 1851)

Eucypris virens (Jurine, 1820)

Prionocypris serrata (Norman, 1861)

Prionocypris zenkeri (Chyzer and Toth, 1858)

Trajancypris clavata Baird, 1835

Herpetocypris reptans Baird, 1835

Psychrodromus (Ilyodromus Sars, 1894*) olivaceus* (Brady and Norman, 1889)

*Scottia browniana** (Jones, 1850)

*Scottia tumida** (Jones, 1850)

Heterocypris salina (Brady, 1868)

Cypridopsis vidua (O.F. Muller, 1776)

Potamocypris arcuata (maculata Alm, 1914*)* (Sars, 1903)

Potamocypris fulva (Brady, 1868)

Potamocypris wolfi Brehm, 1920

Potamocypris zschokkei (Kaufmann, 1900)

* extinct species.

The names of the species are as included in the revised checklist published by Griffiths and Evans (1995). Where a bracketed genus or species name follows it is because this second name is used in some past research papers.

Appendix B

Checklist of ostracod species recovered from the Milton Formation and Nene Valley sediments.

Darwinula stevensoni (Brady and Norman,1870)

*Limnocythere falcata** Diebel, 1968

Limnocythere inopinata (Baird, 1843)

Limnocythere sanctipatricii (Brady and Robertson, 1869)

Cytherissa lacustris (Sars, 1863)

Candona candida (O.F. Muller,1776)

Candona neglecta Sars, 1887

Candona rawsoni Tressler, 1957 = *lactea* Baird,1850

Fabaeformiscandona fabaeformis (Eischer, 1851)

Pseudocandona marchica (Hartwig, 1899)

Cyclocypris globosa (Sars, 1863)

Cyclocypris laevis (O.F. Muller, 1776)

Ilyocypris biplicata Koch, 1838

Ilyocypris bradyi Sars, 1890

Ilyocypris gibba (Ramdohr, 1808)

*Ilyocypris papillata** Robinson, 1990

*Ilyocypris schwarzbachi** Kemph, 1967

Ilyocypris sp. A* (Stoke Goldington form, Robinson, pers. comm.).

Eucypris dulcifrons * Diebel and Pietrzeniuk, 1969

Eucypris pigra (Fischer, 1851)

Eucypris virens (Jurine, 1820)

Prionocypris serrata (Norman, 1861)

Trajancypris clavata (Baird, 1838)

Bradleystrandesia fuscatus (Jurine, 1820)

Herpetocypris reptans (Baird, 1835)

Psychrodromus olivaceus (Brady and Norman, 1889)

Heterocypris incongruens (Ramdohr, 1808)

Cypridopsis vidua (O.F. Muller, 1776)

Potamocypris arcuata (Sars, 1903)

Potamocypris similis G.W. Muller, 1912

Amplocypris tonnensis Diebel & Pietrzeniuk, 1975

* extinct species

The names of the species have been updated according to the revised checklist published by Griffiths and Evans (1995).

Appendix C

Ecology of ostracod species recovered from Quaternary fluvial sediments of Central Northamptonshire.

1. *Darwinula stevensoni* (Brady and Norman, 1870)

Darwinula stevensoni is both eurytopic and eurythermal and is usually found in permanent ponds, lakes and, occasionally, slow-flowing rivers. It prefers shallow water and this is possibly because it is a pouch-brooding species (Griffiths, 1995). *D. stevensoni* is common in Britain today and has been found in late Pleistocene deposits such as those of the March Gravels, Eye, Cambridgeshire (Keen *et al.*, 1990), in Stage 7 deposits at Stoke Goldington, Bedfordshire (Green *et al.*, 1996) and in Cromerian sediments at Sugworth, Oxfordshire (Robinson, 1979).

2. *Limnocythere falcata* Diebel, 1968

Fossils of *Limnocythere falcata,* an extinct species, have been found in Middle Pleistocene sediments at Cromer and Marks Tey, Essex (Robinson, 1978).

3. *Limnocythere inopinata* (Baird, 1843)

Limnocythere inopinata is considered to be a temperate climate indicator species (Robinson, pers. comm.) and is found in lakes and large permanent ponds. It is common in Britain today and has been identified in sediments of the Upper Floodplain terrace of the River Thames at Isleworth (Kerney *et al.,* 1982). These sediment were radiocarbon dated 43,140 +1520 -1280 years B.P. (Birm-319), the age of the Upton Warren interstadial (Coope *et al.,* 1961). The species was also recovered from the March gravels, dated as a late Pleistocene temperate stage, at Eye, Cambridgeshire (Keen *et al.,* 1990) and from Mid-Pleistocene deposits at Cromer and Marks Tey, Essex (Robinson, 1978).

***4. Limnocythere sanctipatricii* (Brady and Robertson, 1869)**

Limnocythere sanctipatricii is a cold stenothermal form and lives in permanent water bodies such as lakes and ponds. It is rare in Britain today (Henderson, 1990). It is also rare in the British Pleistocene record, being found only at late Devensian sites such as that of Star Carr in Yorkshire (Griffiths, 1995).

***5. Cytherissa lacustris* (Sars, 1863)**

Cytherissa lacustris, is a species of cold ponds and lakes (Robinson, pers. comm.; Griffiths, 1995). It lives on the surface of, or in, the benthic layer (the base of a water body). It is present in Britain and has been found in the March Gravels at Eye, Cambridgeshire (Keen *et al.,* 1990).

***6. Candona candida* (O.F. Muller, 1776)**

Candona candida has raised considerable debate about its habitat type. According to Forester and Brouwers (1985), it is often found in slightly brackish water as well as standing, stagnant or clean freshwater and slow-flowing water. De Rouffignac *et al.,* (1995) and Henderson (1990), however, say that *C. candida* is intolerant of brackish water. As for depth of water, Griffiths and Martin (1993) say they have found this species in lakes down to a depth of 300 m, but Delorme (1989), in contrast, suggests that this species is more likely to be found in shallow streams than in ponds or lakes of any depth. It is known that this species can cope with environmental stress and maybe it is found in or all of the above conditions. It lives either on the surface of, or within, the benthic layer. Its eggs are resistant to desiccation (Griffiths, 1995) and are easily spread, by wind or animals and birds, to a wide variety of habitats.

C. candida is common in Great Britain and Late Quaternary sediments (Griffiths, 1995)

7. *Candona neglecta* Sars, 1887

Candona neglecta is an epibenthic species of muddy substrates. It is eurotopic and eurythermal (Griffiths, 1995), and is found often in stressed environments. It is a detritus feeding species that lives in ponds and streams, both on or in muddy sediment. *C. neglecta* can tolerate a fairly wide range of temperatures and depths, but it does seem to have a limited salt tolerance. The eggs of this species are resistant to desiccation. In lake assemblages, Danielopol *et al.* (1985) suggested that some form of depth partitioning takes place between *C. candida* and *C. neglecta, C. candida* occurring mostly in shallow waters. It is common in Great Britain and in Quaternary sediments (Henderson, 1990).

8. *Candona rawsoni* Tressler, 1957 / *lactea* Baird, 1850

Candona rawsoni and *Candona lactea* may be one and the same species(Griffiths pers. comm.). *C. rawsoni* has extant populations in Canada and Siberia (Griffiths, 1995) but is not found in Britain today. *C. lactea,* if it is a separate species, is extinct.

It is debatable as to what environment *C. rawsoni* represents because, although it is most commonly found in cold tundra-like conditions simiiar to those of Siberia or Canada (Delorme & Donald, 1969), it has also been found within interglacial deposits in Canada (Poplawski and Karrow, 1981).

C. rawsoni has been recorded at one site in Great Britain, that is an Ipswichian interglacial deposit at Cropthorne (Maddy *et al.,* 1991).

C. lactea has been recovered from older (Stage 7, 9 or 11) interglacial deposits at Hitchin, Hertfordshire, England (Boreham and Gibbard, 1995). If the two are one species, then these two records extend the period in which the species existed in Britain. If they are separate species then the Pleistocene specimens found in the Nene Valley possibly constitute only the second record of *C. rawsoni* in the British Pleistocene.

9. *Fabaeformiscandona fabaeformis* (Eischer, 1851)

Fabaeformiscandona fabaeformis lives on fine sands feeding on detritus and can tolerate slightly raised salinities. Generally, it is a winter or spring species. In Britain it may occur in slow flowing streams (Vesper, 1975), but, according to Griffiths (1995), this is disputed by some authors. This species is rare in the British Pleistocene. It has been found in the Cromerian West Runton Freshwater Beds (De Deckker, 1979).

***10. Pseudocandona marchica* (Hartwig, 1899)**

Pseudocandona marchica is a temperate species that inhabits muddy sediments in vegetated habitats. It is tolerant of flowing waters. It is rare in Britain today (Griffiths, 1995). Henderson, (1990) did not include *P. marchica* in the present day British fauna; Griffiths (1995) has provisionally done so. This species has been recovered from the Devensian and Early Holocene sediments at Kildale, Yorkshire (Keen *et al.*, 1984), the Stage 7, 9 or 11 sediments in the March Gravels, Peterborough (Keen *et al.*, 1990) and the Cromerian sediments at Sugworth and Little Oakley (Robinson, 1979, 1990).

***11. Cyclocypris globosa* (Sars, 1863)**

Cyclocypris globosa (identified by Griffiths, pers. comm.) generally occurs in the cool, early spring months in rain-fed pools and temporary ponds. It is commonly found in such waters in the north of Britain. Griffiths (1995) records it as unknown in the British Pleistocene. However, one record has been found by the writer in the pre-Ipswichian sediments at Hitchen, Hertfordshire (Boreham and Gibbard, 1995).

***12. Cyclocypris laevis* (O.F. Muller, 1776)**

Cyclocypris laevis is a temperate species that is usually found in shallow well vegetated pools/non-flowing waters. However, it is an active swimmer and can adapt to most aquatic environments. It is common in Britain today. It has been found frequently in the British Quaternary ranging from the Late Devensian, such as at Kildale, Yorkshire (Keen *et al.*, 1984), to the Cromerian such as the site at Little Oakley, Essex (Robinson, 1990).

***13. Ilyocypris biplicata* Koch, 1838**

Ilyocypris biplicata is a species of vegetated running water, pools and ponds, generally preferring cooler waters. It is not found in Britain today. It is not common in the British fossil record which suggests there may have been, even in the past, only a few isolated communities. The species is recorded from Stage 7, 9 or 11 deposits at Trysull, Staffordshire (Morgan, 1973), from deposits of a cool stage no younger than Stage 5e at Stoke Goldington (Green *et al.*, 1996) and in Holocene deposits at West Overton, Wiltshire (Griffiths, 1995).

***14. Ilyocypris bradyi* Sars, 1890**

Ilyocypris bradyi is eurythermal and eurytopic and, therefore, cosmopolitan in its distribution. It does not signify any particular aquatic environment or age. It is frequently found in British Pleistocene sediments such as those at Kempton Park, Sunbury (Gibbard *et al.*, 1981), and Sugworth (Robinson, 1979).

***15. Ilyocypris gibba* (Ramdohr, 1808)**

Ilyocypris gibba is a temperate species of both moving and still waters and is common in Britain today (Henderson, 1990). It has been found at many Pleistocene sites (e.g. Gibbard *et al.*, 1981; Keen *et al.*, 1984; Shotton *et al.*, 1993).

***16. Ilyocypris papillata* Robinson, 1990**

Ilyocypris papillata is an extinct Ilyocyprid of the *gibba* group. It was first recorded from Cromerian sediments at Little Oakley, Essex (Robinson, 1990). These sediments were considered interglacial in origin and, as this species has not been found in sediments believed to be of cooler origin, the species is most likely to be of temperate, permanent waters.

***17. Ilyocypris schwarzbachi* Kemph, 1967**

Ilyocypris schwarzbachi is an extinct species. It has been found in Cromerian interglacial deposits at Little Oakley (Robinson, 1990). These sediments were considered interglacial in origin, and as this species has not been found in sediments believed to be of cooler origin in Britain, the species is most likely to have been found in temperate, permanent waters.

***18. Ilyocypris* sp. A (Stoke Goldington form, Robinson, pers. comm.).**

Ilyocypris sp. A, an extinct species, was first described about ten years ago by Robinson (pers. comm.). It was first found in the Stage 7 sediments at Stoke Goldington, Bedfordshire (Green *et al.,* 1996). It is still unnamed at the time of writing. The sediments at Stoke Goldington were considered to be interglacial in origin and, as this species has not been found in sediments believed to be of cooler origin, the species is most likely to have been found in temperate, permanent waters.

***19. Eucypris dulcifrons* Diebel and Pietrzeniuk, 1969**

Eucypris dulcifrons is an extinct species. It has been recorded at Cromerian sites at West Runton (De Deckker, 1979), Little Oakley (Robinson, 1990) and Waverley Wood (Shotton *et al.,* 1993). These sediments were considered interglacial in origin and, as this species has not been found in sediments believed to be of cooler origin the species was most likely to be one of temperate, permanent waters.

***20. Eucypris pigra* (Fischer, 1851)**

Eucypris pigra usually lives in permanent flowing water, but is sometimes found in the margins of permanent ponds and lakes. It is fairly common in British springs and streams (Henderson, 1990). It is recorded from several British Pleistocene sites including middle Devensian deposits at Kempton Park, Sunbury (Gibbard *et al.,* 1981) and Cromerian deposits at Sugworth (Robinson, 1979).

21. Eucypris virens **(Jurine, 1820)**

Eucypris virens is a species of temporary pools that dry out in the summer (Henderson, 1990) and is commonly found in Britain today. According to Griffiths (1995) this species is found only rarely in the British Pleistocene record. The writer has found, however, a species, *Cypris virens,* recorded from the *Chara* marl of the Hitchin lake beds (Boreham and Gibbard, 1995). This species is not on any current checklists, but it may well be *E. virens.*

22. Prionocypris serrata **(Norman, 1861)**

Prionocypris serrata is a species of temperate, temporary pools and intermittent streams in the southern part of Britain. It is recorded from one British Pleistocene site, in Stage 7, 9 or 11 material at Froghall in Warwickshire (Griffiths, pers. comm.).

23. Trajancypris clavata **(Baird, 1838)**

Trajancypris clavata is a rare ostracod of small, temporary or permanent, ponds. It usually appears in November and matures throughout the winter months (Griffiths, 1995). However, in contrast, Martens (1989) records it as a spring-summer species. Griffiths (1995) does not record finding this species in the Pleistocene record.

24. Bradleystrandesia fuscatus **(Jurine, 1820)**

Bradleystrandesia fuscatus is a species which lives in temporary pools during winter and spring months and is common today in Britain. It is not recorded in the British Pleistocene, the only record found by Griffiths (1995) being in the later Holocene sediments investigated at Castlethorpe in Lincolnshire (Preece and Robinson, 1984). This is probably the first record of this species in the British Pleistocene.

25. Herpetocypris reptans **(Baird, 1835)**

Herpetocypris reptans is a large species which commonly inhabits freshwater pools and large lakes and, rarely, springs. It is also found in temporary ponds. It moves around on water-weed or burrows in soft substrates. *H. reptans* can withstand quite wide temperature ranges and has eggs that survive desiccation. It is fairly cosmopolitan in its distribution (Griffiths, 1995) and is common in Britain today (Henderson, 1990). This species is frequently found in the Pleistocene, for example, the Devensian interstadial deposits at Sunbury, Kent (Gibbard *et al.*, 1981), the Stage 7 deposits at Stoke Goldington, Bedfordshire (Green *et al.*, 1996), and the Cromerian deposits at Waverley Wood in Worcestershire (Shotton *et al.*, 1993).

***26. Psychrodromus olivaceus* (Brady and Norman, 1889)**

Psychrodromus olivaceous lives within the coarse benthic sediments of cold running water, springs and streams (Griffiths, 1995). It is common in Britain today. This species has been found in Late Devensian and Early Holocene deposits in Lincolnshire (Preece and Robinson, 1984) and Middle Devensian deposits at Kempton Park, Sunbury, England (Gibbard *et al.*, 1981).

***27. Heterocypris incongruens* (Ramdohr, 1808)**

Heterocypris incongruens is a swimming species. It is able to live in bleak, frequently cold, temporary habitats (Sywula, 1992). It has even been found in a temporary puddle on tarmac (Horne, pers. comm.). *H. incongruens* is omniverous and feeds on algae, protozoa and/or fish larvae (Griffiths, 1995). In common with a great many other cypridid ostracods, its eggs can survive desiccation, freezing and drying. It is common in Britain in temporary habitats. Sexual populations have been found in several places in Europe and it is a recognized good example of "*geographical parthenogenesis*" (Horne, pers. comm.) Except in early Devensian sediments on the Somerset Levels, *H. incongruens* has not been recorded in the British Pleistocene (Griffiths, 1995). This is probably the first record of this species in the British Pleistocene.

***28. Cypridopsis vidua* (O.F. Muller, 1776)**

Cypridopsis vidua lives in still, vegetated water. It is an active swimmer and has a preference for eutrophic, still waters (Griffith, 1995). It is common in Britain today and has been recorded from the Holocene sediments of Kildale, Yorkshire (Keene *et al.*, 1984), the Stage 7 deposits of Stoke Goldington, Bedfordshire (Green *et al.*, 1996) and the Cromerian sites of Little Oakley (Robinson, 1990) and West Runton (De Deckker, 1979).

29. *Potamocypris arcuata* (Sars, 1903)

Potamocypris arcuata has been found living in a seepage-fed meadow pond at Horsebridge, Hampshire. It is the only modern British site on record (Griffiths, 1995). Griffiths has suggested that the species identified as *Potamocyris maculata* in the fossil record is, in fact, *P. arcuata*. If so, this species has been found in Late Devensian deposits at Kildale, Yorkshire (Keen *et al., 1984).*

30. *Potamocypris similis* G.W. Muller, 1912

Potamocypris similis occurs in lakes and large ponds. It is found at only one site in Britain (Griffiths, 1995). This species has not been recorded before in the British Pleistocene and, thus, this may be its first record.

31. *Amplocypris tonnensis* Diebel & Pietrzeiuk, 1975

Amplocypris tonnensis (identified in these sediments by Griffiths in 1996) is an extinct species. The habitat requirements are not well known as it has been recorded once only in Britain. This was from a deposit, suggested date Early Devensian, at Fisherton, near Salisbury, Wiltshire (Green *et al.,* 1983). The specimens found in the Pleistocene sediments of the Nene Valley (this research) is probably only the second record of *A. tonnensis* in the British Pleistocene.

Appendix D

Ostracods from the Milton Formation and the Nene Valley deposits.

S1.MS

L. falcata 26, *C. neglecta* 1, *Ilyocypris* sp. A 46. (total 73) (carapaces 2) (juveniles 20: 27.4 %).

S2.MS

L. falcata 4, juvenile *Candona* spp. 4, *Ilyocypris* sp. A 16, *E. virens* 10. (total 34) (juveniles 25: 65.8 %).

S3.MS

L. falcata 16, *Ilyocypris* sp. A 18, *I. gibba* 2. (total 36) (juveniles 34: 96.4 %)

S4.MS

L. falcata 50, *F. fabaeformis* 1, *Ilyocypris* sp. A 58, *I. papillata* 1, *H. reptans* 6, *H. incongruens* 3, *B. fuscatus* 7. (total 126) (juveniles 25: 19.8 %).

S5.MS

L. sanctipatricii 27, juvenile *Candona* spp. 7, *C candida* 10, *C. neglecta* 23, *P. marchica* 21, *C. laevis* 36, *E. virens.* 7, *E. pigra* 21, *B. fuscatus* 7, *P. arcuata* 20. (total 179) (juveniles 20: 11.2 %).

S6.MS

E. pigra 4, *H. reptans* 11. (total 15) (juveniles 7: 41.6 %).

S7.CH

C. neglecta 2 *C. laevis* 4, *H. reptans* 10. (total 16) (juveniles 2: 12.5 %).

S8.CH

C. neglecta 13, *I. biplicata* 19, juvenile *Herpetocypris* sp. 1. (total 33) (carapaces 8) (juveniles 20: 60.6 %).

S9.CH

Juvenile *Candona* spp. 11, *C. neglecta* 23, *C. rawsoni/lactea* 9, *C. laevis* 5, *P. serrata* 12. (total 60) (carapace 1) (juveniles 14: 23.4 %).

S10.CH

C. neglecta 4, *C. laevis* 2, *I. biplicata* 6, *I. bradyi* 15. (total 27) (juveniles 6: 22.2 %).

S11.CH

Candona spp. 8, *C. neglecta* 33, *C. rawsoni/lactea* 15, *C. laevis* 15, *I. bradyi* 5, *I. schwarzbachi* 2, *Ilyocypris* sp. A. 3, *P. serrata* 35, *Prionocypris* spp. 10. (total 126) (carapaces 6) (juveniles 37: 29.3 %).

S12.CH

Juvenile *Candona* spp. 19, *C. neglecta* 28, *C. rawsoni/lactea* 18, *B. fuscatus* 6, *I. bradyi* 7, *I. gibba* 3, *I. schwarzbachi* 8, *C. vidua* 9, *P. serrata* 7, *P. arcuata* 7. (total 112) (carapaces 3) (juveniles 57: 50.8 %).

S13.CH

Juvenile *Candona* spp. 8, C. neglecta 6, C. rawsoni/lactea 5, *P. marchica* 4, *I. bradyi* 14, *I. gibba* 3. (total 40) (juveniles 20: 50.0 %).

S 14.CH

Juvenile *Candona* spp. 2, *I. bradyi* 2. (total 4) (juveniles 0: 0.00 %).

S15.CH

I. biplicata 9, *E. pigra* 3. (total 12) (carapace 1) (juveniles 12: 100 %).

S16.CH

Juvenile *Candona* spp. 8, *C. neglecta* 2, *C. rawsoni/lactea 5, I. biplicata* 3, *C. vidua* 18. (total 36) (carapace 1) (juveniles 32: 88.8 %).

S17.CH

Juvenile *Candona* spp. 7, *C. neglecta* 35, *C. rawsoni/lactea* 18, *I. bradyi* 16. (total 74) (juveniles 39: 52.7 %).

S18.CH

Juvenile *Candona* sp. 6. (total 4) (juveniles 4: 100 %).

S19. CH

Amplocypris tonnensis 2. (total 2) (juveniles 0: 0.0 %).

S20.CH

C. neglecta 1, *E. pigra* 6. (total 7) (juveniles 0: 0.0 %).

S21.CH

C. neglecta 1, *I. bradyi* 3, *E. pigra.* 2. (total 6) (juveniles 0: 0.0 %).

S22.CH

C. neglecta 1, *C. candida* 8, *I. bradyi* 9, *P. similis* 9. (total 27) (juveniles 0: 0.0 %).

S23.CH91

H. reptans 17. (total 17) (juveniles 0: 0.0 %).

S24.CH92

L. sanctipatricii 13, juvenile *Candona* spp. 6, *C. candida* 17, *C. neglecta* 22, *P. marchica* 3, *C. laevis* 16, *I. gibba* 1, *E. pigra* 8, *P. arcuata* 18. (total 104) (carapaces 17) (juveniles 15: 16.4 %).

S25.CH92

Juvenile *Candona* spp. 9. (juveniles 9: 100 %).

S26.CH92

Juvenile *Candona* spp. 4, *C. candida* 20, *C. neglecta* 5, *C. laevis* 1, *I. bradyi* 94, juvenile *E. pigra* 2, *P. arcuata* 1. (total 127) (carapaces 17) (juveniles 53: 41.7 %).

S27.CH92

C. candida 4, Juvenile *Eucypris* sp. 1. (total 5) (juveniles 1: 20.0 %).

S28.CH92

Juvenile *Candona* spp. 8, *C. candida* 8, *C. neglecta* 1, *I. bradyi* 9, *P. serrata* 56. (total 80) (juveniles 8: 35.0 %).

S29.CH

Juvenile *Candona* spp. 5, *C. candida* 33, *C. neglecta* 18, *C. laevis* 28, *I. bradyi* 27, *Ilyocypris* sp. A 9, *B. fuscatus* 2, *E. pigra* 1, *P. serrata* 1. (total 124) (carapaces 18) (juveniles 42: 33.8 %).

S30.CH

C. candida 22, *C. neglecta* 12, *C. laevis* 8, *I. bradyi* 13, *Ilyocypris* sp. A. 7, *Eucypris* sp. 1, *E. pigra* 1, *P. serrata* 1, *Prionocypris* sp. 5, *H. reptans* 2. *T. clavata* 2. (total 74) (carapaces 36) (juveniles 14: 20.2 %).

S31.CH

Juvenile *Candona* spp. 18, *C. candida* 23, *C. neglecta* 35, *C. globosa* 14, *C. laevis* 24, *I. bradyi* 45, *Ilyocypris* sp. A. 12, *E. pigra* 10, *H. incongruens* 8, *P. olivaceus* 1, *P. arcuata* 6. (total 194) (carapaces 82) (juveniles 36: 17.2 %).

S32.CH

C. candida 7, *C. neglecta* 22, juvenile *Eucypris* sp. 1, *H. reptans* 10. (total 40) (juveniles 9: 22.5 %).

S33.CH

C. candida 2, *C. neglecta* 5, juvenile *Eucypris* sp. 8, *H. reptans* 22. (total 37) (juveniles 4: 10.8 %).

S34.CH

C. candida 3, *C. neglecta* 4, *Ilyocypris* sp. A. 6. (total 11) (carapaces 7) (juveniles 3: 27.2 %).

S35.WOL

D. stevensoni 1, juvenile *Candona* spp. 15, *C. candida* 6, *C. neglecta* 5, *I. bradyi* 3, *L. inopinata* 1. (total 31) (carapace 1) (juveniles 21: 67.7 %).

S36.WOL

No species present.

S37.WOL

L. inopinata 6, *I. bradyi* 8, *I. gibba* 3, *P. arcuata* 1. (total 18) (carapaces 5) (juveniles 17: 96.4 %).

SAMPLE S 38.VF

L. inopinata 10, *L. sanctipatricii* 11, juvenile *Candona* spp. 11, *C. candida* 72, *C. neglecta* 35, *F. fabaeformis* 6, *P. marchica* 10, *I. bradyi* 14, *I. gibba* 15, *Ilyocypris* sp. A. 21, *C. vidua* 23. (total 228) (carapaces 2) (juveniles 99: 43.4 %).

S39.WEL

Candona sp. 2. (total 2) (juveniles 0: 0.0 %).

S40.WEL

L. inopinata 27, *C. lacustris* 1, *Candona* sp. 2, *C. candida* 14, *C. neglecta* 18, *E. pigra* 1. (total 63) (carapaces 3) (juveniles 22: 36.9 %).

S41.WEL

C. candida 49, *C. laevis* 1, *E. dulcifrons* 1, *P. serrata* 1. (total 52) (carapaces 5) (juveniles 29: 55.7 %).

S42.WEL

L. inopinata 3, *C. candida* 21, *P. marchica* 32, *I. bradyi* 13, *P. serrata* 1, *H. reptans* 11, *C. vidua* 28. (total 109) (carapaces 18) (juveniles 64: 59.2 %).

Appendix E

The British record of ostracods recovered from the Milton Formation and Nene Valley sediments.

Darwinula stevensoni:	Beestonian, Cromerian, Hoxnian, Ipswichian, Devensian. present.
Limnocythere falcata:	Cromerian, Hoxnian, Devensian, extinct.
Limnocythere inopinata:	Hoxnian, Devensian, present.
Limnocythere sanctipatricii:	Devensian, present.
Cytherissa lacustris:	Hoxnian, Ipswichian, Devensian, present.
Candona candida:	Late Beestonian to present.
Candona neglecta:	Late Beestonian to present.
Candona rawsoni /lactea	Hoxnian, Ipswichian, extinct in Britain.
Fabaeformiscandona fabaeformis:	Cromerian, Devensian, present.
Pseudocandona marchica:	Cromerian, Devensian, present (debated).
Cyclocypris globosa:	unknown in Pleistocene record, present in north of Britain.
Cyclocypris laevis:	Cromerian, Hoxnian, Devensian. present.
Ilyocypris biplicata:	Hoxnian, Ipswichian, Holocene, extinct in Britain (debated).
Ilyocypris bradyi:	Cromerian, Hoxnian, Ipswichian, Devensian, present.
Ilyocypris gibba:	Beestonian, Cromerian, Hoxnian, Ipswichian, Devensian, present.
Ilyocypris papillata:	Cromerian, extinct.
Ilyocypris schwarzbachi:	Cromerian, extinct.
Ilyocypris sp. A:	(Stoke Goldington form, Robinson, pers. comm.) Hoxnian, extinct.
Eucypris dulcifrons:	Beestonian, Cromerian, extinct.
Eucypris pigra:	Cromerian, Ipswichian, Devensian, present.
Eucypris virens:	Devensian, present.
Prionocypris serrata:	Hoxnian, present.
Trajancypris clavata:	Devensian, present.
Bradleystrandesia fuscatus:	unknown in British Pleistocene record, present in Britain today
Herpetocypris reptans:	Cromerian, Hoxnian, Ipswichian, Devensian, present.
Psychrodromus olivaceus:	Devensian, present.

Heterocypris incongruens:	Devensian, present.
Cypridopsis vidua:	Cromerian, Hoxnian, Ipswichian, Devensian, present.
Potamocypris arcuata:	Devensian, extremely rare in Britain today.
Potamocypris similis:	unknown in British Pleistocene, extremely rare in Britain today.
Amplocypris tonnensis:	Ipswichian, Devensian, extinct.

Records according to Griffiths (1995) and past research reviewed in Chapter 5.

Appendix F

Ostracods recovered from the Milton Formation and

The Nene Valley Sands and Gravels.

Darwinula stevensoni

Limnocythere falcata

Limnocythere inopinata

Limnocythere sanctipatricii 1

Cytherissa lacustris

Limnocythere sanctipatricii 2

Candona candida 1

Candona candida 2

Candona spp.

Fabaeformiscandona fabaeformis

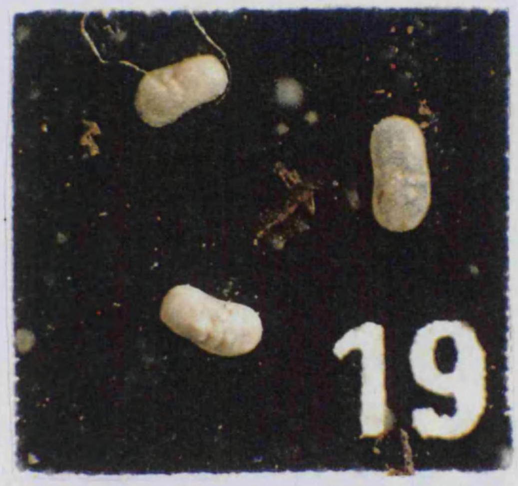
Candona neglecta

Pseudocandona marchica

Cyclocypris laevis

Ilyocypris biplicata

Ilyocypris bradyi



Ilyocypris gibba

Ilyocypris papillata

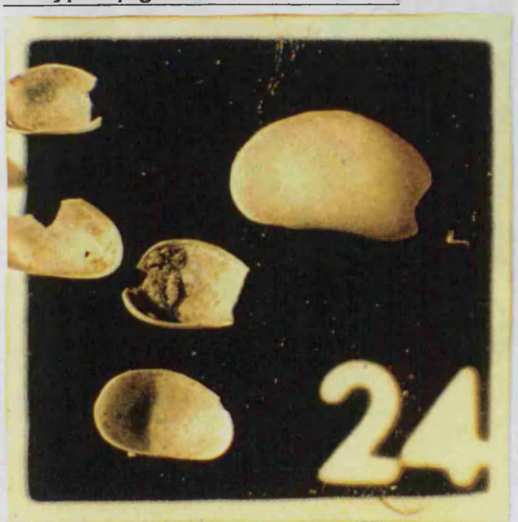
Ilyocypris schwarzbachi

Ilyocypris sp. A

Eucypris sp.

Eucypris pigra

Eucypris sp.



Eucypris virens

Eucypris sp.

Prionocypris serrata

Trajancypris clavata

Heterocypris incongruens

Herpetocypris reptans

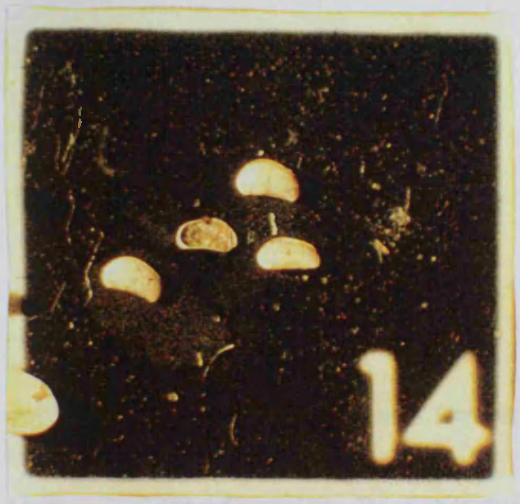
Psychrodromus olivaceus

Bradleystrandesia fuscatus

Potamocypris arcuata

Cyclocypris globosa

Cyclocypris laevis



Potamocypris similis

Amplocypris tonnensis

APPENDIX G: RADIOCARBON AGE REPORT

Allocation No.: 496/0492

Submitter: R Belshaw
Nene College, Northampton

Project Title: Palaeoenvironments of the Nene valley, Gravels Wear, Great Houghton, Northants.

Sampling Location: Clifford Hill gravel pit, Great Houghton, Northampton, England (NW; Natl. Grid Ref. SP 795 597).

Samples Collection: Recovered from freshly exposed profile. Coll. A Smith June 1992 and subm by R. Belshaw, Nene College.

Results:

Site 1

From medium gravel, at 3.45m below surface of topsoil and 2.0m above blue lias, disturbed by large scale cryoturbation.

Pretreatment of Raw Samples: Prior to isotope analyses the raw sample was digested in 2M HCl (80 C for 24 hours) and washed to neutral pH. Treated material split into two fractions, tree roots and residual sandy gravel, before being dried in drying oven.

SRR-4866	**Tree roots**	**3285 ± 45** ^{13}C = -28.0‰
SRR-4867	**Sandy gravel**	**3910 ± 65** ^{13}C = -28.0‰

Site 2

Organic matter in freshwater sediments from base of meandering channel, 5.15m below surface of top soil and 0.3m above blue lias.

Pretreatment of Raw Samples: Prior to isotope analyses the raw sample was digested in 2M HCl, (80 C for 24 hours) and chemically split into "humic" (alkali soluble) and "humin" (alkali insoluble) fractions.

SRR-4868	**Humic**	**36840 ± 65** ^{13}C = -28.4‰
AA-10326	**Humin**	**27820 00 ±** $^{455}_{430}$ ^{13}C = -29.8‰

Note: "Humin" component dated using the AMS technique because of low carbon yield.