ENGLISH HERITAGE

University of Southampton

THE ARCHAEOLOGICAL POTENTIAL OF SECONDARY CONTEXTS

DR ROBERT HOSFIELD & JENNI CHAMBERS
FEBRUARY 2004

School of Humanities (Archaeology)
University of Southampton

The Archaeological Potential of Secondary Contexts

DR ROBERT HOSFIELD & JENNI CHAMBERS

The Archaeological Potential of Secondary Contexts project was undertaken in the School of Humanities (Archaeology), University of Southampton, between October 2002 and February 2004. The research project was funded by English Heritage (project no. 3661), through the Aggregates Levy Sustainability Fund, whose support is gratefully acknowledged.

Much of the work reported here was made possible by John Allen (Royal Albert Memorial Museum & Art Gallery, Exeter) and Dr Chris Green who permitted and provided easy access to, respectively, the museum's Broom artefact collection and the C.E. Bean artefact collection. Thanks to Mr & Mrs Lunt and Mr & Mrs Jennings for generously permitting access to the Broom pits between 2000 and 2003. Thanks also to Dr Phil Toms and Dr Rob Scaife for boldly sampling at Broom in all weathers and surviving treacherous conditions underfoot.

For access to various artefact collections in Hampshire, thanks to Kay Ainsworth (Hampshire Museums Service, Winchester), Robin Iles (Hyde Street Museum, Winchester), and Duncan Brown (God's House Tower Museum, Southampton). Thanks also to Dr Paul Tosswell for access to the Department of Civil Engineering's flume facilities at the University of Southampton.

We would particular like to thank our project officer Helen Keeley for all her support and assistance throughout the duration of the project. Thanks also to Professor Clive Gamble, Dr John McNabb, Dr Justin Dix, and Dr Francis Wenban-Smith for critical comments and general support throughout, to Dr David Bridgland and Dr Andy Howard for critical feedback on early drafts of Chapter 2, Dr Chris Green for our many discussions concerning Broom, Dr Danielle Schreve for her thoughts on bone transport (Chapter 6), and to Phil Harding, Terry Hardaker and Dr Keith Wilkinson for their thoughts on archaeological watching brief practices — naturally all of the final ideas expressed here represent our own views on all of these issues. Thanks also to all those who attended the many seminars and meetings held over the last two years and provided feedback to presentations and engaged in lengthy discussions in bars and pubs afterwards. And finally, thanks to Jenni for much good humour and patience during the many, long report writing sessions…

Dr Robert Hosfield & Jenni Chambers
School of Humanities (Archaeology)
University of Southampton
Avenue Campus
Highfield
Southampton
SO17 1BJ
E-mail: rth1@soton.ac.uk & j.c.chambers@soton.ac.uk
Telephone: +44 (0)23 8059 6864
Fax: +44 (0)23 8059 3032

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This report is presented in two volumes. Volume I includes the executive summary and chapters 1–5 Volume II includes chapters 6–10 and the references. The table of contents, list of figures, and list of tables are included at the front of both volumes for ease of use.

Accompanying this report is a CD (2ndaryContexts). Included on the CD are:

- Microsoft Access 2002 (SP-2) database file 'Bean Collection Database_EHCopy.mdb'.
- Text file 'Readme.txt', to accompany the database file.
- Database image files (in the CD folder D:\Broom\Bean).
- Adobe Acrobat PDF files for each of the report chapters. The digital images from Chapter 3 (Figures 38–50, 89, 93–94 & Figure 116), Chapter 4 (Figures 144–145), and Chapter 5 (Figures 172, 174–185, 188–192, 195–199, 206–214 & 219–221) can be viewed in colour on the relevant PDF files.

EXECUTIVE SUMMARY

This report is concerned with Palaeolithic stone tool assemblages recovered from the flood deposits of Middle and Late Pleistocene (787–11,000 years BP) rivers in the UK. These are described here as *archaeological secondary contexts*. The stone tool assemblages are distributed across southern Britain, while Pleistocene flood deposits (referred to throughout as fluvial deposits) are distributed through the UK. The stone tool assemblages and their associated fluvial deposits vary in age from *at least* 500,000 years old (due to limitations in current geochronological understanding) to the end of the Palaeolithic period (*c.* 11,000 years BP). The importance of archaeological secondary contexts therefore stems from their widespread geographical distribution and extensive chronological coverage.

This report assesses the value of the archaeological secondary context resource in terms of the unique spatio-temporal structure of the data, assemblage taphonomy, appropriate analytical frameworks and the potential of the resource for current and future understanding of the Palaeolithic period.

The report is organised into ten chapters, discussing a series of key themes and case studies:

- Chapter 1: introduction to archaeological secondary contexts; a summary of current understanding; an overview of British Palaeolithic studies.
- Chapter 2: models of fluvial behaviour over the glacial/interglacial cycles of the Middle and Late Pleistocene; the duration of individual phases of fluvial activity (the erosion of floodplain sediments and the deposition of new materials). *The models indicate that fluvial activity phases were episodic and short-lived. Understanding the chronology of the Pleistocene fluvial sediments is critical as they are the context for the Palaeolithic stone tool assemblages.*
- Chapter 3: case study of fluvial sedimentation and erosion activity as represented by the sedimentary sequence at the Lower Palaeolithic locality of Broom, UK; the application of optically stimulated luminescence (OSL) dating to the Broom sediments. *The case study demonstrates the resolution on current OSL dating of Pleistocene fluvial sediments and provides support for the models presented in Chapter 2.*
- Chapter 4: case study of a stone tool assemblage from the Lower Palaeolithic locality of Broom, UK; models of the spatial derivation of stone tools in fluvial systems; models of technological patterning in stone tool production over time and space. *The case study develops important new methodologies and demonstrates that valuable behavioural data can be extracted from secondary context assemblages.*
- Chapter 5: models of the spatial derivation and modification of stone tools in fluvial systems; models of secondary context assemblage formation. *The models emphasise the complexity of artefact behaviour in fluvial environments and reinforce the value of the individual artefact-based models of spatial derivation developed and discussed in Chapter 4.*
- Chapter 6: models of the spatio-temporal data scales and resolutions associated with different categories of palaeoenvironmental evidence; mapping of palaeoenvironmental data against secondary context artefact assemblage data. *The models indicate that the contrasting data scales do not permit high resolution palaeoenvironmental evidence and derived artefact data to be directly equated. Reconstructed palaeoenvironments are therefore examples of some of the types of habitats that existed, but they cannot be explicitly populated with pre-modern human artefacts.*
- Chapter 7: models of the spatial resolution of the secondary context resource; models of the temporal resolution of the secondary context resource; presentation of new analytical frameworks for the interpretation of this resource; exploration of existing research themes using these secondary context interpretive frameworks. *The models evaluate the spatio-temporal structure of the secondary context resource and develop new methodologies. The interpretive frameworks originate from the evaluated spatio-temporal structure of the resource and demonstrate the potential applications of the data.*

- Chapter 8: reviews of current practice in the management, protection and recording of the secondary context archaeological resource; evaluation of priorities with respect to the recording of different data categories; recommendations for modifications in watching brief practice with respect to the future of the secondary context resource. *The review indicates that a wider range of data could be recovered from secondary contexts than currently results from standard watching brief practices. Recommendations are offered that highlight the shifting of data priorities and associated changes in working practice.*
- Chapter 9: case studies of regional secondary context data sets from the River Axe and River Test valleys; testing of secondary context data sets against extant research frameworks; presentation of new structures relating the secondary context resource to current research agendas. *The case studies highlight both the value and the validity of the secondary context resource, and demonstrate that these data can be used successfully to investigate current research questions and themes.*
- Chapter 10: summary of the project results; proposals for further research.

This project demonstrates that archaeological secondary contexts are a critical archaeological resource. It presents new methodologies for modelling the unique spatio-temporal scales associated with the resource. These permit the meaningful interpretation of the data contained within archaeological secondary contexts, expanding both the available analytical scales and the range of archaeological research questions that can be addressed. Proposed new frameworks provide mechanisms to integrate the primary and secondary context resources, and allow behavioural analysis to move from robust demographic signatures over 100,000 year glacial/interglacial cycles to subsistence practice over 100 years at the Boxgrove beach.

The case studies of secondary context assemblages from Broom (Devon/Dorset) and the Test valley (Hampshire) indicate both the value of the data-sets and their previously limited inclusion within archaeological dialogues. However, for their potential to be fully realised in future, there is a clear need for revised strategies with respect to data collection, research funding, and the perceived importance of the secondary context resource within the British Palaeolithic.

CHAPTER 1

INTRODUCTION

1. OVERVIEW

This research project is concerned with archaeological secondary contexts and their potential contributions to archaeological research. The importance of archaeological secondary contexts lies in their predominance within the archaeological records of specific regions and time periods (e.g. the British Lower and Middle Palaeolithic), and in their ability to offer unique analytical scales for archaeological analysis. These scales operate both in space and time, and have been the focus of extensive previous research (e.g. Bailey 1980; Stern 1993, 1994; Gamble 1996, 1999). However, relatively few explicit connections have been drawn between these scales and the available data-sets. The potential relationships between these analytical scales and the principle categories of evidence are therefore explored here, within a wider interpretative framework for the undertaking of secondary context archaeology. The archaeological record of the British Lower and Middle Palaeolithic forms the focus of the research, reflecting both the dominance of secondary context data-sets in the archaeological resource from this period, and the paucity of research directed towards them over the past two decades and more.

Archaeological secondary contexts are defined here as fluvial aggregate deposits situated on river terrace and river floodplain landforms, although it is recognised that this definition ignores other categories of deposits such as aeolian and glacial sediments. The fluvial aggregate deposits incorporate gravels, sands, silts and clays. With reference to their archaeological content, secondary contexts should be considered as artefactual materials that have been removed from their initial place of discard and subsequently re-deposited. This archaeological content is considered here to extend beyond humanly produced artefacts such as stone tools, and to also incorporate palaeoenvironmental evidence such as macro- and micro-fauna, and plant pollen.

An assessment of the archaeological potential of secondary contexts is especially timely in light of the current academic focus on models of colonisation, occupation and landscapes. These approaches have been particularly noticeable within recent research exploring the British Lower and Middle Palaeolithic (e.g. Gamble 1999; White & Schreve 2000; Ashton & Lewis 2002). Such models require testing against regional data-sets that incorporate macro-scales in time and space. The secondary context archaeological resource is the only data set that meets these criteria. However, the specific structure of the secondary context archaeological resource in time and space is currently unknown and must therefore be explicitly assessed.

2. BACKGROUND

The focus upon fluvial aggregate deposits reflects the extensive presence of these secondary contexts within the Lower and Middle Palaeolithic archaeological records of north-western Europe. With specific reference to Britain, Middle and Late Pleistocene fluvial aggregate deposits occur across the full extents of southern Britain (except in those areas where the Anglian and Devensian glaciations have destroyed the evidence of earlier river terrace aggradations (Figure 1)). These deposits have been the focus of extensive geological and geoarchaeological research (e.g. Gibbard 1985, 1994; Briggs *et al.* 1985; Ashton *et al.* 1992, 1998; Singer *et al.* 1993; Bridgland 1994, 1998, 2000, 2001, *et al.* 1995, & Allen 1996; Conway *et al.* 1996; Maddy 1997, & Bridgland 2000, *et al.* 2001; West *et al.* 1999; Thomas 2001; Schreve *et al.* 2002).

Yet despite a long recognition of the occurrence of Palaeolithic archaeology within secondary contexts (e.g. dating back to Evans (1872)), there has been very little explicit investigation of the potential of this resource. Approximately 3,000 findspots containing an absolute minimum of 90,000 artefacts (Roe 1968a) have been documented, yet they have been subjected to only limited interrogation. The absence of explicit investigations is argued to reflect the geoarchaeological context of the resource and the problems that it poses. The resource is best characterised as assemblages of artefacts and ecofacts, ranging in number from one to (in a few cases) several thousands, and occurring within fluvial sediments, most typically gravels and/or sands, but occasionally also including silts, clays and loams.

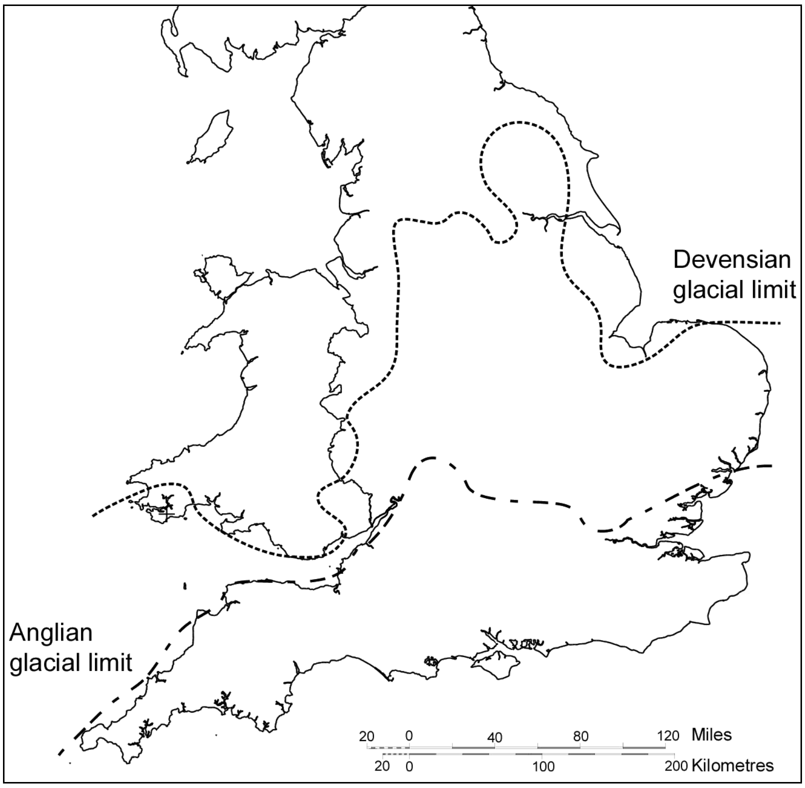


Figure 1: southerly extents of the Devensian and Anglian glaciations (after Wilkinson 2001: Figure 1)

While the early 19th century antiquarian collectors recognised that these artefacts frequently showed traces of fluvial transportation (descriptions of artefacts as 'waterworn' are common), there was no attempt to identify the source(s) of these stone tools. This was predominantly due to the goals of the day, as Palaeolithic archaeologists focused upon broad classificatory (typological) and chronological schemes. These approaches were to show a lengthy resilience in British archaeology. As late as the 1980's (Roe 1981), syntheses of river terrace, aggregate archaeology remained locked in typo-stratigraphic frameworks.

During the last twenty years however, absolute dates from key sites (e.g. High Lodge (Ashton *et al.* 1992), Boxgrove (Roberts & Parfitt 1998), Swanscombe (Conway *et al.* 1996) and Pontnewydd Cave (Green 1984) have upset those traditional frameworks. Moreover, the archaeological focus has shifted from the site-specific into the landscapes and regions of prehistory. This shift has emphasised the potential of the secondary context archaeological resource at both a national scale (providing broad spatial coverage) and over the duration of the British Palaeolithic (full temporal coverage). The significance of these macro spatio-temporal scales is further highlighted when one considers the extremely limited coverage (in time and space) provided by the handful of primary context Palaeolithic sites that have been excavated over the last 150 years (e.g. Boxgrove (Roberts & Parfitt 1998), High Lodge (Ashton *et al.* 1992), Hoxne (Singer *et al.* 1993), Caddington (Sampson 1978), Swanscombe (Conway *et al.* 1996), Barnham (Ashton *et al.* 1998), and Pontnewydd Cave (Green 1984). While these sites provide outstanding, high resolution data, they represent only a tiny fraction of this period. The regional, secondary context archaeological resource provides the lower resolution, regional backdrop that is vital for a complete understanding of the British Palaeolithic.

Yet the employment of the secondary context archaeological resource in the reconstructions of early prehistoric behaviour requires the understanding of its unique geoarchaeological context. The occurrence of Palaeolithic stone tools within secondary context fluvial deposits poses two fundamental problems:

1. What are the spatial origins of the artefacts?
2. What is the duration of the deposition of the secondary context sediments?

These two questions raise a host of sub-issues, all of which are concerned with the degree of behavioural integrity associated with the archaeological assemblages. For example, does an assemblage represent a single behavioural episode with the artefacts re-deposited during a single flood event, or 20 separate behavioural episodes? If the latter, how widely separated were those episodes in space and time? These questions must be addressed if we are to meaningfully interrogate the secondary context archaeological resource as part of our understanding of the earliest prehistoric periods. This project therefore highlights key research questions and approaches, and suggests potential interpretive frameworks for the future interrogation of the secondary context archaeological resource within British Palaeolithic research.

3. CURRENT UNDERSTANDING

There has been relatively little study of the archaeological potential of secondary context fluvial aggregate deposits in terms of:

1. The spatial origins of the stone tools.
2. The age of the archaeology.
3. The potential value of the archaeology for the reconstruction of early human behaviour.

With regard to the spatial origins of stone tools, work on artefact wear (abrasion) during fluvial transportation (Wymer 1968; Clark 1974; Shackley 1974, 1975; Isaac 1989; Schick (in Bunn *et al.* 1980; Murray 1985; Harding *et al.* 1987; Hosfield 1999; Hosfield & Chambers 2002a) has merely identified the scale of the problem and the need for considerable further desktop and field research. In the meantime, the prevalent view remains that where dense concentrations of stone tools occur within river gravels, it can be assumed that they have not travelled far from their place of discard (Wessex Archaeology 1993a: 12). This view glosses over the variable physical states that occur amongst artefacts within a single deposit (demonstrated by Hosfield 1999) and the range of potential mechanisms by which concentrations of stone tools may occur (Hosfield 1999; 2001). There is therefore a clear need to understand the processes by which artefacts are abraded, transported and re-deposited.

Attempts to assess the age of secondary context assemblages face four problems:

1. The stone tools cannot be directly dated and may be considerably older than the deposit.
2. The integrity of the assemblages is unclear (e.g. were the artefacts all re-deposited in the secondary context deposit at the same time and from the same source)?
3. Middle Pleistocene terrace deposits are outside the range of radiocarbon dating.
4. There is currently no clear consensus as to the amount of time represented by a single terrace deposit (e.g. does x metres of sands and gravels represent 40,000 years or 4 years of deposition?).

Fortunately, the dating of fluvial river terrace sequences has been considerably aided by the development of the marine oxygen isotope record. During the 1990's, new geo-chronological models have linked terrace formation with the glacial/interglacial cycles of the Pleistocene and isostatic uplift (Bridgland 1994, 1995, 1996, 1998, 2000, 2001, & Allen 1996; Maddy 1997, & Bridgland 2000; Maddy *et al.* 2001). However, these geo-chronological models operate at the level of macro-scale processes. Terrace landforms and their overlying deposits are associated with individual glacial/interglacial cycles of 70,000–100,000 years duration. Research examining fluvial systems at shorter time-scales (e.g. van Huissteden *et al.* 2001; Vandenberghe 2002; Starkel 2002) has tended to argue that brief climatic oscillations often cannot be traced in the fluvial record, reflecting both the insensitivity of the river systems to these short fluctuations and the subsequent erosion of small-scale sedimentary features. Nonetheless, the work of Gibbard (1985, 1994) and others (e.g. Maddy *et al.* 2001) has indicated that it is possible to identify and date changes in the depositional environment within a single terrace deposit.

There has been very little consideration until recently of the archaeological potential of secondary context materials beyond their role for typological stratigraphy (e.g. as at Swanscombe (Conway *et al.* 1996) and geo-chronology (e.g. White 1998a; & Jacobi 2002). Ashton & Lewis' (2002) recent investigation of late Middle Pleistocene population patterns utilised the secondary context aggregate archaeology from the River Thames, examining variation in the quantity of artefacts between individual terrace aggradations. Hosfield (1999) attempted to explore population patterns in the Solent River system from the secondary context aggregate archaeology, while also trying to discern land-use strategies through an analysis of the temporal and spatial origins of the derived artefact assemblages. While these studies have been partially successful, their scope has been limited by the absence of suitable frameworks for understanding the depositional contexts. Until such frameworks are developed, secondary context aggregate archaeology will remain an under-utilised resource.

4. AIMS AND OBJECTIVES

Current studies in the early prehistory of Britain are typically restricted to primary context, high resolution data sets. This focus upon high resolution data sets reflects the widespread perception that the secondary context archaeological resource is of extremely limited value. This report takes as its starting place the argument that this perception is the product of assumption and not explicit investigation. The project will document the geoarchaeological realities of the British resource and from this base, assess its potential for identifying and answering relevant archaeological questions above and beyond the traditional typo-chronological concerns.

The report is divided into nine further chapters, organised as follows:

- Chapter 2: reviews extant models of fluvial activity across the glacial/interglacial cycles of the Middle Pleistocene; applies Late Glacial and Holocene research to assess the duration of the temporal intervals associated with fluvial sedimentation and incision events; applies Late Glacial and Holocene models to assess the duration of the temporal intervals occurring between episodes of fluvial activity (sedimentation and incision).
- Chapter 3: presents a case study geochronological framework for the Lower Palaeolithic locality of Broom, Devon/Dorset, UK.
- Chapter 4: presents a case study analysis of the secondary context stone tool assemblage from the Lower Palaeolithic locality of Broom, with particular emphasis upon the spatio-temporal component of the data-set.
- Chapter 5: presents new models for the interpretation of spatially-derived secondary context artefact assemblages.
- Chapter 6: assesses the potential of the secondary context resource for the reconstruction of early prehistoric, fluvial palaeoenvironments.
- Chapter 7: evaluates the overall potential of the secondary context archaeological resource for the reconstruction of early human behaviour and early prehistoric landscapes.
- Chapter 8: proposes generic recommendations for the future management, protection and recording of the terrestrial aggregate resource and its archaeological content.
- Chapter 9: presents new interpretative frameworks for the modelling and interpretation of landscape archaeology in the early prehistoric period, as explored from the secondary context archaeological resource.
- Chapter 10: conclusions.

CHAPTER 2

THE TEMPORAL STRUCTURE OF SECONDARY CONTEXT, FLUVIAL SEDIMENTARY SEQUENCES

1. INTRODUCTION

This chapter is concerned with the time periods represented in river terrace sedimentary sequences. Understanding both the time periods associated with the deposition of a gravel unit, and the subsequent interval until the next phase of fluvial activity is critical to understanding and interpreting the archaeological content of these fluvial sediments. If a distribution of derived artefacts throughout the vertical stratigraphy of a secondary context gravel deposit that accumulated over 70,000 years is suggestive of low density, continuous occupation in a river valley landscape, then a restricted distribution of bifaces within a gravel deposit that accumulated over just 2,000 years at the end of a glacial/interglacial cycle may be suggestive of a high density, but short-lived occupation.

The initial goals of this component of the project (module 1 in the project design) were therefore to identify sedimentary structures that might be employed as potential temporal markers, to indicate the time-depth of fluvial sequences and the duration of the depositional and erosive events associated with those sequences. Three themes were therefore addressed:

- The preservation of sand, gravel, clay and silt sediments, and the duration of the fluvial episodes associated with their deposition.
- The proportion of glacial/interglacial cycles preserved within river terrace fluvial aggregates sequences, either as sedimentary units or incised channel features.
- The preservation and duration of depositional hiatus and/or erosive events within fluvial sedimentary sequences.

However, it rapidly became apparent that sedimentary structures could not be used as precise temporal markers, and the three themes highlighted above were subsequently addressed through an exploration of extant models of fluvial activity across the glacial/interglacial cycles of the Middle Pleistocene, and during the MIS-2/1 transition. Although much of the discussion concerns theoretical models and field data associated with Late Glacial and Holocene river systems (due to the high resolution radiocarbon chronologies associated with those systems), the overall focus is upon Middle Pleistocene fluvial deposits, preservation, and the levels of geo-chronological resolution that may be applied to those deposits. This chapter is therefore concerned with both cold-climate (e.g. Rose *et al.* 1980; Vandenberghe 1993, 2001; Collins *et al.* 1996; Lewis & Maddy 1999; van Huissteden 1990; & *et al.* 2001) and interglacial (e.g. Rose *et al.* 1980; Collins *et al.* 1996; Gibbard and Lewin 2002) river systems. Given the breadth of fluvial settings discussed, the considerable variations in fluvial evolution between upland, piedmont, lowland and estuarine river zones are explored with respect to the resulting sedimentary signatures and their potential impact upon the preservation of archaeological material (e.g. Harvey *et al.* 1981; Harvey and Renwick 1987; Meinke 1995; Howard & Macklin 1999).

While attention is paid to variabilities in floodplain types and channel forms under different climatic regimes and within different river zones (e.g. Nanson & Croke 1992; Howard & Macklin 1999), the chapter's primary focus is the temporal resolution of the preserved sedimentary sequences (whether cold or warm, upland or lowland). Fundamentally, this report is written by an archaeologist for other archaeologists, and this chapter seeks to exploit models of fluvial geomorphology to address fundamental *archaeological* problems. While the following statement may sound like heresy to the geography community, our interest does not lie in the subtle variations of river behaviour in their different reaches. The concern is how gross patterns influence the preservation and temporal resolution of the archaeological record.

Themes one (the duration of sedimentation events) and three (the duration of depositional hiatus) are therefore principally addressed with reference to high geochronological resolution studies from the last glacial phase and the Lateglacial/Holocene transition (e.g. Rose *et al.* 1980; Cleveringa *et al.* 1988; Schirmer 1988, 1995; Meinke 1995; Collins *et al.* 1996; Starkel 1988; Maddy *et al.* 2001; van Huissteden *et al.* 2001). These studies are drawn from a wide European catchment including the UK (Rose *et al.* 1980, Collins *et al.* 1996), the Netherlands (van Huissteden *et al.* 2001), Germany (Schirmer 1988, 1995; Meinke 1995), and Poland (Starkel 1988), and the implications of comparing these studies are highlighted.

By contrast, with reference to the second theme (the proportion of the glacial/interglacial cycle preserved within fluvial terrace sedimentary sequences), emphasis is placed upon macro-scale models of river development (e.g. Bridgland 1994, 1995, 1996, 2000, 2001; Vandenberghe 1995; Maddy *et al.* 2001; Gibbard & Lewin 2002). This chapter begins therefore with a brief review of the principle models for fluvial activity over glacial and interglacial stages and glacial/interglacial cycles during the Middle Pleistocene. All of these models are grounded in the marine isotope geochronology of this period (Figure 2), with eccentricity-driven 100,000 year cycles of glacial/interglacial conditions, the so-called Milankovitch cycles (Lowe & Walker 1997: 12–13).

2. MODELS OF FLUVIAL EVOLUTION

An assessment of the timescales of fluvial activity and the geochronologies of the resultant sedimentary sequences must begin with a review of the extant models of fluvial activity across the glacial/interglacial cycles of the Middle and Late Pleistocene. Current models are grounded in a long history of research (e.g. Zeuner 1958; Wymer 1968; Clayton 1977; Rose 1979; Green & McGregor 1980, 1987; Gibbard 1985; Vandenberghe 1993, 1995, 2002, 2003; Bridgland 1994, 1995, 1996, 2001; Maddy *et al.* 2001; Gibbard & Lewin 2002) and all have sought to explain the fluvial sedimentary sequences of northern Europe. These are most classically represented by *terrace landforms* (abandoned floodplains, typically lying above the current river floodplain), below whose surface lie ancient flood deposits, typically consisting of gravels, sands, silts, clays, and small quantities of other sediments (e.g. loams). In many cases, series' of altitudinally-distinct terrace landforms form terrace flights or staircases, best represented in Britain by the lower, middle and upper valleys of the river Thames (Figure 3).

The earliest models emphasised a direct link between climate and fluvial system evolution (e.g. Sörgel 1921; Büdel 1977; Bryant 1983; Gibbard 1985), with fluvial *sedimentation* (the deposition of sand and gravel sediments upon the river channel(s) and floodplain) occurring during glacial periods and river *incision* (the cutting of a new floodplain at a lower elevation) between successive *terraces* (abandoning the old terrace and leaving it lying above the new contemporary floodplain) taking place during the interglacials. However, a number of observations have since contradicted this notion of a direct link (see Vandenberghe 2003 for a complete discussion):

- The presence of interglacial sediments within cold-climate terrace sediments (e.g. Green & McGregor 1980; Bridgland 1994).
- The relatively thin deposits of river terraces in comparison to the duration of the glacial period in which they were formed.
- The absence of river incision during the Holocene (prior to anthropogenic deforestation), in favour of a state of equilibrium between erosion and deposition.
- River incision during cold periods (e.g. van Huissteden 1990, *et al.* 2001), although typically in association with climatic transitions during these cold phases (Vandenberghe 1993).
- The presence of braided (multi-channel), anastomosing (single-channel) and meandering (single-channel) rivers in both cold and warm stages, as opposed to the traditional notion of braided/cold-climate and meandering-anastomosing/warm-climate associations.

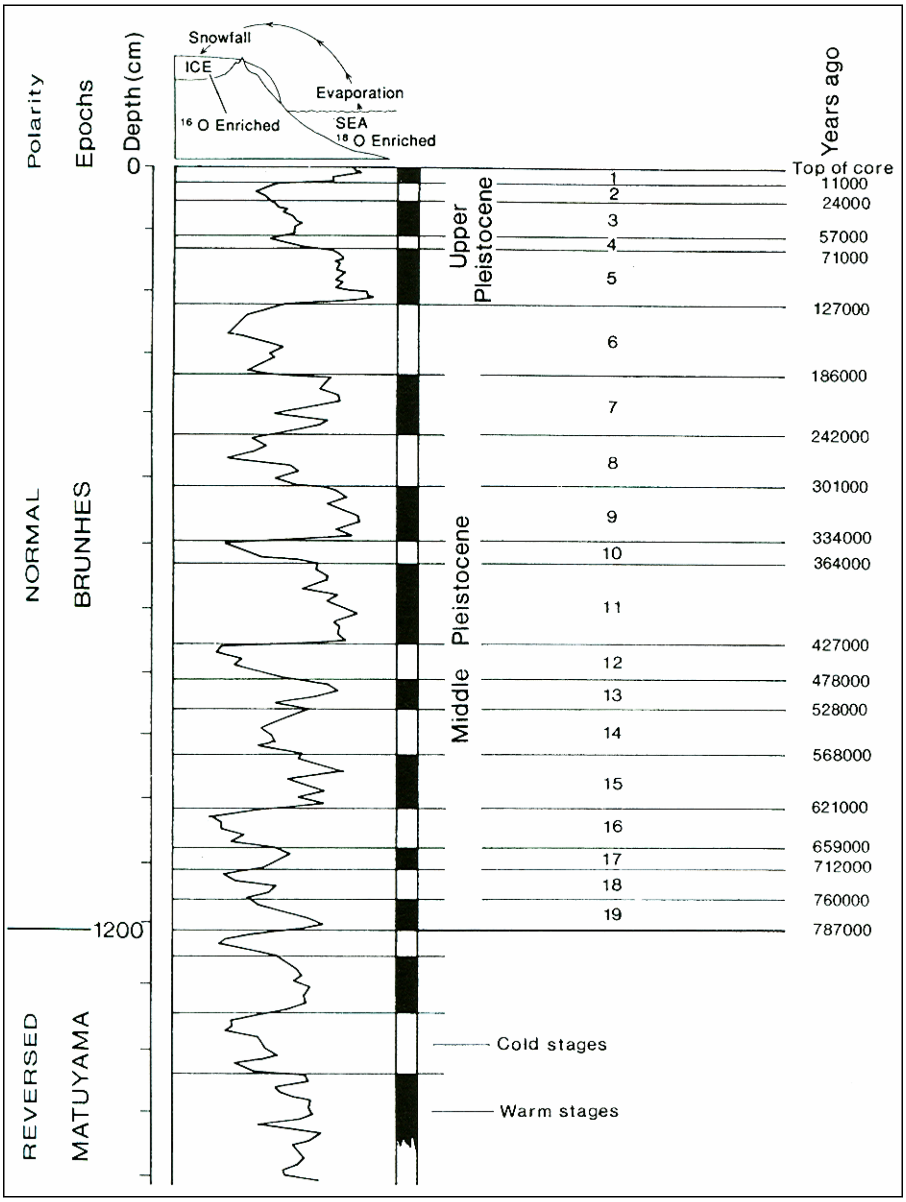


Figure 2: marine isotope record (core V28–238) of the glacial/interglacial cycles of the Middle Pleistocene (Gamble 1999: Figure 4.2)

This research adopts as a starting point the cyclical models of river terrace formation proposed and modified by Bridgland (1994, 1995, 1996, 2000, 2001), which broadly link channel incision and fine- and coarse-grained sedimentation to the glacial/interglacial climatic cycles of the Pleistocene. These models emphasise the impact of climate change upon fluvial activity, through variables such as flood frequency and magnitude, sediment supply, vegetation cover, and soil cohesion, and relate the key phases of aggradation and erosion with periods of climatic transition and instability (Figure 4). In this respect, these models draw considerable parallels with the work of Vandenberghe (1995), and at the broadest level suggest that the preserved component of fluvial sedimentary sequences may represent relatively small proportions of the glacial/interglacial cycle.

However, it is acknowledged that higher frequency climatic changes (at the sub-MIS scale) also play a key role in fluvial activity and river evolution (e.g. Vandenberghe 1995, 2002, 2003; Maddy *et al.* 2001), and to consider these processes, emphasis is therefore placed on higher resolution models of fluvial development within cold and warm-climate regimes and, most importantly, at the transitions between these climatic regimes.

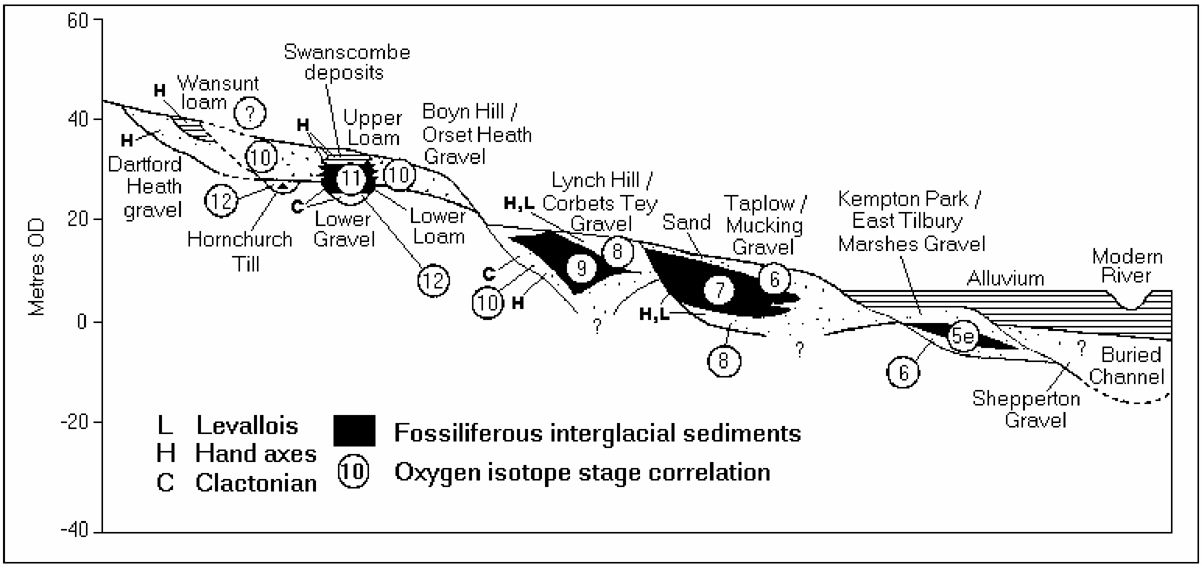


Figure 3: idealised transverse section through the terrace sequence in the Lower Thames valley (Bridgland 1996: Figure 3.4)

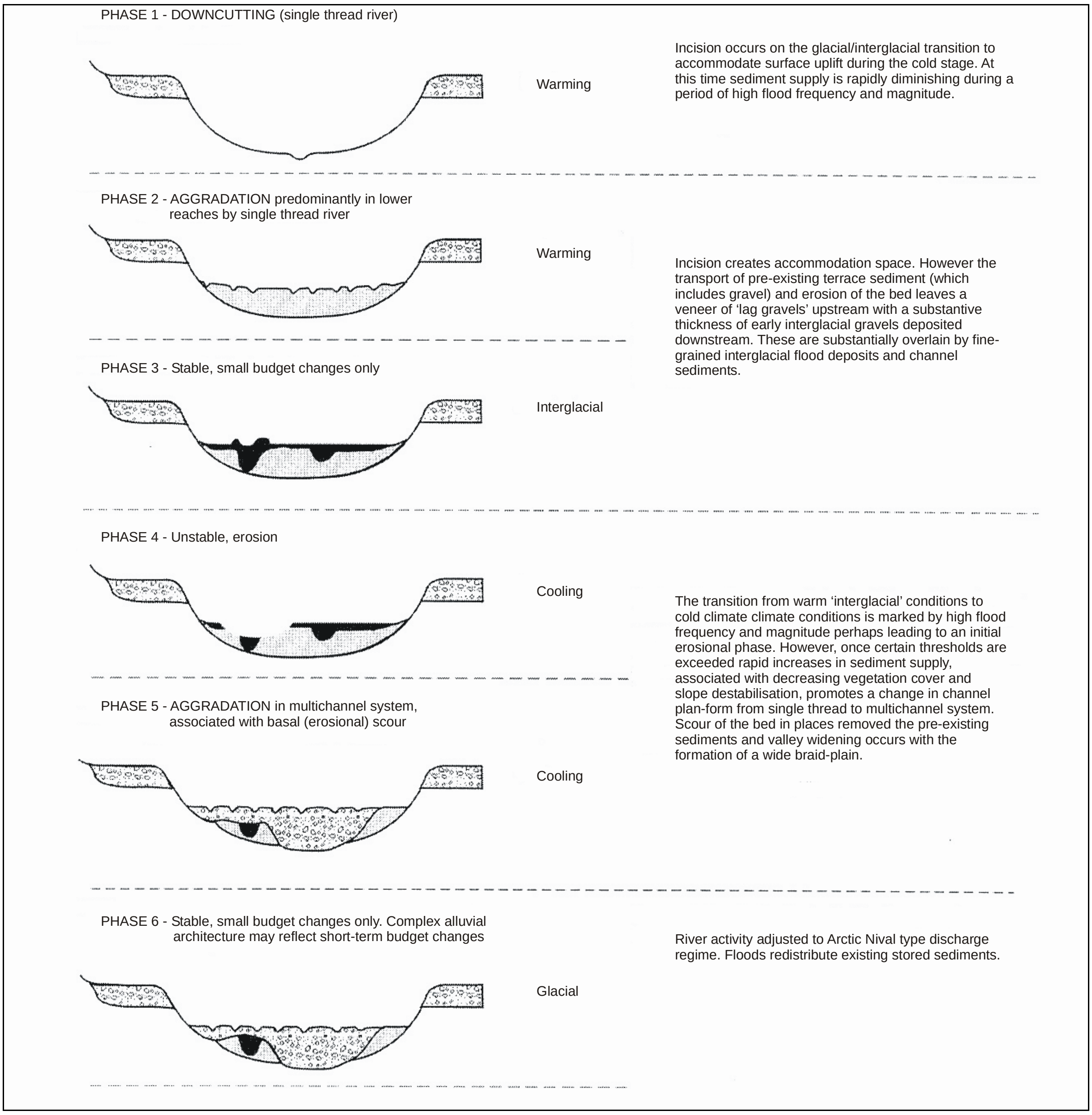
2.1 Fluvial activity under glacial conditions

Bridgland (1994, 1995, 1996, 2000, 2001) has argued that during full glacial conditions, river systems are broadly stable. Bridgland relates this to the rivers being adjusted to Arctic Nival type discharge regimes (annual snow-melt discharge), with these flooding events simply redistributing the existing sediments stored upon the floodplain. Maddy *et al.* (2001) expands upon this theme, highlighting the eventual shutdown of thermohaline circulation during the cold-stage and associated movements of the polar front, resulting in depressions tracking further south, the reduced frequency of high magnitude rainfall events, and a reduction in flood frequency to the nival-type presented above. Vandenberghe (1995: Figure 5 & 633) highlights similar factors, arguing for general stability under glacial conditions, with braided river system sedimentation (reflecting irregular discharge regimes and considerable sediment availability) during the earlier part of the cold phase, gradually being replaced by decreased fluvial activity, a relative erosion/aggradation balance, and increasing aeolian activity.

Notably, all of these models contrast with that of Gibbard & Lewin (2002: 194), which suggests that a 'typical' lowland British extra-glacial river actively accumulated sediment during the Devensian cold stages. It is suggested that this sediment accumulation was dominated by gravel deposition, with the rivers adopting braided or wandering modes, and sediment supplied by bank and channel floor erosion (we propose that this is equivalent to Bridgland's sediment redistribution process) and by slope processes (e.g. solifluction). Moreover, Gibbard & Lewin (2002: Table 2) suggest that this braidplain deposition of gravel and sand is characteristic of the full-late glacial stages of the climatic cycle, rather than the early-full glacial phase of the cycle, with which they associated sediment and substrate erosion, resulting in incision.

Yet while the models of Bridgland (1994, 1995, 1996, 2000, 20001), Maddy *et al.* (2001), Vandenberghe (1995) and Gibbard & Lewin (2002) vary in their specific interpretation of fluvial activity under glacial conditions, they do share a number of key observations with respect to the nature of fluvial activity during glacial phases:

- Coarse-grained (gravel and sand) sedimentation occurs within braided river systems.
- Sediment is redistributed from the existing floodplain and new material is introduced onto the floodplain from the adjacent slopes.
- Sedimentation events occur in response to annual snow-melt events.
- The system is broadly stable.



Incision occurs on the glacial/interglacial transition to accommodate surface uplift during the cold stage. At this time sediment supply is rapidly diminishing during a period of high flood frequency and magnitude.

Incision creates accommodation space. However the transport of pre-existing terrace sediment (which includes gravel) and erosion of the bed leaves a veneer of 'lag gravels' upstream with a substantive thickness of early interglacial gravels deposited downstream. These are substantially overlain by fine-grained interglacial flood deposits and channel sediments.

The transition from warm 'interglacial' conditions to cold climate climate conditions is marked by high flood frequency and magnitude perhaps leading to an initial erosional phase. However, once certain thresholds are exceeded rapid increases in sediment supply, associated with decreasing vegetation cover and slope destabilisation, promotes a change in channel plan-form from single thread to multichannel system. Scour of the bed in places removed the pre-existing sediments and valley widening occurs with the formation of a wide braid-plain.

River activity adjusted to Arctic Nival type discharge regime. Floods redistribute existing stored sediments.

Figure 4: climate-driven fluvial terrace development (after Maddy et al. 2001: Figure 3)

Alongside the nature of fluvial activity during the glacial phase, a key concern from an archaeological perspective relates to the potential for the long-term preservation of the sediments. In this instance, it is suggested that only the terminal phase of braided river sedimentation activity will be preserved. This is based on modern analogues for active braided river systems, which suggest that the process of lateral channel shift by bank erosion is both rapid and spatially extensive (Gibbard & Lewin 2002: 194). It has even been suggested that the surface layer of entire alluvial valley floors may be reworked in a matter of decades (Best & Bristow 1993). Under such conditions, it is clear that while the processes of nival-regime sediment redistribution and reworking activity during the glacial period will generate a succession of sedimentary features and arrangements of fluvial architecture, only the sedimentary features that were created during the final decades or centuries of the specific cold-climate phase will be preserved. This has clear implications for the re-working of archaeological material, and is returned to in chapter 6.

2.2 Fluvial activity during transitional conditions

Vandenberghe (1995), Maddy *et al.* (2001), and Bridgland (1994, 1995, 1996, 2000, 2001) have all argued that fluvial incision and aggradation is a widespread characteristic of phases of climatic transition, both from warm to cold and vice-versa. In all cases the importance of non-climatic factors are stressed, with emphasis placed upon soil and sub-soil cohesion. Nonetheless, there are marked contrasts between the glacial/interglacial and interglacial/glacial transitions, and the associated sequences of events.

2.2.1 The interglacial/glacial transition

Vandenberghe (1995: 633) noted that incision occurs when runoff and soil cohesion are high, with a subsequent aggradation phase occurring when either cohesion or runoff drops substantially. With specific reference to the warm to cold transition (Vandenberghe 1993: 21–22):

- The drop in temperature causes lower evapotranspiration and a higher amount of overland flow (nb — the model assumes that precipitation is broadly constant).
- Vegetation cover persists for a short time, resulting in continued soil and river bank stability.
- The ratio of river discharge: sediment supply increases, resulting in fluvial incision.
- Subsequently, the deteriorating climate disrupts vegetation cover, resulting in soil destabilization, increased sediment supply and fluvial aggradation within the newly formed accommodation space.

Bridgland (2000: Figure 1) and Maddy (Maddy *et al.* 2001: 26–27) provided a related explanation which emphasises incision at the interglacial/glacial transition, as a result of changes in sediment and water supply. The model emphasises initial climatic instability during the cooling phase, potentially resulting in enhanced flood frequencies magnitudes which may have promoted an initial erosion phase. As with Vandenberghe (1993, 1995), the model also highlights subsequent aggradation during the cooling phase. This is linked to increased sediment supply (through mass movement, freeze-thaw activity and vegetation loss) and high water supply (due to high-frequency and high magnitude rainfall events, associated with instabilities in the North Atlantic atmospheric and oceanic circulation during the adjustment to global climatic change).

2.2.2 The glacial/interglacial transition

Erosion, followed by aggradation, is also a key component of the models developed for the glacial/interglacial transition by Vandenberghe (1993, 1995) and Maddy *et al.* (2001). Vandenberghe again highlights vegetation development as a key factor (1993: 24–25):

- Vegetation development occurs gradually in response to climatic amelioration.
- Evapotranspiration initially remains low, resulting in high river discharges at the outset.
- Although vegetation restoration is retarded relative to increasing temperature, it is still sufficient to stabilise soils and consolidate channel banks.
- The combination of high run-off, bank stability and reduced sediment load results in incision and meandering.
- Subsequently, erosion is replaced by aggradation, in response to decreasing discharges due to increasing evapotranspiration.

Maddy *et al.* (2001: 26–27) also highlighted changes in sediment and water supply, although they introduced different specific mechanisms:

- During climatic warming, colonising vegetation stabilises slopes, reducing mass-movement processes and sediment supply.
- The global climatic adjustment causes instabilities in the North Atlantic atmospheric and oceanic circulation, that probably lead to increasing frequencies of deep depressions tracking across the UK, resulting in higher frequency and higher magnitude rainfall events.

- Considerable quantities of water are also released from frozen ground storage, and aquifers (layers of soil and/rock able to hold or transmit water) are re-established.
- The combination of high discharges and low sediment supply results in fluvial incision.
- The completion of the global climatic adjustment brings atmospheric and ocean-circulation to a broadly stable condition, reducing rainfall event frequency and magnitude, which results in falling discharge levels and the replacement of erosion with aggradation.

These models are notably disputed by Gibbard & Lewin (2002: 198), who argue against the occurrence of incision in British lowland rivers during the glacial/interglacial transition (although they recognise that does occur on the continent as documented by Vandenberghe (1993, 1995)). In contrast, they propose a model of channel pattern inheritance occurring during the glacial/interglacial transition (Gibbard & Lewin 2002: 198):

- Increasing mean annual temperatures.
- After a lag delay (estimated to be around 500 years in the earliest Holocene), seasonal flow variability is likely to decline, with permafrost melt, declining winter severity, precipitation, and infiltration providing groundwater sources for all year round flow.
- Stabilisation of gravelly channels inherited from the preceding cold phase occurs, with rivers lacking sufficient energy to transport gravel and alter gross channel form and distribution.

This model highlights issues of archaeological interest with respect to patterns of channel inheritance, in particular in terms of the potential for reduced sediments and artefact re-working under a model of channel inheritance rather than incision. However, it is significant that Maddy *et al.* (2001: 27) have argued for clear evidence of downcutting during the Lateglacial/Holocene transition, as demonstrated by the deep incision of Early Holocene valleys in many unglaciated river basins in southern England, including the Upper Thames. This evidence seems to noticeably contradict the claims of Gibbard & Lewin (2002: 198).

Overall there are marked contrasts between the models presented by Vandenberghe (1993, 1995), Bridgland (1994, 1995, 1996, 2000, 2001), and Maddy *et al.* (2001) with respect to fluvial activity during major climatic transitions. The incision/aggradation models are adopted here, not least because of their apparently widespread relevance to the river systems of northwest Europe (as demonstrated by the studies of Rose *et al.* (1980) and Collins *et al.* (1996)). However, the contrasts of these models with the work of Gibbard & Lewin (2002) is informative, not least because they stress the importance of regional variations (e.g. the apparent absence of incision in British lowland rivers at the Lateglacial/Holocene transition, unlike the rivers of continental Europe), and the variability between upland and lowland river zones (e.g. incision during the early Holocene has been demonstrated for upland British rivers (Harvey and Renwick 1987).

2.3 Fluvial sedimentation under interglacial conditions

The predominance of gravels and sands within Quaternary fluvial sequences, and the widely held belief that they accumulated under cold Pleistocene climates, has resulted in relatively little focus upon documented Pleistocene interglacial sediments (Gibbard and Lewin 2002: 187). Maddy *et al.* (2001: 27) observe only that climatic conditions in the full interglacials resulted in subdued fluvial system activity, with relatively low-energy facies being deposited across the inherited floodplain. Similarly, Vandenberghe (1995) highlights valley bottom stability, with lateral migration of the river across the alluvial plain and soil formation. Yet recent work has highlighted the potential complexity of these sediments, with Gibbard & Lewin (2002: Table 2 & 205) proposing a multi-stage model of lowland river behaviour in response to an interglacial climatic cycle. Given the contrasts of this model with existing views of interglacial sequences, it is reviewed in detail here:

- Late glacial/early interglacial transition: river flow adjusts to decreased seasonal contrasts, permafrost melting and the introduction of year-round precipitation and infiltration. Stabilisation of the inherited channels results, due to insufficient energy for gravel transport or channel form modification. The initial loss of the nival flood-peak causes a reduction in mean flow velocities and water depth, under which large areas of the emergent braidplain/floodplain surface become free from flood incursions for long periods. A complex of surfaces for plant colonisation and soil development is provided, while vertical accretion of fine-grained, organic, fossiliferous sediments begins in braidplain depressions and abandoned channels. Increased plant productivity and vegetation of floodplain surfaces also encourages fine-grained sedimentation, through the stabilisation of floodplain surfaces and the restriction of streams to the courses inherited from the preceding cold stage (*ibid*: 198).

- Full interglacial (early phases): the establishment of forest vegetation further diminishes variations in river flow (the soil-vegetation system stabilises ground surfaces and delays flood responses) and severely reduces inorganic sediment supply to alluvial systems. Stream flow is relatively slow throughout the year (except following exceptionally severe storms), channels stabilise, and minor, fine-grained, organic deposition is predominant in the minor, open channels. Vertical accretion leads to the infilling of the remaining, inherited depressions and pools with detrital, marsh, and peat sediments (*ibid*: 200–201).

- Full interglacial (late phases): continued infilling of floodplain depressions and channels leads to a decrease in the number of channelised flow routes. This restriction of streams to relatively few channels leads to increased periodic flooding and widespread vertical accretion across the majority of the floodplain surfaces. The overall pattern is of stable meandering and/or anastomosing river behaviour, and appears to have been widespread throughout lowland Britain during interglacials. This pattern has a notable consequence in that the flowing channels remain relatively fixed in the positions inherited from the previous late glacial, although the channels are not necessarily in contact with the cold-stage sediments. Marsh and peat sediments continued to accumulate on the floodplain areas beyond the channels, while surface wetness was augmented by spring activity at the break of valley slopes (*ibid*: 201).

- Late interglacial: although there are as yet no Holocene analogues for the late interglacial climatic deterioration, the extant geological record suggests that sedimentation initially continued during the late temperate phase. However, as the climate deteriorated it is assumed that the mean annual temperature declined, discharges became more seasonally variable, while extreme events (may) have become more frequent. Specifically, the opening up of the woodland (e.g. the replacement of mixed deciduous-coniferous woodland with coniferous woodland) would have increased infiltration, while vegetation retreat and thinning may have progressively increased run-off to the extent that storm-induced flow peaks were raised and water velocities increased. These processes may also have been accompanied by increased winter storage of snow on the ground, in response to dropping winter temperatures. The consequent increase in gullying (e.g. on valley-side slopes, in stream headwater areas, and locally upon the floodplain) would deliver increasing quantities of fine sediment to the river. Overall, increased overbank flooding would be expected, delivering thick accumulations of sands and fines across the floodplain surface, and this flooding would also be accentuated by the restriction of the river to single, deeper flow channels (*ibid*: 202).

- Early glacial: the return to predominantly treeless conditions (regional, herb-dominated early-glacial grassland) is associated with typical cold-climate regimes, with highly peaked flow discharges. Energy is therefore provided for stream rejuvenation, channel enlargement, remobilization of coarse debris, rapid removal of fines and substantial incision into the accumulated floodplain deposits (into which pollen and spore fossils are also reworked). The redevelopment of permafrost and inhibition of infiltration ensures rapid surface water flow, which combined with slope erosion and solifluction provides a source of coarse sediment. The initial absence of coarse sediments results in fluvial incision, the removal of fine alluvium, and the planing off of the upper parts of floodplain and channel deposits by laterally mobile, incising rivers, during the early period of the interglacial/glacial transition. It is not currently clear when the gravel transport was re-activated, and it is suggested that this may have varied between different interglacial episodes (*ibid*: 202).

This model of fluvial activity across the span of an interglacial episode adds considerable detail to the models of Vandenberghe (1995) and Maddy *et al.* (2001). It also has several fundamental implications for the three issues highlighted at the beginning of this chapter:

1. Sedimentation styles appear to have changed during the progression of an interglacial stage.
2. Preservation of sediments from different parts of interglacial stages appears to be highly unequal, with sediments laid down early within a warm stage being far more common in the geological record than those from later in the same stage (Gibbard & Lewin *ibid*: 188 & 205). This is due to the widespread 'accommodation space' mosaic that is available for sedimentation during the early interglacial period (this mosaic consists of surface irregularities and channels in the wide braidplain surface inherited from the preceding cold stage river). By contrast, accommodation space and sedimentation is of a restricted nature during the later interglacial, and the sediments are also extremely vulnerable to the subsequent high energy rivers of the succeeding glacial phase.
3. Fragmentation and reworking of the interglacial sediments varies according to the nature of the valley (e.g. narrow valleys with steep slopes compared to wide, unrestricted valleys with non-cohesive or unresistant substrates).
4. The contact between the subsequent cold-climate gravels and sands and the underlying interglacial fine-sediments has often been demonstrated to be erosional, implying the removal of pre-existing sediments and an unknown time interval (Gibbard & Lewin 2002: 204).

Drawing upon all of the models summarised above, it is possible to present a provisional model of fluvial activity across a generic glacial/interglacial, in terms of episodes of fluvial incision, erosion, sedimentation and preserved sedimentation (i.e. the fluvial architecture that can be observed and recorded today):

- Glacial phase: relatively stable systems, but with frequent, small-scale braidplain sedimentation of coarse-grained materials in response to nival-regime flooding. Re-working of braidplain sediments results in the favourable preservation of fluvial architecture dating to the end of the phase.
- Glacial/interglacial transition phase: unstable systems, with high frequency and high magnitude flooding. An initial phase of major incision (resulting in the cutting of a new floodplain) is followed by extensive aggradation of coarse-grained deposits. Preservation of both the incision events (the new floodplain landform) and the sedimentary deposits.
- Interglacial: stable system, with fine-grained sedimentation. Favourable preservation of sediments dating to the early stages of the interglacial.
- Interglacial/glacial transition: unstable systems, with high frequency and high magnitude flooding. An initial phase of minor erosion (removing existing fine- and coarse-grained sediments) is followed by extensive aggradation of coarse-grained deposits. Preservation of the sediments is likely, and preservation of erosion surfaces may also be documented.

The model is summarised schematically (Figure 5), and would appear to suggest that relatively short spans of the glacial/interglacial system are preserved and represented in the resultant fluvial architecture. However, it is stressed that two additional themes require consideration with respect to fluvial activity across the glacial/interglacial cycle and its potential for preservation: i) the evidence for high frequency (sub-Milankovitch) climatic change (i.e. rapid climatic variations, sometimes of large magnitude, occurring over centuries and millennia and superimposed onto the 100,000 year orbitally-driven glacial/interglacial cycles (Lowe & Walker 1997: 15)); and ii) the nature of fluvial responses to it; and the impacts of non-climatic factors, including basin properties (e.g. topography, valley width, subsoil lithology) and system response times (linked to catchment size).

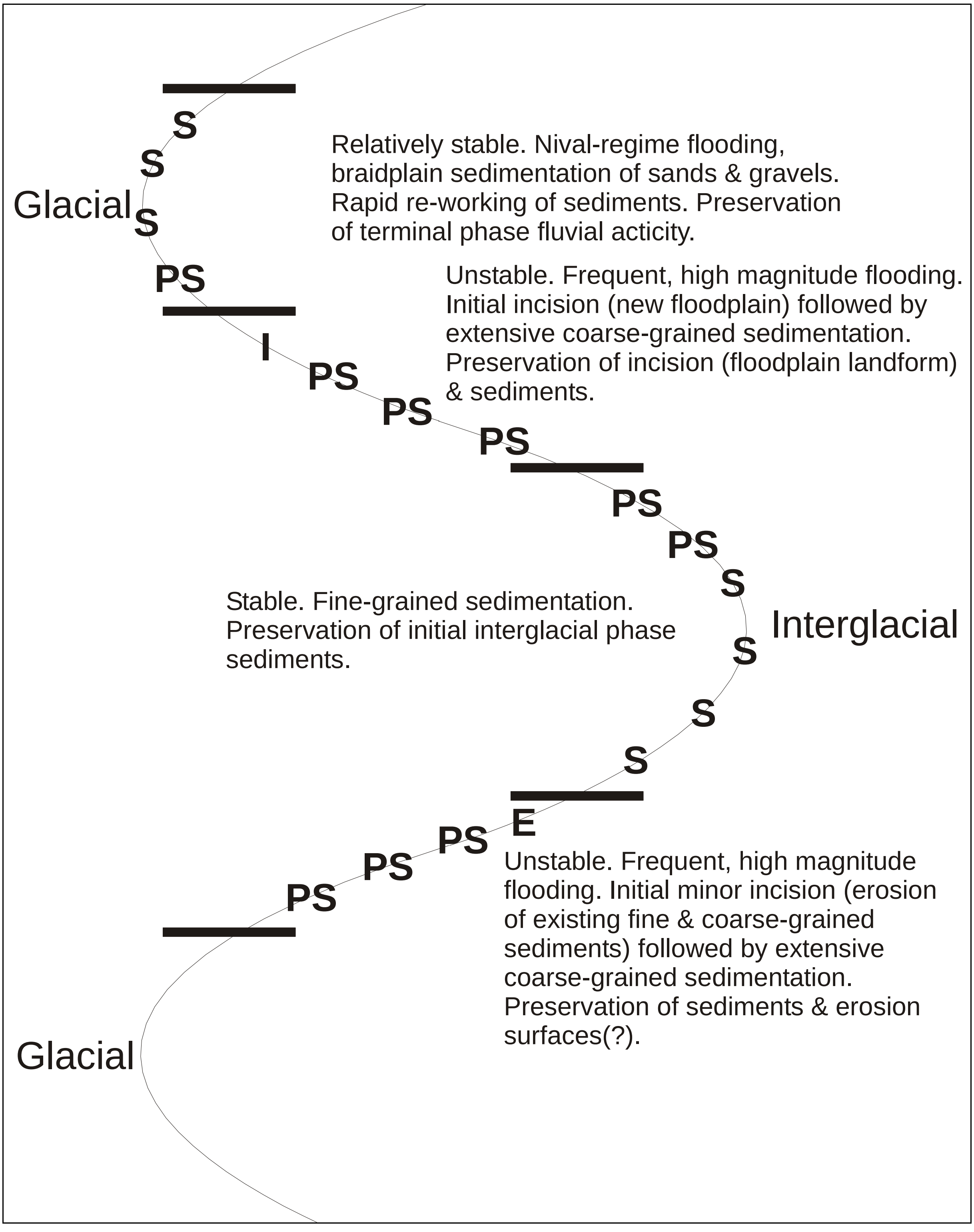


Figure 5: model of fluvial activity over a glacial/interglacial/glacial cycle (after Vandenberghe 1993, 1995; Bridgland 2000; Maddy et al. 2001; Gibbard & Lewin 2002). S = sedimentation; PS = preserved sedimentation; I = incision (floodplain downcutting); E = erosion.

2.4 High frequency climatic changes

A key framework for the understanding and interpretation of high frequency, sub-Milankovitch scale climatic changes was provided by Vandenberghe (1995):

- 100,000's of years (glacial/interglacial sequences). At these scales, fluvial evolution is broadly climatically dependent, within its tectonic framework, in accordance with Bridgland (1994, 1995, 1996, 2000, 2001) and Maddy *et al.* (2001).
- 10,000's of years (a single glacial/interglacial cycle). Fluvial activity and response is now determined by the derived impacts of climate: vegetation, soil cohesion and run-off (discussed above in Sections 2.1–2.3). Short unstable phases alternate with long periods of inactivity, with the unstable phases occurring at the major climatic transitions, as emphasised for Middle Pleistocene sequences by Bridgland (2000), Maddy & Bridgland (2000), and Maddy *et al.* (2001).
- 1,000's years (single phases of instability). The fluvial response is governed by the intrinsic evolution occurring within the system, as recently demonstrated by Howard & Macklin (1999).
- 100's of years (lower order climatic changes). The well-pronounced effects of local thresholds are the most striking at this scale, including climatic thresholds (e.g. the duration and intensity of climatic change) and landform and sedimentary thresholds (e.g. valley gradient, and the diameter and quantity of sediment to be transported).

Within this framework, the 1,000 and 100 year scales are of key interest in terms of high frequency climatic change. At these scales, while climate remains an important factor, the response of fluvial landforms and sediments to climatic change is a complex one, since: (1) fluvial processes are not only dependent upon the climate, but also upon physical parameters such as subsoil cohesion and evapotranspiration; (2) those factors are largely determined by vegetation, which responds in turn to climate; and (3) rivers adapt their pattern and gradient to the new conditions over time. This can be illustrated with a cyclical model of fluvial development (Figure 6), based upon observations of river activity in the Maas and Dinkel systems (Vandenberghe 1995):

- The cycle begins with a temperature drop, causing lower evapotranspiration and higher quantities of surface run-off. Vegetation cover persists for a period, ensuring that the soils and river banks remain stable. The increased ratio of discharge to sediment yield leads to river incision: "at the start of cold periods erosion is induced by a delay in the disappearance of the vegetation cover in comparison to the temperature decline" (Vandenberghe 1993: 26).
- Gradually vegetation is disturbed by the persistence of periglacial conditions (Vandenberghe 2001), resulting in increased sediment supply to the rivers, particularly through the process of run-off. Aggradation to previous levels occurs by the infilling of former channels. Sedimentation takes place largely by braided river systems as a result of the irregular discharge regimes and the availability of large amounts of sediment.
- During the later part of the cold period there is a relative balance between erosion and aggradation. At times fluvial activity decreases dramatically and aeolian activity may become dominant.
- As the climate ameliorates, vegetation development is initially retarded, with herbaceous vegetation remaining dominant. This results in evapotranspiration rates remaining low and discharges becoming relatively high at the beginning of the warm period. Soils are stabilized by the existing vegetation, reducing the sediment load in the channels, and the rivers tend to incise and adopt a meandering pattern: "at the very beginnings of warm periods, erosion is induced by a delay in the full development of forests in comparison to temperature rise" (Vandenberghe 1993: 26).
- Vegetation development and increases in evapotranspiration rates result in reduced discharges, leading to a change of channel activity to infilling.
- During the following interglacial, valley bottom stability is expressed through the lateral migration of the river across its alluvial plain and by soil formation.

Summarising the cyclical model, Vandenberghe (1995) concluded that;

"Incision took place at climatic transitions (from cold to warm and from warm to cold). The incision phases are of relatively short duration and are followed by almost equally rapid aggradation. Between these short phases of instability long periods of stability prevailed characterized by approximately balanced lateral sediment accretion and erosion…This sequence of events and sedimentation cannot be explained only by climatic factors, but must especially be due to cohesion of the basin subsoil in

> *relation to run-off. Incision occurs when both cohesion and run-off are high, while the succeeding aggradation takes place when either the previous cohesion or run-off drop substantially…Finally, delay effects with respect to climate play a crucial role in the origin of the instability phases: the delay in vegetation disappearance at the beginning of a cold period, the delay in forest development at the beginning of a warm period."*
>
> (Vandenberghe 1995: 633–635)

Of critical archaeological interest is the claim that the phases of incision and aggradation were of relatively short duration. How long were these phases? This issue is returned to in Section 3. Of equal interest is the question of the magnitude and frequency of the climatic transitions to which Vandenberghe (*ibid.*) refers. If the climatic transitions are associated with the glacial/interglacial cycles (i.e. two transitions per 100,000 year, eccentricity-driven cycle), then Vandenberghe's model would suggest very long periods of fluvial inactivity. However, it is clear from recent ice core research (e.g. Anklin *et al.* 1993; Petit *et al.* 1999; van Andel 2003) that climatic shifts are not restricted to the major glacial/interglacial transitions. The recognition of the Dansgaard/Oeschger oscillations (brief, high frequency climatic oscillations of varying amplitude) indicates that periods of fluvial inactivity (as defined above by Vandenberghe (1995) were relatively short, and that even within interglacial and glacial stages, there was considerable potential for fluvial activity in response to these sub-Milankovitch climatic oscillations.

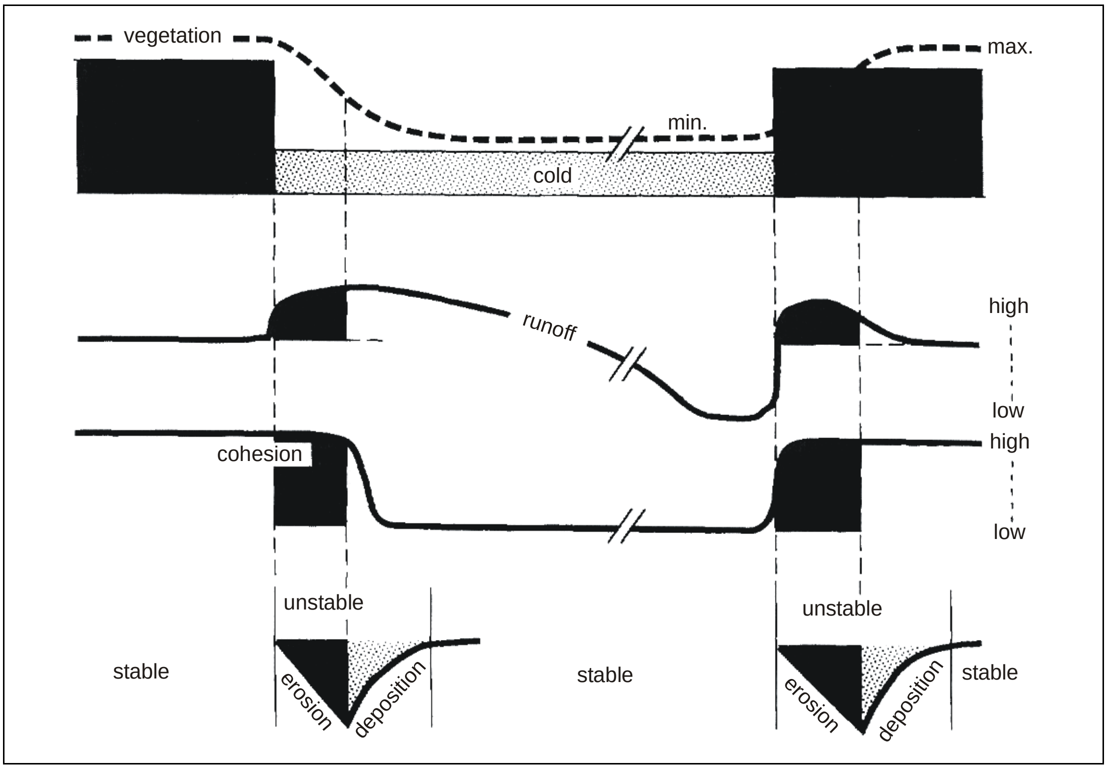


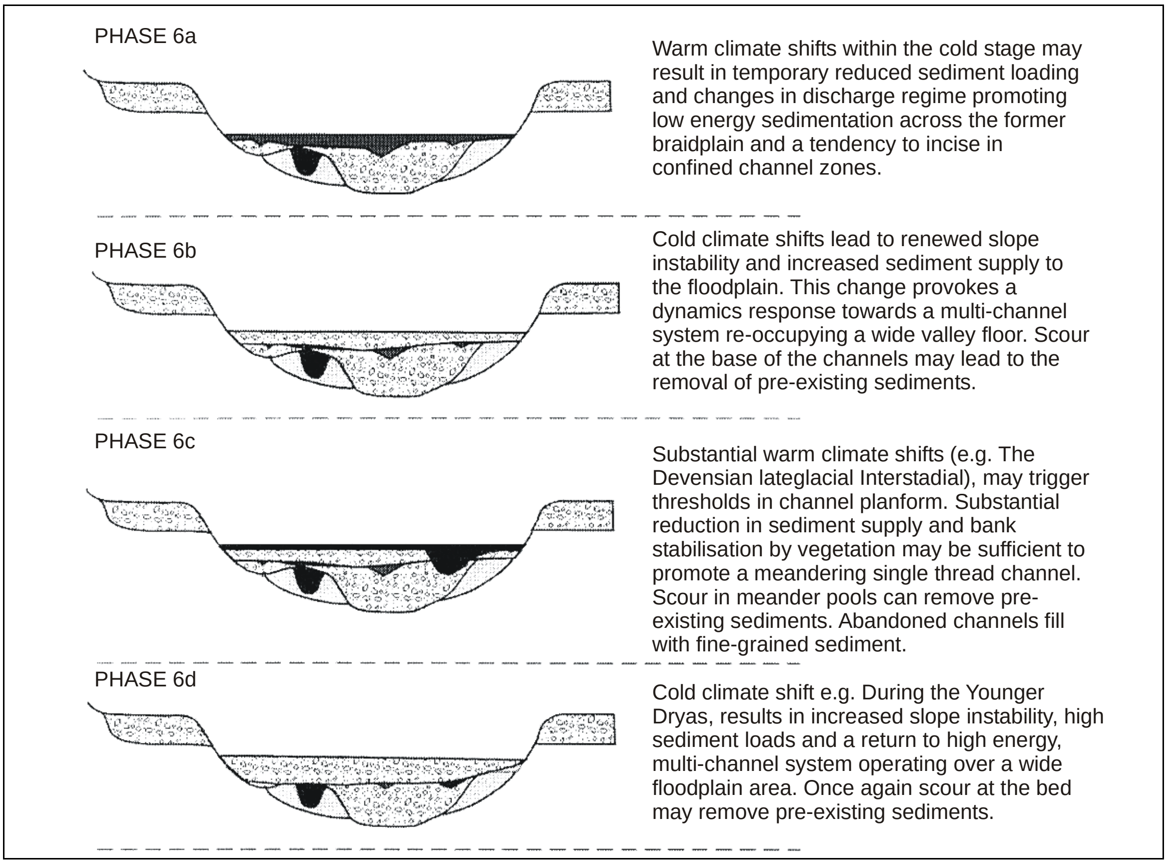
Figure 6: model of fluvial stability-instability alternations in relation to climate and climate-induced parameter (Vandenberghe 1995: Figure 5)

Recent evidence for such fluvial responses to high frequency climatic oscillations has been provided for the last glacial/interglacial cycle by Maddy *et al.* (2001). Complex fluvial architecture in the Northmoor terrace in the Upper Thames valley indicates high resolution responses to climatic shifts (Figure 7). Although the model presented by Maddy *et al.* (*ibid*: Fig. 5; reproduced here as Figure 7) is conceptual, it highlights the importance of climatic control, exerted through its influence upon sediment and water budgets:

- Warm climate shifts within cold stages may result in temporary reductions in sediment loading and changes in the discharge regime. This can promote low energy sedimentation across the former braidplain and a tendency for incision within confined channel zones (phase 6a in Figure 7). During substantial warm climate shifts (e.g. the Devensian Late Glacial interstadial), thresholds in channel planform may be triggered. Substantial reductions in sediment supply and the stabilisation of channel banks by vegetation may be sufficient to promote meandering single thread channels. Scour in meander pools may remove pre-existing sediments while abandoned channels fill with fine-grained sediment (phase 6c in Figure 7).

- Cold climate shifts (e.g. the Younger Dryas event) are likely to result in increased slope instability, increased sediment supply and high sediment loads, and a change to high energy, multi-channel systems, occupying large parts of the floodplain. Scour at the base of the channels can lead to the removal of pre-existing sediments (phases 6b and 6d in Figure 7).

However, while Maddy *et al.* (2001: 33–34) highlight the potential for high resolution fluvial response to high frequency climatic oscillations, they also emphasise the problems inherent in this type of fluvial architecture: the magnitude of high frequency climatic changes results in relatively small-scale sedimentary features that may or may not be fortuitously preserved; while geochronological tool-kits do not always permit the resolution of these features. It is therefore apparent that any discussion of patterns of fluvial activity needs to consider not only the relationships between fluvial activity and low and high frequency climatic changes, but also the potential for the products of the fluvial activity to be preserved over geological timespans and to be detectable to modern geochronological methods and techniques. Moreover, it is increasingly apparent that the same climatic switch will not result in identical fluvial activity in different river systems, or even within different reaches of a single system.



Warm climate shifts within the cold stage may result in temporary reduced sediment loading and changes in discharge regime promoting low energy sedimentation across the former braidplain and a tendency to incise in confined channel zones.

Cold climate shifts lead to renewed slope instability and increased sediment supply to the floodplain. This change provokes a dynamics response towards a multi-channel system re-occupying a wide valley floor. Scour at the base of the channels may lead to the removal of pre-existing sediments.

Substantial warm climate shifts (e.g. The Devensian lateglacial Interstadial), may trigger thresholds in channel planform. Substantial reduction in sediment supply and bank stabilisation by vegetation may be sufficient to promote a meandering single thread channel. Scour in meander pools can remove pre-existing sediments. Abandoned channels fill with fine-grained sediment.

Cold climate shift e.g. During the Younger Dryas, results in increased slope instability, high sediment loads and a return to high energy, multi-channel system operating over a wide floodplain area. Once again scour at the bed may remove pre-existing sediments.

Figure 7: conceptual model of climate-driven sedimentary architecture of the Northmoor Gravel of the Upper Thames valley (Maddy et al. 2001: Figure 5)

2.5 Variability in fluvial response

Variability in fluvial system response has been documented by a number of researchers, in wide range of geographical settings. Cleveringa *et al.* (1988) noted in their study of 16 small river basins in Belgium and the Netherlands that river adjustments had occurred episodically over the last 15,000 years, associated with five periods: end of the Pleniglacial/early Late Glacial; Alleröd; Late Dryas; Boreal; and the Subboreal/Subatlantic. Yet it was clear that not all of these periods were documented in all of the river basins, with fluvial activity associated with the Alleröd and terminal Pleniglacial/early Late Glacial being the most commonly represented (in 13 of the 16 basins). The study region was characterised by low relief, relatively homogenous climatic conditions (both in the past and the present), and unconsolidated geology of Pleistocene or Tertiary age. Cleveringa *et al.* (*ibid*: 125) concluded that variations in river system response to changing climatic conditions were grounded in differences in local-scale parameters controlling discharge, including: the intensity and duration of precipitation; the type of vegetation and litter-layer (interception); the infiltration capacity of soils; and the density of the substrate. However, they also stressed that the stratigraphic sequences of the drainage basins were incomplete as a result of the local dominance of erosional discontinuities. Finally, it was proposed that sedimentation in the lower parts of basins can be chronologically associated with erosional factures in the upper part of the basin, illustrating differences in fluvial response in two stretches of the same river system.

This theme was explored by Houben *et al.* (2001; Houben 2003), in an investigation of the small and mid-scale rivers in the Hessian Depression (Hessische Senke) in Central Germany. The Amoeneburger Becken and the Wetterau are neighbouring, small river basins, located north of Frankfurt am Main in the Hessian Depression. The depression forms a zone of subsidence, the northern continuation of the Upper Rhine Graben, and is bordered by the Rhenish Slate Mountains (Rheinisches Schiefergebirge) in the west and the basalt Vogelsberg upland in the east. The basins themselves are filled with Tertiary sediments, which are covered with Pleistocene loess. The river landscapes lie in the non-glaciated zone between the Scandinavian inland ice sheet and the alpine glaciations, and therefore formed in response to periglacial processes during the Pleistocene glaciations (Houben *et al.* 2001: 249). Analysis and radiocarbon dating of Younger Dryas deposits from the upland and lowland reaches of the Wetter valley revealed apparent discrepancies in the system's responses during this climatic period. Although widely considered to be a phase of colder climate, pollen evidence from the northern Wetterau did not indicate considerable deforestation, while sedimentary evidence from the upstream Wetter near Lich did not indicate a sudden change in fluvial style during the Younger Dryas (*ibid*: 254–255). Yet the majority of the floodplains in the studied basins were affected by increased fluvial activity during this period, with the re-working and deposition of coarse-grained sediments suggesting a climatically-driven change to a braided river system (*ibid*: 260). How can this discrepancy be explained? Houben *et al.* (*ibid*: 260) emphasised the contrasting spatial scales of the palaeo-environmental evidence provided from sedimentological and pollen data, and the differential behaviour of fluvial systems in contrasting parts of the catchment. For example, the upland reaches were influenced by markedly deteriorating climatic conditions, increasing proportions of precipitation stored as snow, high magnitude snowmelt discharges that were capable of entraining and transporting coarse materials, and the minor role of vegetation cover in upland areas. By contrast, the low gradients of the downstream basins resulted in the sedimentation of the coarse-grained sediments, although these lower reaches may have been little affected by the Younger Dryas cooling, hence the absence of major deforestation.

The question of variability in system response has also been highlighted by Vandenberghe (2003), with respect to the role of non-climatic factors in fluvial system development, particularly catchment size, threshold values, and system lag or response times to changes in external conditions. Fluvial evidence from the Netherlands indicated that in contrast to the climatic changes of the Late Glacial, the rapid climatic oscillations that are present in the marine and ice core records of the preceding Pleniglacial are not easily detected in terrestrial environments and it is even more difficult to identify their potential effects upon fluvial systems. For example, a fluvial adaptation to the pronounced Hasselo-Hengelo stadial/interstadial event has scarcely been found in the rivers of the Netherlands (e.g. van Huissteden *et al.* 2001). This may be due to the similarities in duration between the climatic oscillations (centennial or millennial) and the response times of the river to distinct climate change (the Maas and the Warta rivers took several hundred years to respond to the Weichselian Pleniglacial/Late Glacial transition). Given such similarities in timescales, it is not surprising that fluvial systems do not always react to climatic changes of limited duration (Vandenberghe 2002: 19). A further factors behind such variable response concerns the observation that the duration of a climatic oscillation must be long enough to enable a particular system to react to the forcing process. Given that climatic events need to last longer to affect large catchments in comparison to small ones, it is clear that small systems could *theoretically* provide more comprehensive archives of both large and small magnitude climatic events. Unfortunately, such small systems are also extremely vulnerable to subsequent erosion, while the larger systems, although perhaps only documenting the more major climatic events, are more likely to preserve the resultant major sedimentary structures. Finally, Vandenberghe (2003) has noted that the critical threshold values that must be crossed also vary on a regional basis in absolute and relative values. For example, the energy available for sediment removal and transport is determined by river gradient as well as discharge, while the energy required is expressed by the amount and grain size of the river's sediment load. Catchment size will also influence river responses, due to the differential increase in small catchments in the catchment area that is only occupied by surface runoff under permafrost conditions. This trend results in river responses to permafrost development or degradation being more pronounced in smaller rather than larger catchments.

Fluvial environment	**River type**	**Evolution**	**Archaeological preservation**
Upland	> High-energy > Non-cohesive channel banks	> Episodic incision & aggradation. > Dominance of coarse-grained sedimentation in braided & meandering systems. > Limited fine-grained sedimentation.	> Narrow valley floors may prevent long-term terrace preservation. > High magnitude flooding may flush sediment fills from valleys. > Incision results in re-working of archaeological materials.
Upland margins (piedmont)	> Medium energy > Non-cohesive channel banks	> Vertical & lateral instability. > Episodic incision & aggradation. > Dominance of coarse-grained sedimentation in braided, anastomising & meandering systems. > Fine-grained accretion on coarse sedimentary units during overbank 'flood' events.	> Wider valley floors may allow for long-term preservation of terrace units. > Incision results in re-working of archaeological materials.
Lowland	> Low energy > Cohesive channel banks	> From glacial braided to interglacial meandering/ anastomosing systems. > Dominance of vertical accretion through time. > Fine-grained units of sand, silt, clay & peat.	> River system stability & dominance of vertical accretion = burial & preservation on in situ archaeology. > High preservation potential for organic materials.
Perimarine	> Low energy > Cohesive banks	> Sea-level fluctuations results in flooding, peat development & overbank sedimentation in anastomosing & meandering channels. > Cyclical sequences of silt/clay and peat.	> River system stability & dominance of vertical accretion = burial & preservation on in situ archaeology. > High preservation potential for organic materials.

Table 1: examples of fluvial systems, geomorphological evolution and issues of archaeological preservation (summarised from Howard & Macklin 1999: Tables 1–3)

These short examples indicate the potential for variation both in fluvial system response to specific changes in climatic conditions, and the implications for long-term preservation of the fluvial archive. These themes were explored specifically by Howard & Macklin (1999) with respect to the considerable complexity associated with fluvial processes and the archaeological record (Table 1). They focused upon the differential behaviour of upland, piedmont, lowland and perimarine systems (defined for the UK on the basis of physiography and basin relief):

- Upland fluvial environments (high energy river systems with non-cohesive channel banks): high river channel gradients (> 10m km^{-1}), high bedload sediment transport rates, steep valley side slopes (which often merge into the channel without an intervening floodplain), and flow regimes dominated by large, infrequent flooding.
- Piedmont fluvial environments (medium energy river systems with non-cohesive channel banks): river channel gradients between 2 and 10m km^{-1}, steep valley side slopes (but with floodplain development between the valley side and river channel), and the transport of gravel bedload and deposition of fine-grained overbank sediments during flooding.
- Lowland and perimarine fluvial environments (low energy river systems with cohesive channel banks): low channel gradients (< 2m km^{-1}), low angle valley side slopes, well developed floodplains, and the transport of predominantly fine-grained sediment.

There are clear marked contrasts between the different systems in terms of system energy, channel stability, sedimentation type and incision activity, and preservation patterns (Table 1). The last of these has clear implications for the interpretation of archaeological assemblages occurring within fluvial secondary contexts, and is returned to in chapter 7. However with respect to the other aspects of system variability, we reiterate the observation made at the beginning of this chapter: *our interest does not lie in the subtle variations of river behaviour in their different reaches, but rather we are concerned with the gross temporal patterns of fluvial activity and the relative preservation of large and small-scale sedimentary features*. This is not because the variations identified by, amongst others, Howard & Macklin (1999), Houben *et al.* (2001) and Cleveringa *et al.* (1988) are not important for the understanding and interpretation of archaeological data. In an ideal world, these variables could be documented and incorporated. However, the partial and highly fragmentary preservation of Middle Pleistocene fluvial sediments, alongside the extensive modification (e.g. through aerial and sub-aerial erosion) of the surrounding landscapes, and the cyclical restructuring of the UK landscape in response to the high and low-sea level fluctuations severely limits our ability to assess local and regional factors. We propose that Middle Pleistocene data currently make it impractical to confidently distinguish for example between upland, piedmont, lowland, and perimarine fluvial environments (Howard & Macklin 1999), reconstruct catchment sizes and local soil lithologies (Vandenberghe 1993), or model upstream/downstream gradients (Houben *et al.* 2001).

By contrast what is possible is an investigation of the temporal magnitude of fluvial activity phases, whether those magnitudes vary in accordance with the type of fluvial activity (e.g. fine- or coarse-grained sedimentation), and the implications of this temporality for the formation and interpretation of archaeological assemblages.

3. THE DURATION OF FLUVIAL EVENTS

From an archaeological perspective the most important element of Vandenberghe's (1995) timescales concerns the observation that *short unstable phases alternate with long periods of inactivity*. The key question concerns the issue of how short the short unstable phases are? Vandenberghe (1995) suggests that these single phases of instability are *c.* 1,000's of years in duration, although it is emphasised that these phases are not characterised by constant fluvial activity. This is illustrated with respect to precipitation, where the intensity of precipitation and its seasonal distribution are more important than annual values in determining the processes of erosion and deposition. Thus, extreme events at a recurrence interval of years or tens of years leave the largest imprints in the production of sediment (Vandenberghe 2003: 2055). This however still leaves the question of the duration of these short, unstable phases, during which a combination of factors (climatic, climate-derived, climate-dependent, and non-climatic) influence fluvial development (*ibid*). This issue is explored below through reference to examples from the Last Glacial and the Holocene. This approach has been adopted as a result of:

- The limited resolution of geochronological tools suitable for the investigation of Middle Pleistocene fluvial sediments. Thermoluminescence, optically stimulated luminescence, amino-acid racemization, and electron-spin resonance all carry an error range of several millennia (Renfrew & Bahn 1996), limiting the possibilities for using multiple dates to model the depositional history of a fluvial sequence.
- Middle Pleistocene fluvial sequences have typically been subjected to extensive post-depositional erosion and modification, resulting in highly partial and fragmentary records of Pleistocene floodplains.

3.1 Fluvial Event Chronology: Case Studies

Two specific case studies are presented as examples of the geochronologies associated with the short-term phases of fluvial activity highlighted by Vandenberghe (1995). They represent a wide geographical catchment, different river types, and cover the Late Glacial and Holocene periods. These variations are acknowledged, and it is again stressed that this review is seeking to test whether overarching relationships between fluvial activity and specific timescales (e.g. seasonal, annual, decadal, centennial, and millennial) exist within the geoarchaeological record. We therefore feel that the inclusive character of the selected case studies is justified. The implications of this approach for the use of the case studies as analogues for Middle Pleistocene sedimentary sequences are considered below.

3.1.1 Cleveringa et al. (1988)

The processes of river activity and spatial and temporal scales were explored for 16 small river basins in Belgium and the Netherlands (Figure 8). The overall area is characterised by low relief, and generally homogeneous climatic conditions, both in the past and at the present. The drainage basins are all situated in unconsolidated rocks of Pleistocene and/or Tertiary age (Cleveringa *et al.* 1988: 123). Long distance and long-term factors were not considered in the analysis of fluvial adjustment (encompassing both aggradation and incision activities within the study), reflecting the small size of the rivers under study. The potential causes of river adjustment were instead restricted to those parameters controlling discharge, including: the intensity and duration of precipitation; the type of vegetation and litter-layer (interception); the infiltration capacity of soils; and the density of the substrate (*ibid*: 127). The amount of precipitation and the degree of evapotranspiration were also highlighted as key factors impacting upon the total amount of water available for river discharge.

It was clear that river adjustments had occurred episodically over the last 15,000 years, associated with five periods: the Subboreal/Subatlantic; Boreal; Late Dryas; Alleröd; and the end of the Pleniglacial/early Late Glacial. Adjustments associated with each of these periods were not evident in all of the river basins, with the Alleröd and terminal Pleniglacial/early Late Glacial adjustments being most commonly represented (in 13 of the 16 basins; *ibid*: 125).

Based on external models of vegetation cover and climatic development over the last 15,000 years (*ibid*: 125–127; summarised here as Figure 9), and cut and fill sequences, pollen analyses, and radiocarbon chronologies for the river basins, a model of river adjustments and climatic parameters was proposed:

- Pleniglacial/early Late Glacial adjustment: *increased water discharge*. Improvements in climate and the presence of non-adapted vegetation (due to delays in tree migration) influenced run-off (sediment yield) and infiltration capacity. Delayed tree migration also resulted in a low evapotranspiration rate. Alongside the retardation of vegetation development and the temperature rise, increased precipitation and the absence of a closed vegetation cover were also key factors behind the increased discharge. Evidence for a considerable precipitation increase include: evidence that the last phase of the Pleniglacial was dry; the widespread presence of organic deposits in shallow depressions of early Late Glacial and Alleröd age, indicating a high ground water level immediately after the Pleniglacial; and the early onset of the deglaciation in Scandinavia and the Alps at 14,000 BP, resulting in a considerable increase in maritime conditions in the Low Countries since the Late Glacial.

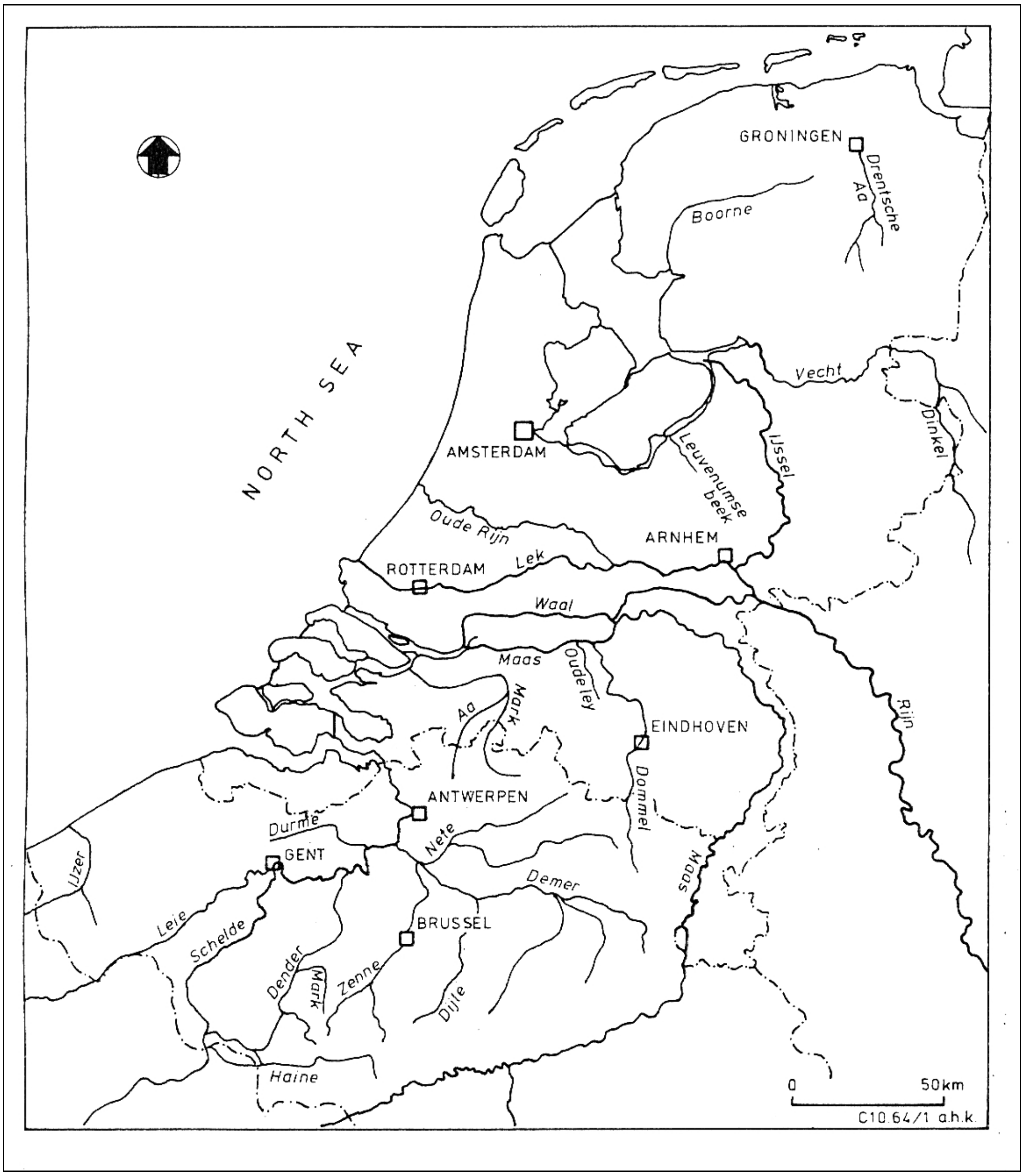


Figure 8: location of the investigated lowland river basins in Belgium and the Netherlands (Cleveringa et al. 1988: Figure 1)

- Late Dryas adjustment: *increased water discharge*. A decrease of evapotranspiration rates occurred due to a substantial temperature drop followed by vegetation regression.
- Boreal adjustment: *minor increase in fluvial discharge* (a possible base level incision). A direct relationship with climatic factors is not clearly indicated, although the ecological shift from pine to deciduous forest may have lead to reduced evapotranspiration. It is possible that the slight increase in water discharge, combined with low sediment yield (due to the dense plant cover and soil forming processes) may have lead to river adjustment.
- Subboreal/Subatlantic adjustment: *slow increase in water discharge.* A slight drop in temperature combined with a minor enhancement of precipitation is indicated, while the increasing effects of anthropogenic activity (on a local and limited scale) must be considered. Overall, the impacts of human activity and

climate change led to increased water discharge, but the gradual nature of the changes resulted in a sporadic crossing of the thresholds for major adjustment in many of the river basins.

Overall therefore, Cleveringa *et al.* (1988: 130) emphasise increased precipitation and decreased evapotranspiration as the main causes behind increased water discharge (and therefore fluvial activity). This is a similar (albeit simpler) conclusion to that drawn by Vandenberghe (1993, 1995) and Maddy *et al.* (2001), summarised above. What is critical from an archaeological perspective however is the relatively short duration of the phases of river adjustment, with those associated with the Late Pleniglacial, the Late Dryas and the Boreal suggested on the basis pollen and radiocarbon data to be *c.* 1,000 years in length (Figure 9).

Cleveringa *et al.* (1988) noted that all four of the river adjustments were only documented in the Leuvenumse Beek valley, with three adjustments recorded in the Dinkel, Dijle and Mark valley, and fewer than three in the remaining basins. This prompted the highlighting of issues of relevance in the potential application of geomorphological models to the understanding of varied archaeological sequences. These are returned to below, but summarised here:

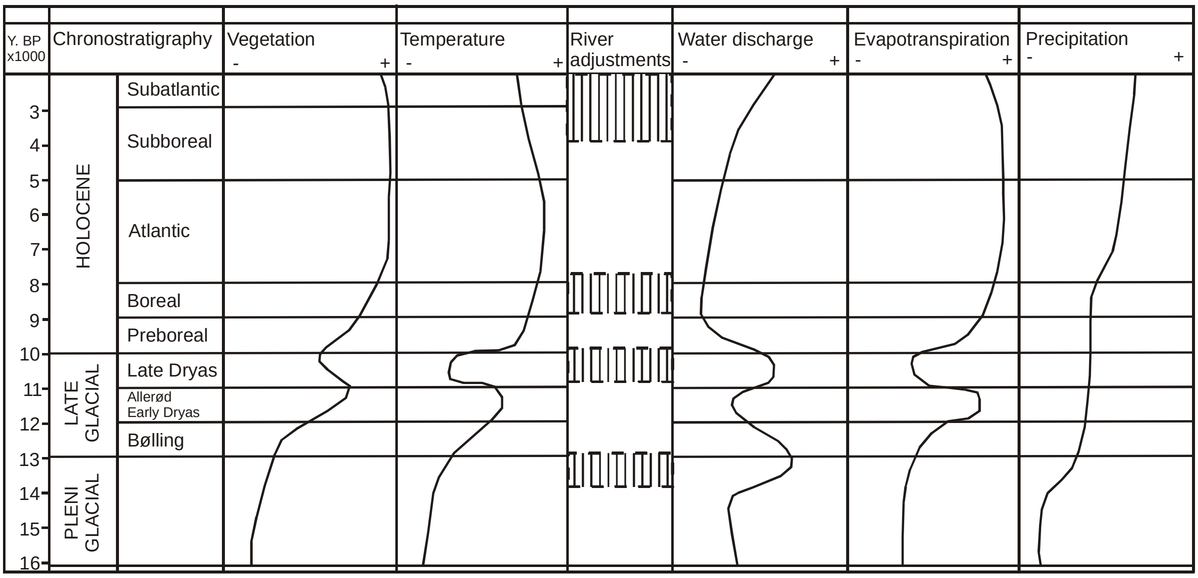


Figure 9: tentative relative curves of climatic parameters related to river adjustments since the Upper Pleniglacial (Cleveringa et al. 1988: Figure 5)

1. Not all river systems react with the same intensity, for the same length of time and to the same degree, to changing conditions (climate and/or vegetational).
2. The number of river adjustments detected is dependent upon research methods and objectives.
3. The stratigraphic sequences of drainage basins are incomplete as a result of the local dominance of erosional discontinuities, while sedimentation in the lower parts of basins can be chronologically associated with erosional factures in the upper part of the basin.

3.1.2 Houben et al. (2001; Houben 2003)

The interplay between climatic factors and local acting controls was explored for small and mid-scale rivers in the Hessian Depression (Hessische Senke) in Central Germany (Houben *et al.* 2001; Houben 2003). The Amoeneburger Becken and the Wetterau are neighbouring, small river basins, located north of Frankfurt am Main in the Hessian Depression (Figure 10). The depression forms a zone of subsidence, the northern continuation of the Upper Rhine Graben, and is bordered by the Rhenish Slate Mountains (Rheinisches Schiefergebirge) in the west and the basalt Vogelsberg upland in the east. The basins themselves are filled with Tertiary sediments, which are covered with Pleistocene loess. The river landscapes lie in the non-glaciated zone between the Scandinavian inland ice sheet and the alpine glaciations, and therefore formed in response to periglacial process during the Pleistocene glaciations

(Houben *et al.* 2001: 249).

Unlike trunk stream deposits, the floodplain sediments of the small to mid-scale rivers in the Depression provided a reflection of landscape processes and change on a local and regional scale, and provide evidence for the environmental changes that have occurred since the Late Glacial. The responses of the fluvial systems to variable climatic conditions during the Late Glacial/Holocene transition are reflected in deposits of different facies. Section excavations and coring at four study sites revealed a mixture of sedimentary units, including coarse-grained sands and gravels, fine-grained overbank deposits (including the Black Floodplain Soil (BFS) of the early to mid-Holocene), and tephritic sediments (*ibid*: 251).

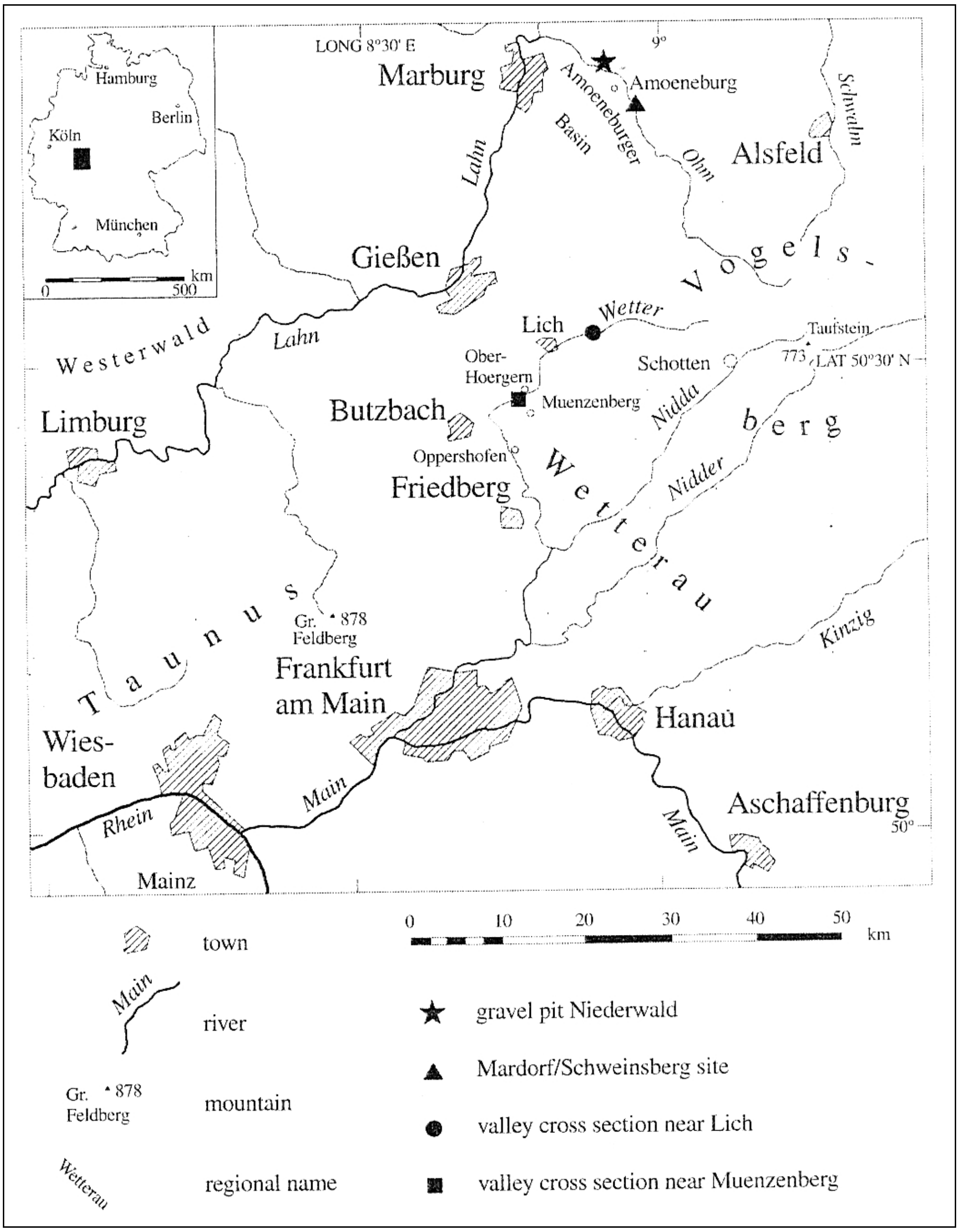


Figure 10: location of the Amoeneburger Becken and Wetterau basins (Houben et al. 2001: Figure 1)

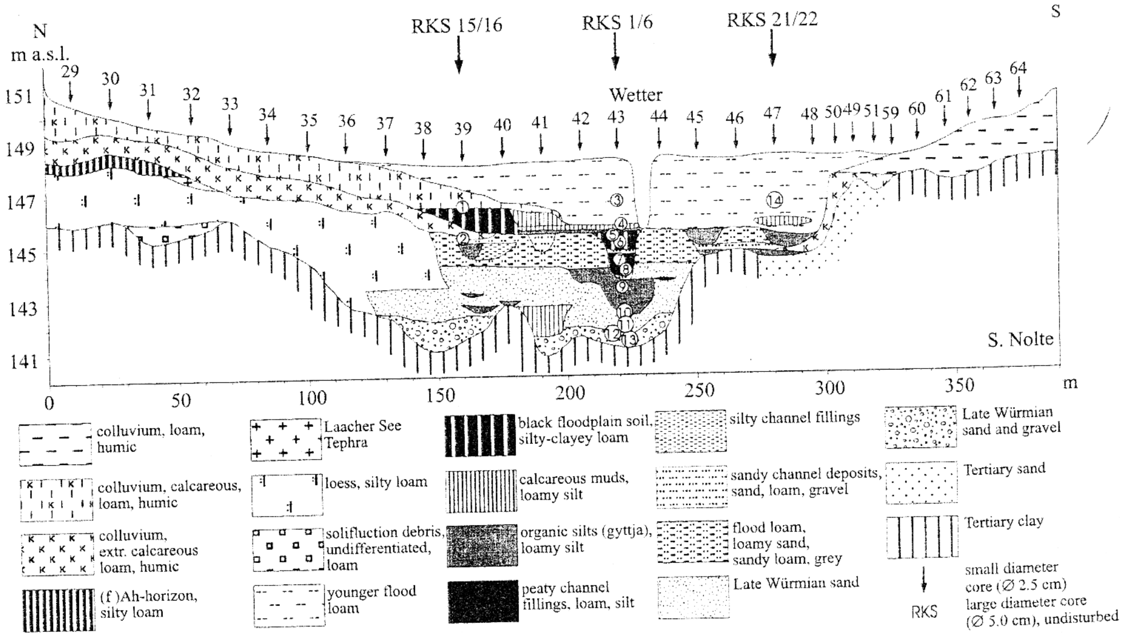
Radiocarbon dating, pollen and macro-fossil analysis, tephrochronological investigations, and magnetic volume susceptibility measurements provided a high resolution record for the Late Glacial to Holocene period, and supported an interpretation of the responses of the fluvial system to varying climatic and other factors:

- Late Glacial period: in the upper Wetter valley, two or more layers of fine-grained overbank deposits overlie Pleniglacial gravelly deposits and sands. The lowermost of these overbank fines appear to relate to abandoned channels, with the pollen and macro remains of the peat and clay fills suggesting a shallowing channel. Radiocarbon dates from the macro fossils of three channel fills indicate that the channel filling occurred between 15,745–15,105 cal BP and 14,485–14,135 cal BP (Houben *et al.* 2001: 252). The change in sedimentation style indicates a shift in fluvial style at the end of the Pleniglacial, from a braidplain to a system dominated by very few stable channels. This change to a pattern of vertically accreting fines and a single thread course is linked to more continuous run-off, due to the decreasing magnitude of seasonal snowmelt events. The dominance of suspended load indicates increased soil erosion during this cold climate phase of the Late Glacial (*ibid*: 259).
- Alleröd period: this period is characterised by the increasing expansion of woodland cover (demonstrated for the Amoeneburger Becken), while the local formation of a well-developed soil horizon is also indicative of a more stable (as well as warmer) environment (*ibid*: 259).
- Younger Dryas period: floodplain deposits of this age are dominated by sands and gravels, up to 3m in thickness in the central Wetter valley near Ober-Hoergern, where these sediments are covered by fine-grained overbank sediments (Figure 11). The radiocarbon sequences highlight the rapidity of fluvial sedimentation events, which occur at a scale of hundreds (10^2) rather than thousands (10^3) of years. Pollen analysis and radiocarbon dating also indicate the presence of older sediments that were re-worked and redeposited during the Younger Dryas. Although this period is widely considered to be a phase of colder climate, pollen evidence from the northern Wetterau does not indicate considerable deforestation, while sedimentary evidence from the upstream Wetter near Lich does not indicate a sudden change in fluvial style during the Younger Dryas (*ibid*: 254–255). Yet the majority of the floodplains were affected by increased fluvial activity during this period, with the re-working and deposition of coarse-grained sediments suggesting a climatically-driven change to a braided river system (*ibid*: 260). How can this discrepancy be explained? Houben *et al.* (*ibid*: 260) emphasise the contrasting spatial scales of the palaeo-environmental provided from sedimentological and pollen data, and the differential behaviour of fluvial systems in contrasting parts of the catchment. For example, the upland reaches were influenced by markedly deteriorating climatic conditions, increasing proportions of precipitation stored as snow, high magnitude snowmelt discharges that were capable of entraining and transporting coarse materials, and the minor role of vegetation cover in upland areas. By contrast, the low gradients of the downstream basins resulted in the sedimentation of the coarse-grained sediments, although these lower reaches may have been little affected by the Younger Dryas cooling, hence the absence of major deforestation.
- Preboreal to mid-Holocene: climatic amelioration is indicated during these periods by vegetation development, particularly the widespread expansion of pine forests, and a lithological shift toward the deposition of organic and fine-grained sediments. This is indicated by an undisturbed laminated sequence of thin peat and clay layers at the Niederwald site. This period is also characterised by the widespread development of the Black Floodplain Soil (BFS; a dark brown to black clayey horizon), between 9,800–6,300 cal BP (the Boreal to Atlantic periods). The BFS is interpreted as indicating a geomorphologically stable floodplain, unique during the Holocene. The very high clay content of the BFS is only explainable by its formation under dense vegetation covering the floodplain. The soil therefore developed by a combination of pedogenesis and the slow accretion of overbank fines. The BFS also marks the last phase of natural floodplain development, since all overlying may carry information relating to anthropogenic impacts upon the landscape (*ibid*: 261).

Overall, Houben *et al.* (*ibid*: 261–262) highlighted three issues of relevance in the potential application of geomorphological models to the understanding of varied archaeological sequences:

1. Changes in fluvial sedimentation in the Hessian Depression during the Late Glacial and early–mid Holocene generally correspond to know, overall climatic stages.

2. However, locally different environment conditions can develop in different physiographic settings.
3. Radiocarbon dated channel fills indicate that fluvial events, principally the deposition of sedimentary units, occur relatively rapidly, with a time-scale of hundreds of years associated with the Late Glacial channel filling. Although a 3–4,000 year span is quoted in association with the development of the BFS, the intervals between radiocarbon dates from different sedimentary units in the Wetter valley near Muenzenberg again support timescales for fluvial events with a magnitude of hundreds rather than thousands of years (Figure 11).



^{14}C-dates

	BP	cal BP, 1 Sigma	Lab.-No.
①	3602 ±67	3980-3780	HD-17826
②	5413 ±43	6282-6179	UtC 4905
③	830 ±80	790-670	UtC 5512
④	1991 ±48	1985-1875	UtC 5416
⑤	7715 ±66	8540-8410	HD-18458

	BP	cal BP, 1 Sigma	Lab.-No.
⑥	7890 ±60	8940-8550	UtC 5415
⑦	9160 ±70	10280-10030	UtC 4403
⑧	9470 ±70	10800-10370	UtC 4404
⑨	9523 ±60	10870-10420	UtC 4405
⑩	10180 ± 190	12270-11090	UtC 4406

	BP	cal BP, 1 Sigma	Lab.-No.
⑪	11640 ±70	13700-13460	UtC 4407
⑫	11340 ±70	13350-13160	UtC 4408
⑬	11360 ±70	13370-13180	UtC 4409
⑭	2040 ±60	2050-1900	UtC 4902

Figure 11: valley cross section near Muenzenberg (Houben et al. 2001: Figure 3)

These case studies therefore suggest a potential common duration for fluvial events of the magnitude of a few hundred years. These observations are also supported by a wide range of other examples of rapid fluvial activity in the extant literature, associated with the river systems from a wide geographical and chronological range:

1. Schirmer (1988, 1995) provides broad chronological frameworks for a series of Middle European rivers (the Amper and Mittel-Isar, Unter-Isar, Donau, Oberrhein, Mittelrhein and Niederrhein, Main, Regnitz, Oberweser and the Mittelweser) over the Upper Würm and Holocene periods. The frameworks indicate the relatively short durations associated with the deposition of both fine and coarse-grained sediments. Examples include the deposition of fine, floodplain sediments over the Schönbrunn terrace during the early Late Würmian, between 13,000 and 11,800 BP; and gravel deposition on the Ebensfeld terrace between 5860 and 4300 BC. Although other chronologies are available suggesting rapid fine-grained sedimentation (e.g. between 5700 and 5300 BP), these events post-date the Neolithic occupation and are therefore likely to at least partially reflect anthropogenic influences such as slope clearance (Schirmer 1995: 45).

2. The Warta river in north-western Poland provides a long chronology of fluvial evolution from the Bølling to the Subatlantic period, punctuated by short periods of rapid fluvial activity (Kozarski *et*

al. 1988). The floor of the Warta valley consists of low bifurcation and transitional terraces, and the floodplain. Radiocarbon dating of organic deposits in the bifurcation terrace at the Zabinko exposure indicates a period of *c.* 600 years during which the palaeochannel was filled (a minimum age of 12,110±140 years BP and maximum age of 12,770±190 BP).

3. Vandenberghe (1993, 1995) documented rapid phases of fluvial activity for the Dinkel and Maas rivers (Netherlands) and the Warta valley (Poland). Up to 8–9m of incision has been recorded in the Dinkel river valley in the eastern Netherlands, between *c.* 13,000 BP (the Weichselian Pleniglacial/Late Glacial transition) and *c.* 11,800 years BP. This phase of fluvial erosion was followed by relatively rapid aggrading of the gullies, which was almost completed by the end of the Late Glacial (*c.* 10,000 BP). Vandenberghe (1993: 23) notes that the phase of fluvial erosion occurred widely in Europe, although it is not clear whether it occurred as or less rapidly in other regions. Radiocarbon dating of organic fills and pollen stratigraphy from the Warta and Maas rivers also highlights rapid fluvial activity in association with the climate change at the Pleniglacial/Late Glacial boundary (Table 2).

	River system		
	Warta		***Maas***
Fluvial styles	*Single meandering channel*	*Fluvial styles*	*Single meandering channel*
Chronological Shift	*c.* 11.6 ka BP	Chronological Shift	*c.* 11.8 ka BP
Fluvial styles	*Multi-channel meandering or anastomising type*		
Chronological Shift	*c.* 11.9 ka BP		
Fluvial styles	*Lateral migration*	*Fluvial styles*	*Multi-channel transitional type*
Chronological Shift	*c.* 12.3 ka BP		
Fluvial styles	*Multi-channel type, with narrow, curved gullies*		
Chronological Shift	*c.* 12.7 ka BP	Chronological Shift	*c.* 12.7 ka BP
Fluvial styles	*Braided type*	*Fluvial styles*	*Braided type*

Table 2: chronology of fluvial events for the Warta (Poland) and Maas (Netherlands) rivers during the Late Glacial (Vandenberghe 1995: 635–636). Chronology in non-calibrated radiocarbon ages.

4. Rose *et al.* (1980) documented fluctuating phases of channel stability and instability for the River Gipping at Sproughton, Suffolk in the UK. Although the channel was stable during the early and middle phases of the Windermere Interstadial and throughout the Flandrian (with limited bedload transport and cohesive banks), it was markedly unstable during the latter part of the Windermere Interstadial and throughout the whole of the Younger Dryas. These phases were characterised by dominant bedload transport, and a channel pattern ranging from deep, large-scale discontinuous gullies, and then to braids. Radiocarbon dates and ages inferred from a coleopteran assemblage (*ibid*: Table 12.1) documented the erosion of discontinuous gully channels between 11,300 and 11,000 years BP, followed by braided and meandering river sedimentation of sands and gravels between 11,000 and 9,500 years BP. Rose *et al.* (*ibid.*) attributed the channel instability to a period of short-lived, high magnitude discharges, with the changes from erosion to deposition and meandering to braiding related to the relative magnitudes of the peak discharges and the quantities of available sediment supplied to the channel from the hill-slopes. Most importantly, it is suggested that the changes indicates the importance of short-lived, climatically induced changes of fluvial energy.

5. Collins *et al.* (1996) also documented changing fluvial activity for the River Kennet, in central southern England. Evidence from the site at Woolhampton highlighted a series of major changes in fluvial activity, linked by pollen and macrofossil data to broad climatic fluctuations: Last Glacial Maximum to the pre-Late Glacial (nival, braided regime, erosion); Late Glacial Interstadial (lower energy flows, incision that increased channel stability, deposition of fines, some erosion at the end of the interglacial); and the Younger Dryas Stadial (increased energy flows, channel deposition of sands and gravels, lateral channel migration, and some channelisation at the end of the stadial).

Radiocarbon dates for the Heales Lock Member of the Woolhampton Formation suggest that deposition of the upper gravels did begin until 11,500–11,000 yr BP at the earliest, and did not persist long after the end of the Loch Lomond Stadial.

6. Maddy *et al.* (2001: 32–33) highlighted the archiving of higher resolution signals of climatic change within individual terrace aggradations, with specific reference to the Northmoor terrace of the Upper Thames valley of the UK. It is emphasised that the sedimentary architecture produced during each aggradation comprises complex cut-and-fill sequences. These sequences reflect short-term changes in sediments, which *may* be triggered by short-term climatic changes (Figure 7). The durations of these climatic changes are proposed to be in the order of one to several millennia (Vandenberghe's (1995) 3rd timescale), although few specific examples are presented (reference is made to cold- and warm-climate shifts within a glacial, such as the Devensian Late Glacial interstadial and the Younger Dryas).

7. There are also a wide range of other studies supporting a model of fluvial activity at the sub-millennial scale, including Bibus & Wesler's (1995)) study of Holocene morphodynamics in the Neckar, Main, Regnitz, Lower Isar, Danube and Upper Rhine; Macklin & Lewin's (1993) identification of relatively brief periods of major Holocene alluviation in UK river systems; and Starkel's (2002) documentation of short, sub-millennial phases of higher flood frequencies and resultant fluvial activity during the central European Holocene (e.g. 8.5–7.8 and 6.6–6.0 ka BP).

Despite the geographical variability and diversity of river systems discussed in the above examples, it is apparent that in all cases, individual episodes of fluvial activity occur relatively rapidly. This appears to hold true whether that activity is channel incision or erosion, sedimentation of coarse-grained sands and gravels, or fine-grained overbank flooding. Thus while the nature of the fluvial activity may vary, in most cases it appears that episodes of fluvial incision/erosion and aggradation (both coarse-grained and fine-grained) occur over a time-spans stretching between a few hundred, or (at the very most) a few thousand years. It is of course emphasised that this fluvial activity (channel migration, incision, erosion and aggradation) was not occurring *constantly* during these periods of decades and centuries, but rather episodically in response to major events (e.g. nival spring floods), such as the 100 year interval flood documented by Schmidt (1994). They key point is that during the periods of fluvial activity these extreme flood events were occurring at a higher frequency (Starkel 2002) than during other periods. Therefore fluvial processes of incision and sedimentation were dominant during these decadal and centennial phases of climatic change and fluvial activity. These chronologies have clear implications for the archaeological interpretation of the European Palaeolithic stone tool assemblages occurring in association with the fluvial sedimentary units of the Middle and Late Pleistocene. In combination with the generic models of fluvial activity across the glacial/interglacial cycle outlined above (Section 2), it can be proposed that:

1. The increasing ice core evidence for multiple, short-term climatic fluctuations at the sub-MIS scale (e.g. Anklin *et al.* 1993; Petit *et al.* 1999) indicates that fluvial activity (erosion and aggradation) will occur both during the major glacial/interglacial transitions, and within the individual glacial and interglacial phases.
2. River system response to minor climatic fluctuations (e.g. within glacial and interglacial cycles) will be sporadic, reflecting catchment size, threshold conditions and other local and regional factors.
3. River system response to major climatic fluctuations (e.g. at the glacial/interglacial and interglacial/glacial transitions) will tend to be more uniform, reflecting the greater magnitude of these events
4. River system response (fluvial incision, sedimentation) will occur relatively rapidly, typically over several hundred rather than several thousand years. It is stressed that these durations are probably over-estimates, since the geochronological sequences on which they are based do not provide estimates for the duration of the 'invisible' breaks in deposition between the superimposed sedimentary units (see below).
5. The fluvial activity associated with the major climatic transitions will be preferentially *preserved* within the fluvial archives over the long-term (compared to the fluvial architecture resulting from

minor climatic oscillations), reflecting threshold factors and the favourable preservation of large-scale sedimentary features.

This modified framework highlights key issues with respect to the interpretation of secondary context assemblages, principally in terms of the duration of the sedimentary events and the differential preservation of large and small-scale sedimentary features. These are fundamental for interpreting the issues of assemblage homogeneity/heterogeneity, and the degree of potential artefact re-working that may have occurred after the *initial* depositional event. However, a key problem still requires investigation: what was the duration of the phases of fluvial inactivity in-between the periods of incision and sedimentation?

4. THE DURATION OF FLUVIAL ACTIVITY HIATUS

Identifying the duration of periods of fluvial inactivity presents a number of considerable problems, reflecting the resolution of currently available geochronological tools, and the highly fragmentary preservation of fluvial sedimentary sequences. Frustratingly, these problems are at odds with the relative ease of identification of breaks in fluvial activity. Commonly recorded features include ice wedge cracks (Figure 12) and other cold-climate indicators, buried soils, weathering horizons, and erosional surfaces within fluvial sedimentary sequences:

1. Conway *et al.* (1996: 119–122) provides a detailed example of a Middle Pleistocene sequence with the documentation of the succession of erosional surfaces in the Barnfield Pit sequence:
    - Erosion surface E1: the base of the channel, cut into Thanet Sand and Chalk (in the northern part of the pit). The surface is marked by some cryoturbation disturbance of the top of the Thanet Sand, on which rests a lag deposit and solifluction material.
    - Erosion surface E2: the irregular top of the basal gravel, marked by a lag deposit resting upon it. The lithology changes from unsorted gravel in clay/silt matrix to well sorted, horizontally-bedded sandy gravel.
    - Erosion surface E3: the irregular surface of the Lower Gravel, with truncated bedding and partial decalcification. The lithology of the overlying beds shows a change to a much lower energy regime of deposition.
    - Erosion surface E4: the surface layer of the Lower Loam is weathered to a depth of *c.* 50 cm and shows decalcification and the development of a soil. The surface is irregular with truncated bedding and the presence of animal footprints. A lag deposit rests upon the surface.
    - Erosion surface E5: the surface of the Lower Middle Gravel shows considerable topography and marks a lithological change from a high energy environment (horizontally-bedded sandy gravels) to a lower energy environment (cross-bedded sands). The bedding of the Lower Middle Gravel is truncated.
    - Erosion surface E6: the upper part of the Upper Middle Gravel shows cryoturbation disturbance and in places a solifluction deposit rests on the surface. The environmental change is from cool fluvial to cold, partially terrestrial conditions.
    - Erosion surface E7: the upper part of the Upper Loam shows marked cryoturbation disturbance together with ice-wedge casts, with a solifluction deposit resting upon the surface.

2. Bridgland (1994) documented extensive evidence for hiatus in fluvial activity, within the Middle Pleistocene sequences within the Thames Valley:
    - Buried soils, including the Barham and Valley Farm soils and the Swanscombe Lower Loam soil, indicating the development of stable landsurfaces (and by inference a temporary cessation in fluvial activity).
    - Gravel deposits showing evidence of cryoturbation and weathering, typified by the ‘Silchester’ gravel at Hampstead Marshall and the deposits at Martells Quarry, Ardleigh.
    - Weathering horizons, such as that at the Baker’s Hole complex where intense rubification indicates both soil development and an interglacial climate.

- Cold-climate indicators, principally ice-crack casts and solifluction deposits, are indicative both of cold climate conditions and exposed landsurfaces.

Figure 12: Ice wedge cast in fluvial sediments, Linch Hill Pit, Oxfordshire

3. Miall (1996) provides a hierarchy of bounding surfaces or unconformities, modified by Jones *et al.* (1999), which highlights the status of the bounding surfaces between the sedimentary units as physical discontinuities within a fluvial depositional sequence. The hierarchy (Table 3) highlights the wide range of scales at which erosional surfaces occur, from scour in the trough of a dune bedform, through channel erosion surfaces to palaeovalleys. These surfaces are associated with contrasting scales of primary processes, in this case bedform migration, channel migration and incision (Bristow 1996: 360–361). Unfortunately, bounding surfaces of the 0th–3rd order occur within the timescales for fluvial activity episodes (100's of years) identified previously and are

therefore of relatively little application here (although they serve as a useful reminder that even during 'periods' of fluvial activity, sedimentation/incision does not occur constantly). The 6th order refers to the 100,000 year Milankovitch cycles of fluvial activity (i.e. terrace development over the glacial/interglacial cycle), which can be observed through the robust evidence of fluvial terrace sequences. The 4th and 5th order surfaces are potentially the most useful, but their timescales essentially refer to the associated processes (e.g. bar or channel development) and not to the interval phases.

The key problem is therefore that the features which document phases of fluvial inactivity or stability cannot be directly dated to provide a measure of the length of the hiatus. For example, while Bryant (1983) has observed that growth rates for ice-wedge casts in modern Arctic stream environments are 0.5 mm year^{-1}, their use as a measure of the duration of stable landscape conditions and continuous permafrost would be fraught with assumptions about comparable climatic conditions. Similarly, the cyroturbated and weathered deposits at Ardleigh could have been produced by either frequent lateral shifting of a network of braided channels or by a long period of deposition in an essentially stable fluvial environment. These two interpretations have strikingly different implications for the chronology of the sequence (and for any archaeology occurring within the deposits), yet distinguishing between them is an extremely difficult task. Finally, although soils indicating stable landsurfaces may be utilised as temporal markers, it is impossible to accurately assess how much time is represented by the soils.

Rank	**Character of bounding surface**	**Depositional unit**	**Examples process**	**Timescale of process**
0th order	Lamination surface	Lamina	Burst-sweep cycle	10^{-6}
1st order	Set bounding surface	Ripple (microform)	Bedform migration	10^{-5}–10^{-6}
2nd order	Co-set bounding surface	Dune (mesoform)	Bedform migration	10^{-2}–10^{-1}
3rd order	Reactivation surface	Macroform growth increment	Seasonal events (10 year flood)	10^{0}–10^{1}
4th order	Convex-up macroform top	Macroform (e.g. point bar)	100 year flood, bar migration	10^{2}–10^{3}
5th order	Flat to concave-up channel base	Channel	Long term geomorphic process	10^{3}–10^{4}
6th order	Flat, regionally extensive	Channel belt sequence	Milankovitch cycles	10^{4}–10^{5}

Table 3: hierarchy of bounding surfaces identifiable in fluvial sequences (Lewis and Maddy 1999: Table 5.2)

The problems of directly dating episodes of fluvial stability are of course removed where high resolution dating of sediments above and below the erosive surface or ice crack can provide an indirect estimate. This has been demonstrated by Vandenberghe (1993: Figure 4) at Belvedere, Maastricht in the southern Netherlands, where there is evidence of cryoturbation and frost-cracking in association with the early and late Pleniglacial. However, when dealing with sedimentary sequences from the Middle Pleistocene, the problems of fragmentary preservation and low resolution geochronological tools do not permit this approach.

However, it is possible to approach this issue from the high resolution ice core records now available for the last glacial/interglacial cycle (e.g. van Andel 2003), and rapidly being extended back into the Middle Pleistocene (e.g.; Anklin *et al.* 1993; Petit *et al.* 1999). The ice core records for the last 80,000 years document 21 interstadial events occurring during stages 5a, 4, 3 and 2 (Watts *et al.* 1996). The duration of these events is uncertain (Vandenberghe (2002) dates the Hengelo Interstadial between 41–38.5 ka BP)), reflecting current geochronological toolkits, but whatever their duration, the average interval between an interstadial event in the period 80–10 kya BP is just *c.* 3,300 years. Assuming that the last glacial/interglacial cycle is a sound analogue for earlier periods (see Section 5), it is proposed that an average duration for periods of relative fluvial inactivity is approximately 3,000 years. This estimate is of considerable importance to the interpretation of secondary context artefact assemblages, since it provides an indicator of the periods over which floodplain landscapes remained relatively stable, and therefore artefacts could *potentially* accumulate upon the time-averaged land surface. It is emphasised that these periods may be considerably longer in systems which for various reasons (e.g. catchment size, threshold conditions) do not respond to each of the high frequency, low magnitude climatic oscillations. Nonetheless, the high resolution ice core record would seem to provide the most useful gauge for currently estimating the intervals between the critical phases of pronounced fluvial activity.

5. ANALOGUE ISSUES

A critical issue concerns whether high resolution Late Glacial and Holocene models of fluvial system development are applicable to the interpretation of Middle Pleistocene sequences. Resolution of this issue focuses upon two points: are the climatic and environmental conditions comparable?; and was fluvial development overtly influenced by anthropogenic activity during the Holocene period?

The question of anthropogenic influence is certainly pertinent for many studies of fluvial systems (e.g. Schirmer 1988, 1995; Macklin & Lewin 1993; Bibus & Wesler 1995; Brown *et al.* 2001). For example, Bibus & Wesler (1995) observed that the younger meander systems of the Neckar floodplain show evidence of human influence in the form of heavy soil erosion in the drainage basin; meander system development in rapid succession; and the rapid accumulation of thick, high-water loam layers. Similarly, Schirmer (1995: 45–46) emphasised a series of human impacts upon the development of central European fluvial systems during the mid and late-Holocene, including augmentation of flood sediment in loess-rich areas (e.g. the thicker flood sediments of the Ebensfeld Terrace on the Oberrhein) and the input of soil materials into fluvial deposits; changes in the type of sedimentation (e.g. the increase in suspension load on the Main river), although river activity rhythms and cycles do not appear to be influenced; and the widening, branching and flattening of the river bed, combined with the augmentation of flood sediment and the elevation of flood levels, promoting a braiding pattern.

In light of these factors, the use of analogue models for fluvial system activity and development should be restricted to the Late Glacial and early Holocene periods. Fluvial development in these periods shows no apparent evidence of anthropogenic impacts, but continues to provide a relatively high resolution radiocarbon chronological record. This however leads directly to the second key issue — whether the climatic and environmental conditions of the Late Glacial and early Holocene periods are applicable to the Middle Pleistocene?

Throughout the last 12 MI stages, climate change has been dominated low-frequency (100 ka) eccentricity-driven cycles (Lowe & Walker 1997: 12–13; Maddy *et al.* 2001), suggesting that the overall pattern of glacial/interglacial cycles over the Middle and Late Pleistocene has remained relatively consistent. However, while the Late Glacial and early Holocene periods essentially document a glacial/interglacial transition, from MIS-2 (the Devensian/Pleniglacial) into MIS-1 (the Flandrian/Holocene), this transition is complicated by the presence of brief climatic oscillations. The UK's Devensian Late Glacial divided into the Windermere Interstadial and the Loch Lomond Stadial, and continental north-west Europe's Weichselian Late Glacial further splits into the Bølling Interstadial, Older Dryas Stadial, Allerød Interstadial, and Younger Dryas Stadial (Lowe & Walker 1997: 9–13). It is clear from the previous case studies that these short-lived climatic oscillations played an importance in the documented phases of fluvial development and rapid activity in northern European rivers during this period. Were such oscillations therefore common during the Middle Pleistocene? This is difficult to currently assess, but available ice core evidence (e.g. Anklin *et al.* 1993; Petit *et al.* 1999) is supportive of parallels between the Late Glacial and the early Late Pleistocene and the Middle Pleistocene. Specifically, the GRIP core (Anklin *et al.* 1993) indicates a series of shifts during the Eemian (MIS-5e) from warm interglacial to mid-glacial period conditions. These changes appear to be both transient (lasting decades or centuries and analogous to the climatic mode switches that have been identified in the late glacial period) or can last up to 5,000 years. The core data indicates 3 warm sub-stages of MIS-5e (5e1, 5e3, and 5e5) and two cool sub-stages (5e2 and 5e4), and it is notable that many features of the Eemian cool events appear to be parallel the changes in the Younger Dryas. Overall however, the most striking feature of this period is the series of high-amplitude, high frequency oscillations, which appear to be evidence of rapid climate change, with cold/warm mode switching completing in as little as 1–2 decades but may also become latched for between 70 and 5,000 years. Over longer timescales the Vostok core (Petit *et al.* 1999) records a comparable sequence for all four of the climatic cycles since 420,000 years BP, with a warm interglacial stage (MIS 11.3, 9.3, 7.5 and 5.5) followed by increasingly colder interstadial events, and ending with a rapid return towards the following interglacial. Finally, the recent stage 3 project (van Andel & Davies 2004) has provided high resolution data from one part of the late glacial/interglacial cycle, and it is notable that van Huissteden *et al.* (2001: 75) have argued that stage 3 can be considered to represent ‘average’ glacial conditions, despite its strong climatic variability characterised by rapid climatic oscillations (as discussed above with respect to the Late Glacial). They suggest that the variability may be an intrinsic property of such average glacial conditions, with only glacial and extreme glacial conditions characterised by far less variable climates.

Overall therefore, while the situation is not yet certain, the available evidence appears to suggest that the climatic and environmental patterns of the Late Glacial (short-lived climatic oscillations) do appear to be replicated throughout the Middle Pleistocene, in association with glacial, interglacial and transitional phases. Given the apparent link between rapid climatic oscillations and relatively short phases of fluvial activity during the Late Glacial it is proposed here that similar relationships would have been prevalent during the Middle Pleistocene and that therefore the use of Late Glacial and early Holocene analogues is a valid approach.

6. SUMMARY

This chapter began to highlighting three issues that are critical to the understanding and interpretation of archaeological assemblages occurring within fluvial secondary contexts:

- What are the patterns of deposition and preservation of sand, gravel, clay and silt sediments, and what is the approximate duration of the fluvial episodes associated with their deposition?
- What is the approximate proportion of the Middle Pleistocene glacial/interglacial cycles preserved within river terrace fluvial aggregates sequences, either as sedimentary units or erosional features?
- What is the duration of the depositional hiatus and/or erosive events within fluvial sedimentary sequences?

These issues were explored through an examination of extant models of fluvial activity across the glacial/interglacial cycle, studies of Late Glacial and Holocene fluvial activity, and the latest ice core-derived models of climatic fluctuation during the Middle and Late Pleistocene. The results are summarised below:

1. Fluvial activity (including both sedimentation of fine and coarse-grained deposits and erosion/incision of floodplain and channel features) is associated with climatic change, although the relationship is not linear, but rather highly complex. Evidence from the last glacial/interglacial cycle and the Holocene indicates that these periods of dynamic climatic change were relatively brief, and that the resultant phases of fluvial activity were also relatively short-lived, typically lasting hundreds rather than thousands of years. It is stressed that fluvial activity was not occurring constantly during these phases simply that those activities were the dominant system processes (e.g. reflecting increased frequency of high magnitude spring floods). These periods of dynamic climate change are associated both the major glacial/interglacial climatic transitions (occurring approximately every 50,000 years during the 100,000 years eccentricity-driven cycles of the Middle Pleistocene) and also with the minor climatic oscillations (stadial and interstadial events) that occurred within the glacial and interglacial parts of the cycle. It is likely that all fluvial systems responded to the major climatic transitions, reflecting both their overall duration and the magnitude of the events. However, system response to minor climatic oscillations would have been far more variable, reflecting both climatic factors (e.g. the length and magnitude of the event) and non-climatic system variables (e.g. catchment size, threshold values, and local and regional palaeogeography). Preservation of sedimentary units would have been favourably weighted towards large-scale features created in response to high magnitude events, while the small-scale products of minor climatic oscillations would have been highly vulnerable to

subsequent erosion.

2. Fluvial activity across the interglacial/glacial cycle is characterised in terms of major events at the glacial/interglacial and interglacial/glacial transitions, and a series of sporadically represented minor climatic oscillations throughout the cycle:

    - Late glacial/early interglacial and late interglacial/early glacial transitions: relatively rapid phases of incision, followed by coarse-sediment, all in response to changes in sediment and water supply. Vegetation development, evapotranspiration rates and related factors (e.g. run-off rates, bank stability) are key factors in this phase. The duration of these phases are unclear, but current MIS and ice core data would *suggest* periods of less than *c.* 5,000 years.
    - Interglacial: relative quiescence, with small-scale fluvial activity (e.g. channel migration and fine-grained sedimentation) in response to minor climatic oscillations (e.g. stadial and interstadial events). Evidence from the last glacial/interglacial cycle suggests that minor climatic oscillations (e.g. interstadial events) may occur *on average* every 3–4,000 years.
    - Glacial: general stability, with minor fluvial activity (e.g. channel migration and sediment deposition) in response to minor climatic oscillations.

    It is extremely difficult to estimate the proportion of the glacial/interglacial cycle represented within fluvial sedimentary sequences, primarily because the response of individual systems to climatic events is highly variable, whilst the sedimentary products of any responses are often vulnerable to subsequent erosion during the cycle (especially where the features are small-scale). We would cautiously suggest that as a general rule of thumb, less than 10% of the glacial/interglacial cycle is represented within sequences, with the majority of preserved sedimentary features associated with the major climatic transitions. This applies both to large-scale systems (which are less likely to respond to minor climatic oscillations, and also to small-scale systems, where the sedimentary products of minor events are vulnerable to subsequent erosion).

3. The time intervals between episodes of active fluvial activity (incision, erosion and deposition) are difficult (if not impossible) to estimate from sedimentary sequences. Evidence from ice core records suggests an average interval between minor climatic oscillations of approximately 3–4,000 years. However, it is critical to recall that not all of these events will lead to fluvial system response (see above) and that even where fluvial activity does occur, the physical evidence may be subsequently eroded. There is therefore a contrast between the time intervals between climatic events, fluvial activity and preserved fluvial activity.

6.1 A Floating Geochronology

The issues discussed above highlight the considerable problems facing the construction of a geochronological framework for Middle Pleistocene fluvial sedimentary sequences (and their archaeological content). Ultimately these are all grounded in the resolution of currently available geochronological tools. The major currently available dating technique for fluvial sedimentary sequences is optically stimulated luminescence (e.g. Lewis & Maddy 1999; Hosfield & Chambers 2002b), and it is clear that the error ranges associated with sample ages do not allow for the correlation of sedimentary architecture with individual climatic oscillations identified in the ice core records. Nor does the technique support the correlation of sedimentary units recorded in different sites or different exposures of a single site. However, OSL ages do permit the identification of the age of sedimentary features at the MIS scale (e.g. Hosfield & Chambers 2002b) and these estimates can be correlated against other sources of geochronological evidence such as amino-acid ratios (e.g. Lewis & Maddy 1999). This relatively coarse degree of geochronological resolution supports the preliminary framework of fluvial activity over the interglacial-glacial cycles (point 2 above). In regions with significant rates of uplift (e.g. southern England), these cycles of fluvial activity are preserved as fluvial deposits in association with discrete terrace features (Maddy *et al.* 2001).

Within this framework, fluvial activity is associated with climatic change, including both the high magnitude, low frequency climatic shifts associated with the glacial/interglacial transitions (and vice-versa) and the minor, low magnitude, higher frequency climatic oscillations association with all phases of the cycle. As discussed above, it is highly probable that not all of these climatic events will be represented within the sedimentary archive of a river terrace deposit. This is due both to the differential response of river basins to high/low magnitude climatic events (fluvial systems may simply not respond to very low magnitude, high frequency climatic oscillations), and the vulnerability of sedimentary features (especially those of a relatively small-scale) to subsequent erosion and removal from the archive. It is therefore argued here (following Bridgland 1994, 2000, 2001) that the majority of preserved coarse-grained sediments and fluvial architecture *probably* relate to the major phases of interglacial/glacial and glacial/interglacial transition, although it is stressed that the current resolution of geochronological dating tools rarely enables this to be unequivocally demonstrated.

These problems of low resolution geochronological tools, incomplete representation of climate shifting events within the fluvial archive, and incomplete preservation of sedimentary features in the archive therefore hugely complicate any attempts to define a sub-MIS geochronology. Even where there is a clear sequence of distinct terrace features relating to glacial/interglacial cycles (e.g. as with the Middle and Lower Thames), the individual sedimentary units and features within the terrace deposits cannot be precisely aged, and only sometimes can they be relatively dated with the cycle. This is typically dependent upon the presence of unequivocal interglacial sediments within the terrace deposits, since these can indicate the approximate ages of the sediments lying stratigraphically above and below them. For example, the presence of MIS-7 interglacial sediments in a terrace deposit (securely dated on the basis of fauna, amino-acid ratios and OSL) would *suggest* ages of the MIS-8/7 transition and the MIS-7/6 transition for the coarse-grained sedimentary units above and below them. Yet it cannot be assumed that such sedimentary features (especially those that are small scale) represent the major climatic transitions, rather than being a fortuitously preserved relic of a short-lived climatic oscillation during an interglacial or glacial phase. Moreover, the stratigraphic sequence and position of sedimentary units can also be misleading, given the potential for extensive erosion and differential preservation in local parts of the deposit.

Yet at the same time what is clear is that these sedimentary units represent sporadic but high magnitude fluvial activity (e.g. nival spring flood events) over relatively short periods of time, perhaps as little as 1 or 2 decades, and rarely more than a few hundred years in duration. We are therefore left with an unusual scenario, in which the chronology of the individual sedimentary features is relatively well understood in terms of its magnitude (primarily 10^1 and 10^2 years — based on Late Glacial analogues), although the exact age of the features remains unknown. These features cannot be related to the climatic oscillations and switches evident in the high resolution ice-core record, both because of the lack of high resolution dating techniques for the deposits (preventing direct correlation) and the complexities of system response and sporadic preservation (preventing indirect correlation between the number of sedimentary features and the number of climatic oscillations and switches). The broader age of the features can be estimated, based on:

- Geochronological dating tools (e.g. OSL, AAR, faunal and pollen assemblages).
- Geochronological models of terrace sequences, based on Bridgland's (1994, 1995, 1996, 2000, 2001; Maddy *et al.* 2001) framework of terrace formation and fluvial activity across the glacial/interglacial cycle.
- The spatial scale of the sedimentary features, which is *indicative* (but no more) of the magnitude of the climatic transition/oscillation with which it was associated.

The geochronology is therefore absolute at the scale of MIS cycles, but is a relative one at the sub-MIS scale, although the duration magnitude associated with individual sedimentary features and fluvial events can be estimated on the basis of Late Glacial analogues. We refer to this as a semi-floating geochronology. What does this mean for the interpretation of archaeological debris (typically stone tool assemblages) occurring in secondary context within fluvial sedimentary units?

6.2 Implications for archaeological material

The implications of the proposed geochronological framework for archaeological interpretation operate in two scales: firstly, with respect to the analysis of temporal trends in archaeological data, for example the similarities and contrasts between two assemblages occurring in sediments of different ages; and secondly, with respect to the interpretation of the archaeological assemblages' temporal homogeneity/heterogeneity, in terms of the processes involved in the incorporation of the cultural debris (e.g. stone artefacts) within the fluvial sediments.

In terms of the analysis of temporal trends, the cyclical terrace forming frameworks of Bridgland (1994, 1995, 2000, 2001) have provided a mechanism for the analysis and comparison of secondary context archaeological data at the MIS scale for over ten years (e.g. White 1998a; Wymer 1999; Ashton & Lewis 2002). However, it is clear from the discussion above, that it is currently not possible to analyse and compare secondary context data at the sub-MIS scale in terms of an absolute geochronological framework. This is a desirable goal, since it would support the investigation of high resolution research questions, for example whether there is evidence for changing behavioural strategies (e.g. in terms of stone tool manufacture) in response to short-term climatic shifts and limited phases of warm and/or cold climate. Unfortunately, current geochronological tools and methodologies do not provide absolute ages for sub-MIS events and cannot tie specific sedimentary features to particular events. However, even if these tools and methodologies were available, it would still be necessary to consider the second issue: the process of artefact and assemblage incorporation within sedimentary bodies and their temporal dimension.

6.2.1 Duration of fluvial depositional events

Studies of fluvial system development during the Late Glacial and early Holocene suggest that fluvial events such as channel erosion or floodplain sedimentation occur relatively rapidly, over a few hundred or a few thousand years. These time-scales are likely to be over-estimates, and reflect the limitations of both the Late Glacial radiocarbon chronologies and the stratigraphic resolution of the sedimentary records. The key issue from an archaeological perspective is therefore that the archaeological content of a single sedimentary context can be bracketed within a timescale of (at most) several hundred years rather than several thousand or tens of thousand of years. It should be noted that this approach highlights the need for high resolution recording of fluvial sedimentary sequences with respect to their archaeological content, in particular the sub-division of sediments on the basis of cut and fill features and erosion surfaces. Most important however, is the point that this temporal bracketing of the archaeological content refers only to the process of the incorporation (entrainment) of the artefacts within the fluvial system and subsequent deposition as part of the sedimentary body. It does not therefore permit the immediate asking of research questions that operate at the decadal or centennial scale (e.g. is there evidence in the stone tool assemblage for localised traditions in tool-making that lasted for a handful of generations). The reason for this is that the artefacts could have lain on the floodplain or valley slopes for millennia prior to their incorporation, and that the artefacts could be a variety of markedly different ages.

6.2.2 Dormancy in the fluvial record

Late Glacial and Holocene studies suggest that river systems respond to short-lived, low magnitude and high frequency climatic oscillations, albeit not inevitably and in a complex fashion. The duration of these oscillation events is uncertain, reflecting current geochronological toolkits, but whatever their duration, the average interval between an interstadial event in the period 80–10 kya BP is just *c.* 3,300 years. Although the nature of fluvial system response to these climatic oscillations is variable, this would suggest that the potential for heterogeneous artefact 'assemblages' to accumulate, undisturbed, upon floodplains through repetitive artefact discard over several millennia or tens of millennia is slight. It is proposed that artefact accumulations would be re-worked into fluvial sediments every few thousand years, as a result of fluvial activity in response to minor climatic oscillations. It is stressed that these assemblages are temporal palimpsests (they might of course actually represent single occupation phases but this cannot be demonstrated), but of the order of a few thousand, rather than a few tens of thousand, of years. It is also noted that the time-depth of these temporal palimpsests will vary, most obviously between small river systems, which tend to be most sensitive and responsive to the high frequency, low magnitude climatic oscillations (Vandenberghe 2003), and the larger systems, in which there is greater potential for undisturbed artefact discard and accumulation over longer time-spans. Unfortunately however, this assessment of the temporal palimpsest scale also does not permit the asking of research questions that operate at the millennial scale (e.g. is there evidence in the stone tool assemblage for either 'standardisation' or variability in tool-making over thousands of years). The reason for this is the most awkward of archaeological problems when dealing with secondary contexts — namely that the artefacts may have been re-eroded out of older sedimentary units.

6.2.3 The glacial/interglacial cycle

The considerable evidence for localised erosion of fluvial architecture within Late Glacial and Holocene sequences (e.g. Rose *et al.* 1980; Vandenberghe 1993; Collins *et al.* 1996) is augmented by the fragmentary records for the Middle Pleistocene (e.g. Bridgland 1994; Maddy *et al.* 2001) and highlights the potential problem of artefact erosion and re-working. Adopting Bridgland's (1994) model of terrace formation it should be clear that artefacts re-worked from the oldest sediments on a terrace feature into the youngest sediments may be spanning two or even three MI stages. There is no simple solution to this problem, although we propose in chapters 4, 5 and 7 that the physical condition of artefacts can be a useful indicator of the degree of re-working (both vertical and horizontal) that artefacts have undergone (see also Hosfield & Chambers in prep.). Nonetheless, it is clear that when dealing with secondary contexts the starting assumption must be that the assemblage is a mixed collection of re-worked artefacts of different ages, and that one is dealing with a time-averaged palimpsest of the order of tens of thousands of years. It should be clear that this has fundamental implications both the types of questions that may be asked and for the interpretation of the data.

Overall therefore, an episodic model is proposed, with periods of major fluvial activity during phases of climatic transition, separated by longer periods of *relative* system dormancy, interspersed with minor climatic oscillations. The proportion of glacial/interglacial cycles represented within river terrace sequences is difficult to estimate, due to the low resolution geochronological tools, the variability of individual system response to sub-MIS low magnitude climatic oscillations, and unfavourable preservation of small-scale sedimentary features. As a preliminary estimation it is suggested that no more than 10% of the cycle is represented within a terrace sedimentary sequence, based on current ice core and MIS chronologies. Overall therefore, the sedimentary and archaeological materials occurring in river terrace sequences were as probably deposited during a series of episodic intervals within the glacial/interglacial cycle, associated with the formation of the terrace landforms at the major climatic transitions. The second key to understanding the archaeological material however, stems from the recognition that; (1) materials may have been eroded from older sediments prior to their terminal deposition; and (2) the age of the material's manufacture, use and discard may be considerably older than the age of the deposits from which it is ultimately recovered. Addressing these issues forms the core of chapters 5 and 8.

7. CONCLUSIONS

It is clear that at the current time the most robust geochronological framework for the analysis of archaeological assemblages in secondary context (fluvial sedimentary units) operates at the MIS scale. This reflects both the current limitations of geochronological tools and extant models of cyclical terrace development and large-scale fluvial activity across the glacial/interglacial cycle. Absolute chronologies at the sub-MIS scale are currently impractical, but the evidence for fluvial activity during the Late Glacial and early Holocene periods has highlighted some important issues with respect to the potential future interpretation of secondary context data:

- Individual fluvial events (e.g. gully erosion, coarse-grained braidplain sedimentation, fine-grained overbank flooding) occur relatively rapidly, with time-scales of an identifiable magnitude of 10^2 and 10^3 years, in partial response to short-term climatic oscillation and change.
- The relatively rapid duration of these individual events is a widespread, shared phenomena, although the specific response of individual river systems (and individual reaches within those systems) to the same climatic events can vary markedly.

- The ice core record indicates a high frequency of low magnitude climatic oscillations during the Middle and Late Pleistocene, occurring within the broader 100,000 year framework of glacial/interglacial cycles and the major phases of climatic change.

These observations and data both highlight the climatic instability of the period, and indicate that there is *potential* for secondary context assemblages that both accumulated (through discard in the fluvial landscapes) and were incorporated within fluvial sediments over relatively short time-spans (10^2 and 10^3 years in magnitude). Such high resolution geochronological timescales permit the asking of a variety of research questions, including issues of standardisation in lithic production, and stasis and change in stone tool technology. However, these data also highlight the problems of artefact re-working through sediment erosion, and it is clear that considerably more work is required to address those problems. We therefore hope that this paper's focus upon geochronological frameworks and fluvial sedimentary contexts has emphasised the potential of secondary context data and the value of such work.