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Holocene fluvial and marine influences and
settlement interactions in the lower Ribble
valley, Lancashire, U.K.

Submitted in candidature for the degree of Doctor of Philosophy
to the University of Stirling, May 2004

by

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12/05

Abstract

CHITI B 2004. *Holocene fluvial and marine influences and settlement interactions in the lower Ribble valley, Lancashire, U.K.* University of Stirling, Ph.D.

The evolution of the lower course and estuary of the river Ribble (Lancashire, U.K.) during the Holocene is the object of study, along with the history of sediment fluxes in them and their influence on past human settlements. Investigation of the valley floor geomorphology and terrace fill stratigraphy and sedimentology, as well as palaeoecological analysis and a number of ^{14}C essays, allowed the reconstruction of Late Pleistocene and Holocene alluvial history and chronology of a reach at the transition point between fluvial and estuarine influences; the archaeological evidence is evaluated in this context.

Alluviation and incision cycles led to the formation of four river terraces. The oldest terrace, rich in coarse-grained materials, seems to be of Pleistocene age. ^{14}C dating on the second terrace would point to an Earliest Holocene or Younger Dryas age; the fill, however, comprises abundant fine-grained overbank sediments. Large parts of the unit were reworked during a phase of lateral channel activity that occurred prior to ca. 8900 cal BP; between then and ca. 6900 cal BP the river underwent meander cut-offs, after which limited lateral activity occurred. New alluviation occurred around 4700 cal BP, possibly related to the aggradation of the third terrace, though its fill is only certainly known, from archaeological evidence, to be of pre-Roman age. Channel size increase occurred by the time the terrace was deposited. The fill features abundant clayey sediments; it was incised at or after the end of the Roman period. The last terrace was deposited in the late first millennium AD mainly as overbank silts, and has since been incised again.

Fluvial response appears mainly related to climate changes, river activity corresponding to shifts to wetter, cooler climate. Human action likely enhanced fluvial response in the historical period, leading to post-Roman incision and deposition. There seems to be a good connection between sediment production in the catchment and deposition downstream. Local factors also show a major importance in determining river response. Early Holocene fluvial history finds no match in other Northern English rivers; a different response to the same climate changes is apparent, possibly related to differences in sediment supply conditions.

No clear evidence is found supporting an influence of sea-level change on river processes. On the other hand, it appears plausible river sediment input has a driving influence in enhancing or causing minor regressions recorded on the estuary.

The conditions existing in Roman times could have allowed access from the sea to the Roman sites at the upper end of the Ribble estuary and by its North shore; a relative sea-level minimum could have caused a shift of focus in naval traffic from the former to the latter site.

Declaration of originality

I hereby declare that this Thesis and the work reported herein is entirely my own work (except where otherwise acknowledged in the text), and has not been included in another Thesis at any university or other institute of tertiary education.

Bernardo Cliti

A handwritten signature in black ink, appearing to read 'B. Cliti'.

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Acknowledgements

Le grandissime montagne, ancora che sieno remote de' marini liti, scacceranno il mare del suo sito. // Questi sono li fiumi che portano le terre da lor levate delle montagne e le scaricano a' marini liti e, dove entra la terra, si fugge il mare.

[The most great mountains, whereas they be remote from the marine shores, will drive the sea from its site. // These are the rivers which carry the earths by them lifted off the mountains and do disburden them at the marine shores and, whither the earth entereth, the sea doth flee.]

—Leonardo da Vinci; Arundel code, 42 v.

Più terreno lascian li fiumi dove è vicino li popoli, che dove non è spezie umana, perché in tali lochi si lavoran li monti e li colli, e le piogge portan via di terren remossi con più facilità che li terren duri coperti di gremigna.

[More ground the rivers leave where peoples be close, than wither human kind be not, since in such places the mounts and hills are worked, and the rains carry away from loose soils with greater ease than the hard grounds covered by weed.]

—Leonardo da Vinci; Atlantic code, 133 (160 v.a.)

I would like to thank Professor Mike Tooley and Dr Richard Tipping, who assisted and advised me in the course of this work, Dr Alison Jones, who introduced me to fieldwork and investigation techniques, Stuart Bradley, who assisted me during some long and difficult fieldwork tasks and Kevin Clarke, who kindly allowed access to the Higher Brockholes quarry and facilitated the investigations on the site.

Many other persons encouraged and supported me during the work – too many to be all named here. Among them all, I will only mention my father, without whose support in a difficult moment this work would have been abandoned long ago.

1 – Fluvial-coastal systems interactions – problems and potential for human activity

1.1. Context and rationale

Estuarine areas can have both favourable and adverse influences on human activities. On one hand, estuaries are areas of difficult access, often badly suited to near-shore settlement, and form a barrier to communications along the coast up to a relevant distance inland – potentially, as far as at the river's tidal limit; on the other hand, estuaries can act as access corridors, facilitating communications between land and sea. An example of this is found in the relationship of the Roman military occupation with the Ribble estuary in Lancashire, North-West England (see sections 2.3.2 on page 45 and 2.3.3 on page 48). The presence of the estuary prevented North-South crossing near the coast, since the first site suitable for a bridge was only found towards the Ribble's tidal limit near Preston. As a consequence, the main "coastal" North-South roman road actually did not run close to the coast, and the coastal areas beside the estuary remained relatively isolated and widely neglected by the Romans. However, major Roman settlements were placed where both Roman North-South trunk roads in the region crossed the River Ribble as well as further West along the Ribble estuary, suggesting the estuary could have held a

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strategical importance for military or commercial access to the region by sea and that one of the Roman settlements could have functioned as a seaport.

The issue can also be raised for prehistory (see section 2.3.1 on page 41). During this period it is believed that sea-level regressions and transgressions affected low-lying valleys, bays and mosses, dramatically changing the areas available to human exploitation (Middleton *et al* 1995); Mesolithic lifestyle was likely influenced by such changes. Moreover, the Ribble estuary was a major geographical feature contributing to the isolation of North-West Lancashire, favouring conservatism of human cultures over much of prehistory (Cowell 2000).

Fluvial and near-shore marine systems are highly dynamic over the long term (Shennan *et al* 2000a; Shennan *et al* 2000b). A river course and its estuary are connected and interdependent systems; the events and processes affecting them are, however, different (Macklin *et al* 2000). Estuaries are dynamic systems with high frequency change and complex sedimentation processes (Rees *et al* 2000; Lyons 1997; Burton *et al* 1995), with high sedimentation rates (Mamas *et al* 1995; Rees *et al* 2000), and highly mobile channel systems (Rees *et al* 2000). Over millennia the aspect and extension of both a river's course and estuary can widely change; permanent human settlements are likely to be particularly affected by such changes, while at the same time human action can be a major direct or indirect factor of change (Macklin 1999; Passmore *et al.* 1992). As a

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consequence of their complexity, estuarine systems can be largely unpredictable - though this will also depend on the spatial and temporal scale of study.

Variability of estuarine systems is a consequence of variations in the two kinds of processes that interact in them - fluvial processes and marine processes. Progressive sea-level rise during the Holocene led to increasing storage of marine sediments (Rees *et al* 2000), besides encroaching upon lowland areas and extending upstream the tidal influence on the rivers. Fluctuations in this trend occurred during the Holocene, likely causing repeated changes of the estuarine dynamics.

The effects of fluvial activity on estuarine dynamics have also a major importance. However, fluvial effects are often underrated, since most analyses by sea-level change or estuarine dynamics researchers assume that fluvial sediment supply is constant through time (*e.g.* Shennan *et al* 2000a, Lyons 1997). Fluvial sediment supply and its delivery to estuaries, however, is not constant, and underwent wide changes during the Holocene (Long *et al* 1998; Macklin 1999; Macklin *et al* 2000; Rees *et al* 2000; Macklin & Lewin 2003). The study of the long-term evolution of this complex system in interdependent ways has only recently begun (Passmore *et al* 1992; Shennan & Andrews 2000), but is critical as past settlement has always concentrated here for diversity of

resources and trade and can only be fully explained through understanding the dynamism of the sediment system.

1.2. The research

Alluvial archaeology seeks to understand how past human populations affect the riverine environment, and how communities react to changing fluvial processes. Recent palaeohydrological studies can have significant importance for archaeology (Brown 1996b); in particular, an assessment of channel positions in the past can influence greatly the understanding of possible settlements on the site.

The overall aim of this study is to understand the Holocene evolution of a typical English West-coast river-estuary system - the lower River Ribble in Lancashire - by reconstructing long-term changes in sediment supply, transport and storage and linking these to past human valley floor settlement and economic uses. Along the section of valley considered a change takes place between reaches dominated by fluvial processes and reaches dominated by estuarine ones; the relative influence of the two kind of processes on each part of the valley is expected to have changed during the Holocene along with changes in local relative sea-level and fluvial regime.

Major Roman settlements existed along the lower course of the Ribble (see section 2.3.3 below), among which a town at Walton-le-Dale, near the Ribble's

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present tidal limit; in order to understand fully this settlement's importance for the Roman forces, it is necessary to assess its relationship to the Ribble estuarine and fluvial system. Besides contributing to a clearer understanding of the Roman occupation of the region, the study around Walton-le-Dale and the surrounding area offers a starting point for a wider knowledge of the River Ribble through the Holocene (not studied in detail in the past), as well as of the general dynamics of the interactions between estuarine and fluvial influences on river patterns. This research evaluates the different geomorphic and sedimentological effects of these major systems in the Ribble Valley upstream of Preston by developing a new fluvial chronology for the lower valley and relating it to the well-known sea-level record (Tooley 1974, 1978, 1982, 1985; Zong & Tooley 1996, 1999), land-use change chronology (e.g. Barnes 1982; Macklin 1999; Middleton *et al* 1995; Walling 1996) and new archaeological records, particularly from Roman use of the estuary (Buxton & Howard-Davis 2000; Cowell 2000; Edwards 2000; Hardwick 1856; Howard-Davis & Buxton 2000; Hunt 1997; Pickering 1957).

2— North-West England and the Ribble

2.1. Regional features

2.1.1. Coastal processes of North-West England

2.1.1.1. *Context of Late Devensian and Holocene sea-level changes*

(a) Overview

The status of the British Isles changed several times from insular to peninsular during the Quaternary glacial stages, mainly as a consequence of the lower sea-level. They became islands for the last time after the end of the last glacial period, in the early Holocene (Funnell 1995; Sutcliffe 1995), likely before ca. 8000 ¹⁴C years BP (ca. 8900 cal BP) (Shennan *et al* 2000a). During the Holocene an eustatic rise of the sea-level up to the present took place, as well as an isostatic uplift of the areas of crust left free of the ice sheets burden. The combination of these two major effects, besides a number of purely local factors, causes the pattern of relative sea-level change (local sea-level in respect to land) to differ widely between different localities (Shennan & Horton 2002). Generally speaking, in the areas close to the centre of a former ice sheet, where the maximum crustal movement occurs, the land uplift above the sea-level prevails,

resulting in the relative sea-level change having a negative trend. In areas far from the centres of uplift the eustatic sea-level rise prevails, with a positive trend throughout the Holocene. In intermediate situations, around the margins of the former ice sheets, the graph of relative sea-level through time first falls, then rises again, the effect of the crustal uplift typically prevailing in the early Holocene only. In the late Holocene, after the post-glacial isostatic adjustment had mostly taken place, in most areas of Britain the sea-level trend settled to a general, slow rise up to the present mean level. In the Humber estuary, for example, after 4000 cal BP the rate of relative sea-level change decreased to ca. $+1 \text{ mm}\cdot\text{year}^{-1}$, from a former average of $+3.9 \text{ mm}\cdot\text{year}^{-1}$ and after having risen by ca. 9 metres since 7500 cal BP (Long *et al* 1998).

Sea-level change as a consequence of glacial stages is obviously a global phenomenon. However, a correlation of eustatic effects at a global level – taking into account the water storage and release in and from ice at a planetary scale – is presently still too complicated to be performed (Mörner 1982; Lambeck *et al.* 1990). Single regional areas, such as North-West Europe (the regions around the North Sea basin) can however be small enough to show a general uniformity and coherence in their behaviour so that they can be used to experimentally test models and hypotheses (Shennan 1987; Mörner 1980). In such cases, possible influences from eustatic or isostatic effects in other regions of the Earth may be synthesized as simple, uniform effects. For example according to some models (Lambeck *et al.* 1990) the influence of deglaciation in other continents could be

responsible for a rise of up to 3 meters in sea level in late Holocene North-West Europe.

Even at such regional scales, often the current models still fail to describe satisfactorily the relative sea-level changes measured at different sites (see (c) below). For example, though field data from the North-West coasts of Britain seem to agree with published models with only minor discrepancies (Lloyd *et al* 1999; Shennan *et al* 2000b), the same does not happen along the British East coast (Shennan *et al* 1994, 1995), where only broad agreement between models and data is observed.

Differences in relative sea-level change patterns within the same region can be due to local effects and processes that add up to the eustatic and isostatic effects, such as sedimentation changes, storm-surge episodes pattern, changes in Holocene tide range, post-deposition sediment consolidation or anthropogenic influences (Long *et al* 1998). Though relative sea-level change controls the broad patterns of coastal evolution, local site-specific factors contribute to short-term process change (Shennan *et al* 1999). A rising sea-level entering a narrow estuary can increase the tidal range within it (Zong & Tooley 1996), affecting the measured relative sea-level data (see (c) below). The difference in scale and resolution of effects in various locations implies that even a regional correlation can seldom exceed a resolution of one or two hundred years (Shennan 1987).

(b) Patterns of uplift

Vertical crustal movements due to ice load in cold stages remain a factor of major importance in correlating relative sea-level changes in different sites. Isostatic changes in level do not only imply a general lowering of the areas under an icecap; the asthenospheric material displaced by such load is likely to cause rising in the areas surrounding the ice with the formation of a “forebulge” ring. The phenomenon is described in various models (Lambeck *et al* 1990; Wingfield 1995) and supported by field data – such as the different behaviour of coasts described in northern and southern Atlantic coasts of Europe (Devoy *et al* 1996). Upon the end of a glacial stage the eustatic rise in sea-level will therefore combine with an isostatic crustal uplift in the areas formerly covered by ice and with an isostatic subsidence in the immediately surrounding ones. The additional load of meltwater also causes isostatic subsidence of the sea floors; Lambeck (1997) reports two distinct isostatic trends combining to influence local differences in relative sea-level along the North and West coasts of France, a North-South one related to the Fenno-Scandian ice-sheet load and an East-West one from the increased load of water in the Atlantic Ocean.

The effect of differential crustal uplift is evident in the pattern of mid-late Holocene raised shorelines left in Scotland by rising relative sea-levels. Shorelines appear generally as breaks of slope at the inland margin of carselands (former estuarine flats) (Smith *et al* 2000). The Main Postglacial

Shoreline, dating to 7720–6360 cal BP, relates to the culmination of the Main Postglacial Transgression (phase of relative sea-level rise), and was once thought the highest shoreline in Scotland; it is now apparent that around the periphery of the uplifted area it is overlapped by the later Blairdrummond shoreline, dating to 4870–1860 cal BC (Smith *et al* 2000). By comparing rates of relative sea-level rise, Jardine (1975) suggests the land uplift in South-West Scotland was rapid in comparison with contemporaneous uplift in areas further from the uplift centre, such as the Netherlands, South Sweden and even North-West England. A major difference in relative sea-level change due to differential isostasy is visible along the East coast of Britain, where Shennan *et al* (2000b) report opposite trends in Northumberland (negative) and the Fenlands (positive). Differences of up to 20 m (at ca. 8000 cal BP) between eight different areas can be explained here by ice and water isostasy. While in the southern part of the area relative sea-levels remains below the present value throughout the Holocene, in Northumberland the level is above present by ca.4000 cal BP. Wide variations are also observed along the French coastline (Lambeck 1997), with differences of up to 20 m before ca. 10000 ¹⁴C BP (ca. 11 400 cal BP), ca. 15 m around 8000 ¹⁴C BP (ca. 8900 cal BP), and still ca. 10 m around 6000 ¹⁴C BP (ca. 6800 cal BP). Even within the same regions, however, the variations in crustal uplift cause relevant differences, with a possible variability up to a few metres (Lambeck 1997). Such differences at a smaller spatial scale are observed, for example, between the North and South coasts of the Solway Firth (Lloyd *et*

al 1999) and likely the outer and inner parts of the Humber estuary (Shennan *et al* 2000b).

Therefore, only local or regional relative sea-level curves can be constructed unless a correction is applied first (Lambeck 1997). In order to compare relative sea-level changes between different areas the relative uplift or subsidence between them must be taken into account: negative trends in relative sea-level could be an effect of the local crustal movement in the uplifting area, while positive trends are more likely due to an actual (eustatic) sea-level rise; the opposite happens in the subsiding area. Along these considerations, Shennan *et al* (1983) compared relative sea-level changes only in the periods of time where a transgressive tendency was recorded in the uplifting area or a regressive tendency was recorded in the subsiding one, obtaining a good agreement between different areas of North-West England.

(c) Sea-level changes in the sediment record

Raised marine landforms (Andrews 1986) can record ancient high relative sea-levels (see also (b) above). Most information about past relative sea-level change, however, comes from sedimentary sequences deposited in coastal areas, at and around the tidal range. Sediment types, deposition environment and provenance change in response to changing sea-level, ranging from purely freshwater to pure subtidal marine sediments (Ridgway *et al* 2000). Rees *et al* (2000) identified eight distinct sediment suites in the Humber estuary,

deposited in different facies showing increasing marine influence from local freshwater sediments (the oldest suite) through brackish, saltmarsh and mudflat facies to a largely marine environment. The different sediment suites, some of which feature an erosional contact with the underlying materials, are interpreted as corresponding to oscillations between flood and ebb tide asymmetry over the Holocene.

Whenever sea-level oscillations occur, the typical result in the sediment record of low-lying coastal areas is of alternating sequences of minerogenic and biogenic sediments (Tooley 1978, 1981; Howard & Macklin 1999). The minerogenic layers – mainly intertidal silts and clays – and the biogenic ones – saltmarsh peat – actually feather into each other as higher sea-levels submerge near-shore areas depositing intertidal mud above former saltmarshes or as, upon a fall in sea-level, saltmarshes expand and deposit peat over former mudflats. According to Zong & Tooley (1996), the coastal processes (such as saltmarsh expansion and peat formation) can keep up with a rate of relative sea-level rise smaller than $+4 \text{ mm a}^{-1}$, while a rate of 4 mm a^{-1} or more would lead to flooding of the shore environments; the actual value depends from the local conditions. It is assumed the transition to saltmarsh occurs at the mean high-water level of spring tides (Tooley 1978). The landward limits of the minerogenic layers and the seaward limits of the biogenic ones would therefore record points of relative sea-level maxima and minima. In practice, alternating silt/clay and peat in sediment cores are examined; what information can be gained, by means of (usually) ^{14}C dating along the contact between marine and

freshwater sediments, is rather about the periods of transgressive or regressive short-term trends, or *overlaps* (Tooley 1982; Shennan 1987). Tooley (1982) suggests at least 40 dates per 1000 years are needed to ensure the results are significant.

In order to obtain more precise data about the environment of deposition of perimarine sediments, pollen and Diatom analysis are commonly used (e.g. Tooley 1978; Shennan *et al* 1994, 1995; Zong & Tooley 1996, 1999; Zong 1997; Zong 1998; Shennan *et al* 1999; Metcalfe *et al* 2000). Reconstructing plant species or communities indicative of particular environmental conditions is also possible through the analysis of macroscopic remains (Godwin & Clifford 1938; Behre 1986). Such methods can also be used to infer sea-level change by proxy: for example, the start of freshwater marsh peat deposition can be due to a rise of the ground water-table, possibly related to a sea-level rise, especially if pollen from coastal plants is also recorded (Lloyd *et al* 1999). Diatoms are particularly useful to assess the degree of salinity of sediments' deposition environment, through changes between communities of prevalently freshwater, brackish or marine *taxa* (Palmer & Abbott 1986; Vos & De Wolf 1993; Underwood *et al* 1998). The chronology from cored sequences can also be integrated with analysis of palaeomagnetism and geochemistry in order to better locate and understand possible time breaks in sedimentation, that often are not obvious (Ridgway *et al* 2000). In order to achieve a most secure and continuous environmental characterization the use of a combination of different techniques and indicators is advisable (Metcalfe *et al* 2000; Ridgway *et al* 2000).

2.1.1.2. Regional sea-level changes record

(a) The Solway Firth

The coasts of the Solway Firth, between Cumbria and southern Scotland, have been extensively studied for Holocene sea-level changes. Jardine (1971) describes an abundance of shorelines and raised marine deposits at several sites along the North coast of the Solway Firth. Jardine (1975) also provides a reconstruction of relative sea-level trends in the area during the Holocene. The main Holocene transgression reached a maximum relative sea-level of about +3 metres, and appears diachronous along the North Solway coast, starting between 9400 and 7200 ^{14}C BP (ca. 10700 and 8000 cal BP). Its culmination is also diachronous, a bay in the present Lochar valley being abandoned by the sea by 6600 ^{14}C BP (ca. 7500 cal BP) whereas transgression continued in the eastern part of the firth until ca. 5600 ^{14}C BP (ca. 6400 cal BP), and until 5000 ^{14}C BP (ca. 5700 cal BP) at least at the head of Wigtown Bay.

The data used by Jardine (1975), however, were re-interpreted by Haggart (1989) resulting in a different picture, in which a more rapid main transgression occurs between 8000 and 7000 ^{14}C BP (ca. 8900 and 7800 cal BP) to a maximum altitude of about +5 metres.

Both the North and south coasts of the Solway Firth are later examined by Lloyd *et al* (1999). The occurrence of the Holocene transgression along the North coast is estimated by them between 7700 and 7400 cal BP, thus agreeing more

with Haggart (1989) than with Jardine (1975). A relevant difference is observed along the South coast, where the transgression is dated to between 7500 and 6800 cal BP. The maximum relative sea-level suggested is an average of +4 metres at 7700–7500 cal BP; in at least one instance, however, intertidal clastic sediment is observed at over 7 metres OD. A static or only slightly rising relative sea-level is suggested between 6000 and 2500 cal BP. Further data are provided by Smith *et al* (2003a, 2003b) from the lower valley and estuary of the Rivers Nith and Cree (South Scotland). The Main Postglacial Transgression shows different timings in the two sites. On the Nith the transgression, already in progress around 8600–8350 cal BP, is interrupted by a brief fall after 8020 cal BP, resuming after 7800 cal BP and culminating to the Main Postglacial Shoreline by 6720 cal BP. The Cree data point to an Early Holocene interruption between 9400 and 9900 cal BP, with the formation of an extensive estuarine surface at ca. -1 m OD. A fluctuating rise follows, culminating at 7000–7500 cal BP in a prominent shoreline with an associated estuarine surface at 7.7–10.3 m OD. The relative sea-level curve then exceeds in both sites the Main Postglacial Shoreline: on the Nith it does so by fluctuations also above it, on the Cree with a fall and new rise to a shoreline at around 7.8–10.1 m OD after 5800 cal BP. On both sites the sea-level then falls to a lower shoreline, reached on the Cree at 5.5–8.0 m OD after 3100 cal BP, before falling to the present levels, reached at ca. 1800 cal BP on the Nith. No evidence for sea-level change is observed afterwards.

(b) Tooley's North-West England record

Data about Holocene sea-level changes in North-West England between Cumbria and the Mersey come from the work of Tooley (1974, 1978, 1980, 1982, 1985), Zong (1998) and Zong & Tooley (1996, 1999).

The postglacial sea-level rise took place in North-West England mainly between 8000 and 7600 ¹⁴C BP (ca. 8900 and 8400 cal BP), and was more or less completed between 6000 and 5000 ¹⁴C years BP (ca. 6800 and 5700 cal BP) (Tooley 1978, 1982; Zong & Tooley 1996). After that time, however, a series of short-time minor oscillations (not greater than ± 2 m) occurred with a smaller time scale (Tooley 1982). Such changes were in the range of tidal variations and catastrophic events, and bigger than residual crustal movements. They did not imply massive changes in British geography, but they caused large changes at a local scale, especially in the estuarine environment and on the tidal limit of rivers.

The work of Tooley (1974, 1978) in North-West England had at first lead to the identification, starting with the postglacial rise, of a series of ten distinct marine transgression phases, named *Lytham I-X* after the site where they had been recorded. The sea-level curve thus proposed is shown in Figure 2a; the highest possible sea-level was reached by it between I and V centuries AD.

Later works, however (Tooley 1982, 1985; Zong & Tooley 1996) give a less clear outline of the situation. Rather than trying to measure dated sea-level index points, the works try to identify periods of positive and negative overlap

tendencies; no more attempts are made to draw an actual sea-level curve. Tooley's (1982, 1985) results for the southern and northern part of the North-West England coast are shown in Figure 2b. 12 periods of transgressive overlap intercalated to 12 periods of regressive overlap (also shown in Figure 2b) are identified; the Lytham I-IX transgression events are superseded by this sequence of sea-level tendencies. According to Tooley (1982) the consistency of the record of transgressive and regressive overlaps suggests an overriding process such as positive and negative eustatic sea-level movements. The regressive and transgressive periods are identified throughout North-West England and are significant for the whole region; in no single site are all of them visible.

The highest relative sea-levels recorded still fall in the first centuries AD. Though the mean high-water level of spring tides, estimated at about +4.5 m, reached only about 1 m above the present value (Tooley 1980), higher values were likely reached in the inner parts of coastal embayments, since when rising sea-level enters a narrow estuary the tidal range can increase. The tidal range in Morecambe Bay could have reached values up to 5-6 m greater than present (Zong & Tooley 1996), and it is possible an effect of similar magnitude occurred in the inner Ribble estuary.

2.1.2. Fluvial processes in North-West England

2.1.2.1. *Post-glacial evolution and landscape change*

(a) Overview

All of North-West England lay within Devensian ice limits (Harvey 1997). The modern rivers in the region developed from meltwater streams during the Devensian ice sheet retreat, between 16 000 and 14 000 ¹⁴C BP (ca. 19 000 and 16 800 cal BP) (Thomas 1985); their catchments, especially those of the Eden and Ribble, had expanded during the Pleistocene by capturing the headwaters of West coast rivers (Harvey 1985).

All river systems in NW England underwent a similar sequence of development in Late Pleistocene and Holocene; they are still undergoing adjustments within the contemporary environmental context (Harvey 1985). Braided streams were likely prevalent in Late Pleistocene (Lewin 1981), and semi-braided channels are still locally found in upland streams, while in lowland reaches a meandering pattern is more usual (Harvey 1985). A low potential evapotranspiration in respect to precipitation produces winter maximum river flows, without extreme differences in mean monthly values (Harvey 1985).

The general trend in North-West England since Late Devensian is of fluvial incision; variations in this trend led to the deposition of terraces (Ferguson 1981; Harvey 1985). Many terraces are associated with nickpoints in the river's long

profile; but there has not been a sufficient time for nickpoint recession to be a major factor in terrace formation (Johnson 1969). Generally high terraces of Late Pleistocene age and low terraces of Late Holocene age are found, while in the Early to Mid-Holocene there is no evidence of terrace formation and little fluvial change, most activity consisting of incision of the Pleistocene deposits and deposition in the estuaries (Ferguson 1981; Harvey 1997; Hooke *et al* 1990).

(b) Holocene climate changes and river response in the region

The major Holocene changes in climate seemingly occurred at a global scale (Wendland & Bryson 1974; Anderson *et al* 1998; Barber *et al* 2003); both vegetation and human cultures were affected by them. Fluvial processes are also very sensitive to climate changes; changes in climate as small as 1-2 °C in temperature and 10-20% in precipitation can induce several-hundredfold changes in the frequency and magnitude of flood events (Knox 1993). The end of the Younger Dryas period was marked by a relevant ca. +7 °C rise in mean temperature, with dramatic changes in fluvial regime (Brown 1997); such a rise possibly took place within an interval as short as 50 years, more rapid than possible ecological and geomorphological adjustments. On a short time scale rivers apparently tend to be more active in periods of climatic change; for example, major fluvial changes and adjustments, with increased flood frequency and magnitude, have been registered in the AD 1250-1550 and AD 1750-1900 intervals, periods of climate worsening and improvement respectively on the insurgency and end of the so-called *Little Ice Age*, during

which, on the contrary, river beds seem to have been more stable (Rumsby & Macklin 1996).

In North-West England, Holocene climate records come from the variation in surface wetness recorded in Bolton Fell Moss (Barber *et al* 2003; Huges & Barber 2004) and Walton Moss (Huges *et al* 2000), two raised ombrotrophic bogs North-East of Carlisle. A similar record was obtained from Burnfoothill Moss, sited North of the Solway Firth (Tipping 1995a; Tipping & Milburn 2000). Common trends in the records suggest a wetter (and cooler) climate episode starting in correspondence with the Early to Mid-Holocene transition, between ca. 8200 and 7800 cal BP, and lasting until after 7000 cal BP. Another phase of generally wetter climate seems to start between 5200 and 4500 cal BP, ending slightly after 2000 cal BP; the climate in the Roman period is suggested to be better than the present time also by other sources (Lamb 1977; Howard-Davis & Buxton 2000), though at Walton Moss a wetter episode is recorded towards its end. The latest millennium also appears to feature a wetter climate. At a smaller time scale, shorter climatic oscillations are visible in the raised bog records. The records from different sites, however, do not agree as well at this scale, suggesting some local climate control. Minor wet shifts within the 7000–5000 cal BP dry period show poor agreement between sites. There is better agreement during the 4500–2000 cal BP wet period, drier shifts being visible in two of the records around 3900–3600, 3300–3100 and 2500–2300 cal BP. The relatively drier 2000–1000 cal BP period again shows no good agreement; a better agreement

seems to exist later, with seemingly drier conditions around the middle of the last millennium.

There are few studies about river activity periods and their causes in North-West England. It is suggested that rivers responded to climate changes, while base-level (sea-level) change had no major influence on them (Johnson 1969; Harvey 1985). The terraces formed with downcutting due to climate changes; nickpoints formed where streams flowed on bedrock (Johnson 1969). In the Late Holocene, fluvial activity rises in response to the climatic deterioration after the Atlantic optimum, with aggradation of terraces and deposition of alluvial fans (Musk 1985; Harvey 1997).

(c) Vegetation changes during the Holocene

Data from fossil pollen sequences provides information about vegetation changes in time. Holocene changes in North-West England are exemplified in the sequences from the three sites of Red Moss (Hibbert *et al* 1971), Knowsley Park (Greig 1996) and Fenton cottage (Greig 1996).

The landscape of North-West England was already stable in the Early Holocene, with a near-complete woodland cover (Harvey 1997). The passage from a prevailing *Betula/Pinus/Juniperus* association to a *Betula/Pinus/Corylus* one is recorded at Red Moss around 9800 ¹⁴C BP (ca. 11 200 cal BP); it changes to *Corylus/Pinus* around 8900 ¹⁴C BP (ca. 10 000 cal BP). Coryloid expansion at Knowsley Park is recorded around 9200 ¹⁴C BP (ca. 10 400 cal BP); after around

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9000 ¹⁴C BP (ca. 10 200 cal BP) herbs almost disappear. By Around 8700 ¹⁴C BP (ca. 9800 cal BP) the expansion of *Pinus*, *Ulmus* and *Quercus* starts at Knowsley Park; *Ulmus* appears at Red Moss around 8200 ¹⁴C BP (ca. 9100 cal BP). The colonisation by broadleaved forest occurs between 7000 and 5000 ¹⁴C BP (ca. 7800 and 5700 cal BP) (Pennington 1970). Mixed oak forest prevails at Red Moss from around 7100 ¹⁴C BP (ca. 7900 cal BP); at Knowsley Park *Pinus* is replaced by *Alnus* around 7000 ¹⁴C BP (ca. 7800 cal BP), and woodland reaches its maximum between 6000 and 5000 ¹⁴C BP (ca. 6800 and 5700 cal BP) with *Quercus*, *Ulmus*, *Tilia* and some *Betula* and *Corylus*. The first evidence of woodland clearance at Knowsley Park is recorded around 5000 ¹⁴C BP (ca. 5700 cal BP) with the decline of *Ulmus*, that marks the beginning of Neolithic-type farming in the region (Cowell 2000); the same happens at Red Moss. The broadleaved forest disappears first from the high altitudes, while in the lowland broadleaved trees are replaced by cultivations (Pennington 1970). During the Bronze Age the upper woodland limit drops from over 400 to ca. 280 m OD in Rossendale, on the uplands South of the Ribble valley; peat spreads on the higher areas, while below is a mosaic of woodland, heath and grassland (Tallis 1999). Human activity is recorded from around 4900 ¹⁴C BP (ca. 5600 cal BP) at Fenton Cottage, shortly after the *Ulmus* decline; *Tilia* declines around 3000 ¹⁴C BP (ca. 3200 cal BP). From around 2000 ¹⁴C BP (ca. 1950 cal BP) reduction of woodland is recorded; at Fenton Cottage human interference is visible in the reduced percentage of *Quercus* and *Alnus* in the 4300-3700, 2200-1700 and 1000-500 ¹⁴C BP periods (ca. 4900-4000, 2190-1610 and 910-530 cal BP). Only

around 1000 ¹⁴C BP (ca. 910 cal BP) secondary *Fagus* woodland appears at Knowsley Park.

(d) Land-use and human influence

Changes in fluvial patterns must also be seen in the context of human influences (Harvey 1985). Since the Neolithic, human influence has affected vegetation and landscape, and through them river sediment loads (Walling 1996). Differences in response to climate change in early and in mid-late Holocene times are considered to reflect changes in sediment supply and channel-slope coupling; in particular, Neolithic cultivation increased soil erosion and delivery of fines to valley floors (Macklin & Needham 1992). Rates of deposition tend to rise during periods of forest clearance and agricultural expansion upstream (Brown & Quine 1999). According to Passmore *et al* (1993) increased activity of braiding processes in the late Roman period, in the XIII and XIV centuries and in the XVIII and XIX centuries could be related to a change in flood pattern and sediment supply, not only due to climate changes, but also to mining activities and changes in land use and even river channelization. However, an assessment of mean annual sedimentation on a sample of British valley floors was performed through radioisotope analysis for the last 100 years (Walling & He 1999), and found to have remained roughly constant despite the relevant anthropogenic changes occurred during this period of time. It is proposed this fact needs not imply an insensitivity of recent

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river processes to environmental changes, but rather a delay in response due to the complexity of the sediment delivery system.

The vegetation is influenced by human action from the Neolithic (ca. 6000 BP) (Brown 1997) at the latest. Some woodland clearance, though of minor importance only, is recorded in North-West England in the Late Mesolithic (up to ca. 6000 cal BP) (Middleton *et al* 1995). The clearances continue in the Early Neolithic (ca. 6000-5200 cal BP), when soil erosion, with increased runoff, could have been induced on some mossland edges (Barnes 1975). The Early Bronze Age features some evidence of local clearance of secondary woodland (Branch & Scaife 1995), but seems otherwise little different from the earlier periods.

It is in the Iron Age that more widespread anthropogenic landscape changes start to occur. Clearance is recorded by Birks (1963-64) at Chat Moss (near Manchester) around 695 BC; most Iron Age woodland clearance, however, occurs between 400 BC and AD 400 (Turner 1981). According to Turner (1981) and Higham (1986) in the I and II centuries AD an extensive clearance of the woodland had not yet taken place in North-West England; according to Pennington (1970) clearance occurs in the Lake District from AD 200 to 390. MacKay and Tallis (1994), however, report a phase of clearance in the Forest of Bowland (North of the Ribble valley) towards the end of the Iron Age, with tree decline from ca. 100 to ca. 36 BC, when a 60% drop in tree pollen is recorded. Tree densities in the Forest of Bowland remain low throughout the Romano-British period, while non-arboreal pollen - such as Gramineae, cereals,

Compositae and *Plantago* - rises. The expansion of *Plantago* suggests cattle rearing. Renewed agriculture and clearance are recorded at the end of the Roman period.

In the Anglo-Saxon period (AD 472-ca.700) the population is sparse, with little agriculture (MacKay & Tallis 1994). The Viking invasions in Lancashire (IX-X centuries AD) appear not as destructive as often believed by historians, at least in the Forest of Bowland: a gradual decline of arboreal and rise of non-arboreal pollen occurs between AD 700 and the late XII century, but no signals of large-scale forest destruction are recorded. Four periods of tree expansion in the following centuries are interpreted by MacKay & Tallis (1994) as being the consequence of the Norman forest law (ca. AD 1190-1290), famine and plague episodes (AD 1400-1550 and 1600-1700) and the post-Napoleonic war agricultural decline (after AD 1850). The rise of trees in the XV and XVII centuries would reflect the fall of rural populations in Lancashire, due to Malthusian crises from a subsistence economy and possibly accompanied by plague, and the consequent slackening of woodland clearance. After AD 1500 trees decrease sharply while *Calluna* and *Plantago* increase, in relation to the parcelling of common land, the dissolution of monasteries (AD 1525) and utilization of their land and the abolition of the Norman forest law (AD 1507). Forest regeneration, with tree pollen over 40%, takes place between AD 1550 and 1730, during the *Little Ice Age*. With the introduction of potato Malthusian crises are prevented and plague and famine cease; the fact is reflected in major decreases of trees and high Gramineae and Cyperaceae in the late XVII and

XVIII centuries. The late XVIII and early XIX centuries see a peak in cereal production, especially during the Napoleonic wars (1790–1815); after their end cereals fall again, as the rural population turns to livestock rearing, and trees rise again.

In recent times new anthropogenic factors intervene to affect river processes. The effects of XIX Century urbanization are not fully clear; wide-scale urban paving, however, causes increased runoff with possible channel enlargement (Harvey 1985). Many streams in the region, among which the Douglas, the South tributaries of the Ribble and the Hodder, are dammed for potable water (Harvey 1985); dams can have major effects on the downstream reach (Gregory 1987; Beckinsale 1972), and water abstraction causes a reduction of discharge and changes in regime (Harvey 1985). Some artificial modifications of the lower Ribble channels are described in section 2.3.5 below.

2.1.2.2. *Sediment transfer*

(a) *Controls in sediment accumulation*

Along the different sections of a river system a distinction is classically made between *upland*, *piedmont* and *Lowland/perimarine* reaches. Upland rivers (e.g. Harvey *et al* 1981; Harvey & Renwick 1987; Macklin *et al* 1992a, 1992b; Merrett & Macklin 1999) are high-energy, high-gradient streams, typically featuring alternating episodes of incision and aggradation over Holocene timescales

leading to the formation of terrace sequences; coarse-grained sedimentation prevails, with braided and meandering channel patterns, while fine-grained material is scarce. Piedmont rivers (*e.g.* Hooke *et al* 1990; Macklin *et al* 1992a; Tipping 1995b; Passmore & Macklin 1997) have medium energy and gradient; they are characterised by vertical and lateral instability with episodic aggradation and incision and formation of terraces. They have steep valley sides, but wider valley floors and floodplains. Coarse-grained sedimentation prevails in channels, with gravel bedload and braided, anastomosing and meandering patterns; fine materials are deposited over the coarse sediments as overbank units. Lowland rivers (*e.g.* Rose *et al* 1980, Brown *et al* 1994; Burrin & Scaife 1984; Van De Noort & Ellis 1997) are low-energy and low-gradient reaches, with low-angle valley sides, and well-developed floodplains where stability and vertical accretion prevail. Fine sediments are deposited in meandering and anastomosing channels with levées and backswamps.

In North-West Britain the most active channels are found in piedmont reaches (Newson 1981); here low sinuosity “wandering gravel” patterns are common, with morphologies intermediate between upland torrents and sinuous lowland rivers. In the upland and piedmont reaches Holocene rivers incised in response also to isostatic uplift, but mainly to the rapid decline of glacial sediment supply (Macklin & Lewin 1986; Harvey & Renwick 1987; Richards *et al* 1987; Hooke *et al* 1990); a partial refilling occurred after human land-use change.

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Divided channel patterns are uncommon in present time Britain, though they were common during the Holocene. Anastomosing systems with channel bank wet areas, likely derived from Lateglacial braided systems through progressive siltation of anabranches (Macklin 1999), were often found as equilibrium forms in Southern and Eastern England, before large scale channelization and reclamation made them largely disappear (Macklin *et al* 2000). Braided channels are uncommon at present; the largest braided reaches are found in areas with wide valley floors and well-developed Holocene and Pleistocene alluvial terraces (Passmore *et al* 1993). Generally, braiding is more frequent on more active rivers having a higher rate of aggradation (Passmore *et al* 1993). Old maps show braiding present in the Tyne, Afon Ystwyth and Tay in the XVIII and XIX centuries; its cessation could be related to the cessation of mining activities (Macklin & Needham 1992). Macklin *et al* (1992a) relate channel braiding to climate change during the *Little Ice Age*.

Late Pleistocene inheritance had a major influence on Holocene river development and basin sensitivity to perturbations. Sediment supply and size were widely determined by the materials made available in the catchments by glacial and periglacial processes (Macklin 1999), that persisted in the Early Holocene contributing sediment to the rivers until depleted (Harvey 1997). The abundant coarse sediments made the rivers competence-limited, with infrequent significant transport and valley floor modification, usually during major floods only (Macklin 1999). Moreover, the spatial pattern of Holocene

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sedimentation and erosion is often largely controlled by Late Pleistocene glacial and periglacial valley bottom landforms (Macklin 1999): upland and piedmont reaches are commonly divided in compartments by cross-valley moraines or alluvial fans, with alternating narrow transport zones and wide sedimentation ones. Upstream of the constrictions, rivers tend to have a lower gradient, with inactive meanders and accretion of fine sediments. In these cases, river processes can also have unique responses (Taylor & Lewin 1997).

Present rivers of North-West England tend to feature coarse channel-beds, often with pool and riffle sequences; contemporary sediment appears to be mainly derived from channel margins - either bedrock, Pleistocene glacial or periglacial deposits or Holocene alluvium (Harvey 1985). Peaty debris is also common in some areas, such as the Forest of Bowland, as well as sandy sediments derived from bedrock, solifluction deposits and glacial outwash; areas of Palaeozoic bedrock tend to feature abundant silty sediments, while glacial till areas mostly yield silt and clay (Harvey 1985). Floodplains act as important fine sediment sinks, and can account for over 25% of sediment load deposition (Lambert & Walling 1987, Walling & Quine 1993).

It must be noted how any change in some of the factors characterising the course of a river widely affects the other factors: changes in sediment load or competency will result in changes in the water table, erosion or deposition downstream and consequently wide changes of river channel pattern (Beckinsale 1972). On the other hand, changes in channels may themselves

cause changes in the erosional or depositional pattern downstream, also through changes in the mean gradient that the river will tend to restore (Gregory 1987). The pattern of river activity is also subject to purely local factors or unique situations - both environment- and human-related - that can dramatically alter its response to wider-scale conditions, producing major differences even among adjacent reaches (Taylor & Lewin 1997).

(b) Aggradation and downcutting

Most main rivers in North-West England feature a sequence of two or more fluvial terraces above their floodplain (Harvey 1985). The upper and older terraces mostly feature coarse sediments, deposited in a high-energy context, possibly by braided channels; the lower terraces are usually finer-grained, except in some upland valleys. Harvey (1985) reports up to three terraces on the Lune and two or more on the Eden. The formation of the high terraces could be ascribed to variations of discharge or sediment supply during the Post-Glacial pre-stabilization phase, while the low terraces could have deposited on account of variations due to anthropogenic factors, such as agriculture and woodland clearance (Harvey 1985).

Johnson (1969) provides a general survey of the terraces in the Mersey and Weaver catchments. A common sequence of terraces is recognised in the examined reaches throughout the catchments; the main aggradational unit extensively recognisable in the area, the Mersey High Terrace, is estimated to

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start being deposited before 10500 BP (ca. 11 700 cal BP) and being complete before 7500 BP (ca. 8200 cal BP). Its erosion and the formation of the younger terraces are deemed to be mainly related to climatic fluctuations.

The oldest terraces recognised by Johnson (1969) are higher than the Mersey High Terrace. On the Etherow catchment a gravelly high terrace is intermittently found, becoming more extensive upstream but not evident downstream of the confluence with the River Goyt. The long profile that can be inferred for it would suggest it to be graded to a high base-level. On the Weaver-Dane catchment a fine-grained high terrace is found, visible only upstream and having an even less steep gradient. On the same catchment, Johnson (1969) recognises a middle terrace group composed of coarse sediments reworked from glacial deposits, and that could be correlated to the Mersey High Terrace. A similar terrace can be traced from the Mersey up into the Goyt catchment. Continuing on from the Goyt in the Etherow catchment a middle terrace is also found, correlating downstream with the Mersey High terrace and becoming the floodplain upstream; extrapolated, its long profile would get to ca. 6 m OD near Liverpool. On the Bollin-Dean catchment, the Mersey High Terrace is the most extensive, especially at the confluence with the Mersey.

A lower terrace, between the Mersey High Terrace and the floodplain, is recognised by Johnson (1969) in the mid-Dane valley and two are recognised in

the Mersey-Goyt catchment, where they are composed of fine gravel and sand loam.

The valley of the River Dane was more recently studied by Hooke *et al* (1990). Three groups of Postglacial terraces are recognised above the floodplain in this piedmont reach. The high terrace group, composed of gravels, is supposed to be of Late Pleistocene age. The middle terrace group, also gravelly, is also undated, but deemed to have been deposited between the Late Pleistocene and Early Holocene. Its dissection, however, took place in the early Holocene, and was complete before 4725 cal BP. The following major aggradation deposited the low terrace group as mostly fine sediments; the onset of its aggradation, ascribed to a major phase of Medieval soil erosion, is dated to after ca. 1180 cal BP (AD 770). A new phase of dissection incised the low terraces during the last ca. 300 years; old maps show that the present floodplain developed after ca. AD 1840. The Mersey High Terrace is correlated by Hooke *et al* (1990) to the lowest member of the high terrace group or the highest member of the middle terrace group.

More studies about deposition and erosion in North-West England focus on the upland reaches of the Hodder catchment on the Bowland Fells. Two erosion phases are recorded here, with deposition of debris cones and fans (Harvey & Renwick 1987), the first one dated after ca. 5400 ¹⁴C BP and before ca. 1900 ¹⁴C BP (ca. 6400 and 1840 cal BP), the second one dated at ca. 900 ¹⁴C BP (ca. 820 cal BP). The Hodder headwaters feature an upper terrace dating around 5400 ¹⁴C

BP (ca. 6400 cal BP), before the first erosion phase, and a lower terrace coeval with it. Downvalley, the youngest of three terraces is dated at 5000 ^{14}C BP (ca. 5700 cal BP) or older. In middle Langdale, on the Howgill Fells (Harvey *et al* 1981) the base of an organic horizon dates alluvial deposition to before ca. 2580 ^{14}C BP (ca. 2700 cal BP), and the deposition of overlying debris cones to after 940 ^{14}C BP (ca. 860 cal BP).

(c) Lateral change

According to Harvey (1985), laterally stable channels are presently found either where they flow in bedrock or between otherwise not erodible or defended banks, or where low gradient channels flowing in till do not have sufficient energy to erode boulder clay banks. Low-gradient mobile channels with fine-grained banks tend to assume meandering configurations, whereas those with higher gradients and cobble bed tend to braided configurations; lowland meandering channels tend to stability. Laterally active channels tend to long-term progressive change more than to short-term adjustments. Where the latter occur, an equilibrium exists between the effects of channel-producing major floods occurring every 1-3 years and moderate channel-modifying events occurring several times a year.

During the Holocene, a major phase of prevailing lateral activity occurred on the Dane (Hooke *et al* 1990) from before 4725 cal BP and ca. 1180 cal BP (AD 770), between the dissection of the middle terrace and the aggradation of the

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low one. The alluvial plain of the Dane (Harvey 1985; Hooke *et al* 1990) was built by the river during the last ca. 160 years by meander widening and migration; such process did not affect the valley bottom in its entirety, and in some points the channel remained laterally stable flowing within the incised low terrace without building a floodplain. The floodplain of Langden Brook (Bowland Fells) is also less than two centuries old (Harvey 1985). On braided streams such as the Langden Brook slow channel changes occur by channel widening and formation of channel bars, but major changes usually occur by avulsion during flood events. On meandering streams such as the Dane new meanders are formed when more riffles and pools develop along a very long meander, and secondary bends develop from them (Harvey 1985). Lateral change by meander migration and growth here prevails on change by cutoff, with a tendency to a progressively increasing channel sinuosity.

Post-cutoff channel adjustment was studied on four recent cutoff events on the Rivers Bollin and Dane (Hooke 1995). All cutoffs resulted from progressive bank erosion or floodplain scour rather than from overflow, and all happened during peak flows, though in two cases it was during a low magnitude, high frequency flood event. Rapid widening and sedimentation occurred in the new channels immediately after breaching; the adjustment occurred mainly by formation of riffles and bars, with a variable morphology in the first 2-4 years. The morphology then became more regular, and in one case was stable after ca. 8 years. In one case, gradient steepening and acceleration of bank erosion propagated upstream, while elsewhere the erosion remained localised. Quite

high rates of vertical accretion occurred at the old channel entrances. The adjustments in the new channels were completed within 6-12 years, while oxbow lakes persisted for much longer.

2.2. The area of study

2.2.1. Geology

The area of the Ribble valley covered by this research (see Figure 1) is the one extending between the town of Ribchester (SD650350) upstream and the Old Tram Bridge South of Preston (SD542286) downstream. The surrounding region lay within the Devensian ice cap limits, and most of the terrain is covered by the Northern Drift till, an extensive formation of reddish brown till deposited by Irish Sea ice that covers the lowlands of North-West England from the West coast up to 200 m OD (Kear 1985). The bedrock underlying the till is mostly Triassic red Bunter Sandstone (De Rance 1877); outcrops of Millstone Grit are also found, for example at the Walton Law hill at Walton-le-Dale (SD561281; see Figure 1) (Hunt 1997). The Ribble Valley is carved through the drift cover; the valley bottom is often directly carved in bedrock, the surface of which is rather irregular (De Rance 1877). The present course of the Ribble flows in some points on the bedrock surface, but even at a short distance from such points the bedrock surface can lie at a depth of several metres. Several deeply cut brook valleys join the Ribble, but none except Bezza Brook (SD592311; see Figure 1)

has incised to bedrock (De Rance 1877); the same brook flows again on bedrock near its mouth inside the Ribble valley.

The plains of the Rivers Ribble and Darwen are cut to the high-tide water mark near their confluence (De Rance 1877); traces of a deep palaeochannel bed downstream from there were found during the excavation of the Preston Docks (Dickson 1887, 1888; Huddart *et al.* 1999). Three terrace levels can be identified in the Ribble valley (Price *et al.* 1963; Harvey 1985). Like other rivers in the region, the Ribble has eroded its bed to progressively lower levels, while its meandering action reworked major parts of the higher terraces (De Rance 1877). There is no suggestion the Ribble ever flowed outside its current valley floor in the Postglacial period (Edwards 2000).

2.2.2. The lower Ribble River

2.2.2.1. *General description*

The Ribble valley between Ribchester and Preston has the characteristics of a piedmont reach, though close to the limit of the lowland area. The river here has a single-thread, meandering channel; its width ranges between approximately 30 and 70 metres. A meandering pattern is also present upstream of Ribchester, though upstream from there the meanders become progressively smaller and less regular. Downstream of Preston, the low-tide channel used to meander in the estuary until its artificial straightening since the

XIX Century (Stevenson & Son 1837, Dickson 1888). In the Ribchester to Preston reach the river runs in a series of ample curves swinging sideways from one valley side to the other. In this reach the valley has a width ranging between 0.5 and 1.5 kilometres. Between a main bend and the next one the river flows at an angle of at least 45° from the valley axis, and up to over 90° in some cases; the main bends touch the foot of the valley edge slopes, with the only exception of the area between Samlesbury and Cuerdale (SD592305 and SD576294; see Figure 1).

The Ribble's active channel – mostly gravel-bedded – is presently entrenched along the entire study reach, flowing between steep 2 to 5 metre high banks. Even at the tip of meanders, point-bars generally appear as low sand and/or gravel spits a few metres wide, backed by a steep bank; field observations of ongoing channel bank erosion are scarce. Therefore the Ribble presently seems to be mostly laterally stable in the studied reach, while net incision seems to have prevailed at least up to recent times. Several instances of locally ongoing deposition can be observed at present, where point bars and mid-channel to channel-side bars seem to be forming out of finer material than the one generally found on the riverbed. However, no extensive active floodplain can be identified, nor has the Ribble significantly altered its course after the incision of its lowest terrace.

The valley is mostly incised in till, reaching in several places the underlying bedrock, and is flanked by steep slopes up to 40 m high. The river, meandering

from one side to the other, subdivides the valley bottom in separate areas, one inside each meander; each separate area is backed on the landward side by the steep valley edge. As a consequence, the entire reach acts as a barrier to communications: there are no bridges between Ribchester and Brockholes, nor are there roads running lengthwise inside the valley and directly connecting the areas inside each bend; even the Ribble Way – the 70-mile footpath following the entire course of the Ribble – runs clear of the valley between Brockholes and Ribchester, keeping high above it (see Figure 1).

The valley floor is thus fragmented in separate meander areas, each of them containing one or more farms. Each meander area is separately accessible through dead-end lanes leading from the main roads running on both sides above the valley brow to the farms in the valley. Only where the terrain allows communication along the valley axis are there valley bottom settlements larger than the groups of buildings associated with each farm – namely Ribchester (SD650350), parts of Preston (SD546285) and Walton-le-Dale (SD554285) and the village of Samlesbury (SD592305) (see Figure 1).

2.2.2.2. Relationships with human features

The valley-scale natural characteristics of the studied area have obviously influenced the human use of it. At the field scale, however, the human features have been only partly conditioned by the landscape.

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Most of the terrain is occupied by fields; trees - isolated or in lines - are scarce, and woodland is mostly confined to the valley border slopes. The fields are mostly divided by fences, though a number of hedges still survive; the traces of now removed hedges are sometimes still visible on the ground. In a few instances a hedge or fence follows a terrace edge, but not very often. Most breaks of slope between the terraces seem not to be sharp enough to condition the pattern of field subdivision that is apparently independently superimposed on the ground morphology. Only where the break of slope is sharper has it been chosen as a natural boundary and marked with a hedge, as at Waterside Farm/Lower Magdell Bank (SD654349); in such cases the hedge itself likely had a part in maintaining a sharp break of slope, keeping it from erosion and the plough's action. Often the route of hedge or fence lines would suggest they follow the curve of some feature on the surface, but in most such cases they are rather influenced by the course of the river (being more or less parallel to it, independently from possible breaks of slope) and the shape of the available area of land.

Drains and ditches, as well as the brooks that flow across many meander areas collecting water from the former or actually arising from them, are more influenced by the terrace pattern and often follow for some distance a terrace edge or the course of a palaeochannel; even the drainage pattern, however, is only partially influenced by geomorphology.

Even if their edges are widely degraded, the elevation difference between the terraces is sufficient to condition the flooding frequency and pattern of the terrain and its consequent suitability for human use. The human settlements in the valley clearly tend to be sited on higher terraces: of 22 farmsteads (some now disappeared, but still shown on OS maps) sited on the valley floor in the study area, 15 stand (or used to) on parts of the highest terrace, as does the town of Ribchester itself.

The more recent settlement areas on the valley floor, such as the village of Samlesbury and some southern outskirts of Preston, did generally obliterate the surface morphology, preventing any accurate survey. Such recent settlements seem, however, to largely ignore the difference between lower and higher terraces, occupying suitable areas irrespective of the ground's elevation, and where needed are aided in this by artificial embankments.

2.2.3. The Ribble estuary

The Ribble estuary extends from Penwortham, just downstream of the area of study, to the Irish Sea south of Lytham St Anne's (see Figure 1). It is a partially mixed shallow macrotidal estuary (Lyons 1997), with an almost straight shape and a relatively narrow width along two thirds of its length. Most of its banks are occupied by marshes or by embanked reclaimed farmland.

As many estuaries of its type (*e.g.* Metcalfe *et al* 2000), the Ribble has a marked tidal asymmetry, leading to a tendency to sediment storage and transport

towards the inner parts, especially at times of low river flow (Burton *et al* 1995). The spring flood tide's high velocity results in a bore in the middle and upper estuary, in which turbulence contributes to resuspend and transport sediments upstream; the ebb tide has a lower velocity, peaking near the surface, with little vertical mixing and a tendency to stratification of freshwater above saltwater (Lyons 1997). The mid-estuary sediment flux is negligible at neap tides, but at spring tides the tidal pumping effect results in net landward transport (Lyons 1997); thus, the tendency of the estuary is for its inner parts to be silted up. A study of intertidal sedimentation rates in the Ribble Estuary through the analysis of radiocaesium profiles covering the last few tens of years (Mamas *et al* 1995) has found increasing sedimentation rates in the inner estuary, from 30-40 mm a⁻¹ at mid-estuary to 45-55 near its landward end.

2.3. Historical record

2.3.1. Pre-Roman human presence

Archaeological data from pre-Roman times are scarce in Lancashire, and only a rough picture can be drawn. There is little prehistoric monumental evidence, and most data come from isolated artefact finds; much of such material is not diagnostic of a precise period (Middleton *et al* 1995).

The finding near Poulton-le-Fylde of the remains of an elk associated with bone barbed points (Hallam *et al* 1973) shows the presence of Palaeolithic hunters in

the region between 15450 and 13450 cal BP, in the Windermere Interstadial (Jacobi *et al* 1986).

Mesolithic populations could have moved seasonally between lowlands and uplands (Cowell 2000). In the lowlands, human occupation seems to have concentrated along river valleys and well-drained sandstone ridges close to wetland, coastal or estuarine areas; near the coasts, lithic concentrations suggest either collection of raw materials or specialist task sites (Cowell & Innes 1994). Major human coastal activity is not recorded until the Neolithic (Huddart *et al* 1999). Traces of possible residential camps are found in the Alt valley and Wirral, but only southwards, in Cheshire (Longley 1987), are possible semi-permanent sites found. Inland (especially westwards), isolated finds or small concentrations of artifacts are mostly recorded – usually in river valleys or by mossland edges – suggesting only a low-intensity activity; task sites are found on small well-drained areas, with much débitage and few implements or microliths, suggesting tools were produced or used on-site, then removed to elsewhere (Middleton *et al* 1995). Most lithic material consists of flint from boulder clay – widely available in the region – that offers no information about human movement through different parts of it; some lowland flint, however, is recorded in the central Pennines (Stonehouse 1989). There is little evidence to suggest Early Mesolithic vegetation management (including clearance) related to hunting (Middleton *et al* 1995). Clearance episodes occur in the Wirral in the Late Mesolithic, with cereal pollen recorded (Cowell & Innes 1994), suggesting some sedentarization; a similar picture is recorded later in the Alt valley, at the

end of the sixth millennium BP. Cereals in the West Lancashire plain are interpreted by pollen assemblage as dating to around 5900 BP (Tooley 1978), five centuries before actual Neolithic, though cultivation in seasonally-tended plots, compatible with hunting/gathering mobile lifestyle, is also possible (Cowell 2000).

The rate of Neolithic culture spread is uncertain; the earliest dates are around the late sixth millennium BP (Keen & Hough 1993, Middleton *et al* 1995). Continuity from the Mesolithic is evident in the distribution of sites and lithic finds (Middleton *et al* 1995). Most lithic concentrations are still found around coasts and estuaries, especially in the Fylde, while scattered off-site activity is still mostly recorded inland; nonetheless, it is possible that marine food loses importance (Richards & Hedges 1999). The pollen evidence confirms continuity from Mesolithic to Neolithic land use (Barnes 1982), with small clearances continuing through the elm decline (Oldfield & Statham 1965) and possible soil erosion and increased runoff on some mossland edges (Barnes 1975). There is an increased presence of cereals, though cereals are not found in later clearances in North Lancashire (Middleton *et al* 1995). Here hunting/gathering lifestyle seems to have persisted, only partly substituted by farming (Cowell 2000); its adoption could have been induced in local populations by territorial stress due to marine inundation encroaching upon valleys, bays and mosses in Late Mesolithic (Cowell & Innes 1994; Middleton *et al* 1995). Hunting/gathering seems to have mostly characterized the region well after a Neolithic culture and economy prevailed elsewhere in Britain; the regional landscape, a mosaic of

coastal/estuarine land, wetland and dry land, probably offered the resources that could allow such lifestyle to persist (Cowell 2000). New elements appearing in the Neolithic are burial mounds, mostly in the Pennine foothills (Cowell 2000), which however do not necessarily imply a sedentary lifestyle (Thomas 1991). Similar sites could have had a seasonal role for tribes moving over the region (Bradley & Hodder 1979).

The later period also sees no relevant change in land-use patterns (Barnes 1982, Howard-Davis *et al* 1988). There are traces of early Bronze Age woodland clearance (Tallis & McGuire 1972); however, clearance activity remains limited, comparable to the episode recorded during Late Neolithic, and the landscape is still mostly wooded. Mires seem to be heavily exploited, unlike the woodland (Middleton *et al* 1995). The density of Early Bronze Age metalwork finds is low (Davey 1976), with a higher proportion of tools versus weapons than is found in other regions (Davey & Foster 1975); this could be due to a lower population without a strong social stratification (Ehrenberg 1989). Lithic material from inland mostly consists in single finds or some concentrations at mossland edges, suggesting short-distance mobility between activity sites similarly to the Mesolithic and Neolithic (Middleton *et al* 1995). Other scattered occasional finds suggest temporary exploitation of coastal areas such as fens or dunes (Cowell 2000) and of tidal flats (Roberts *et al* 1996); it is possible the coast was just used for grazing, hunting or fishing (Huddart *et al* 1999). The human population North of the Ribble appears to be different from other areas, with a separate, more conservative, culture that largely maintains Neolithic characteristics,

keeping a mobile lifestyle until the Iron Age, when it had seemingly been abandoned in the other parts of the region (Cowell 2000). In the southern Fylde relevant human activity is recorded on the higher till ridges standing above the surrounding mires; the intensity of occupation is reduced in the Iron Age, after a climatic deterioration at the end of the Bronze Age (Middleton *et al* 1995). Then little activity remains in and around mosslands, with no settlement evidence; this could be related to the expansion of mosses with the development of an inhospitable wet landscape, and will not change in the Romano-British period. In the Iron Age substantial and permanent clearance is recorded throughout the landscape between uplands and coast.

2.3.2. Roman occupation in the region

Most Roman settlements in the region were not on the sites of existing indigenous ones; their positions were rather chosen according to the needs of the region's Roman garrison (Bennett 1983). The development of civilian settlements adjoining forts (*vici*) was likely controlled by the forts' garrisons or they were even purposefully established and programmed, being inhabited by civilian personnel rather than by people attracted by the fort (Bennett 1983, Buxton & Howard-Davis 2000).

A common picture of the period's rural settlements consider the *vici* as isolated semi-urban islands within a sparsely occupied territory with scattered indigenous settlements (Jones & Walker 1983); but according to others North-

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West England had a substantial rural population (Higham 1979). Local populations, unlike in the South, either did not particularly like Romanization or could not usually afford Roman artefacts, or only traded in perishable goods, that would not survive in the archaeological record (Bennett 1983).

Roman forts were positioned in the landscape according to strategical criteria, taking into account the garrison's needs, often at sites with few or no pre-roman activity (Bennett 1983). Most forts stood by major crossroads; their strategical position seemed to be chosen with attack range rather than defence in mind (Edwards 2000). A third criterion was ease in receiving supplies: though many forts had areas of land (*territoria*) set aside for their exploitation by the garrisons, with few exceptions the garrisons did not produce their own supplies; these were either obtained locally from civilian communities or transported along the road network (Higham 1986, Edwards 2000). Military supplies were abundant and various, the soldiers being accustomed to a lifestyle requiring an expensive equipment of many sorts, not commonly available locally. The supplies traffic was huge, comprising abundant livestock and animal products of considerable variety, spices and sophisticated foods, clothing, metalwork, transports and other equipment (Higham 1986).

Such traffic depended on long communication lines. A remarkable part of the military supplies for the northern part of the province was transported from southern England and Wales by sea (Higham 1986), but a number of main

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roads were also built by the Romans through the region. The road network was likely planned before the forts, which were then positioned and built in order to service them (Edwards 2000). According to Hardwick (1856) three couples of military holds could have deliberately founded, respectively, along the Mersey, Ribble and Lune in order to support two parallel roads (one inland, the other closer to the coast) crossing the Lancashire plain towards the North. The coast road was likely preferred as a trading or postal route, and possibly for troop movements to and from the North – though it is possible that the inland road was used instead, being traced along a line of fortified quarters. In the Roman period the bridges crossing the Ribble were upstream of Ribchester and, probably, at Walton-le-Dale; bridges have continued to exist around such points in the following centuries, separated by a long stretch of uncrossed river. Codrington (1903) provides an account of the Roman road network in Lancashire. The inland main road ran (almost in a straight line) from Manchester towards Ribchester, reaching the Ribble about 400 metres East of the latter. North of the Ribble the road joined another main road from Ilkley and the East, then reached the Ribchester Roman fort (see section 2.3.3.1 below). At Ribchester the road actually found an important junction, meeting two more roads there besides continuing North itself. From Ribchester the road led North towards Lowborough, while another road went North-West reaching Lancaster. The other North-South road ran closer to the coast. It came from Warrington, reaching Wigan (where it joined another road coming from Manchester) and continuing to Walton-le-Dale (see section 2.3.3.2 below), and on to Lancaster.

From Ribchester a connection road led West, meeting the coastal road near Fullwood and continuing West (a stretch known as *Dane's Pad*) in the South Fylde to Kirkham (see section 2.3.3.3 below).

2.3.3. Roman settlements on the Ribble

Along the Roman major road system connecting southern Britain with the northern boundaries, two main settlements appear to have existed on the lower river Ribble, in correspondence of the present villages of *Ribchester* and *Walton-le-Dale*. A third one, apparently smaller, was at *Kirkham*, West of the two others and North of the Ribble estuary.

2.3.3.1. *Ribchester*

The best and earliest known of the Roman settlements along the Ribble is the fort at Ribchester (SD650350; see **Figures 1 and 8**). Extensive information about the site is provided by Edwards (2000) and Buxton & Howard-Davis (2000).

Ribchester was site of a military fort, in operation at least from the middle first to the middle second century AD, and probably (albeit not continuously) later. Its Roman name, BREMETENNACUM, is confirmed by an inscription found on the site. The presence of Roman remains at Ribchester was first recognized by W. Camden in the late XVI Century. The issue was raised again several times during the centuries. The first true archaeological excavations date to the early

XIX Century; several excavations were performed since then on various parts of the settlement, the latest being in the early 1990s.

No pre-Roman settlement seems to have existed on the site, though the finding of Bronze Age burial urns suggests human presence not far from there in that time.

The fort was certainly occupied at the time of Agricola's governorship; its foundation apparently dates back to some time before, possibly in the middle I Century. The fort was placed at the last point where the valley floor was surrounded by gentle slopes, necessary for the passage of the main North-South road, that apparently ran less than 700 m East of it. A main road junction existed where, after crossing the Ribble, the road from South met one of the Roman cross-Pennine roads, coming from York and Tadchester. This road continued East from there leading downstream along the Ribble river and estuary, connecting the North-South road and the fort with the settlements at Walton-le-Dale and Kirkham (detailed in sections 2.3.3.2 and 2.3.3.3 below) and meeting the coast road by Walton-le-Dale. The Roman fort stood West of the main junction, along the route of the East-West road, that apparently led to its North-West gate, approaching it from an oblique direction and turning abruptly into it at the end. The North-West gate seems to have been the fort's most important one. Most extra-mural activities were concentrated on this side, and another road started here, running North-West, probably towards Lancaster. The North-East gate possibly led to the East road (though it could as

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well have been connected to the North-West one), while the two remaining gates, looking towards the river, had probably only local importance.

The known documents characterise the garrison at Ribchester as cavalry. Asturian cavalry is first reported; a unit of Sarmatians is reported to take over around AD 175. In the late II Century a large part of the *vicus* by the North-West side of the fort was demolished, and the area covered with a layer of gravel; the reasons for this are not clear, though the fact could be related to the arrival of the Sarmatians (possibly to provide a parade ground). During the II Century the fort's defences, initially built in turf and timber, were also rebuilt in stone. It is possible that a hiatus in the fort's activity, with reduction or withdrawal of the garrison, occurred prior to the rebuilding, in the Hadrian period, with a return to full strength in the Antonine period.

The "Sarmatian" unit likely remained the garrison at Ribchester until the end of its activity, though by then a large part of the troops would have been local recruits. From around 200AD Sarmatian veterans started to be discharged from the Roman military and settled locally; due to their presence, during the III Century the site came to be known as *BREMETENNACUM VETERANORUM*. The amount of findings from the III Century suggests an intense activity for the Fort, which also remained occupied for most of the IV Century. Its final abandonment (the latest coin found dates 373AD) was probably gradual, when the Roman remote administration ceased to function and the garrison's orders and wages were discontinued.

The Ribchester settlement seems to have had a certain importance. The fort was possibly of larger size than conventional ones. Extra-mural activity extended on a wide area around it; a bath-house and *vicus* existed by the fort since the earliest times. The former, sited East of the fort, apparently remained active until the end of the fort's activity, even after a large part of the *vicus* (North-west of the fort) had been removed; the extra-mural findings of late coins concentrate around the bath-house area.

A recurrent issue about the Ribchester settlement has been its function as a seaport, the Ribble estuary extending enough far inland at the time. This possibility was first hypothesised by J. Whitaker in the late XVII Century, and was since raised again various times. The idea found mainly support in the name of nearby *Anchor Hill* and to a flat-bottomed ditch apparently connecting to the river, interpreted as a slip for ship launch and repair. The former, however, is more likely explained with the presence of an anchoress in the Middle Ages (Edwards 2000), while the latter's apparent connection to the river was probably due to bank erosion by the river itself. The same Whitaker in the 1770s observed how the Ribble was still eroding much its bank under Ribchester. He later thought a more likely location for a port on the Ribble would have been far downstream, by Freckleton, and envisaged only boat and barge traffic up the Ribble. Actually, no findings up to now support the existence at Ribchester of traffic of vessels bigger than small boats.

2.3.3.2. *Walton-le-Dale*

(a) *The site*

The second important Roman settlement lies South of Preston, at the confluence of the river Darwen with the Ribble, placed at present between the two rivers in the area known as *Walton Flats* (SD282552; see Figures 1 and 9; also Figures 3 and 4). Its identification is still very uncertain - some would identify it with COCCIUM, others with RIGODUNUM, connecting the name (in its alternate form RIBODUNUM) with the etymology of the name "Ribble". The settlement was discovered much later than the fort at Ribchester. Hardwick (1856) reported the presence of Roman materials in the area, and the site was systematically excavated for the first time by Pickering (1957).

A human presence around the site could have existed since the Mesolithic and Neolithic (Cumbria and Lancashire Archaeological Unit 1988; Newman & Olivier 1999; Newman & Olivier, unpublished; LUAU 1996). It is not impossible that a pre-Roman settlement existed in the area before its founding, though the evidence is not conclusive; Hardwick (1856) maintained to have found traces of a previous settlement under the lowest Roman archaeological strata, but Pickering (1957) interpreted the same traces as Roman.

The earliest Roman activity at Walton-le-Dale dates to the Hadrianic period (AD 117-138) (Cumbria and Lancashire Archaeological Unit 1988). Except maybe for the very first times, the settlement never had the characteristics of a

fortified hold, but rather of a town, though its regular configuration suggests it was under military control. The town buildings seem to have been arranged on the two sides of a main road, approximately running from South to North and evidently crossing the Ribble nearby. In spite of the two apparent reconstructions performed in the late Hadrianic and mid-Antonine periods (Newman & Olivier 1999; Newman & Olivier, unpublished; Cumbria and Lancashire Archaeological Unit 1988) the town seems to have been continuously devoted to the same kind of activity, with buildings similar to each other, featuring fire-pits and water reservoirs. Hardwick (1856) had already suggested the presence of brick-kilns or pottery manufacturing, after the finding of tiles and bricks fragments as well as lumps of kneaded fine clay; later works do not present precise interpretations, only going as far as hypothesising some form of industrial production involving fire and water.

At the end of the II century A.D. the town was once more reconstructed and finally apparently changed to a more generic settlement, with nonspecialized activities and possibly storage facilities. The occupation of the site continued until the mid-III and likely early IV century AD.

The archaeological site consists of two halves, respectively North and South of a small road (*Winery Lane*), defined by Pickering (1957) as *site A* and *Site B*, respectively. In correspondence of *Winery Lane* a river channel ran in Roman times (Newman & Olivier 1999; Newman & Olivier, unpublished; Cumbria and Lancashire Archaeological Unit 1988); the settlement seems therefore to have

been placed *across* a river, standing on the two sides; a bridge can be expected to have existed along the main road.

An excavation trench across *site B* (Newman & Olivier, unpublished; Cumbria and Lancashire Archaeological Unit 1988) revealed remains of longitudinal wooden planking at the North limit of the archaeological area, in correspondence with the ancient river channel bank. Such remains could be interpreted as some kind of drainage or even as a wharf; this could lead to the hypothesis that at least some sort of naval or boat traffic occurred at Walton-le-Dale.

The two parts of the Roman archaeological site are located on two "islands" of gravel and clay, slightly higher in level and surrounded by later alluvial accumulations (Pickering 1957); river channel changes have erased all the remaining parts of the Roman town, which probably extended over a larger area. A channel in the same position as in the Roman times still existed in 1736 (Hardwick 1856, Pickering 1957), when it formed the downstream side of a small meander of the river Darwen, which completely surrounded *site B*. Though this part of the channel seems to have substantially retained its position since the Roman age, the same cannot be said of the meander's tip and upstream half, that have been found to clearly cut the Roman levels on the South and East sides of *site B* (Newman & Olivier, unpublished; Cumbria and Lancashire Archaeological Unit 1988). The course of the channel must have therefore moved in post-Roman times to a position running more strictly

around *site B*. From such position the meander likely grew to its 1736 size and shape. *Site A* is also bound on its South, West and North sides by post-Roman erosional edges; more channel changes downstream of the site are responsible for the destruction of the rest of the Roman area.

The Walton flats are situated very close to the Ribble's and Darwen's tidal limit, that on both rivers presently occurs shortly upstream of their confluence. Such a limit has not been stable in the past, and it is known to have reached much upstream: in the first half of the XVI century John Leland reported the Ribble being tidal until more than half-way between Walton-le-Dale and Ribchester (that would mean Elston or possibly Balderstone Hall), and even more at spring tides (Edwards 2000). In 1773 Thomas Pennant reports the tidal limit to be lower, about 2 miles above Preston (that would mean at Cuerdale or shortly above), and deems likely no large ships could have arrived at Ribchester (Edwards 2000).

(b) Hypotheses about Walton-le-Dale: the port question

To assess the peculiar characteristics of the Roman Walton-le-Dale by comparison is a hard task, since "civilian" Roman settlements (or anyway non-fortified installations) have been studied much less than forts (Newman & Olivier 1999; Newman & Olivier, unpublished).

The historical record reports the Walton Flats area as heavily affected by flooding (Hunt 1997), so that the area could be used only as seasonal pasture;

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only with the construction of embankments around the area the land could be put to agricultural and urban use. We can expect that the situation was different during the Roman occupation, since a major settlement could thrive in the same spot.

Presently the courses of the Ribble and Darwen are tidal just to beyond their confluence. The tidal limit of the Ribble and Darwen also may have changed through time (see section 2.3.3.1 above), and in Roman times it was not necessarily the same as it is presently. Though we cannot assess *a priori* the extent of such difference, it seems likely the limit was higher, the mean high-water level of spring tides reaching about 1 m above the present value and possibly more inside the estuary (see section 2.1.1.2(b) above). It is therefore possible that the town could have featured a port facility of some importance. In such a case, Walton-le-Dale could have been one of the places where military supplies were disembarked before going further North and East by land or simply being sorted among the Lancashire garrison. On the other hand, according to Higham (1986) most military traffic was concentrated along Hadrian's Wall, and this could greatly reduce the possible commercial importance of the site in favour of more northern ports. The massive industrial activity could however hint to the production *in situ* of some commodity from raw or semi-finished materials shipped by sea (and possibly somewhat easier to stock on the ships); or, on the contrary, raw material could have arrived by land in Walton-le-Dale and finished commodities then shipped either North- and/or Southwards.

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In order to assess what the actual importance and function of the Walton-le-Dale Roman settlement could have been is therefore necessary to analyze the fluvial and estuarine patterns and processes since that age and, more generally, throughout the Holocene.

2.3.3.3. *Kirkham*

The third Roman site along the Ribble stood at Kirkham (SD438318; see Figure 1), sited North of the Ribble estuary. The site was recently excavated, and the resulting information is provided by Howard-Davis and Buxton (2000).

The site lies at Dow Bridge, by the East side of the town of Kirkham and beside the course of Dow Brook, which flows South meeting the estuary at the Naze Point. Both the Roman site and the present Kirkham stand on high ground, atop the ridge of a long and narrow moraine running East to West (Longworth 1985). There is no suggestion of a pre-Roman activity on the site, which actually seems to have been wooded prior to its occupation by the Romans. The whole Fylde area, actually, seems to have been sparsely inhabited during the Roman age (Middleton *et al* 1995; see section 2.3.1 above).

The site seems to have started as a series of temporary camps by a small fortlet. A fort was later built there, though it remained active for a short time only. The Kirkham site was well connected by river and road to the sites at Walton-le-Dale and Ribchester, and with them to the wider regional road system. The East-West cross-Pennine road (see section 2.3.2 above) led from Ribchester

down the Ribble to Walton-le-Dale, then continued on to Kirkham; the attempts to extend it further West towards the coast of the Fylde or the mouth of the Wyre have been inconclusive up to now, and evidence for Romano-British settlement West of Kirkham is generally absent.

The size of the settlement implies only a small permanent garrison was stationed there. This suggests the site was not concerned with policing the surrounding area; it rather was probably an outpost serving some specific function. A tower structure inside the fortlet suggests it could have been a signal station and/or a beacon or lighthouse. It is likely the whole site focussed toward the sea, since there does not seem to have been much in the surrounding land that could justify its presence. It is also likely the shore was closer to the site than at the present time, the estuary forming a bay on its North side (Tooley 1980); in such case, the Kirkham moraine would have offered dry, safe ground suitable for building the outpost at a relatively short distance from the water.

The start of the Roman activities at Kirkham is still uncertain. The coarse pottery finds point to the early II Century AD, with nothing clearly pre-Hadrianic, while South Gaulish samian pottery points to the late seventies or early eighties AD. One coin dates to AD 71, suggesting an Agricolan presence. In the first phase of occupation, the Kirkham site apparently consisted of a location where temporary camps were set. Three separate ditches (later filled with midden waste, a practice also observed at Ribchester – Buxton & Howard-Davis 2000) suggest at least three camps were separately built at different times.

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Semi-permanent structures suggest the camps were occupied for a rather long time, though not so long that permanent quarters would be built.

The second phase of occupation sees the building of a small (about 40 metres in side) permanent fortified structure. This phase is not dated with any certainty, but there does not seem to have been any hiatus in the site's occupation between it and the previous phase. It is actually likely the activity of the camps and fortlet did widely superpose in time. Within the fortlet timber structures existed, and among them what likely was some sort of tower, possibly with signalling or beacon function. The occupation of the fortlet lasted long enough for the need to re-excavate the ditch and rebuild the palisade to arise.

The third phase of occupation starts in the early II Century (probably around AD 120). The fortlet is then replaced with, and partly integrated in, a more standard stone-walled fort. The partial integration of the fortlet's structures in the new fort (among which, apparently, the tower) suggests the hypothesised function as a beacon or signal station was still important. The fort implies the presence of a larger garrison. The fort's defences, built in turf, were reveted in sandstone that had to be brought from elsewhere, possibly Blackpool or Preston, either by barge or by road – the road connecting the site to Walton-le-dale (see section 2.3.2 above) could have had a relevant importance in this case. The fort's occupation, however, only lasted a short time, possibly not more than 40 years; the site was abandoned by the middle II Century.

The fort's activity seems to have lasted too short for the establishment of an extra-mural settlement large enough to survive after the fort's abandonment; some extra-mural activity seems however to have outlived the fort, lasting until the late II or early III Century AD.

Unfortunately, most of the fort's interior area is occupied by modern buildings, and could not be excavated. What observed during the excavation, however, together with the site's local context, strongly suggest its purpose was strongly connected to the sea. The tower in the fortlet could have worked as a beacon to mark a safe landing spot, that at the time could have been at a short distance South of it (possibly less than twenty minutes by foot) in an embayment of the estuary. The landing would not have needed any special structure or an actual port; a sheltered beach was probably sufficient.

Traces of extra-mural activity around the site are hazy, but can be seen throughout its occupation period. Grazing animals, likely horses, were apparently present in the area; this could also be related to the area being left to become overgrown (and hence fit for grazing) in between the different camps. Traces of salt-marsh plants suggest that either fodder was also brought on the site from the surrounding grounds, or that the horses were also allowed to feed down by the estuary.

In the third phase, the area immediately surrounding the fort seems to have been cobbled, also covering the backfilled ditches from the former camps; this suggests the existence of a certain level of traffic and activity, possibly

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connected with the traffic from the East road, and possibly a function as manoeuvre or parade ground or as marketplace.

The start of the occupation of the Kirkham site could have been related to the Agricolan advancement. It is possible that the Agricolan forces advanced both by land and by sea, with the deployment of troops at convenient places. The site at Kirkham could have been chosen as it was known to be a point of safe landing in a good position in respect to other safe harbours and other Roman facilities in the area (the fort at Ribchester and the roads network).

The fortlet and tower could have been built shortly after in order to mark the landing point. The fortlet could subsequently have functioned as an entrepôt for the storage of goods disembarked nearby before they were sent West by road (or, again, boat) towards Walton-le-dale and Ribchester; or, on the contrary, for the storage of goods due to be embarked. Meanwhile, troops would also land at Kirkham and set temporary camps before moving on towards their assignments.

The only possible purpose for the building of a fort at Kirkham is seemingly as an entrepôt. It stood by the mouth of an important river, which was navigable up to Preston or possibly further by barges, and anyway flanked by a road leading inland towards another important garrison. Through Kirkham, the Ribble estuary would have acted as an important access for sea-borne goods to the region's road network. A comparison between the activities of Ribchester and Kirkham in the II Century suggests a connection between them, likely

though road traffic and trade, and possibly related to the Walton-le-Dale industrial activity (peaking in the II Century). The construction of the fort could have been related to an increment of boat or road trade along the Ribble and/or the coast (between Kirkham and the Roman sites on the other estuaries in the region, all sited within one day of navigation). The findings at Kirkham confirm the abundance of goods imported from the continent: most of the pottery (only some local pottery was found) as well as large quantities of food, such as olives and olive oil, figs and wine.

It seems the site at Kirkham could have been abandoned once the heavy trading connections ceased to work; in the same period the Ribchester fort started its decline and its extra-mural activities moved their focus away from the Kirkham road.

2.3.4. Middle Ages

The Roman interlude notwithstanding, a tendency to cultural continuity seems to go on in the region. An apparent lack of post-Roman settlement could be due to the already mentioned (section 2.3.2 above) tendency of local populations not to use or acquire metal or ceramic Roman artefacts (Bennett 1983). The culture of the local populations could hence have maintained a continuity from the Iron Age through the Roman period to the early Middle Ages; though the Roman settlement of the forts and *vici* ended, settlement and occupation of the region continued (Bennett 1983). Roman settlements placed on good agricultural land,

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however, tend to have superimposed Medieval settlements; the old forts could also have survived as religious foci, with churches often built within their perimeter, where likely Christian cult was already practiced during Roman times (Bennett 1983). Even later, during the Anglian invasion, there likely was no “genocide” of the native farming population, that largely remained the same living alongside the invaders (Higham 1979); a similar thing seems to have happened during the Norse invasions (MacKay & Tallis 1994).

Middleton *et al* (1995) report many Medieval place names in the Fylde, few of which refer to features such as “moss” or “carr”; it is possible wetlands were not a particularly dominant feature, and over all they were not intensely exploited (some remain today). Indeed the area featured acidic mosses far from river valleys, that were not very productive save possibly for peat cutting; such mosses also widely acted as barriers to communication and actually were purposefully used as such, as in the case of two abbeys founded in areas enclosed between mossland and the coast.

2.3.5. More recent times: historic cartography

A general idea about the recent history of the lower Ribble valley and estuary can be gained through comparison of maps of different ages. A study of the available ancient cartography (Yates 1786, Greenwood 1818, Stevenson & son 1837, Ordnance Survey 1849) suggests that during the last century and a half the course of the river Ribble (as well as the lowermost part of the river

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Darwen's) did not undergo any relevant natural changes, as was already noted by Harvey (1985). The Ordnance Survey (OS) topographic maps – the oldest available edition, surveyed in 1847–49 – can be perfectly superimposed to the recent OS maps, as does the map contained in the Stevenson & son (1837) report. The original aspect of the low-tide channel in the estuary, as it appears in the report's map, also basically matches that seen in the earlier maps. The lower accuracy of the earlier maps does not allow a perfect superposition with the later ones; nevertheless both in Greenwood's (1818) and in Yates' (1786; see Figure 4 for a detail) map the rivers appear similar to later times, and few relevant natural changes seem to have happened since then. The level of accuracy of the maps is not sufficient to appreciate possible minor changes to any degree of certainty.

The only major changes visible from historic cartography are presumed artificial. The straightening of the small meander along the last stretch of the river Darwen (see section 2.3.3.2 above), shortly before its confluence with the Ribble, is noticed by Hardwick (1856) to have happened in the XVIII Century; there is however no official record of such cutting (Pickering 1957). The meander was recorded in a map by Robert Porter in 1738 (Hunt 1997), the earliest map known of the area around Walton-le-Dale (see Figure 3), and was cut before 1786 (as Yates' map shows no trace of it; see Figure 4). An engraving from 1728 (also reported by Hunt, 1997; see Figure 5) could suggest an adjoining meander had disappeared shortly before. Yates' map also shows another smaller channel running between the Darwen and the Ribble upstream

of the Flats in correspondence with the narrowest point between the two rivers; this channel, also visible in Porter's 1738 map, was an artificial mill-race (Hunt 1997). The axis of Walton-le-Dale town then ran South and West of the mill-race, along the road going South towards Bamber bridge; from there the road going up the Walton Law started, crossing the race on a bridge. The present main road from Ribble Bridge runs closer to the Ribble's bank and mostly North of the former course of the mill race, before leading East; the Bamber Bridge road detaches from it.

A meander of the Ribble just south of Ribchester shows a much less marked curve in the 1818 map, but if this actually may correspond to a change in the channel or rather be due to the inaccuracy of the maps cannot easily be told; the curve is actually more pronounced in the 1786 map. In both maps, channel bars appear along the Ribble in the same places as the present ones.

In the old maps (Yates 1786, Greenwood 1818, Ordnance Survey 1849) the estuary, especially its inner part, is shown to be much wider and to feature a widely meandering main low-tide channel. The present straight, narrow aspect of the estuary (see Figure 1) is largely artificial. During the course of the XIX Century (Stevenson & son 1837, Dickson 1888) the lowest part of the Ribble River and the Ribble estuary were heavily affected by dredging and channelling works that straightened the low-tide channel and the last part of the river's course for easier navigation. Wide areas of mudflat have also been reclaimed

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for farming on the two sides of the channel, in fact narrowing the inner part of the estuary.

3– Methodologies

The methodologies used comprise a general field survey for mapping and levelling the terrace pattern, stratigraphical and sedimentological analysis on the various terrace units (also performed by radar techniques), pollen analysis of palaeochannel fill sediments and a number of ^{14}C dates.

3.1. Field survey

As a first approach to the study of the lower Ribble valley, an extensive field survey was undertaken, in order both to collect data about the valley itself and to locate suitable sites for the subsequent phases of study. The area covered by the survey comprised the Ribble valley floor from Waterside Farm (SD654349) and Ribchester (SD650350) to the embankment of the old tram line crossing the valley directly South of Preston (SD542286-SD541275; see Figure 1).

The choice was dictated by various factors. The valley reach between Ribchester and Preston has different characteristics from both the upstream and downstream areas, being flanked by higher and steeper slopes (see section 2.2.2 on page 36). Two prominent Roman settlements also stood at its upstream and downstream end (see section 2.3.3 on page 48). The Ribble is tidal from near the downstream end of the study area, which therefore marks the limit between the piedmont and the lowland/perimarine parts of the Ribble (see section 2.1.2.2(a)

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on page 26); however, downstream of Walton-le-Dale the valley enters the Preston urban area, that leaves little terrain free for geomorphological study.

3.1.1. Fieldwalking and geomorphological mapping

3.1.1.1. *Method*

The surface geomorphology of the valley floor was observed and mapped throughout the area of study, with the exception of urban areas and, in a few cases, those inaccessible on the landowners' request.

The survey was intended to locate and record all apparent breaks of slope visible on the ground surface, or consistent changes in the ground surface elevation. Each break of slope was followed along all its recognisable extent, where possible also across obstacles such as hedges, ditches, buildings or roads, and mapped. As a base for mapping, Ordnance Survey 1:10 000-scale cartography was used. Where matching breaks of slope or a consistent lower ground elevation traced the course of a buried palaeochannel, they were mapped as such. Other elements of the ground morphology were also noted and mapped, mostly along the valley edges, such as alluvial cones or colluvial slopes.

The single elements mapped were matched with each other in order to identify separate sub-horizontal surfaces with a consistent elevation difference from

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each other. Several of them – likely to represent the surface of river terraces – could be defined in each surveyed area.

In the Higher Brockholes area the study of 1946 aerial photographs (courtesy of English Heritage) helped to reconstruct the original aspect of the terrain, before the construction of the motorway and the establishment of the sand and gravel quarry presently occupying the site.

3.1.1.2. Difficulties and sources of error

Many factors made observation difficult and the interpretation of what was observed uncertain. The most problematic is probably the effect of agricultural practices. Though many terrace edge breaks of slope are still visible, many others, as well as palaeochannel edges, have been eroded to various degrees by farming, even to the point of being totally indistinct during mapping. Many such landforms have not been affected in a uniform way. Though outstanding at a given point, they tend to become fainter and more gradual until they can be followed no more. In some cases this effect is natural, as it happens with the former secondary channels in Higher Brockholes (see Figure 12 and section 4.2.3.3(a) on page 141), the step along their inner bank progressively reducing towards the point in which the channels themselves disappear joining with the main one. In other cases the effect is an artefact of the step having been lost by farming activities. As a consequence, though the general course of the terrace limits is known, their exact position remains hypothetical at many points. It is

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not impossible, moreover, that some landforms – and some terrace fragments with them – remain undetected.

A major source of uncertainty in the interpretation of the terrace sequence and the identification of each terrace area is given by the structure of the valley bottom itself. Because of the river's wide meandering planform already mentioned, the valley bottom is functionally divided into discrete areas with no continuous stretch of ground surface between each other; in the only part of the valley where this does not happen the survey was prevented by the presence of the M6 motorway and the village of Samlesbury (see Figures 1, 9). Therefore, no single part of a terrace surface could be followed (and levelled) continuously beyond the limits of each meander area. This resulted in a series of separate local terrace sequences that had to be joined only by altitude comparison in long profile of the valley (Figure 7).

Anthropogenic disturbance was also a frequent obstacle to observation and interpretation on the field; apart from the destruction or confusion of surface landforms through farming activities, production of false landforms can happen (such in the case of false breaks of slope left along the line of hedges now disappeared). Even if it does not totally cancel the surface morphology (unlike larger settlements), also a single anthropogenic element (such as a building, ditch or tree line) can mask single landforms or part of them enough to make uncertain their surveying and subsequent interpretation.

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3.1.2. EDM levelling

3.1.2.1. *Field survey of ground surface*

The geomorphological survey was followed by the levelling of the valley floors by means of a Leica EDM (*electromagnetic distance measurement*) system. The horizontal location and relative elevation of a number of points on the ground was recorded throughout the valley. The points were taken singly or in rows; their position was chosen in order to cover all the different surfaces defined by the geomorphology and assess their elevation differences, with the aim of gaining a comprehensive picture of the river terrace sequence along the examined reach. The rows of points were taken when possible either roughly lengthwise in respect to the valley axis or along the Ribble's course.

The EDM position at each station was chosen each time in order to cover in a single station the widest possible extent of ground – wherever possible, a whole meander area. The reference points taken in order to connect the points surveyed from different stations were taken if possible in correspondence to fixed human-made features such as gateposts or manhole corners; where no such markers were available, temporary pegs in the ground were used. In order to assess the points' actual elevation above OD, two benchmarks were enclosed in the survey near the upstream and downstream ends of the area covered, respectively at Sunderland Hall (SD623336) and on the Ribble Bridge between Walton-le-Dale and Preston (SD553287).

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3.1.2.2. *Correlation of the surveyed points*

The data recorded on the field were manipulated with the EDM's own software, LISCAD. The sets of points surveyed at each station were connected to each other (matching the reference points' position and elevation), obtaining a single network of points covering the whole surveyed area. LISCAD also allowed systematic corrections to the points' elevation, such as in the case of a row of points taken with the EDM's reflector kept at a different height. The data, including horizontal position and elevation of each point as well as a point identifier, were then exported from LISCAD in ASCII text format.

3.1.2.3. *Lateral projection and correlation of the terraces*

The levelled points were used to obtain a long profile of the valley floor in which the different surfaces recognised on the field could be distinguished. Only some of the valley floor surfaces could be correlated along the length of the river's channel, since the exact course of the Ribble at the time each terrace was deposited is largely unknown (except for fragmentary palaeochannel information), while its present course meanders from one side of the valley to the other, often flowing sidewise rather than lengthwise in respect to the valley axis. Therefore, it was chosen to project the points at right angles to the valley axis itself, obtaining a long profile of the valley; such choice is not unique in Quaternary fluvial research (Hooke *et al* 1990; Tebbens *et al* 1999; Passmore & Macklin 2002).

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In order to project the points laterally, the LISCAD data output were elaborated with two simple programs in QuickBasic®. The programs allowed the visualization of the points from an ideal side view, distance along the valley axis versus elevation, and the assignment of different identifiers to the points aligned along surfaces at different elevations. The data were then saved again in plain text format.

3.1.2.4. Data plotting

The data were finally imported in a spreadsheet. The points from the different surfaces were re-ordered in the different columns of the spreadsheet's table; data for the present river surface were added. The spreadsheet was then used to plot a graph of the valley's long profile.

A trendline was added in the graph to the series of points corresponding to each terrace surface, in order to reconstruct the surface's average profile along the course of the valley.

3.1.2.5. Difficulties and sources of error

The character of the valley bottom's landscape also affected the EDM survey, with the overall effect of increasing the cumulative errors and worsening precision. Features such as buildings and tree lines often acted as obstacles hindering the line of sight, while the fragmentation of the valley bottom slowed down the survey by forcing complicated drive-arounds each time the EDM

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station had to be moved across the Ribble. This extended the time needed for the survey and worsened the job's continuity. In some cases, as happened between Elston and Lower House (SD600320 and SD607324; see Figure 1), part of the reference points used to join the points surveyed from different stations could not be found upon returning on the field, because the markers left to recognise them had disappeared, or even because the feature taken as reference had itself disappeared, as in the case of a tree stump that was removed by the owners of the field it stood in between two phases of the survey. In such cases, fewer reference points had to be used.

The single biggest obstacle to the EDM survey, however, was the 2000/2001 livestock foot and mouth disease epidemic, that prevented the access to the fields for several months. As a consequence, the survey could not be completed in its upstream part; the data only cover the Ribble valley up to Sunderland Hall (SD623336; see Figure 1).

3.2. Sediment logging

Where it was feasible, stratigraphical and sedimentological information was sought for the river terraces identified by field survey.

3.2.1. Data collection

Sedimentological and stratigraphical data were collected by a) observing open sections through the valley sediment fill; b) by means of sediment cores

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extracted from the surface or, in some cases at Higher Brockholes, by observing the stratigraphy in freshly dug test pits; c) examining the logs of pre-existing civil engineering boreholes drilled in the area.

Figures 10, 11, 12, 13 show, in a series of close-up maps, the location of the various cores, boreholes, pits and open faces used.

3.2.1.1. *Pre-existing data*

(a) Method

A search was made in the British Geological Survey (BGS) archive for borehole data existing in the area of study. The results were patchy, since the data concentrated along trunk roads, power lines and aqueducts. In one case the concentration of boreholes along the same line (the course of the M6 motorway across the Ribble Valley, (SD578311-SD581303) caused an excess of data, and a selection had to be made. A number of boreholes, regularly spaced along the motorway's course, were chosen, preferring the ones with a depth of 10 or more metres in order to be sure the valley fill stratigraphy would be adequately covered by them. Some of them had to be discarded since they contained no useful data; for example, those (drilled during the M6 widening works) whose stratigraphy only featured made ground from the original motorway embankment.

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More recent boreholes covering the Walton Flats area were drilled by Central Lancashire Development Corporation (in connection with the area's development project) and by the Lancashire County Council (in connection with the construction of a new trunk road). Since their logs were not yet repositied in the BGS archives, they were obtained by courtesy of P. Gibbons (*personal communication*, 2000). The logs of four boreholes sited in the Higher Brockholes area were kindly provided by the administration of the Higher Brockholes quarry.

The locations of the civil engineering boreholes used in this study are shown in Figures 11, 12 and 13.

(b) Sources of error

The main difficulty in comparing data from pre-existing boreholes stands in their different origins. The borehole logs were produced at different times and occasions by different persons, often with different concerns and hence little surveyor consistency. The features of the stratigraphical units can thus be differently noted or emphasized. This is evident in comparison of bedrock units described in the 1981 (Figure 24a-c) and 1975 (Figure 25) boreholes from the Walton Flats – the areas covered by the two sets of boreholes overlap, and therefore the differences must be ascribed to the surveyors.

A similar problem may derive from the surveyors' mind-frame. While drilling a series of boreholes, civil engineers may expect to find similar features, since the

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area's stratigraphical history is not their concern, and likely will not emphasize possible sedimentological or stratigraphical differences that could be related to different terrace fills.

3.2.1.2. *Sediment coring*

(a) Method

Where no borehole data were available, or where it was useful to integrate such data with further information, the stratigraphy was also recorded through additional sediment cores. The cores were extracted by means of a gouge-shaped Eijkelkamp hand-operated corer (Tooley 1981). The corer, pushed vertically through the ground surface, penetrated the softer sediments in order to sample them in 1 m long sections of about 2.5 cm diameter. Most sediment cores were extracted along transect lines, in order to reconstruct the stratigraphy of a terrain section.

Rough observations were also made of the sediment stratigraphy where a number of test pits were excavated by the Higher Brockholes quarry management in order to estimate the amount of useful material in an area before starting extraction. Such observations produced visual logs without precise depth measurements (though some of the sediments could also be examined closely, though not *in situ*, from the material in the excavator's bucket).

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(b) Sources of error

The hand-corer is theoretically equipped – through 1-metre extension poles – to reach down indefinitely through the ground, and it can practically be used by one person to reach depths of over 6 metres before it starts to get too cumbersome (though this depends on the nature of the sediments being cored through). However, the corer cannot usually penetrate hard or coarse-grained materials such as gravel; all the cores extracted had to end where the corer hit gravel (or, at best, a few centimetres inside the gravel). Another frequent problem was caused by the corer's open semi-cylindrical chamber, which was often unable to retain very loose sediments such as waterlogged sand. This caused a gap in some cores' sequence, where precise sedimentological features could not be recorded. Even when sediments were correctly retained, the open coring chamber meant the risk of sediment contamination could not be ruled out. Finally, sediment logging through coring could provide little sediment structure detail.

3.2.1.3. Exposed sections

(a) Method

The last important source of stratigraphical and sedimentological data was the observation of natural or artificial sub-vertical open sections through the alluvial units of the valley floor.

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The natural sections found along the Ribble's banks, produced by incision or bank erosion, were seldom fresh enough to be useful; where they were, they contributed some information about the composition of the younger terraces. The banks incised through the terraces by the tributary stream were, generally, even less useful, being either too low, too weathered or too covered by vegetation; one exception (see section 4.2.3.1(b) on page 124) was found by Sunderland Hall (SD623336; see Figure 10).

The best sources of information were artificial sections: the open faces cut during the extraction works in the Higher Brockholes quarry (see section 4.2.3.1(b) on page 124). The faces, over 6 metres deep at some points, cut through the valley floor at Higher Brockholes for several hundred metres, presenting on a wide scale the structure of the Higher Brockholes area and also allowing access to the fill of some palaeochannels. To perform a complete logging of the faces was impractical, due to their great extension, their often poor conditions (the faces having been roughly cut and/or already weathered) and the fact that extraction works were going on in the quarry at the time of the survey. After a general observation, the faces were cleaned (where needed) at different points and their stratigraphy recorded either as a vertical log or by sketching or photographing the section; depths were measured in respect to the ground surface. The sections chosen were deemed as far as possible representative of the general stratigraphical structure in the face; some features,

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however, could have been missed, especially where bedding was laterally complicated or the face's quality was very poor.

(b) Sources of error

Some of the quarry faces observed were not fresh, having been cut a few months before, and had already widely deteriorated at the time of study. Even the freshly cut faces were not made expressly for a stratigraphical study: a neat vertical surface was found only in some places, as it was not expressly sought by the quarry workers; unless the extraction pit's edge wasn't due to be covered again in a short time, an oblique or multi-stepped surface was usual. This limited the extent to which the stratigraphy could be recorded along the faces, which often could be easily logged only at some points. The observation of the face along its other parts allowed the recording of sediment structures, though with limited detail and a degree of uncertainty.

3.2.2. Data representation

All stratigraphical and sedimentological logs were re-drawn in a standardized way in order to make them easily comparable. The same graphical symbols, based on Troels-Smith's (1955) notation, were used in all logs as well as in the open face sketches; they are described in Figure 15. A description of the stratigraphical units in each sequence was provided beside the graphical logs;

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in the case of pre-existing boreholes, the description was mostly reported as originally written by the surveyors. The logs are shown in Figures 16-27;

The cores and boreholes aligned along a same transect line were represented side by side in their actual order. Stratigraphical sections were also reconstructed interpolating the information from borehole or core transects. In all cases, the sections or series of vertical logs were represented as seen looking upstream (roughly North-East), including those open faces that actually faced upstream, and that were observed in the field by looking downstream. Thus, all sections or series of sediment logs (Figure 16-Figure 36) have their North or North-West end on their left-hand side and their South or South-East end on their right-hand side.

3.3. Ground penetrating radar analyses

Ground penetrating radar, or GPR, is a relatively new method of recording stratigraphical sequences and profiles. The GPR process involves shooting radar (electro-magnetic) pulses into a section of ground being studied; the radar waves sent into the ground are partly reflected back upwards to a receiving antenna. The returning signals are then processed using appropriate computer software to create a side profile of the sedimentary layers. Profiles can then be analyzed to determine stratigraphical content and boundaries. Though not providing any information about the fine-scale characteristics of the sediments, GPR has a primary usefulness in facilitating analysis of laterally extensive

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sections of alluvium. GPR can be used to produce cross-sections of the valley floor stratigraphy, spotting buried structures (such as palaeochannels) even at a depth of several metres (Jackson *et al.* 1998; Taylor *et al.* 2000) and providing information about the deposition history (Rønning 1995), also by allowing the recognition of the general alluvial facies of the sediments (Vandenberghe & Van Overmeeren 1999).

The GPR equipment used for this study was a Sensors & Software Pulse EKKO 100 system, obtained from the NERC Geophysical Equipment Pool in Edinburgh.

3.3.1. GPR functioning

A GPR system has three main components: a transmitter and a receiver, each of them equipped with an antenna, and a control unit for timing of the outgoing pulses from the transmitter and recording of the return ones from the receiver. The antennae are placed on the ground, at a fixed distance away from each other. The appropriate distance depends on the frequency used; if the two antennae are too close together distortion can occur in the received data, caused by interference from resonance of the antennae. The system can be fitted with different-sized antennae working at different frequencies. Typical frequencies for medium to wide scale surveys range from 25 to 200 MHz. From the receiving antenna the data are transmitted via fibre-optic cables to the control

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unit. The whole process is controlled with a special software by a computer connected to the control unit, and the data recorded on file.

The function of the transmitting antenna is to radiate short high-frequency electro-magnetic pulses into the ground. The pulses are refracted, diffracted and reflected in correspondence with discontinuities in the ground – primarily as changes in dielectric permittivity and electric conductivity. Some of the energy emitted with each pulse from the transmitting antenna is reflected back and reaches the receiving antenna as a return signal. The two-way travel time of each pulse from the transmitting to the receiving antenna is proportional to the distance of the reflecting obstacle from them.

The return signal constitutes a mere portion of the energy emitted with the outgoing signal. Since the signal is attenuated while travelling through the ground, the deeper the signal travels, the smaller the portion of it that returns to the receiving antenna. A greater penetration can be obtained with lower antenna frequencies; this, however, will proportionally reduce the vertical resolution of the output (Davis & Annan 1989).

For the GPR surveys for this study, 100 MHz antennas were chosen, as the best compromise between penetration and resolution. 50 MHz antennae, also tested on the field, would have yielded useful results too; their size of about 2 metres in length, however, rendered them much more cumbersome, making them unsuitable for performing long surveys quickly enough.

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The practical use of the GPR in the field is illustrated in Figure 6. The transmitter and receiver, fitted to handles, are kept with their respective antennae lying parallel on the ground; a rope tied to the handles' supports enables the antennae to be maintained at the same distance. The antennae are moved in fixed-length steps (25 cm steps were adopted for this survey), with the help of a plastic measuring tape laid on the ground; at each station a radar pulse is emitted and the returning echoes recorded. The control unit and computer are connected to the transmitter and receiver by means of fibre-optic cables, and must be separately carried, preferably at a distance of at least 5 metres in order to avoid interferences in the radar signals from their metal parts.

Each GPR reading can be taken manually at the desired point; the handiest way to quickly perform a GPR survey along a transect line, however, is to have the system take the readings automatically at fixed time intervals. Through its software, the GPR system can be programmed to take a certain number of readings, stopping automatically when the number is reached. The time interval between readings can also be specified, enabling the operator to move the antennae of the chosen step between one reading and the next. The system can emit an audible beep sound during the emission of the pulses, in order for the operator to avoid moving the antennae during a reading.

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The results from the whole series of readings taken in this way are saved in a single file; the GPR transects in this study were mostly surveyed in sections 25 to 50 metres long.

3.3.2. GPR transects

A GPR survey was performed along each of five transects – three short and two long ones. A first short transect was taken at Higher Brockholes, above and parallel to a quarry face, in order to allow a comparison between the GPR output and the ground structure actually observed in the face. The other two short transects were taken in the Walton Flats, across a palaeochannel and close to the site of the Roman town (see section 2.3.3.2 on page 52); a series of sediment cores was also taken along the same lines. The position of the two long transects was chosen in order to provide cross-valley sections upstream and downstream of Walton-le-Dale. Figure 14 shows the location of each GPR transect.

3.3.3. GPR output

Each GPR reading in a row ideally corresponds to a single radar pulse sent vertically into the ground, and is ideally composed by the radar echoes returning vertically along the same path. The resulting echoes can be visualised along a vertical trace, whose length is proportional to the signals' return time (two-way travel time): the intensity values of the return signals, separately

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recorded for each trace, are displayed as signal voltage amplitude versus two-way travel time. In order to reduce the random noise that can affect the received signals and confound the output, a number of consecutive pulses can actually be emitted for each reading; the system averages the returning signals, with a substantial increase in the signal to noise ratio. A value of 16 stacked and averaged pulses was adopted for this study.

The GPR software can display the raw output data during their acquisition, trace after trace. The traces can be visualized in two ways, commonly referred to as “wiggle” and “colour”. In the first one, or variable area mode, each trace is represented by a vertical wiggling line, generally with a black fill of the positive (or negative) area. With the second display technique, or variable intensity mode, the intensity values of the return signal are represented by grey tones (as in this case of this study) or by colours.

In the ideal condition of purely vertical transmission of radar pulses, each GPR trace would show, along its length, the reflectors (changes in electric conductivity, usually corresponding to structural changes or discontinuities in the sediment) at a distance proportional to the reflector’s depth. A whole GPR diagram is composed of a row of traces (corresponding to the readings taken along the surveyed transect) displayed side by side; it hence consists of a cross-section of return signal amplitudes (intensities) versus location along the two-way time (depth) axis and the horizontal distance axis. If the signal intensities in each trace represent the position of ground discontinuities, all together the

row of traces would show a virtual section through the ground. The wiggle diagrams are neater than the colour ones, but with the software used the latter resulted in a more compact visualization, which was more practical during data acquisition.

The complication comes from the fact that the radar pulses emitted by the antenna do not travel only along the vertical downward path, but also diffuse laterally. An object can thus be picked up by the GPR also when it is not directly under the antennae, and will appear on the trace at a depth proportional to its actual diagonal distance from them. With surface reflectors these signals average out, resulting in linear traces in the GPR diagram; point reflectors, however, will produce hyperbolic figures in the raw output diagrams, as the direct vertical return signal will be flanked in the adjacent traces by progressively fainter and apparently deeper signals.

3.3.4. Data processing

After the acquisition of the raw data a number of elaborations and corrections optimising the diagrams' interpretation were performed on them with the GPR software.

The GPR return signals become fainter with depth, due to their progressive attenuation as they travel along an increasing thickness of sediments. The GPR software allowed the differential variation of the signal's gain, increasing it

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along the traces and amplifying the lower signals in order to maximise the depth at which they could be read. An exponential amplification gave the clearest results.

Many raw output diagrams showed diffuse interferences, likely due to the abundance of electro-magnetic disturbance in the near-urban area where the GPR survey was performed. A 40% low-pass filter served to clean most interference, enhancing the diagrams' readability.

The diagrams from each transect section, separately surveyed with the GPR, were then joined lengthwise by the software in a single file, generating a single diagram covering the entire length of a transect. Since each separate GPR section was usually surveyed starting from the previous section's end point, the diagram thus obtained showed a continuous sequence of regularly spaced traces, with the same result as if the whole transect had been surveyed together in one long row of readings. Since the joining of diagram sections was done according to each section's starting distance along the transect, the distance scale was respected even in the points where a gap existed between two sections, due to the presence of an obstacle. In such cases the software filled the gap by interpolating the GPR data of the two adjacent traces.

Through a "migration" process of the output signals across the diagrams, the hyperbolic figures produced by the lateral transmission of GPR signals could be made to collapse in point figures, in order to obtain a diagram more closely corresponding with the actual ground structure. A side-effect of migration is

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that point-shaped traces – such as single interference peaks – will be expanded, producing inverted hyperbolas; such cases, however, were few and well enough recognised.

The calculations needed for the migration process depended on the radar waves' transmission speed through the ground; since the speed – given the variations in the ground's composition – was not constant, the process could not be perfect. However, the results obtained with a transmission speed of 0.07 m/ns were satisfying, collapsing most hyperbolic figures completely and producing a much neater diagram. Such a value corresponds to the average transmission speed through silt (Davis & Annan 1989), which from the sedimentological observations was expected to be the most abundant component of the valley alluvium. Since the other main components, sand and clay, have an average transmission speed of only 0.06 m/ns, the actual, general average speed of the GPR signals could be expected to be slightly below the silt's value of 0.07 m/ns. However, since the composition of the sediments, and with it the actual speed through them, could vary with each bed (and along the same GPR trace), seeking a greater precision was deemed superfluous. The unmigrated data were retained, to avoid possible losses of information.

The final step was to insert ground surface elevation data in the diagrams. The data, collected along the GPR transects' path during the EDM survey, were entered in the software and represented in the diagrams with a vertical scale considering, once again, an average speed of 0.07 m/ns.

3.3.5. Results

The final wiggle and colour output diagrams were saved by the software as displayed on the screen in 1-bit black and white or 4-bit 16 grey scale .pcx format, respectively. The wiggle and colour diagrams produced by the software have different image scales and proportions, the former being almost twice the size in height and about five times in width than the latter. The diagrams as exported by the software are in a vertical position, and need to be turned 90°.

The files were then imported with a graphics package for their printing and interpretation. The package allowed the resizing of the wiggle diagrams to the same horizontal and vertical scale of the colour ones; this allowed an easier examination of the two kinds of output and their comparison by superposition for best interpretation. The wiggle diagrams, being clearer, were used in the final representation of the data (Figures 28, 29, 30, 32).

Better results can be obtained if GPR data can be supported by direct stratigraphical information about the sediments being analysed, obtained either through open exposures or core sequences (Taylor & Macklin 1997; Beres et al 1999; Vandenberghe & van Overmeeren 1999; Regli et al 2001). Comparison of the GPR diagrams with sediment core stratigraphies from the transects along which both had been performed (see section 4.2.5.1(b) on page 184) allowed a direct estimate of the diagrams' depth scale. This was obtained by averaging the correspondences of the measured depth of stratigraphical discontinuities in the cores with the depth (in pixels) of the corresponding GPR reflectors in the

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diagram. The resulting graphical scale was then added to the final representation of the diagrams. Though it is directly obtained by the actual stratigraphy, it remains a rough estimate, since the real depth scale in the diagrams does change according to the different composition of each bed.

3.3.6. Problems encountered

The main problems related to the GPR survey were due to time constrictions.

The GPR equipment could only be loaned from NERC for a limited time, as it had been booked before and after for use in other research projects; this time was further reduced by a delay in the equipment's shipping back from the survey directly preceding this study's one. Part of the time was finally lost in the survey of about 600 metres of transects on a site that, due to the foot and mouth disease outbreak in 2000, had to be abandoned before the data collected there were sufficient to be used in this study.

Because of the limitations, and for the reasons noted above, the work had to be focused on the acquisition of the greatest amount of data in the shortest time possible. Apart for some quick test scans, options such as surveying with different frequencies could not be systematically performed, nor there was time to repeat the survey (for example with a greater number of stacked and averaged traces) if for any reason (such as noise or interferences) the data were not particularly clear.

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The limitation of the software caused another inconvenience. The wiggle mode display produced very long diagrams, resulting in proportionally long exported pictures. The wiggle diagram for the longest transect in Fishwick Bottom exceeded the size limits of the .pcx graphic format, the only one the software could export the diagrams in, and the resulting file was unreadable. As a consequence the interpretation of the Fishwick Bottoms transect had to be performed on the colour diagram only (Figure 31).

3.4. Palaeoecological analysis

Palaeochannel fill sediments at Higher Brockholes were analysed for pollen and Diatom content. The pollen analysis was performed in order to reconstruct the vegetation changes in the area, and to better understand processes of floodplain colonisation and stabilization and the possible effects of human influence. The size of the palaeochannel analysed suggests the pollen can be expected to be mostly of local source (Jacobson & Bradshaw 1981). Diatom analysis was aimed to assess the degree of environment salinity, and through it possible estuarine influences at the time of deposition.

The results of the analysis are presented in section 4.2.3.5 a pagina 158.

3.4.1. Sample collection

The organic-rich part of a palaeochannel fill was sampled along its entire thickness from a cross-section of the channel in a quarry face, by means of small

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monolith tins. Each sample was then wrapped in foil and kept at low temperature in a sealed sampling bag.

From the tin samples, sub-samples were taken at 5 cm intervals along the stratigraphical sequence. The tin sample's surface was removed before the collection of each subsample, which was extracted within a vertical thickness of ca. 0.5 cm and kept in a sealed and labelled glass sampling vial (Moore *et al* 1991). More sub-samples, for Diatom analysis only, were taken from sediment samples extracted as sediment cores from another point along the channel or collected as solid "chunks" from the material excavated from quarry test pits.

3.4.2. Pollen extraction

From each subsample an amount of ca. 0.5 cm³ was taken for pollen extraction. Two *Lycopodium* tablets were added to each subsample (Stockmarr 1971). The extraction was performed by KOH digestion followed by sieving of the fraction between 10 and 100 µm and acetolysis; the extracted material from each subsample was stained with safranin, then suspended in silicone oil and kept in a labelled glass sampling vial.

3.4.3. Pollen counting

From the pollen subsamples slides were prepared, that were then examined at a magnification of 400×. The observation systematically covered each slide's surface in subsequent non-adjacent traverses; the pollen grains observed were

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determined and counted up to a count of at least 200 grains (excluding aquatic plants and spores) and at least 50 exotic (*Lycopodium*) spores.

3.4.4. Presentation of the data

The data were entered in TILIA 2.3 (Grimm 1991), the software used to produce pollen diagrams. The diagrams included graphs for individual taxa and for trees, shrubs, herbs, aquatics, spores, charcoal fragments and sulphide spherules. The values for trees, shrubs and herbs were expressed as percentages of total land pollen; the values in the other graphs were expressed as percentages in respect to land pollen.

3.4.5. Sources of error

The quality of the sub-samples varied widely, and in some cases visibility of the pollen grains on the slides was greatly hampered by the abundance of other mineral and vegetable fragments. In one case, the pollen count in the whole slide could not reach the minimum limits sought.

3.4.6. Diatom analysis

Diatom extraction from the sediments was performed by hot digestion in 20% H₂O₂ for 20-30 minutes or until all organic matter had been oxidised. The

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resulting suspension was evaporated directly on a cover slip, then mounted in Naphrax.

When observed on the microscope, no Diatoms were found in any of the prepared slides. Slides from different samples were prepared several times with varying amounts of H₂O₂ and digestion times, with no difference in the results. When the same preparation process was applied to samples of water and mud freshly collected from a pond, however, Diatom frustules were found in the slides. It was concluded that the absence of Diatoms in the samples from higher Brockholes was not due to their destruction during extraction, and that the sediments were actually barren of Diatoms.

3.5. ¹⁴C dating

A number of sediment units with sufficient organic content were sampled for radiocarbon dating.

3.5.1.1. *Sample collection*

The samples were taken with monolith tins or Kubiena tins from open cleaned sections. In the case of the Higher Brockholes palaeochannel (already mentioned above) the same tin samples subsampled for pollen analysis were used for dating. In one case, the outermost rings of a dead tree trunk were directly sampled by cutting off a chunk of wood. All samples were wrapped in foil and kept at a low temperature in a sealed sampling bag.

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Each sample was then carefully sub-sampled, taking care to avoid cross-contaminations. After removing the surface of the sample, a sub-sample of ca. 3 cm³ was cut from it and immediately wrapped in foil, then put into a labelled sealed plastic bag and kept at a low temperature. Where the sample was meant to date a unit's top or bottom, the subsampled material comprised the unit's topmost or bottom-most ca. 2 cm; from the wood sample, the outermost ca. 2 cm were subsampled.

3.5.1.2. *Dating essays*

The dating of the sub-samples was performed, in two separate batches, by the NERC Radiocarbon Laboratory in East Kilbride. Their codes for the essays are reported in **Table 1**.

The results were finally calibrated with the CALIB 4.3 software (Stuiver & Reimer 1993); they are presented in section 4.2.3.4 on page 151.

3.5.1.3. *Difficulties encountered*

All the dated samples were collected from open faces (except the tree trunk one, essay AA-48971; see table 1), and all of them relate to the same river terrace (see section 4.2.3.4 on page 151). More samples (potentially yielding 4 to 8 more dates), referring to different terraces, had been planned to be collected from buried palaeochannel sediments by means of a closed-chamber corer, since the gouge corer could not have prevented contamination of the samples. This

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method of sample collection, however, was not as straightforward as the collection from open faces with sampling tins, and necessitated greater planning, preparation and time. The operations were unfortunately interrupted by the outbreak of foot & mouth disease in 2000, and could not be resumed.

4 – Results of study

4.1. River terraces on the lower Ribble

4.1.1. Surface geomorphology

4.1.1.1. *Valley floor*

Breaks of slope, separating ground surfaces at different elevations, are visible throughout the valley floor. Although some of them mark palaeochannel edges (*see below*), most of them are likely to represent the edges of river terraces. Different terrace surfaces can be recognised in each meander's area, and observation at various points along the valley suggests the existence of four distinct river terraces. A complete map of the terraces as deduced from the geomorphology is shown in Figures 8-9.

In some cases, as in the Lower House/Balderstone Hall meander (see Figure 8), the terrace edges run concentrically inside the river's bend, suggesting its course has broadly maintained a similar planform geometry since the incision of the highest terrace – though the course of the active channel seems to have undergone a northerly migration over time. Elsewhere – as in the Fishwick Bottoms and Brockholes areas (see Figure 9) – the disposition of terraces is variously complicated and includes isolated residual parts of higher terrace

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surrounded by lower ground, recording discrete shifts (avulsion) of river channel course. The breaks of slope that could be observed on the ground feature height differences ranging between approximately 0.5 and over 1.5 metres. Few breaks of slope were easily traceable for a long distance, however: the ground features have been partially lost by time and agricultural land use, and in many cases a wider-scale surface landform (such as terrace edges over a scale of hundreds or thousands of metres) had to be reconstructed from different visible fragments.

On most fluvial surfaces palaeochannels are also found (see Figures 8-9), still visible as hollow elongate features on the surface; most of them are easily recognisable as such. The palaeochannels observed on the surface of the higher terraces appear smaller than would be expected by comparison with the present course of the Ribble (see sections 4.2.2.1, 4.2.3.2 and 4.2.3.3 below). As with the breaks of slope, few palaeochannels are easily traceable for a long distance.

The directions of the palaeochannel courses vary widely. Many run concentrically, broadly parallel to the active channel and the terrace edges, in the middle of a terrace surface, as at Balderstone Hall or Elston. In other cases, such as at Fishwick Bottoms, Brockholes or Osbaldeston Hall – sites that have likely seen the greatest changes in the river's course (also see sections 4.2.3.3 below and 4.2.5.3 below) – the main palaeochannels can lie almost at right angle to the present course of the river and/or with the valley axis. Palaeochannels closely following the active channel on one side, especially on lower terraces,

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are also not uncommon, as in Elston (Plate 1), Alston/Boot Farm or South of Ribchester.

Few of the palaeochannels located on the valley floor can seemingly be considered active secondary channels: the present river channel is too much entrenched to reach them at ordinary flood time. During exceptional floods, however – once every few years – the Ribble can overflow the lower and even higher terraces, the water bypassing meanders along the course of old channels (local farmer's observation, Boot Farm). Many palaeochannels host temporary puddles or ponds over the winter (Plate 1, Plate 2), filled by rain and surface runoff. There is, however, no active flow in the channels. In such cases as Brockholes or Osbaldeston Hall there is peat formation continuing to present times in palaeochannels running along one valley edge (where the present river channel runs closer to the opposite valley edge).

4.1.1.2. Valley edges

The valley edges overlooking the highest terrace are partly eroded and lined with colluvial deposits, overlying part of the terrace and confounding its true landward limits. The slopes can be variously gullied or incised; in some instances they flow smoothly to meet the horizontal surface of the terrace (as by Waterside Farm, SD654349, or Sunderland Hall, SD623336), while in others (for instance by Elston New Hall, SD594321, or in the Fishwick Bottoms, SD555293) they join it in a more sharp break of slope, sometimes suggesting there could be

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tiny remnants of an even higher terrace; however, the evidence is not sufficient to support this possibility. The valley slopes directly lining lower terraces tend to be steeper and more regular, having probably been trimmed more recently by the river.

A number of alluvial cones overlie the terraces along the valley edges (Figures 8-9), generally standing out in correspondence with water drainage paths rather than at the mouth of secondary valleys; the cones' sizes do not exceed a couple of hundred metres across.

Several permanent or semi-permanent brooks of various sizes join the Ribble along the examined reach; some originating in the valley bed itself, from the ditches and drains between the fields, some flowing down from the valley edges. All those which flow in the main valley from outside have their own deeply entrenched valleys. Those (as Tun Brook, SD585321, see Figure 1) that join the Ribble where it directly skirts the valley edge can show some traces of delta at their mouths. The brooks flowing across the fields have entrenched their courses following incision of the Ribble; traces of shifts in their courses are often still visible. Moreover, many such brooks constructed small terraces along their lowest reach, that can often be correlated with the main Ribble terraces.

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4.1.1.3. *Effects of human influence*

Human influence is visible throughout the area, both as artefacts and anthropogenic landforms. Quarries are the most relevant – and most disruptive – of such landforms. An abandoned sand and gravel quarry occupies most of the distal part of the Lower Hall/Bezza Brook meander area (SD585318, see Figure 9), preventing any possibilities of interpreting the geomorphology. The gravel pits have totally removed most of the original ground surface, and the remaining fragments are too small to offer any clue to surface landforms, besides having undergone enhanced erosion and remodelling by water seepage. The pits themselves are now densely wooded and seasonally flooded (part of them is also used by local farmers to dump rubbish); vegetation growth and new soil formation have masked the sections that existed during the quarry's activity.

Most of the Higher Brockholes area (East of the M6 motorway) is occupied by an active sand and gravel quarry, progressively extracting the sediment fill. The quarrying process in different areas of the Brockholes meander has been observed for two years as it proceeded. This allowed a full record, in some parts of the meander, of both the surface geomorphology and the sediment sequence to be analysed (the data gained from the site are presented in section 4.2.3.1 below). Other parts of the Higher Brockholes area had been quarried away and/or disturbed or overlain by other structures or activities of the quarry before the field inspections began. Such information could only be partly

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reconstructed through available pre-quarrying data, but what information was lost in surface geomorphology was more than regained with the extensive stratigraphical and sedimentological data obtained from the fresh sections of the actively proceeding quarry.

By the North-Eastern corner of the Higher Brockholes area (SD585314, see Figures 9, 12) are the traces, now re-occupied by woodland, of smaller scale quarrying activity on the valley edge slope. The quarry seems to have been devoted to extraction of material – boulder clay – from the slope itself, and the possibility the extraction could have also affected some fragment of old, high terrace is not supported by enough evidence.

In no place has the Ribble built up prominent levées along its channels. Artificial embankments (recently rebuilt and enhanced) are present around the Walton Flats (SD282552), occupied by low terrace surfaces, in order to preserve it from flooding. Other kinds of earthworks are once again associated with the quarries: waste material from the quarry works has been accumulated as an embankment around the Eastern and South-Eastern side of the Higher Brockholes quarry (SD589306, see Figures 9, 12), to act as a screen between it and the surrounding farmland and village of Samlesbury and forming artificial hills as part of the project of rehabilitation of the area as a leisure park after the end of the extraction. An accurate survey and comparison with pre-quarrying technical data allowed the recognition of former high terrace surfaces where the artificial hills stand. There seem to be no outstanding waste heaps associated

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with the Lower Hall quarry, but the embankment of a tramway (likely used for the extracted materials' transport) is still partly visible along its South side. The traces of the Roman fort's boundary earthworks at Ribchester (SD650350) must be mentioned; no outstanding earthworks associated with what remains of the Walton Flats Roman area are visible today.

Some aqueducts are present in the area, mostly running under the ground surfaces; a minor pipeline across the Fishwick Bottoms area (SD559287, see Figures 1, 9) lies at ground level, appearing as a small embankment and probably conditioning at a minor scale the surface drainage; a similar feature is seen along the NW side of the Lower Brockholes area (SD576309, see Figures 9, 12). A much bigger effect on surface drainage, as well as the one of overlying to a vast extent the surface geomorphology and completely dividing areas in two parts, is caused by the imposing earthworks of bigger road and rail communications that run across the valley: the disused railway and tramway embankments at the downstream end of the surveyed area, directly South of Preston (SD542286-SD541274, see Figure 1), and over all the M6 motorway (SD578311-SD581303, see Figures 1, 12), that separates the Higher and Lower Brockholes areas as well as the Cuerdale and Samlesbury ones, and - by preventing surface drainage between the former two - likely favours the persistent filling of the Higher Brockholes palaeochannel ponds (SD580312, see Plate 2) over the Winter season.

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Buildings are obviously the most relevant source of disturbance concerning the recognising of superficial landforms. Major built up or “developed” areas, such as the settlements of Ribchester and Samlesbury, large parts of Walton-le-Dale and the southern outskirts of Preston with the main road connecting them, render any kind of survey impossible. Isolated buildings or groups of buildings, such as many farms, and their annexes (boundary fencings or hedges, etc) can also hamper survey, both through direct disturbance of the terrain and by acting as visual barriers. Buildings now removed can also leave areas of disturbed (artificially levelled) terrain. Across the local farmland fences are more frequently found than hedges, and also are a lesser hindrance than the latter; these, besides acting as visual barriers, also actively modify the ground’s shape, producing features that sometimes (especially if the hedge has disappeared) can be mistaken for traces of terrace breaks of slope. Tree lines can have similar effects. In some cases (as at Sunderland Hall, SD623336, see Figures 8, 10) hedges run along active ditches or streams, making it difficult to assess whether a difference in level exists between their banks.

One last example of anthropogenic disturbance in the area is that of the golf course almost entirely occupying the small meander area in front of Cuerdale Hall (SD575297, see Figures 1, 9): here it was not possible to recognise any landform with sufficient certainty inside the course’s perimeter.

4.1.2. Surface elevation and terrace profiles

Through the levelling of the valley floor (see section 3.1.2 on page 71) a longitudinal profile was obtained (Figure 7). In the profile four distinct terraces could be recognised, lying at different levels above the present river. The four terraces have been defined with names referring to key places where each terrace was observed and identified; from the highest to the lowest, they are **Ribchester Terrace, Brockholes Terrace, Walton Terrace and Cuerdale Terrace.**

4.1.2.1. *Identity and aspect of the terraces*

A general overview of the topography and morphology of the Ribble terrace sequence in the studied reach follows; the complete map of the terraces is shown in Figures 8-9. The picture presented here is the most consistent that could be drawn by considering the overall elevation profiles along the valley and with the contribution, where available, of stratigraphical and sedimentological data (see below).

(a) Ribchester Terrace

The highest and oldest terrace found in the Ribble valley is the *Ribchester Terrace*. The village and Roman fort of Ribchester (SD650350) stand on one of its most extensive fragments (Buxton & Howard-Davis 2000; Edwards 2000; see Figure 8). Lying at up to 5 metres and more above the present river surface, it

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flanks the valley borders and its surface often fades out under features related to it - slope or cone sediments - that partially cover it, making it difficult to recognise the precise landward limits of the terrace.

Fragments of terrace ascribed to the Ribchester unit are found throughout the Ribble valley, the most extensive ones being at Ribchester, Alston/Boot Farm, Elston (Figure 8), Lower Hall/Bezza Brook nursery and Fishwick Bottoms (Figure 9). Here (SD559287) and in the middle of the Brockholes area (being presently crossed lengthwise by the M6 motorway; SD580305) smaller remnant Ribchester Terrace fragments survived entirely isolated from the valley edges (after shifts in the main course of the river), being surrounded by lower terraces on all sides. Other smaller fragments along the valley sides are found along the rest of the valley. The larger surviving areas can also feature visible palaeochannels on their surface.

(b) Brockholes Terrace

The second highest terrace formation recognised in the Ribble valley is the *Brockholes Terrace*, forming the greater part of the Higher and Lower Brockholes areas and lying on average slightly over 4 metres above the present river surface. It is the most extensive surviving terrace, seven out of the fifteen main meander areas considered having half or more of their ground surface ascribed to it: Ribchester/Lower Alston Farm, Osbaldeston Hall, Sunderland Hall, Alston/Boot Farm, Elston (Figure 8), Brockholes, Fishwick Bottoms

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(Figure 9). Evident and abundant signs of palaeochannels are visible throughout most terrace fragments, often running concentrically suggesting meander widening or migration; the surface of the terrace can also extend inside indentations of the Ribchester Terrace edge, also suggesting the growth of meanders, as happens South-West of Ribchester (SD650350; see Figure 8) and North of Penwortham Lane (SD543275; see Figure 9).

(c) Walton Terrace

The *Walton Terrace*, lying at an average 3 metres above the present river surface, is much less extensive than its predecessors. The only localities in the study area where it does extend laterally, occupying a significant portion of the valley floor, are at Osbaldeston Hall (Figure 8), at Cuerdale (Figure 9), and the area between Walton-le-Dale and Penwortham Lane (Figure 9), apparently including a relevant part of the Walton Flats. Elsewhere the Walton Terrace floodplain seems to have been a strip of less than half a kilometre width, running along valley sides or between higher terraces (as in the Fishwick Bottoms, Figure 9).

Most of the Walton Terrace limits could not be observed directly in the Walton Flats (SD282552), since they lay under an urban area at the time of survey; they could, however, be reconstructed by studying the stratigraphy from the boreholes drilled in the area before it was built upon (see section 4.2.4.1 below). The terrace boundaries' position in the Walton Flats (see Figure 9) is to be

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considered approximate, with the exception of the short stretch North of Winery Lane, which at the time of survey was still lying in an open field. The Walton Terrace constitutes most of the central part of the Walton Flats, and seems to extend East under the present (and historical) Walton-le-Dale settlement. Its North limit (as shown in Figure 9) is hypothetical. The area's tendency to be frequently flooded (Hunt 1997) could suggest lower ground to extend across the North part of the Walton Flats; however, the flooding seems to have affected also part of the Walton Terrace grounds, and it needs not be a significant factor. The South-West limit of the terrace runs in part along the former course of the Darwen (see sections 2.3.5 above and 4.2.5.2 below and Figure 3) and extends forming a spur along it. Directly South of it, a separate Walton Terrace fragment seems to be present North of the River Darwen, formerly connected to the Walton Terrace ground in the adjoining area North of Penwortham Lane (see sections 2.3.5 above and 4.2.5.2 below and Figure 3); the two parts of the Roman archaeological site correspond to these Walton Terrace areas (see Figure 9).

(d) Cuerdale Terrace

The *Cuerdale Terrace* is also mainly found as linear stretches occupying the sides of the present river banks around 2 metres on average above the present river surface, and delineating what would have been a narrow floodplain locked between the edges of the higher terraces, as happens along the present

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Cuerdale area. In some cases the Cuerdale Terrace is missing altogether, the Walton (or higher) Terrace directly forming the present channel banks.

An outstanding exception is at Balderstone Hall (Figure 8), where a wider stretch of ground is found, seemingly identifiable as part of the Cuerdale Terrace. Several palaeochannels are visible there, running concentrically and suggesting progressive meander widening. The only other Cuerdale Terrace fragment bearing clear traces of palaeochannels, most likely formerly belonging to the River Darwen, is in the Walton Flats area (Figure 9).

(e) Lower and higher elements

Some of the points do not appear to fit in the four-terrace scheme, being either too high above the Ribchester Terrace or too low below the Cuerdale Terrace. It is likely that the surfaces the high points were recorded on - 1 metre or more above the Ribchester Terrace, and close to the foot of the valley edges - are actually part of the slope scree or colluvium or of alluvial fans along the valley sides. It is not impossible, however, that some of them may represent small fragments of a higher and older terrace, now almost completely reworked.

The low elements (1 metre or less above the present river surface) are too few and apparently not consistent enough to suggest an extensive aggradation event subsequent to the Cuerdale one. It appears, however, that some minor depositional units have been formed locally at various points along the river after the incision of the Cuerdale Terrace, and that most such units have been

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re-incised afterwards leaving small terrace-like fragments between the sides of the higher terraces and the present river banks. Such small units are found in several places along the present river channel, especially towards the upstream half (such as Lower Magdell Bank, Osbaldeston Hall, Hothersall Hall and Sunderland Hall, Figure 8); their elevation above the river's present low-water level is usually not more than 1 metre. All observed occurrences of these late depositional units have been re-incised, with steep sub-vertical banks often directly over water.

4.1.2.2. Observations about the terrace profiles

The terrace surface altitudes approximately range in the area of study between 6 and 23 metres OD. The elevation difference between each terrace and the ones above and below is, on average, about 1 metre, though this difference varies much due to various irregularities. The ground surface in correspondence with many palaeochannels seems also to lie up to 1 metre below the surrounding terrace surface, whereas the present low-flow level of the Ribble can be up to 3 m lower than the youngest terrace surface.

Towards the downstream end of the area of study the terraces appear graded to a base-level. The Ribchester Terrace, in particular, appears to be graded to a base-level of 8–9 m OD; a corresponding relative sea-level is not recorded within the Holocene (see section 2.1.1.2(b) on page 16).

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The terraces' gradient appears to be lower towards the upstream end of the EDM surveyed area. The gradient could increase, then decrease again moving upstream in the area left un-surveyed due to the foot & mouth disease: at the upstream-most sites visited (Waterside Farm/Lower Magdell Bank, SD654349, and Ribchester, SD650350) all four terraces were observed to lie several metres above the Ribble, while mid-way between there and Sunderland Hall (between Hothersall Hall, SD627343, and Osbaldeston Hall, SD640345) the lowest terrace lies less than 2 metres above the Ribble. These, however, are observations unsupported by precise measurement; it is better not to advance hypotheses without more precise data.

4.2. Stratigraphical and sedimentological data on the aggradation of terrace fills

4.2.1. General observed structure of the terraces

The Ribble valley between Ribchester and Preston is deeply incised in glacial till, down to underlying bedrock (Bunter Sandstone). The altitude of the bedrock surface, which can be weathered, varies widely from place to place, in a space of hundreds or even only tens of metres; the valley floor can therefore lie within either till (boulder clay) or sandstone. Both valley sides are made up entirely of till.

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The terrace sediment fill overlying the valley bed generally features coarser (gravelly) material at the base, overlain by finer (sandy and silty) material (De Rance 1877); this appears to be broadly true for all terrace fills (see also sections 4.2.2.2 below, 4.2.3.2 below, 4.2.4.2 below, 4.2.5.2 below). In the areas where the bedrock surface rises (as happens along the South-Eastern side of the Lower Hall area), the lower parts of the sequence need not be present, the upper (finer) sediments directly lying on solid or weathered sandstone. At such places the bedrock can even directly form active channel bottoms, as in the Ribble North of Lower Hall farm (SD598315) or in Bezza Brook by the nursery of the same name (SD591311). The sandstone surface dips down quickly: less than 500 metres downstream of the nursery, and about 100 m before joining the Ribble, Bezza Brook ceases to have a rock-cut channel bottom.

4.2.2. Ribchester Terrace

The Ribchester Terrace is the oldest surviving valley fill, deposited after the valley was carved within boulder clay. Much of the terrace was reworked during the incision and redeposition processes that lead to the formation of the three younger terraces. In many cases some of the original Ribchester Terrace gravels could still lie untouched at the base of the sediment sequence under the younger terrace fills, especially where the bedrock surface is deeper.

4.2.2.1. Sources of data

All direct information about the stratigraphy and sedimentology of the Ribchester Terrace is provided by sequences from pre-existing boreholes (from civil engineering surveys) and a manual sediment core.

(a) Boreholes and sediment cores

Several boreholes were drilled in conjunction with the M6 motorway widening works where it crosses the valley floor between the Higher and Lower Brockholes areas (SD578311–SD581303), lying along its roughly North-South course and aside from it where new slip roads were due to be built. Four such boreholes were sited where the motorway ran across a part of the Ribchester Terrace, and record its stratigraphy. Four more boreholes were drilled further East, in conjunction with the Higher Brockholes quarry works, the northernmost one through Ribchester Terrace sediments. The positions and identifier of the Brockholes boreholes are shown in Figure 12; their sediment sequences are shown in Figure 22.

Boreholes 256, 203, 202 and 249 lie within Ribchester Terrace sediments; 256 and 249 are closer to the terrace's erosional boundary with the Brockholes Terrace, while 202 and 203 lie in the terrace's interior area. In boreholes 256, 203 and 202 a gravelly unit about 2 m thick is present mid-way up the sequence – 2 to 3 m from the present (artificial) surface, underlain by 4 m or more of sandy materials. Above the middle gravels only sandy/gravelly materials are seen in

borehole 203, while in 202 a sandy and clayey sequence is found. The lower part of the sequences mostly feature sandy and/or clayey materials; some fine gravel is frequently present, but no other mainly gravelly units are visible. In borehole 249 only a unit of gravelly sand slightly over 2 m thick is visible between the bedrock (the top surface of which is considerably higher than in the other boreholes) and the overlying almost 6 metres thick M6 fill. Such unit's composition appears similar to that seen in the other three boreholes' lower part, though it lies at a level comparable to their middle gravel unit.

Two more pre-existing civil engineering boreholes show the Ribchester Terrace stratigraphy in the Elston area (SD600320), where they lied along the path of an aqueduct (see Figure 11). Finally, a manual sediment core was extracted from the terrace near Sunderland Hall (see Figure 10). Their sediment sequences are shown in Figure 16.

In Elston, boreholes 25 and 26 lie within Ribchester Terrace sediments. Borehole 25 was interrupted before reaching the base of the alluvium; the part of the sequence covered by it shows two metres of sand and gravel directly overlain by an equal thickness of clay. The complete sequence found in borehole 26 is different, being somewhat gravelly throughout its entire thickness, and particularly towards its top. The lower units are finer, being mainly sandy but still containing gravel. Above, the sediments are mainly gravelly; sand and gravel in the middle unit, sand and clay in the top one. Some clay also appears in the sandy unit just below the main gravelly one. The 3 metres deep sequence

from the Sunderland Hall core starts with sand and gravel and gradually fines up, becoming less gravelly and more clayey up to the silty/clayey topsoil.

(b) Observations from GPR transects

Figure 31 shows the GPR output diagram from the Fishwick Bottoms transect (see Figure 14), with an interpretation of the features visible in it. The diagram appears less clear than the others, due to the fact that only the “colour” (variable intensity) diagram could be used. The graphical approximate depth scale shown in the figure is the one derived from the comparison of the Walton flats diagram with sediment core data (see sections 4.2.5.1 below and 3.3.5 on page 90).

At the North (left in Figure 31) end of the transect is part of the Ribchester Terrace. Within the terrace fill a palaeochannel section can be recognised, about 20 metres wide and with an approximate depth of over 3.5 m; the ground surface does not reveal its presence. Beside the channel on its South (right) side, as well as further North (left) of it along the diagram, traces of trough cross-bedding seem to be present, possibly suggesting the position of older buried channel bottoms – though this can only be a tentative interpretation.

Another long transect (Figure 32) was taken downstream, in the area between Walton-le-Dale and Penwortham Lane, shortly downstream of the Darwen-Ribble confluence. The whole width of the valley could not be spanned, due to

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the land on the North bank of the Ribble being urban; the GPR survey line covered the width of valley floor South of the Ribble, starting not far South of its present course and ending almost at the valley edge's foot. The graphical approximate depth scale shown in the figure is the one derived from the comparison of the Walton flats diagram with sediment core data (see sections 4.2.5.1 below and 3.3.5 on page 90).

The high ground visible by the diagram's South (right) end corresponds to an area identified as part of the Ribchester Terrace. The section of a buried channel, about 30 metres wide and reaching an approximate depth of 3 m, seems to be recognisable here near the right (South) end of the diagram; the size of such channels would appear larger than the channel observed at Higher Brockholes from open section (see section 4.2.3 below), but still much smaller than later and present ones. At the channel's left, the terrace's structure shows what may be interpreted as trough cross-bedding and could represent parts of former channel beds; the whole complex, over 70 metres wide, could also be interpreted as the section of a braided-type channel (see also Vandenberghe & van Overmeeren 1999).

Under the buried channel section it may be possible to see the surface of the bedrock or till – the actual bottom of the valley's alluvial fill – rise towards the valley edge (standing shortly South of the transect's and diagram's end). The presence of a tall metallic fence at the transect's end must be taken into account in interpreting such traces; however, the interference caused by the fence would

have been expected to produce different GPR traces (similar to those seen elsewhere in the same diagram).

The profiles of what could be interpreted as two buried very small channel or ditch features (ca. 10 metres across) can be faintly seen further North, at around 400 m.

4.2.2.2. Structure of the terrace

The Ribchester Terrace fill appears to contain large quantities of gravelly sediments; however, clayey material is apparently also frequent, both as discrete beds and as a secondary component of coarse-grained sediments. The sediment sequences observed vary greatly from each other; generally speaking they seem to be characterised by fining up sediments from gravelly to sandy materials and up to uppermost layers of clay. Where the bedrock lies deep enough, below the uppermost gravels clayey units can be present, themselves overlying sandy (and slightly gravelly) sediments. This lower part of the sequence apparently tends to feature relatively poorly sorted sediments, often containing fine (silt to clay) and coarse (coarse sand to gravel) material mixed together. The upper part of the sequence seems to be about 4 metres thick at Brockholes (but only 2 m at Elston); the main gravelly unit has a thickness of about 2 metres. The lower part of the sequence, where present, can be more than four metres thick. Though it is not expressly described as such by the borehole engineers, the possibility that all or part of it may actually represent

weathered bedrock or be an uneroded part of the glacial till formation must be taken into account, as well as the one of it being resedimented till or glacio-fluvial sediment.

Sequences of the type described above are represented in boreholes 203 and 202 (Figure 22) and S4 (Figure 23) in the Brockholes area, in borehole 25 at Elston (Figure 16) and in the Sunderland Hall core (Figure 16), and likely also in Brockholes' borehole 256 (Figure 22). Possible correlations between the various units seen in the Ribchester Terrace boreholes at Brockholes are shown in Figure 22. What is seen in borehole 26 at Elston (Figure 16) seems to be a stratigraphical variation in which gravelly sediments lie somewhat higher and extend to the sequence's top, ending with a layer of clay-rich sandy gravel. The limited stratigraphy visible in borehole 249 (Figure 22) could represent another variation.

4.2.2.3. Evolution of the terrace

The palaeochannel evidence upon the Ribchester Terrace is fragmentary, as is what survives of the terrace itself. The palaeochannels observed mostly run more or less lengthwise in respect to the valley axis; in the North Penwortham Lane area a possible braided channel section was picked up by the GPR (see section 4.2.2.1 above). The picture possibly suggested is of a straighter, possibly braided course running along a narrower valley.

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The shape of the valley edges, however, also features major indentations adjacent to parts of the Ribchester Terrace, especially at Alston (SD613337; see Figure 8), North of Penwortham Lane (SD543275) and at Fishwick Bottoms (SD555293; see Figure 9). At the latter site are also two palaeochannels running transversally in respect to the valley axis, unlike the other Ribchester Terrace palaeochannels observed. The evidence suggests that during the Ribchester stage some valley widening occurred as growing meanders carved in the valley edges. It is thus possible the Ribble assumed two different patterns during the Ribchester stage, braided and meandering, or that a “wandering gravel” anabranching system existed; the scarcity of the available evidence, however, does not allow any more detailed hypotheses.

The extension of the Ribchester Terrace in the Lower Hall/Bezza Brook meander just upstream of the Brockholes one (SD593314; see Figure 9) suggests that at the time the bend had already formed in the position it still occupies presently, though it likely did not still cut so far in the North valley edge (its distal part is indeed formed by a later terrace). The till spur between Boilton Wood and red Scar Wood (SD585314) acted therefore as an obstacle, preventing the Lower Hall/Bezza Brook meander from migrating or growing downstream, and causing it to be compressed sidewise and widen lengthwise only, carving in the North valley edge. When the Ribble incised the Ribchester Terrace, this allowed the preservation of part of it as a defended cusp (*sensu* Davis 1970) jutting out from the North valley edge along the direction of the spur. This Ribchester Terrace fragment (SD589309) extends towards South-East and

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transversally to the valley axis, its tip reaching rather close to the South valley edge. The part of the terrace that survived inside the Lower Hall/Bezza Brook meander (SD593314) lies just across the Ribble, and all the post-Ribchester Terrace floodplains appear to have been narrow at that point, being constricted on both sides between the higher terrace areas.

The BREMETENNACUM Roman fort at Ribchester (that stood over what is presently the South-West border of the town; SD650350) stood on the Ribchester Terrace (see Figure 8), in what must have been a stable area safe from flooding and still easily accessible from outside the valley (downstream of there the valley edges become steeper). In its present position the Ribble has cut off the East corner of the fort's perimeter, but at the time of the fort's construction, the river must have flown clear of it, though not far away (Buxton & Howard-Davis 2000; Edwards 2000). Only during the later centuries has the Ribble's channel shifted its course towards North-West, carving its bank in the Ribchester Terrace and eroding part of it away. The course, however, seems to be stable again, and the position is apparently safe at present.

4.2.3. Brockholes Terrace

The Brockholes Terrace is the best studied of the lower Ribble terrace fills. Thanks to the quarry works ongoing in the Higher Brockholes area a great quantity of information could be obtained about the structure and evolution of the terrace.

4.2.3.1. Sources of data

Data about the stratigraphy and sedimentology of the Brockholes Terrace come from a number of different sources. A major amount of data was collected in the Higher Brockholes quarry; more data come from different sites in the study area.

(a) Sediment cores and test pits

All sediment cores extracted from the Brockholes Terrace are from the Higher Brockholes area; their location is shown in Figure 12. A number of cores were extracted along a transect (marked ABCD in Figure 12) running across two palaeochannels; another core (marked P in Figure 12) was extracted West of the ABCD transect, further down the same palaeochannel.

The stratigraphy found in the cores is shown in Figure 17. The palaeochannels crossed by the transect both show clayey and silty fills, in different layers, with laminations and with frequent presence of peaty material. Fine sand also tends to be present, and the channel sequence can feature sandy levels intercalated to the clayey sediments. The sequences are topped by peat units, some of which (especially near the middle of the channels) were still growing at the time of the survey, during channel flooding as seasonal ponds.

A number of quarry test pits, opened by means of an excavator before extending northwards the extraction area active at the time were also observed

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at Higher Brockholes quarry. In Figure 12, Greek letters (α to θ) mark their approximate location. The sediments visible in the test pits are shown in Figure 18, in an approximate form; to log more accurately the stratigraphy inside the pits was not possible due to time constraints and safety issues. Nevertheless, the pits yielded some useful information that can be compared with that observed in the nearby cores.

The pits labelled γ , δ and η are aligned in the higher ground area between the two palaeochannels at points B and C (see Figure 12); δ and η show a large amount of sandy sediments, consistent with what is observed in the transect cores at 42 and 60 m (Figure 17), approximately aligned with the two pits. In pit γ different sediments are present, closer to what is recorded in the open faces South of there.

Pits ζ and α were excavated by the North edge of the palaeochannel at B (see Figure 12). They show peaty sediments overlying silty and sandy ones, and may bear resemblance to the transect cores at 12, 24 and 38 m (Figure 17). Pit ϵ , closer to the palaeochannel's South edge, in its sandy and peaty sequence recalls most the core at 42 m (Figure 17), which it also lies close to.

Pits β and θ were dug close to the lowest point of the palaeochannels' depression. Though lying in different palaeochannels, their stratigraphies were very similar, featuring thick layers of peat overlying soft clayey and silty sediments. Such a sequence is consistent with what is observed in the same

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channel at core P (Figures 17, 12) and in the palaeochannel South of there at point G (Figures 34, 12), most likely a continuation of that channel.

(b) Open faces

South of the palaeochannels at points B and D (see Figure 12) the structure of the Brockholes Terrace was observed along open quarry faces, marked E and FG in Figure 12. A section of the face at point E is shown in Plate 3; it features a rather regular structure, with finer sediments in two thick units, the top one very rich in clay, above a lower coarse unit of sands and gravels.

The filling material visible at the face's top, mixed with the topsoil, is found throughout the immediately surrounding area, and is seen in the faces at points E, FG, H (see Figure 12). Its origin can likely be traced back to the construction of the M6 motorway across the Brockholes area and, later, to its widening.

The face at points FG (in Figure 12) at the time of survey was less fresh than the one at point E and not as deep, ranging from less than 2 metres from the former soil surface at its North end to about 5 metres at its South one. The stratigraphy was logged at several points along the face, starting from its North end (at the time of the survey), as shown in Figure 19. The face also cut through another palaeochannel, apparently another part of the one already sampled in the transect at ABCD and core P. Its stratigraphy was also recorded at several points and is shown in Figure 19; its section is drawn as Figure 34.

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The stratigraphical sequence North of the palaeochannel broadly continues the one observed at E – sand and gravel at bottom, then silty/sandy materials, then silty/clayey ones. The gravel top rises higher at 30.3 metres and at 59 m (see Figure 19), where a coarse sand layer is visible intercalated in them.

The sequence found in the palaeochannel's fill, above the same sandy gravels and a silty sand unit, features clayey sediments at the bottom, but its bulk is made up by a thick mass of peat, overlain by overbank-type clayey silts. The bottom clayey units, especially the one labelled 4 in Figure 34, were also recognised in the palaeochannels at North, in core P and inside the quarry test pits. The channel sequence is buried by a great amount of artificial filling material.

More open faces allowed information to be gained about the stratigraphy and sedimentology further South-Eastwards, as shown in Figure 12 (areas marked H and IJKL). One of the faces at point H is shown in Plate 4; in the same plate the face at points IJ can also be seen in the left background. The face at points IJKL was not as neat a cut as the ones North: at the time of the survey, it had been already weathered over a winter and started to slump in many places; moreover, it had never been a smooth vertical cut, but in most points the excavators had left it as a two- or three-step or oblique surface. Figure 21 shows logs taken along a section approximately mid-way along the face (at about J). In Figure 20 are drawings of the face at other points along it.

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A basal gravel unit is present here as at the other places examined, overlain as well by finer materials; the stratigraphy, however, appears to be more complicated. The section of face shown in Figure 20a, observed at about 185 m from the face's South end (between points H and I in Figure 12) appears representative of the sediment structure North of point I and at other points, such as by the face's South end (point L). Here the finer sediment unit - unlike that recorded in the E-F section - shows marked cross-bedding in its middle part, while the top generally maintains a sub-horizontal bedding. It is also evident how the gravelly unit's top can vary in height.

Figure 20b and 20c represent the face as observed at points I and K, at two similar small channel sections. At the bottom lie dark peaty sediments; at point I (Figure 20b) only their top part was visible, on the ground in front of the face's foot. At point K (Figure 20c) a section of the channel's basal fill could be observed as consisting at the bottom of compact, finely laminated leaf-rich peat, intercalated with thin clayey silt beds with only minor organic content. The silty beds become thicker and sandier upwards, until only thin peaty beds remain between them. Above the channel bottom fills lie bulky silty clayey units, that extend until merging upwards and laterally with the topsoil and silts already observed (as in Figure 20a); it was not clear if the silty clay and the overbank silts actually faded into each other. At point K (Figure 20c) only clayey sediments are visible above the bottom peaty fill, while at point I (Figure 20b) silty and sandy materials are also present. The clayey unit at point I also

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featured some measure of bedding or graded layering and shows organic content in some beds.

The sediments lying beside the two small channels again show intense cross-bedding. The sedimentology is also more varied, with intercalated peaty beds and grain size increasing in some beds to coarse sand. Such structuring is also visible within the gravelly unit, and gravel-rich beds are found intercalated with the sandy and silty sediments; the gravelly unit's actual "upper limit" actually appears not to be precisely defined.

Between the two small channels (at point J in Figure 12) the face was two-stepped and not neat enough to be entirely drawn; it however allowed the vertical logging of the stratigraphy at seven points along a 25-metre section. The results are shown in Figure 21: towards the top, finer sediments are found, with mostly horizontal or sub-horizontal bedding; the middle part of the sequence features fine to coarse sediments, variously graded and cross-bedded, and frequently intercalated with organic-rich beds. At the bottom, such bedding seems to be also visible in the upper part of the gravelly unit, and gravelly and finer beds are often intercalated together. The nature of the sediments and the conditions of the face did not allow the measuring of dip direction.

The quarry faces across the Higher Brockholes area also revealed the presence of features that were interpreted as buried ditches. Their sections were only partially visible at the time of observation; the steepness of their visible sides

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and apparent width/depth ratio, however, suggested them not being natural channels. The section of one of them, lying North-East of the faces at point H (see Figure 12) is shown in Plate 5. The ditch's bottom fill features silty sandy clay with a high content of peaty material and is overlain by nearly 1 metre of peat, containing abundant wood branches and pieces (some of which were cut by axes) and some clasts of compact clay. The sequence is buried to ground level by the usual artificial fill. Beside the ditch, the basal gravel unit can be observed, only little more than 1 metre below the surface.

The kind of general stratigraphy observed at Higher Brockholes was confirmed in the Lower Hall meander just upstream (Figures 1, 9), where a quarry also occupies a relevant part of the area. No open sections were present, since the quarry has been inactive for a long time; the observations made suggest the presence of the same kind of sediments and sequences.

One more open face was observed upstream near the South-Western corner of the Sunderland Hall meander area, as shown in Figure 10. Here a brook had cut deeply in Brockholes Terrace sediments, leaving at one point (in front of a bend) a nearly vertical exposure approximately 3 to 3.5 metres deep. From the face's foot (in correspondence with the brook's water surface at the time of survey) a sediment core was extracted, to a depth of 45 cm (where the manual corer hit gravel). The bottom 1.5 metres about of the sequence consist of a grey silty/clayey unit, apparently slightly fining up and with many interspersed plant fragments; the sequence above was not precisely logged, also due to the

difficulties in reaching it; it apparently contained silty and sandy materials. The Sunderland Hall face stratigraphy is shown in Figure 16.

(c) Pre-existing boreholes

Data from civil engineering boreholes expand the information gained from the field observations described above. Some of the boreholes drilled in conjunction with the M6 motorway widening works record Brockholes terrace stratigraphy, as well as two of the ones drilled in conjunction with the quarry works (see section 4.2.2.1 above). A solitary borehole from the middle of the Lower Brockholes area completes the set. The position and identifier of each borehole is shown in Figure 12.

Figure 22 shows the sediment sequences from the M6 boreholes; many of them were drilled through the pre-existing motorway embankment, and their original sequence is topped, and likely often truncated, by its filling material. Boreholes 207 and 258 lie within Brockholes Terrace sediments. Below over 6 m of artificial fill, the sequence in 258 shows a simple sequence of 2 m of basal gravels overlain by 1.5 m of sandy material, consistent with what observed in the nearby open face at point E (see Figure 12). The sequence in borehole 207 – below a similar thickness of fill and above over 5 m of gravel – features nearly 4 m of clayey sediments, possibly consistent with what observed just East, and could be related to another palaeochannel (now buried under the motorway).

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The logs from the quarry boreholes are shown in Figure 23. Boreholes S2 and S3 lie within Brockholes Terrace sediments; they show a simple sequence with gravelly materials overlain by silty sand.

The stratigraphy from the borehole in Lower Brockholes, also shown in Figure 22, appears to have been just broadly sketched by the surveyors - “running sand” down to around 6 metres, lying directly on bedrock, without any more precise observation. The absence of a coarse basal unit must also be noted.

(d) Observations from GPR transects

A test GPR transect was taken along the South-East quarry face at Higher Brockholes (see Figures 12, 14 and 33), on the ground above it approximately between points J and K (see Figure 12). The output diagram is shown in Figure 28 (elevation data are not included in the figure).

The face’s brink was bordered by a line of heaped filling material from the quarry excavation, and the GPR transect had to be taken at several metres of distance from it. For this reason a direct comparison of the GPR diagram with the stratigraphy observed on the face itself (Figures 20 and 21), similar to what performed in the Walton Flats between the GPR diagrams and the sediment core data (see section 4.2.5.1 below), was not possible.

In the South-East (right) part of the diagram in Figure 28 the section of the palaeochannel at point K can be recognised, following North from its point of

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intersection with the face. On both sides of the channel, the diagram's traces suggest the sediments' bedding have a general oblique trend towards left (North-West), though with many irregularities. The possible sedimentology corresponding to the discontinuities observed in the diagram is also shown on it, as inferred from what observed along the face. Such indications must be considered a possible interpretation only, given the absence of direct correspondence with the observed stratigraphy.

For the same reason, the actual depth of the sediments could not be directly inferred from the stratigraphy. The graphical approximate depth scale shown in Figure 28 is the one derived from the comparison of the Walton flats diagram with sediment core data (see sections 4.2.5.1 below and 3.3.5 on page 90).

Continuing South from the Ribchester terrace, the Fishwick Bottoms GPR transect (Figure 31; see section 4.2.2.1 above) cuts across part of the Brockholes Terrace. The stratigraphical boundaries between it and the Ribchester Terrace fill do not appear clearly in the diagram. A palaeochannel can be seen here at around 170 m along the diagram's length, about 20 m wide and approximately 3.5 m deep. Traces of former channel bottoms seem to be visible also beside it.

The South (right) part of the diagram also refers to part of the Brockholes Terrace. A palaeochannel is visible here at around 750 m, similar in size to the one seen at 170 m. Another palaeochannel, near the South (right) end of the diagram, appears wider but shallower, being about 40 m wide with an

approximate depth of 2 metres. North (left) of it a shallower feature is visible, possibly a shallower channel or a pond. The diagram suggests the presence of another palaeochannel section at its South (right) end, truncated by later river erosion (the transect ended close to the present river bank).

Extensive traces of cross-bedding and oblique bedding can be seen along this part of the diagram, suggesting lateral accretion and channel migration (Taylor & Macklin 1997; Jackson *et al* 1998; Vandenberghe & van Overmeeren 1999); the channel features identified above could also be interpreted as wider, migratory forms. The general pattern seems to be consistent with the bedding observed in the Higher Brockholes transect (Figure 28).

4.2.3.2. *Structure of the terrace*

The structure of the Brockholes Terrace could be widely observed in the open sections of the working quarry at Higher Brockholes. It is the best understood of the terrace fills.

(a) Terrace fill

The generalised sequence found in the Brockholes Terrace is, as in other terrace fills, broadly fining upward. At the base are extensive sandy gravels lying on more or less weathered bedrock (Bunter Sandstone), while finer materials (sand and silt, with some clay) are at the top. Such a sediment succession can be seen in borehole 258 in Figure 22, and boreholes S2 and S3 in Figure 23, in the face

shown in Plate 3, in the logs taken south of it (0-66 m in Figure 19), in Plate 4 and in the logs and sketches from the South-East face (Figures 20 and 21). The quarry observations provide a more laterally extensive and detailed picture of this sequence and its variations on the short to medium horizontal range, particularly showing the fact that at some places (such as along the South-East face (marked HIJKL in Figure 12, see Figures 20 and 21) the boundary between the basal gravels and overlying fine material is widely irregular and often not well defined. Between the basal part (mostly sandy gravels, several metres thick) and the top part (sand or finer materials, 1 to 2 m thick) there can be an area (1 to 3 m thick) in which coarse and fine sediments coexist and alternate in various ways, with gravelly beds often overlying finer sediments (such as sandy or clayey silt) and frequent oblique bedding or cross-bedding.

Such styles of bedding, as well as flatter, overbank-type ones, can also be observed in the finer materials above. Organic-rich layers are frequently intercalated with the sediments in the middle and upper parts of the sequence.

The Brockholes Terrace stratigraphy shows a great deal of horizontal variation; in order to provide a general overview of the terrace's structure a schematic generalised section of the Higher Brockholes area is shown in Figure 33. The picture does not represent an actual continuous section through the Higher Brockholes area: it is an interpolated composition of the sections from point A through L (in Figure 12), based on all the different observations performed on the various cores, pits and open faces in the area.

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At point A, by the left (North) side of Figure 33, the basal gravels are shown to rise in height almost to the surface. However, this is only a possible deduction drawn from the fact the corer hit impenetrable material at a low depth from the surface. Such hard material could as well be boulder clay continuous with the valley border (that rises at a short distance to the North) or even some artificial fill (widely observed elsewhere in the area). If gravels actually rise in this way, they could actually represent an unrecognised fragment of higher (Ribchester) terrace, locked between the Brockholes units and the North valley edge.

The gravel's top also rises by the ditch shown in Plate 5, sited North-East of the faces at H (at a point that would be "behind" point H in Figure 33). Here the sediment sequence is much simpler than is found further South-West (as represented in Figure 33): only about 1 metre of overbank-type sandy silts bordering almost sharply with the basal sandy gravels. Their top comes up here to such a shallow depth, but in the nearby face at H (see Plate 4) they were observed to extend down for several metres - the bedrock surface remains deep.

The area at points E-F in Figure 33 appears to have a quite regular structure. Its top two-thirds consist of fairly uniform overbank-like silty/clayey sediments, while below them sandy materials can be observed, as well as mixed (sandy/clayey) ones. The limit with the basal gravel seems to be almost sharp, though it shows wide variations in altitude towards the South (right) end, the only point where the sequence seems to be more complicated.

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The structure of the terrace at points H-L in Figure 33 is very different. Though some overbank silts appear on top, most of it shows various degrees of complexity. Besides lying at a variable depth, the gravel surface is also much less well defined, with coarse, gravelly beds often intercalating with finer, sandy or silty ones. Organic-rich layers - from thin dark laminae to centimetres-thick peaty beds - can be intercalated with any of the inorganic sediments, sometimes suggesting very small channel features. Wood remains can also be found throughout. Except for the overbank material on top, all parts of the sequence show abundance of oblique bedding and often cross-bedding.

Under most of the Northern part of the Higher Brockholes area the bedrock surface lies relatively deep. There can be more than three metres of gravels under the sediments represented in Figure 33 before the bedrock is found, as could be seen where the quarry pits reached deeper. Towards the Southern side of the area, however, the bedrock surface rises (as shown). Similarly, a shallow bedrock surface can be observed further upstream on the South side of the valley, in the bed of Bezza Brook (SD592311) and at Lower Hall (SD598315).

(b) Observed palaeochannels

Two buried channels can be seen in the South-East quarry face, at points I and K (see Figures 12, 33); drawings of the channel sections are shown in Figure 20b and 20c. Their beds are just 4-5 metres wide and are apparently cut in the gravel unit's surface to approximately 5.5 m depth from bankfull level. The

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South channel bottom fill (Figure 20c, Figure 33 at K) was mainly formed by peat growth and accumulation of plant material (mostly leaves) in different phases, separated by phases of minerogenic (silty) deposition. The minerogenic beds prevail near the sequence's top, while the peaty material is preponderant towards the bottom.

The bottom fill of the North palaeochannel (Figure 20b, Figure 33 at I) was not observed, lying below the foot of the quarry face. However, traces of peaty material visible at the face's foot and on the floor of the quarried area suggest the fill to be similar to the one observed in the South channel. Traces of the peaty fill can also be seen in front of the South channel (point K in Figures 12, 33); in both cases, however, they cannot be followed for more than a dozen metres or so.

The sediments overlying the channel bottom fills are finer than the surrounding ones, being mainly silty clay; the face's conditions weren't good enough to assess whether they are continuous with the surface overbank silts topping the sequence elsewhere. In the South channel sandy silts are also present, with evidence of cross-bedding. The ground above both channels is nearly one metre lower than the surrounding Brockholes Terrace surface. The cross-profiles of the channels appear to be asymmetrical, the South side being steeper than the North one (see Figure 33).

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The cross-section of another palaeochannel was observed in Higher Brockholes along the North-West quarry face at point G (see Figures 12, 33). A detailed section is shown in Figure 34. The channel appears to have been about 19 metres wide; the bottom of its organic-rich fill reaches about 3.7 metres from bankfull level, while its floor on the gravels lies at about 4.4 m. The units in the channel's fill are laterally extensive, and were observed further North-East along its course during the quarry excavations. At the base of the sequence lie two finely laminated organic-rich clayey units: the lower one, dark brown, is finer but denser in texture; the upper one is very soft, with an unctuous texture and a cream-yellowish colour (grey in its middle part). This sediment seems to have deposited in a very reducing environment. Though its surface does not react immediately with drops of HCl, the sediment does react intensely when mixed with it (as it happened during the pollen preparation). The most intense (and longest) reaction is with H₂O₂, apparently leaving only a reddish oxidised iron residue. Above the bottom sediments lies a peat unit, up to nearly 1 m thick (somewhat clayey in places, especially towards the bottom); several large tree trunks and other branches were found embedded in its body, as well as in the clays below. The peat is topped by two distinct silty units, showing at their boundary trace of the development of a soil profile; the upper one is partly missing, possibly having been artificially removed.

The whole sequence was finally buried by artificially dumped material that partially levelled up the surface. Such material, already noted above as being probably related to the nearby motorway construction, has been widely used in

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the area for filling ditches and levelling the ground. Below the sequence described lie sandy sediments, showing a composite bedding with various small-scale sub-sequences. It is uncertain if this unit represents channel bed sediments - an active channel facies or, as its fine-grained composition (contrasting with the Ribble's gravel bed in this reach) would suggest, a channel abandonment one - or if it pre-dated the channel stratigraphically above it, though the elevation of the surrounding gravels' top would support the first option more than the second one. The sandy channel bottom sediments, dated by AA-49826, are however fine enough to suggest the flow was not particularly strong.

By the Northern side of the valley at higher Brockholes an area of lower ground flooded by seasonal ponds (Plate 2) marks the course of two more palaeochannels, running side by side and converging towards their South-West end. The palaeochannels seem to represent a continuation of the one observed at point G (see Figure 12). A cross-section of the channels is depicted near the left (North) side of Figure 33, at points BCD. The section was reconstructed from the ABCD core transect in Figure 12, but core P and some of the quarry test pits provided further information about the channels' stratigraphy (see Figures 17, 18).

In the section two infilled channels can be seen, the North one being about 40 metres wide, the South one about 60. The South channel's maximum depth at the transect's point, as found in the cores, is of about 3 metres from bankfull

level, with organic-rich clay directly lying on gravel. In the North channel the bottom of the organic-rich fill lies at about 2.2 m from bankfull level, while the depth of the channel's gravelly floor is between 3 and 3.2 m. Between these palaeochannels is an entirely sandy ridge, showing a fining-up tendency. The quarry test pits δ and η (see Figures 12, 18) show the ridge broadly maintains the same structure downstream, towards the two channels' confluence point; in the other direction, however, the stratigraphy appears similar to the rest of Brockholes Terrace, as can be seen in quarry pit γ . The Lower Brockholes borehole (see Figures 12, 22) is also apparently placed between two palaeochannels near their point of confluence; its entirely sandy stratigraphy could reflect the analogous situation.

The sequences in both channel fills feature laminated clayey/silty sediments topped by layers of peat; the latter is in part still growing at the present time during winter flooding, especially by the middle part of the channels. Sequences recorded in core P and test pit β and θ (see Figures 12, 17, 18) show that both channels become deeper further downstream.

Along the core transect the fill of the North channel appears simpler than that of the South one's, with only one layer of clay and silt overlying sands. It is not clear whether such sands were deposited as bed sediments or if they were pre-existing; though they show a coarsening-up tendency no obvious discontinuity was noticed in them. The fill of the South channel has a compound structure featuring two different clayey units, one at the bottom (at one point directly

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overlying the gravels) and one near the top, overlain by the peat; in between lies a fining-up silt and sand unit.

Core P and the quarry test pits β and θ (see Figures 12, 17, 18) show the content of the channels' fill further South-West, where they become deeper again. The top layer of peat is thicker in the test pits (up to around two metres); under it are found thicker and softer clayey units rich in organic and plant inclusions, some of which are recognisably similar to sediments observed in the channel section at G (Figures 12, 34). The sequence in core P is complicated by several sandy intercalations and is generally sandier.

Quarry test pit ζ shows how much the North palaeochannel extends in width. Clayey and sandy sediments similar to the ones seen in pits α , β and θ and core P are found in borehole 207 (see Figures 12, 22), located even further downstream in the direction of the joint palaeochannel's course.

The sequence observed upstream at Sunderland Hall (Figures 10, 16), exposed in the incised bank of a brook, features fine materials above the gravels, starting at the base with a dark fine silty clay, with abundant inclusions of vegetable material, that could resemble sediments observed in Higher Brockholes in some quarry test pits and in core P. The sequence could represent a localised "backwater" feature similar to some of the abandoned channels already observed downstream.

The fill of the buried ditch shown in Plate 5 could seem to be a simpler version of what is observed in the channels: organic-rich clayey sediments lining the bottom overlain by peat. The finding, embedded in the peat unit, of wooden artefacts (including the tip of a fence-pole, pointing upwards and clearly not *in situ*) and clasts of clay suggests, however, that the unit did not entirely form by natural accumulation or growth: part or all of the materials could have been redeposited in various ways, have collapsed in due to human activity or even have been dumped there. Above the ditch sediments once again lies an artificial fill: apparently similar materials have been used to fill up most surface hollows surrounding the main palaeochannel (along the course of which another ditch likely used to run); along quarry faces several instances were observed of peat layers compressed and deformed by the materials dumped directly over them.

4.2.3.3. *Evolution of the terrace*

(a) Brockholes area

At the time of the incision of the Ribchester Terrace the Ribble likely formed three meanders between Lower Hall (SD598315) and Lower Brockholes (SD576303). The first one likely occupied the same position it occupies at present time around the Lower Hall/Bezza Brook area (being probably somewhat less elongated); the following meander veered right around the defended cusp protruding from Boilton Wood (see section 4.2.2.3 above) and

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flowed back North-East towards Boilton Wood across what would become the Higher Brockholes area. After reaching the North valley edge again, the river curved left along it and formed a third meander, flowing South again across the future Lower Brockholes area. The areas inside all bends were still mainly occupied by parts of the Ribchester Terrace; the part inside the third bend - the one still surviving as a high ground fragment between Higher and Lower Brockholes (SD580305) - likely extended to the South valley edge.

Therefore, the Ribble at Brockholes flowed along the North valley edge - far from its later (and present) course. After the Ribchester Terrace incision a new floodplain was deposited, part of which would have formed the Brockholes Terrace. The floodplain at first must have been just a narrow strip following the course of the Ribble between Ribchester Terrace areas, touching the valley edge North of the Brockholes area; its structure, preserved in the North-West part of Higher Brockholes (hatched area in Figure 12), can be seen in the face at point E (Figure 12, Plate 3) and seems to have been deposited in a regular, simple way, mostly as horizontally bedded sand and finer materials above sandy gravels.

After the aggradation that had deposited the first Brockholes floodplain ceased, the Ribble continued to develop its meanders. However, the Lower Hall meander upstream was still blocked by the till spur and, prevented from migrating downstream, maintained a stable position and could only grow sidewise. The third meander, adjacent to the valley edge North of Brockholes,

was also prevented to widen or migrate, and found itself locked by the till slope and the preceding bend. The second bend could not migrate downstream as a whole, since its upstream branch was blocked in place as the downstream branch of the Lower Hall/Bezza Brook meander, but it could freely expand towards the South. In the process of meander evolution the Brockholes channel widened its South bend by progressively migrating South-West, eroding the Ribchester Terrace and expanding the new floodplain, meanwhile constricting the third bend towards the valley edge and causing it to become narrower. In the meantime the North bend could itself have grown in length towards North-East to a shorter extent, possibly eroding at the base of the other Ribchester Terrace fragment, though there are no data to either support or discount this possibility. Most of the Higher Brockholes area was formed with the part of floodplain created during the growth of the Higher Brockholes meander (observed at points H I J K L in Figures 12 and 33).

This floodplain was deposited as growing point-bars along the inner side of the widening meander without net aggradation or incision in respect to the original, narrow floodplain. Other palaeochannels observed at Higher Brockholes lie in the inner side of the South bend, running concentrically with it; the ground surface morphology above them features a rather steep inner (North-East) slope and a much less steep outer (South-West) one (see Figure 33). Such characters are consistent with the interpretation of such surfaces as *glacis terraces* (*sensu* Miller 1970), formed in connection with secondary channels running inside a river's bend and collecting water at high-flow times, that

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partly reworked the floodplain created by the widening bend. Similar features have also been interpreted as cut-and-fill sequences without net reduction in elevation (*row terraces*) (Macklin *et al* 1992a; also Moores *et al* 1999); in such cases, however, dating of different units returned sensibly different ages, unlike the results of dating at Higher Brockholes (see section 4.2.3.4 below). The peaty units seen in one of the secondary channels (see Figures 12, 33 at point K, 20c) are not necessarily extensive. The fact they could not be followed for a long distance on the ground in front of the quarry face suggests they could be related with a hollow in the channel's bottom (possibly a channel pool), and that most of it remained dry when not in use. The Ribble during the Brockholes stage, therefore, could show a degree of multi-channel pattern, though to what extent is not clear.

Similar features are not seen in the Lower Brockholes area; here the river flowed less sinuously, and only had the space to form small bends. Rather than forming widening bends, the channel seems to have moved – possibly by discrete shifts and local avulsions – between two or three nearly parallel courses (see Figure 12) during the time the Higher Brockholes bend widening was occurring. Such channels could also have been active at the same time, though it is not possible to tell with the available data.

On its outer (South-West) side the main Higher Brockholes channel was actively eroding into Ribchester Terrace sediments, and the palaeochannel in its last position is still adjacent to the Ribchester Terrace on its West bank. The

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extreme North point of the surviving Ribchester terrace fragment seems to lie under the M6 motorway, just North of the observed channel section (sited in correspondence with the channel's bend towards North-East), and not far from the open face where the section was observed. The structure of the face at point F (Figures 12, 33) was interpreted (and represented in the figures) as part of the same terrace unit as the adjacent face at point E, though having a less regular stratigraphy. It is possible, however, that the face actually cut through the Brockholes/Ribchester Terrace stratigraphical boundary, and that the irregularities (especially where the gravels rise higher just beside the palaeochannel) actually represent Ribchester Terrace sediments, whose discontinuity with the surrounding Brockholes Terrace ones was not recognised on the field.

The complex Brockholes bends were finally cut at some place South of the present Brockholes area, likely not far from where the Ribble flows at present. The channel running by the North side of the valley was abandoned, and a new straight course was cut through the Ribchester terrace South of it; the Ribble left its old course somewhere South of the Higher Brockholes area and joined it again South of the Lower Brockholes area. The event isolated a fragment of Ribchester Terrace (SD580305), that remained as an area of higher ground between Higher and Lower Brockholes, surrounded on all sides by lower terraces. All traces of the floodplain at the cut-off site have been lost, as the Ribble has since incised again.

(b) Other areas

The evolution of the Brockholes Terrace at other sites along the study reach can be interpreted by analogy with the stratigraphy and sediments observed at Brockholes.

The palaeochannels observed on the Brockholes Terrace at Fishwick Bottoms (SD555293; see Figure 9), also visible in the GPR diagram in Figure 31, seem to have a size consistent with the ones observed at Brockholes. Some follow an across-valley pattern suggesting ample meandering; the presence of growing meanders and migrating channels is also suggested by the shape of the Ribchester Terrace edge in the area and by the oblique structures (interpreted as possible lateral accretion surfaces) observed in the GPR diagram.

The Fishwick Bottoms area seems to have undergone a similar development to the Brockholes area. The Brockholes Terrace was first deposited as a floodplain apparently lying mostly within extensive Ribchester Terrace areas, to the North and likely the South side. The Ribble then widened this floodplain, mainly at the expense of the Ribchester Terrace, similarly to the pattern of development already observed at Higher Brockholes. On the North side of the valley a meander seems to have grown eroding away the Ribchester Terrace and becoming progressively narrower, as the following bend was compressed against the foot of the Walton Law spur and prevented from migrating downstream. The meanders were finally straightened by a cut through the

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southernmost spur of the Ribchester Terrace (SD559287), which isolated this fragment of higher ground.

Another instance of a confined meander during the Brockholes stage was observed near Osbaldeston Hall (SD640345), where a bend of the Ribble cut an indentation in the South valley edge. The indentation (see Figure 8) had possibly already been started during the Ribchester stage, but it was probably deepened further during the Brockholes stage. The locked bend could have caused the meander to be compressed as the previous one expanded widening the floodplain, similarly to what already observed at Higher Brockholes and Fishwick Bottoms. A peat-filled hollow along the indentation's edge (also visible in present Ordnance Survey maps) records the former presence of the meander.

The whole of the Hothersall Hall area (SD627343; see Figure 8) seems to be part of the Brockholes Terrace. The several length- and cross-wise palaeochannels observed there are not sufficient to allow a reconstruction of the river's evolution during the Brockholes stage; some widening of the valley through the erosion of its North edge appears however to have taken place. A large indentation in the North edge suggests a process of locked meander compression could have taken place also here, possibly leading to the erosion of the Ribchester terrace along the South valley side by the laterally growing meander.

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At Sunderland Hall (SD623336; see Figure 8), just downstream, another bend of the Ribble became locked against the North valley edge in what is still its present position. This could also have favoured the lateral expansion of the previous bend, bringing it towards its final (and present) position and contributing to the erosion of the Ribchester Terrace along the South valley edge. Downstream of Sunderland Hall, the downstream bend met the South valley edge almost at a right angle, and eventually carved another indentation forming the Alston/Boot Farm meander (SD618332). The river maintained that position afterwards.

(c) Later stage; Higher Brockholes channel fills

The sequence observed in the channel cross-section at point G in Figure 12 (see Figure 34) is likely to record the environmental and facies changes the channel underwent in the process of its abandonment and filling up. If unit 2 (or part of it) in Figure 34 represents channel-bed sandy sediments (from a possible abandonment facies), unit 3 could suggest the transition to a lower energy “backwater” environment, corresponding with the channel’s avulsion upstream (South of the section in Figure 34; see Figure 12). The channel would have ceased to be the main course of the Ribble then, acting as a secondary channel with only a very low flow. Unit 4/4a/4b is the most easily recognisable, and was observed to extend along the palaeochannel at least as far along it as where the test pits β and θ were dug, though it was not observed where the channels were wider and shallower (transect ABCD in Figure 12). The unit was apparently

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deposited in a very reducing environment, and could reflect the total isolation of the dead channel from the active one with ensuing establishment of swampy, stagnant water conditions, asphyctic near the bottom. The water input through groundwater, precipitation or overflow from the active channel would have been enough to maintain the abandoned channel more or less permanently flooded, but the active flow along it would have been very small or nonexistent. Unit 4a appears to represent a temporary change within unit 4/4a/4b. The transition from unit 4 to 4a and again to 4b seems to be connected to a variation of the chemical conditions, the material in unit 4a apparently having been deposited in a slightly less reducing environment; such change could have been due to local factors.

Clayey peat - unit 5 in Figure 34 - starts to be deposited above the silty clays of unit 4/4a/4b. The growth and accumulation of peat marks the final stage of the channel's filling-up; the conditions could have been analogous to those observed at the present time in the North branch of the channel (section ABCD in Figure 12), and suggest a seasonal pond, being filled with water in the autumn and winter mainly by precipitation and surface flow and slowly drying up during the spring until being reduced to a grassy hollow by the late summer, though the underlying ground would mostly remain waterlogged. During the drying-up phase the shallow pond would have been invaded by plants; as the puddle progressively retreated the dead plants and mud dried up in a soft crust that was soon covered by grass. When the channel was flooded

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again in the autumn the remains of aquatic plants and grass would lie at the bottom and eventually become a new layer of peat.

Some amount of flow during the stagnant water and seasonal pond phases could be suggested by the presence of large tree branches and trunks, that on the other hand could also have come from trees growing along the channel's banks. At least some of them did actually lie transversally to the channel axis.

The seasonal pond conditions continued on as the channel was slowly filled by peat; they were finally truncated by renewed deposition of alluvium that buried the peat under unit 6 and 7 (Figure 34). These silty clayey units could each represent one single deposition event or a series of smaller events. The presence between unit 6 and 7 of bed 6a, seemingly an incipient floodplain soil, suggests a brief interval occurred between the deposition of unit 6 and 7.

The stratigraphy found in transect ABCD (Figures 12, 17, 33) appears simpler than elsewhere along the channel; particularly, a bed corresponding to unit 4 is not found here, though it was observed both upstream (Figures 19, 34) and just downstream (in the quarry test pits β and θ , Figure 18). The actual level of the unit, however, seems to be deeper than the channels' bottom along transect ABCD; it is possible that the reducing conditions connected to its deposition only existed at a certain depth. The fill of the South channel (point D in Figure 33) features two distinct organic-rich clayey layers separated by a thick sandy unit, while in the North channel (point B in Figure 33) only one clayey unit is

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found, lying at an intermediate height in respect to those in the South channel. This suggests the main flow could have first shifted from the South to the North channel, then back to the old position.

4.2.3.4. ¹⁴C dated samples

Chronological information about the Brockholes Terrace comes from a number of ¹⁴C essays on sediment samples. The samples were ¹⁴C dated at the NERC radiocarbon laboratory in East Kilbride; the resulting dates, both raw and calibrated, are shown in Table 1 (all dates are reported at 2σ). Not all the dates described below appear consistent with what is expected from the sediment sequence.

In several figures the original position of the dated samples is shown in its stratigraphical context. The samples dating the base of a unit are represented with a triangle pointing up, while the ones dating a unit's top are represented with a triangle pointing down. A diamond represents the samples from within a sediment unit.

(a) Samples from the Higher Brockholes SW section (IJKL in Figure 12) and adjoining quarry pit

The original positions of these samples (AA-48971 to 48975) are shown in Figure 12; except for date AA-48971, they are shown in their stratigraphical context in Figures 33, 20b and 20c.

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Date AA-48971 (6723-6411 cal BP) was obtained from the outermost rings of a *Quercus* tree trunk found lying on the floor of a quarried area. The trunk was not *in situ*, but had been dumped there by the quarry workers, who declared they had extracted it from gravel during the work on that area; the sample was taken in order to assess a maximal age for the gravelly units.

Date AA-48972 (7560-7319 cal BP) was obtained from fine leaf and wood debris lying in the uppermost part of the gravels close to the boundary with finer sediments, in order to obtain an age for the sedimentary transition.

Date AA-48973 (8929-8430 cal BP) and AA-48974 (7248-6801 cal BP) - obtained from leaf-rich peat - refer to the fill of one of the small buried channels observed in the Higher Brockholes quarry sections, the South one; they were respectively chosen from the lowermost and uppermost part of the peaty fill. Besides measuring the time of deposition of such peaty units at the channel's bottom, they were meant to aid to frame, respectively, the end of the deposition of coarse materials and the beginning of the deposition of fine ones.

Date AA-48975 (10474-10221 cal BP), from thin peaty intercalations in the clayey silty layers of the Higher Brockholes upper fine unit above another buried channel section, was meant to confirm the time of deposition of the finer materials in the later stage of the sequence.

(b) Samples from a Higher Brockholes palaeochannel sequence (G in Figure 12)

This series of dates covers the entire sequence of the fill in the palaeochannel at point G (see Figures 12, 33, 34). The original positions of these samples (AA-49826 to 49833) are also shown in Figure 12; in Figure 34 they are shown in their stratigraphical context. The ¹⁴C date codes are also shown in the pollen diagrams obtained from the sequence (Figure 38a-c; see section 4.2.3.5 below).

Date AA-49826 (9228-8658 cal BP) was taken from organic-rich silty clay from the base of a small coarsening-up sequence near the top of the sandy unit below the channel. Compared with the dates from units further South, the date was meant not only to find out the unit's age, but to assess whether it consisted of bed sediments deposited in the channel or whether it rather pre-dates the channel cut.

Date AA-49833 (4869-4573 cal BP) corresponds to a thin layer of organic material, interpreted as an incipient floodplain soil profile developed between two successive silty alluvium units. It is the uppermost datable material in the channel's sequence, and was meant to date its final burial by flood materials.

Dates AA-49827 to AA-49832 refer to samples taken at the bottom and top of each different unit in the palaeochannel's sequence – laminated clay or silty clay and peat, as shown in Figure 34 – in order to assess both their age and the speed at which the various phases of the channel filling process followed each

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other. Dates AA-49827 (8453–8217 cal BP) and AA-49828 (9526–9135 cal BP) respectively refer to the bottom and top of unit 3, the lowest organic-rich unit in the channel fill; dates AA-49829 (7157–6749 cal BP) and AA-49830 (5985–5726 cal BP) frame unit 4/4a/4b, silty clay from reducing environment; dates AA-49831 (5916–5654 cal BP) and AA-49832 (4813–4418 cal BP) are from the bottom and top of the peat unit (unit 5).

(c) Sample from Sunderland Hall

The only ^{14}C date obtained away from the Higher Brockholes area is date AA-48976 (7790–7613 cal BP) Its original position is shown in Figure 10; it is shown in its stratigraphical context in Figure 16. The date was obtained from clayey silts rich in organic inclusions sited near the bottom of the exposure at Sunderland Hall. The age confirms that the unit formed in the same period as the Higher Brockholes area.

(d) Discussion of ^{14}C dates

The results of the ^{14}C essays from Higher Brockholes are reported in Table 1; a diagram showing the dates in relation to each other is found in Figure 37.

Date AA-48971 was meant to obtain a possible maximal age for the gravel unit in Brockholes (though it couldn't be ruled out different parts of the gravels could have deposited independently); however, its age of around 6500 years BP

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is younger than many other dates from the area. The stratigraphical position of the tree trunk from which the sample was collected, anyway, was not directly observed, but rather based on observation by the quarry workers who had extracted the trunk. As has been shown in section 4.2.3.2, the distinction between the gravel unit and overlying finer materials is not sharp in the reworked part of the Brockholes Terrace, into which the trunk lay (points H I J K L in Figures 12 and 33); layers of gravel could have been moved and redeposited above finer materials, particularly inside the secondary channels. It is likely the trunk actually lay inside one such channel (possibly upstream the one observed at point I in Figure 12), covered by a layer of reworked gravelly material. The situation appears to be similar for date AA-48972: the sample apparently lay shortly below the gravels' top, but its age (around 7500 years BP), comparable to the channel bottom sediments lying nearby, shows the gravelly layer overlying it must have been deposited at the same time, reworked by the action of the secondary channel itself.

An opposite issue is raised by date AA-48975: though being stratigraphically younger than most other Brockholes dates, its age of over 10 000 years BP is older than any other in the area. The possibility that a single fragment of older terrace survived along the face the sample was collected from is extremely unlikely, and is not supported by the observed stratigraphy there; the best explanation is that the sample actually represents reworked material from the Ribchester Terrace that was being eroded along the river upstream. The presence of clasts of solid clay and ochre embedded in the face not far from

where the sample was collected (see Figure 20b) further supports an input of reworked older material along the secondary channels.

The oldest reliable dates for the Brockholes area are AA-48973, from the bottom of one of the buried secondary channels (at K in Figures 12 and 33), and AA-49826, from the sandy sediments under the main palaeochannel (at G in Figures 12 and 33 and in Figure 34). The first one should be reliable enough, since it comes from a laminated peat that likely was *in situ*. The high content of leaves that could have been reworked or deposited some time after having been shed could still make it possible for the sediment to be younger than the date would suggest. The degree of preservation of the leaves, however, suggests they either were deposited fresh or were not significantly old when it happened, and supports the date's reliability. Date AA-49826 could also have been affected by the input of older material; its age, however, seems plausible, and for now it will be accepted, though the possibility it can be younger must be taken into account.

Dates AA-48973 and AA-49826 returned a similar age, being both between 8500 and 9000 years BP. If we accept both, this would show the accumulation of leaves at the bottom of the secondary channel at K was starting - suggesting a diminution of the channel's activity and filling-up prevailing upon scouring - at the time of the main channel's abandonment. The date also shows the channel had already reached its final position by around 9000 BP, and that the process of meander widening happened before that time. The possibility that the

sediments represent materials pre-existing to the channel is made unlikely by comparison with AA-48973 and with the other dates: if the sediments pre-dated the channel (having likely been deposited together with the first Brockholes floodplain as observed North along the face, at point E (Figures 12 and 33, Plate 3), they could be expected to be considerably older than the materials deposited after widening of the meander and reworking by the secondary channels.

Dates AA-49827 and AA-49828 refer to the basal unit of the main palaeochannel's fill, the organic-rich clay identified as unit 3 in Figure 34 that could represent the time after the channel became largely inactive. Date AA-49827 refers to the unit's base, while AA-49828 refers to the unit's bottom. The ages resulted from the ^{14}C analysis, however, are inverted: AA-49827 dates to slightly earlier than 8000 years BP, while AA-49828 is older – almost 9500 years BP, slightly older even than the underlying date AA-49826. Such an age is stratigraphically inconsistent, and we could suppose that a contamination with older carbon happened, unit 3 perhaps containing materials reworked from the adjacent Ribchester Terrace. In the absence of further data both date AA-49827 and AA-49828 are better rejected, even if the age of the former could be consistent enough with the rest of the chronology and channel abandonment sometime in the period 9200–8200 cal BP.

Next in the sequence comes date AA-49829, referring to the base of unit 4 (the highly reduced yellowish clay), that locates the establishment of stagnant water conditions to around 6900 years BP; date AA-48974, from the top of the peaty

sediments in the secondary channel, gives the same age to the end of its activity. The relative sharpness of the contact of unit 4 with unit 3 does not rule out the possibility of a hiatus between their depositions, though this cannot be either disproved or confirmed due to the unreliability of date AA-49828. Dates AA-49830 and AA-49831 refer respectively to the top of unit 4b and the base of unit 5 (the peat), and are consistent in dating the transition from a permanently to a seasonally flooded environment and the onset of peat accumulation at slightly after 6000 years BP. The final burial of the peat by renewed silt deposition is located at around 4700 years BP by dates AA-49832 (from the top of unit 5) and AA-49833 (from the organic horizon between the silty unit 6 and 7). The fact date AA-49832 appears contemporary to date AA-49831 shows there was no significant time hiatus between the end of the peat accumulation and its burial under silts, nor between the deposition of unit 6 and 7.

4.2.3.5. Palaeoecological analyses for the organic fill of a palaeochannel at Higher Brockholes

Pollen analysis was performed on samples from the sequence found at Higher Brockholes in the palaeochannel cross-section at point G in Figure 12 (see Figure 34). The extent of the sampling for pollen covered the whole organic-rich part of the sequence, from the bottom of the brown clay to the top of the peat (units 3 to 5 in Figure 34), excluding the sandy sediments below and the artificial fill above. The pollen diagrams are shown in Figure 38a-c. The sequence's main stratigraphical boundaries are marked beside the depth axis.

Some grey silty clay (see section 4.2.3.1(a) above) found in the lower part of core P, and whose extension was confirmed in some of the quarry test pits excavated nearby (though they were not observed in the shallower cores along the transect), resemble estuarine muds and could suggest the possibility that the channel was, in the past, affected by estuarine sedimentation. Diatom analysis was performed on such sediments in order to assess the possible brackishness of their depositional environment, but it yielded no results (all the palaeochannel sediments examined in the area have proved non-diatomaceous).

(a) Results

The pollen diagrams for trees and shrubs are shown in Figure 38a; the dominant *taxa* are *Alnus*, *Corylus*, *Quercus* and *Betula*. *Alnus* is abundant throughout the sequence. Its relative abundance is very high in the lower and upper parts of the diagram (reaching a maximum at 196–186 cm), while it decreases between 266 and 226 cm. *Corylus* apparently behaves in a complementary way, its relative abundance falling above 216 cm and apparently at the very bottom of the diagram (276 cm). Within the 266–216 cm interval it shows two peaks, at 261 and 226 cm. The abundance of *Quercus* is nearly constant, possibly also showing a fall between the 226 and 216 cm values; the exception to this is a marked peak at 171–176 cm, the significance of which will be discussed in (b) below. *Betula* does not show great variations in

abundance in different parts of the diagrams; two possible small peaks are visible at 236 and 196 cm.

Traces of *Fagus* and *Fraxinus* only appear near the diagram's top, while *Pinus* and *Salix* are present throughout. *Ulmus* is most abundant at the base (276 cm), but immediately decreases and is only sporadically found above 251 cm, with the only exception of the uppermost sample (156 cm). *Tilia* appears in the lower part only.

Figure 38b shows the diagrams for herbs, aquatic plants and spores. The dominant *taxa* are Poaceae and Cyperaceae; both of them are most abundant between 261 and 216 cm. From 250 cm they seem to vary more or less in the same way, while up to 261 cm the former are more abundant than the latter. Above 216 cm, they show a local increase around 181 cm. There are no clear traces of cereal pollen. The Ranunculaceae are also almost always present, and most abundant around 186–176 cm. *Plantago* species are most abundant within the 261–216 cm interval. The genus reappears in the higher part of the diagram, seemingly with a different species pattern. *Artemisia* makes its appearance in the lower and upper parts of the diagram. *Filipendula* appears sporadically throughout it. Most other herbs are mainly present around 186–176 cm or above.

The aquatic plants are generally most abundant between 246 and 226 cm. Polypodiaceae and *Pteridium* are found more or less throughout the diagram,

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and their abundance is possibly higher in its upper half; however the undifferentiated Fern spores reach their maximum in the 241–216 cm interval, with a peak at 236 cm. The significance of such peak will also be discussed in (b) below.

The general proportions between plant types (Figure 38c) show a prevalence of herbs and shrubs between 261 and 216 cm. Trees and shrubs dominate the lower part of the diagram, ending with the trees falling abruptly between 266 and 261 cm and both herbs and shrubs rising. Between 221 and 196 cm the trees rise again slowly, at the expense of both shrubs and herbs. A localised increase in herbs, at the expense of both shrubs and trees, is visible at 181–186 cm. The diagram's top (156 cm) shows another slight decrease of tree (but not shrub) pollen.

The aquatic plants have the greatest abundance between 246 and 221 cm, reaching a maximum at 241 cm in correspondence with the minimum trees+shrubs value. The spores (mostly undetermined Ferns) have a minor but constant presence up to 256 cm; above that depth they steeply increase, reaching a marked peak at 236 cm, in correspondence with a slight increase in trees. It must be noticed that the total pollen count for the 236 cm sample – due to a poor quality of the sample itself – was very low, and the relative values of the *taxa* need not be statistically significant; therefore both the Ferns' peak and the apparent increase in tree pollen could be artefacts. Above 236 cm, however, the spores' abundance is higher; it then constantly decreases to a minimum

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around 176-171 cm. The diagrams of both spores and aquatic pollen show a slight increase in relative abundance between 171 cm and their top at 156 cm.

The pattern followed by sulphide spherules and charcoal fragments appears broadly similar (the only exception being the 246 cm sample), having a large peak at 266 cm but disappearing (or nearly so) above 216 cm.

(b) Discussion of significance

The disproportionate amount of *Quercus* pollen in the samples from 176 and 171 cm depth suggests the diagram was biased by the presence of an Oak tree just above the sampling site or very close to it. The pollen percentages being thus distorted, a correct interpretation of these levels would be difficult and would maintain a high degree of uncertainty; for simplicity, the two samples are rejected here.

Due to its poor quality, as already mentioned, the sample from 236 cm depth yielded a very low pollen count; neither the 200 land pollen grains count nor the 50 exotic grains one could be achieved. The pollen taxon totals from the sample are not necessarily representative; particularly, the high peak of unidentified *Filicales* could likely not be real. The sample is better rejected.

The lowest part of sequence (defined as pollen zone A in (c) below) corresponds with organic-rich clay (unit 3 in Figure 34) that could have been deposited when the water in the channel was not yet completely stagnant. If some more or

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less constant flow still existed in the channel, the pollen assemblage found in unit 3 could refer to a wider recruitment area, and partly reflect the vegetation in the catchment upstream. This possibility could also be supported by the fact the ^{14}C dates from unit 3 suggest the presence of reworked material, and by the large quantity of deteriorated pollen grains – higher than in any other sample – found at 276 cm depth (Cushing 1967), though they mostly were simply crumpled rather than degraded. The results of the analysis for zone A are better be taken as uncertain.

(c) Interpretations

The pollen diagram was used to subdivide the channel fill sequence in different zones, according to the prevailing *taxa* in the pollen assemblage. The pollen zones thus defined are shown in Figure 38a-c, and described below.

Pollen zone A: *Alnus/Ulmus/Quercus/Corylus*; prevailing woodland. The pollen assemblage could also partly reflect prevailing woodland cover in the catchment (see (b) above).

A marked peak of charcoal fragments between pollen zones A and B marks a sharp transition to prevailing grassland. Abundant microscopic charcoal is usually an indicator of fire (Patterson *et al* 1987); the peak observed at 266 cm depth could reflect wildfire, or also a local but thorough woodland clearance event. A similar peak is observed at the same depth in sulphide spherules, thought to be produced by microbial

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decomposition of organic matter under reducing conditions in stagnant water (Wiltshire *et al* 1994, Ellis & Brown 1999); the presence of the peak suggests the onset of asphyctic conditions occurred rapidly, with the sudden death of aquatic vegetation.

Pollen zone B: *Corylus/Poaceae/Alnus/Quercus/Cyperaceae*; prevailing grassland and open or patchy woodland. Stagnant, reducing conditions are established in the dead channel.

Pollen zone C1: *Corylus/Alnus/Cyperaceae/Poaceae/Quercus*; maximum expansion of grassland. Sedges multiply around the dead channel while obligate aquatics rise to their maximum; the abundance of *Potamogeton* (appeared in pollen zone B) confirms stagnant water conditions (Brown 1996a). The pollen zone corresponds with unit 4a, that suggested a somewhat less reducing deposition environment; the pollen assemblage could suggest an increased water input. The concurrent rise of ferns suggests possible wetter climate conditions.

Pollen zone C2: *Corylus/Alnus/Poaceae/Quercus/Cyperaceae*; prevailing scrubland/grassland. The fall of sedges around the dead channel and the decline of obligate aquatics (*Potamogeton* having been substituted by *Nuphar*) marks the transition towards a seasonally flooded pond invaded by water-lilies and the start of peat growth. Ferns reach their maximum here.

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Pollen zone D1: *Alnus/Corylus/Cyperaceae/Poaceae/Quercus*; woodland regeneration in the area, alder prevailing over oaks, while grassland retreats.

Pollen zone D2: *Alnus/Corylus/Cyperaceae/Quercus/Poaceae*; the arboreal pollen reaches its maximum, with alder- and oak-dominated woodland; minimum of grassland. Ferns decline, possibly suggesting a somewhat drier climate (the slight increase in bracken makes it unlikely the fall is due to the thicker woodland cover). Sedge peat, however, continues to accumulate and fill up the dead channel.

Pollen zone D3: *Alnus/Cyperaceae/Corylus/Quercus/Poaceae*; alder and oak woodland still dominating. A possible slight increase of grassland, and the presence of *Rumex*, *Artemisia*, *Urtica* and *Plantago lanceolata* could hint to minor clearance activity, though the microscopic charcoal keeps at a minimum and the apparent slight decline of woodland could be simply due to an increase in the proportion of sedge pollen. The renewed rise of sedges and ferns (*Polypodium* prevailing this time in the woodland environment) and the return of obligate aquatics suggests a shift to wetter conditions with an almost permanently flooded pond.

4.2.3.6. Overview

Observations in the Higher Brockholes area and at other sites along the Ribble point to the Brockholes Terrace fill having formed through two different

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processes: vertical aggradation and lateral reworking. The terrace was first deposited by simple aggradation of mostly fine (overbank) sediments; a phase of lateral activity followed, with mobile channels and migratory meanders. The Ribble widened its floodplain during that phase, eroding parts of the Ribchester Terrace and, in some cases, the valley edges, and reworking both coarse and fine materials in the process, resulting in complex sedimentary structures (Lewin 1978). Though the two phases need not be totally separated in time, observations at Higher Brockholes suggests lateral change to have widely occurred without valley floor aggradation taking place at the same time. During this phase, the Ribble seems to have been at least in part a multi-channel system.

At the end of the lateral activity phase the Higher Brockholes meander, and apparently others along the Ribble as well, underwent cut-offs and were abandoned. The earliest ^{14}C dates, from palaeochannel bottoms at Higher Brockholes, point to an age of around 8900 cal years BP for the end of meander growth; hence the cut-off there occurred after that time. Traces of a similar cut-off could be best observed in the Fishwick Bottoms area; after both events, the Ribble generally maintained the new course, and wide-scale lateral activity did not generally continue, the channels becoming more stable. This suggests the events could have happened broadly in the same period, possibly in relation to a reach-scale change in the fluvial processes.

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Nothing more than the filling of the abandoned channels seems then to happen on the Brockholes Terrace until around 4700 cal years BP. Asphyctic, stagnant water conditions are established around 6900 cal years BP, possibly marking the total isolation of the abandoned channel from the active one and the transition from a “backwater” environment to an oxbow lake; the process seems to be coincident with the destruction of woodland by fire, and possibly could have been accelerated by that event (*e.g.* through the loosening of channel banks due to the loss of vegetation cover). The start of peat growth at around 5800 cal years BP could be related to a change in the ground water table and/or of the climatic conditions, only allowing the abandoned channel to be intermittently flooded. The accumulation of peat is interrupted when it is buried by overbank sediment, accumulating in two separate events or groups of events; a time hiatus sufficient to allow the start of soil formation must have existed between these alluviation episodes, though the dates (see section 4.2.3.4 above) show the events occurred within a short period of time.

The overall pattern of valley floor development in the Brockholes area is hence of a progressively enlarging meander that reworks and widens a floodplain recently deposited after the incision of a higher terrace; the process is followed by a phase of apparent stability, during which the abandoned channels are progressively filled up by peat, and ends with new episodes of minerogenic deposition. The outstanding aspect of this picture is its duration, with the phase of stability alone extending for up to 5000 years throughout the early and mid-Holocene. This places the incision of the Ribchester Terrace to the extremely

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early Holocene or even to the latest part of Devensian Lateglacial, and its deposition almost surely in the Devensian Lateglacial. The whole process of construction of the Brockholes Terrace, including the Ribchester incision, the aggradation phase and the meander widening phase, could have happened in a shorter time than the ensuing period of stability, though there are no dates for either this or for the actual age of deposition of the Ribchester Terrace.

After about 6900 years BP nothing more than the filling of the abandoned channels seems to happen in the Higher Brockholes area; the dates show that a feature such as an abandoned channel turned into a permanent pond can last a thousand years, and that its filling up by peat can proceed over similar timescales if it is not interrupted by other factors.

The actual time of the channel's abandonment could likely be placed between about 9000 and 6900 years BP. We also don't know if such abandonment happened suddenly or gradually; in the second case, the deposition of the clay in unit 3 could correspond to the "backwater" phase, after the opening of the short-cut through the Ribchester Terrace South of the present Brockholes area and before the old channel was totally plugged. In such a phase the channel would still have been connected to the active channel, but would have featured at most a very low flow, allowing the deposition of fine materials as unit 3. Once the channel had been totally isolated from the new, straighter main course of the Ribble the flow would have ceased, and anoxic conditions would have been established with the deposition of unit 4/4a/4b.

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The Higher Brockholes area, at least in the parts along and beside the course of the old channel, seems to have been characterised by wet ground, with growth of peat in the surface hollows – the channel itself as well as ditches, ponds and puddles beside it. Apparently, most such features were eventually covered with filling material, possibly with the aim of levelling the ground surface and making it more suitable to farming.

4.2.4. Walton Terrace

4.2.4.1. Sources of data

(a) Pre-existing boreholes

Where sections of the Walton Terrace are visible along the Ribble's banks, no significant amounts of coarse sediments can be seen. A number of civil engineering boreholes provide more accurate information on the terrace's stratigraphy, that shows a great deal of variation between different sites.

The sequences shown in Figures 24a-c and 25 come from series of civil engineering boreholes drilled in 1981 (Figure 24a-c) and 1975 (Figure 25). The boreholes were arranged in a grid pattern covering more or less regularly a large portion of the Walton flats area; their positions are shown in Figure 13. Different general types of sediment facies associations were recognised in these boreholes, and are indicated in the figure as [A], [B], [C], [D] and [E]; the

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observation of the different sequence types and their distribution helped to reconstruct the likely extension of different terrace units in those areas that could not be surveyed directly, having been already affected by urban development (see section 4.1.2.1 above).

Type “D” boreholes correspond to the Walton Terrace fill; here a sand and gravel unit lies over weathered bedrock and is overlain by very clayey fine-grained units, typically silty clay, with very few sand; in one case (borehole 8) clay-bound gravel is present between the two.

Most of the 1975 boreholes lie in a separate group from the bulk 1981 ones, East of them and across the present trunk road. From their elevation (comparable to the type “D” boreholes or slightly higher) and their position they would be expected to belong to the Walton Terrace; however, the sequences found there (labelled “E” in Figure 13) differ from “D” type ones. Type “E” sequences also vary more between different boreholes than type “D” ones. The basal gravels in type “E” boreholes lie deeper in two of the boreholes, where the bedrock’s surface is also deeper; in one other borehole boulder clay is visible below the gravels (the borehole – number E127 – did not reach the bedrock). Above the gravels are still mostly clayey sediments, but always with some sand content and often organic material; towards the top are sandy units, though still with some clayey content.

The difference between type “D” and type “E” boreholes could indicate a horizontal variation in the structure of the upper terrace, or that part of an even

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higher terrace (the Brockholes Terrace) is present in the type “E” area. The number of boreholes is not sufficient to confirm this possibility, however, and the difference in elevation between the “E” and “D” type boreholes is much smaller than would be expected if the former lay within the older terrace fill. No surface morphology could be recorded here, since these boreholes lie within Walton-le-Dale town area; this should also be taken into account in examining the upper parts of the “E” sequences. The area has been part of a village or town for several centuries; actually (as can be seen in Figure 3), the main axis of Walton-le-Dale used to run South-West of the present main road, where now are the backyards and where the boreholes were drilled.

Two of the M6 motorway boreholes and a quarry works one (see section 4.2.2.1 above) also record Walton terrace stratigraphy. The position and identifier of each borehole is shown in Figure 12.

Boreholes 195 and 197 (Figure 22) lie within Walton Terrace sediments; they too feature a lower gravelly half – below about 4 m depth – overlain by upper fine-grained clayey materials.

Borehole S1 (Figure 23) also lies within the Walton Terrace, near its boundary with the Cuerdale Terrace; its sequence is still broadly fining-up, with gravelly units overlain by finer material and a thick topsoil.

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Borehole 27 from the Elston aqueduct (see section 4.2.2.1 above) was drilled by the bank of the Ribble, possibly in correspondence with a former crossing of the aqueduct, within a narrow fragment of Walton Terrace. The borehole's position is shown in Figure 11); its sediment sequence is shown in Figure 16.

The sequence found in the borehole is entirely gravel-rich: above a small basal sandy/gravelly unit (less than 1 metre thick) lies a thick clayey/gravelly one, up to the sequence's top.

(b) Observations from GPR transects

In its central part the Fishwick Bottoms GPR transect (Figure 31; see section 4.2.2.1 above) cuts across a section of the Walton Terrace, lying between parts of Brockholes Terrace (see Figure 14). Once again, its stratigraphical boundaries with the adjoining Brockholes Terrace fill are not clearly visible. The structure of the Walton unit seems here rather uniform, its upper half having a more or less horizontal bedding, suggesting regular accumulation of overbank sediments. The bedding seen in the lower half of the unit is not as plain; it could represent truncated Brockholes Terrace materials or a separate accumulation during the Walton Terrace aggradation. The most outstanding Walton Terrace feature in the diagram is the very large palaeochannel section on the North (left) side, between 370 and 470 m along the transect. It is more than 80 metres wide, a size comparable to the present active Ribble channel, and its approximate depth reaches about 3.5 metres. The channel's South (right) bank,

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between 460 and 500 m along the diagram, seems to show a discontinuity with the rest of the Walton terrace's fill, in correspondence with a slight prominence of the ground (at ca. 500 m). The discontinuity could correspond to a former position of the channel's South bank, that later moved North (the prominence could represent the former channel margin).

North of the Ribchester terrace edge, the GPR transect in the area between Walton-le-Dale and Penwortham Lane (Figure 32; see section 4.2.2.1 above) traverses the Walton terrace ground; the disconformity at its stratigraphical boundary with the remnant Ribchester terrace South (right) of it is visible in the diagram between 360 and 380 metres. The diagram shows that, despite the terrace's nearly flat surface, where no features were mapped during field survey, several possible buried channel features are present. The section of a large palaeochannel is visible by the North (left) side, between 20 and 90 m along the diagram's length; its width of ca. 70 metres and approximate depth of over 3 metres are consistent with the large buried channel observed in the Fishwick Bottoms GPR transect (above). South of the palaeochannel (between 90 and 140 metres in Figure 32) trough cross-bedding traces can be possibly recognised; the size of the structures, if they were interpreted as palaeochannel traces, would seem to fit a much smaller channel than the adjoining one.

The section of a smaller buried channel is visible more South along the diagram, at about 280 m in Figure 32; its width is about 25 metres, while its approximate depth seems to reach about 4 metres. A similar channel, though possibly

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slightly shallower, could be present North of it, at ca. 220 m. Another very small buried channel feature seems to be recognisable at about 350 metres along the diagram; it seems to reach the same depth of the channel at 280 m, though it is not wider than 5 or 6 metres, and could represent a buried ditch.

The large palaeochannel at 20-90 metres in Figure 32 was possibly the Ribble's main channel. The ones at 280 and 220 metres may have belonged to the Darwen, presently flowing ca. 200 m from the GPR transect and joining the Ribble shortly upstream of its Northern (left) end; the structures seen beside the large palaeochannel could be related to a former point of confluence of the River Darwen with the Ribble.

4.2.4.2. *Structure of the terrace*

A picture of the general structure of the Walton Terrace is best gained from the Walton Flats area (Figure 13), thanks to its extensive borehole cover, even if only a small part of it could be examined directly, the rest having been affected by urban development. The type "D" facies boreholes (Figure 24a-c; see section 4.2.4.1 above) show that the Walton Terrace here features a 1-2 metre thick basal gravelly unit directly overlain by much finer materials, the finest sediments found as extensive terrace units in the Ribble valley: 2-3 metres of silty clay or clayey silt, with little or no sand. In one instance only (borehole 20, Figure 24c) a sandy bed, 30 cm thick, is present between the gravels and the overlying silt and clay. Borehole 17, on the South side of the Darwen's former

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course (see sections 2.3.5 above and 4.2.5.2 below and Figure 13), features a thicker (3 m) gravelly unit and a thinner (<1 m) clayey/silty unit, still directly overlying the former. In borehole 8 (Figure 24a) a bed of clay-bound gravel is present.

The stratigraphy in these boreholes, being close to a major tributary's confluence point (see Figures 9 and 13), could reflect the proximity to the River Darwen or the combined influence of both it and the River Ribble. The 1975 boreholes (see section 4.2.4.1 above), lying in the East part of the Walton flats (Figure 13), actually show a different picture of the Walton Flats structure. Their type "E" facies sequences (Figure 25) feature more than one metre of sandy sediments at top (though still with some clayey content); between them and the underlying gravels are abundantly clayey and often organic-rich sediments, but always containing sand as well. The sequence in borehole E129 (Figures 13, 25) features 1.3 metres of artificial fill; it could lie along the course of an old mill race, now filled up (see Figures 3 and 4).

In Figure 35 a schematic section of the Walton Flats area is shown, reconstructed from manual coring (see section 4.2.5.1 below) and borehole data. The path of the section corresponds with the thin dash-dot line shown in Figures 13 and 14; two segments of Walton Terrace are visible in it. The base of the Walton Terrace sequence lies here on weathered bedrock or on till (near the South-East end, right-hand side in the figure), at 4 to 5 metres depth from the surface. In the North-Western (left) segment the sequence starts with about 1

metre of coarse material (sand and gravel), overlain by another metre-thick gravelly unit, but with a clay matrix. The latter, shown in Figure 35, is present in borehole 8 (Figure 24a), but not in borehole 5 (Figure 24a) further North-East, where the finer sediments above reach down to the sandy gravels. In the South-Eastern (right) segment the sandy gravels can be seen becoming thicker South-Eastward, up to nearly 3 metres. Above the gravel unit(s) a unit of silt and clay lies, about 2 metres deep (less where the clay-bound gravels are present); some sand can be present between the gravel and clay/silt. Towards the East (right) end of the figure the clay/silt unit becomes sandier and thinner, as the gravels' surface rises and a sandy (sub)unit is added on top.

Data about the Walton Terrace from other sites are too scarce to allow a more general reconstruction of the terrace structure. The stratigraphy in boreholes 197 and 195 in the Brockholes area (Figures 12, 22) seems to be closer to what is found in the type "E" boreholes in the Walton Flats than in the type "D" ones, being mainly sandy above the basal gravels, but also with a clayey content. Though the top of the gravels lies at about the same altitude in the two boreholes, their thickness is very different: in borehole 195, where the bedrock lies deeper, the gravels reach nearly 4 metres of thickness, versus the 1.30 metres found in borehole 197. Though similar to the gravels above it (apart from possibly being less sandy), the lower gravelly sub-unit in borehole 195 could be older, representing truncated older terrace sediments that, lying in a hollow of the bedrock surface, survived incision. The bed of boulder clay

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recorded under the gravels in borehole 195 suggests the underlying sediments (described as red brown sands) actually to be weathered bedrock, as well as the analogous ones seen in borehole 197.

The lack of detail in the log from borehole S1 (Figures 12, 23), also in the Brockholes area, makes comparison with other boreholes difficult. The stratigraphy seen at Elston in borehole 27 (Figures 11, 16) appears different from that observed in the other sites, though still rich in clay; its thick clay and gravel unit could be compared with the apparently similar (though thinner) sequence seen in borehole 8 from the Walton Flats (Figure 24a).

4.2.4.3. *Evolution of the terrace*

Along most of the study reach the part of the valley bottom occupied by the Walton Terrace and later units has a limited lateral span. The terrace was deposited as a floodplain in a narrow strip lying along a path tracing the course of the Ribble at the time of the incision of the Brockholes Terrace. The incision had cut through parts of both the Ribchester and Brockholes Terrace, and the Walton Terrace can border on both older fills, especially at Brockholes (SD580305) and Fishwick Bottoms (SD559287), where it was deposited as a mid-valley strip.

Only at two points did the Walton Terrace form a wider floodplain. Downstream of the Fishwick Bottoms the floodplain became wider, forming an uninterrupted stretch of floodplain from the future Walton Flats (SD282552) to

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the area North of Penwortham Lane, immediately downstream between the Flats and the old tramway embankment (SD542286-SD541274).

At Osbaldeston Hall (SD640345) a similar process to the one already occurred during the Brockholes stage apparently occurred during the Walton stage. A bend of the river seems to have become locked against the valley edge and the Ribchester terrace along a side of the Brockholes stage indentation (see section 4.2.3.3(b) above), promoting lateral growth of that meander and the following and preceding ones to grow laterally, widening the Walton stage floodplain and possibly eroding to some extent the North valley edge.

The observations made about the Walton Flats and North Penwortham Lane areas have helped to reconstruct a picture of the Darwen/Ribble confluence in the past. A reconstruction of the confluence area before the incision of the Brockholes Terrace is not possible, since the two higher terraces were not preserved there. Hence the information we can have dates back to after the deposition of the Walton Terrace. At some time during the Walton stage, as suggested by the palaeochannel picked up by the GPR (see section 4.2.4.1 above), the River Ribble's course through the floodplain apparently ran South of the present one. At some stage the River Darwen's confluence with the Ribble was probably several hundred metres downstream of the present location, though its position did likely move through time across the area, and its final course - at the time of the Walton Terrace incision - was probably not far from the present position. The sedimentology of the confluence area was

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influenced by proximity to one or the other river; the Ribble apparently deposited sandier sediments, as can be seen in the type “E” sequences in the Walton Flats (Figure 25) and the other Walton Terrace sequences upstream (Figures 16, 22; see section 4.2.4.1 above).

The Walton-le-Dale Roman town also stood on Walton Terrace grounds (see section 4.1.2.1 above), in the area now corresponding to the Walton Flats. The entire area likely must have been safer from floods then than it was in later centuries (see section 4.1.2.1 above). The town most likely featured a bridge over the Ribble, as well as, possibly, one over the Darwen. It is unlikely that the location of the town (see Figure 9) was, at the time, on the North side of the Ribble, but it is not impossible that when the town was built the Ribble was somewhat closer to it. The whole settlement could actually have been entirely built in the stretch of land between the Rivers Darwen and Ribble, the former flowing somewhat South of its present course and joining the Ribble downstream of the site, as the palaeochannel evidence gathered in the area (see above) suggests it did in the past. The evidence from the archaeological excavations (see section 2.3.3.2 on page 52), though, supports the scenario of the settlement actually straddling the river Darwen, whose course hence would have run slightly North of the present one, likely joining the Ribble just upstream of the present confluence. Most of the original Roman-time area has since been eroded by river action.

We only have indirect information about the age of the Walton Terrace – that is, the fact that the Roman town at Walton-le-Dale was built upon it. The time of deposition of the Walton Terrace must therefore precede the earliest Roman activities in the town, in the early second century AD (around 1800 BP; see section 2.3.3.2(a) on page 52). The findings on the site of seemingly Neolithic and Mesolithic material during excavations in the 1980s (Cumbria and Lancashire Archaeological Unit 1988; Newman & Olivier 1999; Newman & Olivier, unpublished; LUAU 1996) could shift the latest date for the Walton Terrace deposition to much earlier times, possibly up to the VII millennium BP. The finds consisted only of lithic implements and flakes (Cumbria and Lancashire Archaeological Unit 1988) without other associated features (LUAU 1996), and rather than being *in situ* could have been reworked from older sediments and redeposited in the Walton Terrace fill; the fine-grained context of their finding, however, would not support this hypothesis.

Accordingly, the onset of the Walton Terrace deposition cannot be precisely established by the available data, nor can the time of the Brockholes Terrace incision that preceded it; only hypotheses can be advanced. It is possible that the Brockholes Terrace incision phase started in correspondence with the isolation of the abandoned channel at Higher Brockholes (around 6900 cal BP; see sections 4.2.3.4 and 4.2.3.6 above), and that the long period in which the Higher Brockholes abandoned channels were left undisturbed was due to the fact the Ribble was flowing at a lower level and was not prone to great lateral shifts or to otherwise affect the areas beyond its immediate surroundings.

Alternatively, the incision could have started between 6900 and 4700 cal BP (see section 4.2.3.4 above); if the transition from a permanently to a seasonally flooded environment (around 5800 BP; see sections 4.2.3.4 and 4.2.3.6 above) was connected to a fall in the ground water table, that could be the time the incision started. In both cases, the renewed deposition that buried the channel with units 6 and 7 (see section 4.2.3.2 above and Figure 34) around 4700 cal BP could represent peak overflow events during or at the end of the aggradational phase that deposited the Walton Terrace. The final level of its surface at Brockholes is only one metre below the level of the Brockholes Terrace, well within the range of peak flood events and about the same level of the lowest parts of the Brockholes surface topography – the palaeochannels.

Such hypotheses would be consistent with the lithic artefacts in the Walton Terrace being *in situ* rather than reworked. The fact, observed in section 4.2.3.6 above, that after the major Fishwick Bottoms and Brockholes cutoffs the behaviour of the river changed also could support the first of the possibilities discussed above, with the erosion event occurring between ca. 8900 and ca. 6900 cal BP. However, these remain hypothetical scenarios; the incision of the Brockholes Terrace and the deposition of the Walton one could as well have occurred after 4700 cal BP (the latest date on the Brockholes Terrace, see sections 4.2.3.4 and 4.2.3.6 above).

4.2.5. Cuerdale Terrace

4.2.5.1. Sources of data

(a) Boreholes and sediment cores

The abundant sections visible along the present banks of the Ribble show the Cuerdale Terrace to be made up mainly or entirely of fine sediments, apparently overbank sand and silt. Additional information could be gained from manual sediment coring and civil engineering boreholes.

The Walton flats 1981 survey boreholes (see section 4.2.4.1 above) also provided information about the Cuerdale Terrace. Their locations are shown in Figure 13; their sequences are shown in Figure 24a-c.

Type “A” boreholes are associated with the Cuerdale Terrace fill. Above coarse (sandy/gravelly) materials it mainly features overbank-type sandy, clayey silts.

Type “B” boreholes feature sandier upper sediments, and tends to comprise a larger (thicker) gravelly unit; it is found inside the bends of former meanders of the Darwen (see sections 2.3.5 above and 4.2.5.2 below), and seems to be associated with meander growth and possibly point-bars.

The boreholes labelled as “C” seem to be influenced by proximity to a channel. The sequence from borehole 22 (Figure 24c) could actually represent an

artificially filled-up former Darwen meander (see sections 2.3.5 above and 4.2.5.2 below and Figure 3).

The information provided by the boreholes in Figure 24a-c was supplemented by means of manual gouge coring along two transects in the Walton flats (also shown in Figure 13). Figures 26 and 27 show the sequences found in the cores.

The sequences found along the two transects appear mainly to be type “A” facies associations (see above), consistent with that found in the civil engineering boreholes. The transects also run across the course of a palaeochannel set within the Cuerdale Terrace, whose sediment fill appears in the sequences of some of the boreholes (100 to 121 m in transect A, 8 to 25 m in transect B) in the form of organic-rich clayey units. Such sediment sequences appear different with what seen in type “C” boreholes further South-East (see Figure 13). The difference likely reflects the different conditions of the two channels’ filling: the channel crossed by the two transects was naturally abandoned and slowly filled up, being also covered by some of the same overbank silts being deposited in the surrounding area, while the channel along which boreholes 18 and 22 lie was artificially cut off and filled up (see sections 2.3.5 above and 4.2.5.2 below).

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(b) Observations from GPR transects

The two short GPR transects taken on the Walton Flats (see Figure 14) run about NW-SE across a flat stretch of low ground (presently surrounded on two sides by artificial embankments) that was identified as belonging to the Cuerdale Terrace. The GPR transects run on the same lines along which sediment cores were taken for stratigraphy (see (a) above and Figure 13). The approximate position of the cores along the transects, as well as their stratigraphical sequences, are shown in Figures 29 and 30; Figure 30 also shows the stratigraphy and the approximate position along the transect of borehole 4 (see Figure 13), lying close to the transect line but not along it.

Comparison with the data from the cores helped the interpretation of the stratigraphy represented in the GPR output diagrams. The interpretation is shown in Figures 29 and 30 below the GPR output and can be compared with that shown in Figures 35 and 36, respectively (see section 4.2.5.2 below).

By comparison with the stratigraphy from the cores a correspondence between GPR “depths” (two-way travel times of the radar pulses) and actual observed depths of the sediments could also be found; such correspondences were averaged to obtain the graphical depth scale shown in Figures 29 and 30. Given the heterogeneity of the sediments and ensuing variation of transmission velocity, such a scale is to be considered an approximation only, and cannot be used to assess the exact depth of sediment boundaries.

In the diagram from the South-West transect (A) (Figure 29) the section of the palaeochannel running across the field (also visible on the surface) can be seen. The diagram suggests the shape of the channel's bed, which in correspondence with the section could be interpreted as somewhat W-shaped. The GPR trace interpreted as the channel's bed is the one consistent with the core data (depth at which gravel hit). A GPR reflection above it appears consistent with its interpretation as the upper limit of the silty/clayey materials in the channel's bottom fill. The upper limit of the gravel was also traced along the rest of the diagram consistently with the gravels' depth in the cores; such a discontinuity, however, does not appear to always stand out sharply, though this could also be an effect of the attenuation due to depth. The sand layers found in the South (right in Figure 29) part of the transect seem to stand out better. It could indeed be possible to tentatively recognise in the diagram the section of an older buried channel feature South (right) of the main palaeochannel, approximately in correspondence with the 75 m core. Its bottom, lower than that of the main palaeochannel, is filled by a sand pocket (see section 4.2.5.2 below). The feature could represent the channel in a former and deeper position, before net aggradation and slight lateral migration occurred.

In the diagram from the North-East transect (B) (Figure 30) the palaeochannel's section also appears consistent with that observed in the cores. The narrower channel section is visible in correspondence with the 25 metres core. The diagram also suggests the presence of another buried channel feature South (right in Figure 30) of the main one, between the 60 and 75 m distance marks.

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The stratigraphical discontinuity between the Cuerdale and Walton Terraces can be seen in the right part of the diagram.

4.2.5.2. *Structure of the terrace*

(a) Terrace fill

The typical stratigraphy of the Cuerdale Terrace seems to correspond to what has identified as type "A" sequence in the Walton Flats boreholes (Figures 13, 24, 25; see section 4.2.5.1 above). What is found in the cores extracted along the two Walton Flats transects (Figures 13, 26, 27; see section 4.2.5.1 above) is consistent with this picture. Here a layer of sand and gravels less than 1 metre thick (not seen in the channel bank sections) lies at the base of the sequence over weathered bedrock, whose top is usually between 4.5 and 5 metres deep from the surface; above the sand and gravel lie 2 to almost 4 metres of overbank-type materials (sandy clayey silt). The gravel unit apparently tends to become thicker towards South-East, where it reaches around 2 metres of thickness. A sand bed can be present between the gravel and overbank fines; sand beds can be also found intercalated within the latter.

A section of the part of Cuerdale terrace crossed by transect A, reconstructed from the cores data, is reconstructed in Figure 36; the analogous section along transect B is enclosed in Figure 35. The Cuerdale Terrace fill seems to consist here of a floodplain of overbank sandy silts. The typical stratigraphy, a 2-unit

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sequence of sandy gravel and overbank sandy silts, is visible in Figure 36 and by the North-West (right) end of Figure 35.

The River Darwen used to flow through the Walton Flats forming two small meanders that have now disappeared (see also section 2.3.5 above). The first such meander can be seen in Figure 3; the second one's position is marked by the palaeochannel crossed by the two borehole transects (see Figure 13). Inside the bends of these meanders a somewhat different stratigraphy is found (identified as type "B" sequence in the boreholes - see Figures 13, 24a-c and section 4.2.5.1 above): the gravel unit here is thicker and the overlying sediments tend to be coarser, with more sand and less silt. A section of the distal part of one such palaeo-meander can be seen in the middle part of Figure 35, showing the thicker gravelly unit and the sandier overlying fines (especially towards the right side, that is closer to the meander's tip - see Figure 13). The palaeochannel forming such meanders is described in (b) below.

It is not known whether the gravels underlying the Cuerdale Terrace overbank and palaeochannel sediments were deposited together with the Cuerdale Terrace, or if part or all of them are pre-existing units, likely continuous with the adjoining Walton terrace gravels.

(b) Observed palaeochannels

The stratigraphy of the palaeochannel running within Cuerdale Terrace sediments across the Walton Flats was reconstructed through some of the sediment cores extracted along cross-transects A and B, running at about mid-distance along a palaeomeander length (see Figure 13 and section 4.2.5.1 above).

The stratigraphy found in transect A is shown in Figure 26 (cores at 121, 115, 107, 100 m); the stratigraphy found in transect B is shown in Figure 27 (cores at 8, 16, 25 m). The palaeochannel's bottom sediment fill appears to be made up of various layers of clay or clayey silt, all together less than one metre thick, laminated and rich in organic matter and plant remains (though no peat is found). Beds of sand or silty sand can be found intercalated between the clayey layers. Above the organic-rich clay are up to two metres of clayey, sandy silts, not different from the overbank-type sediments forming the floodplain on the channel's sides, except possibly for the presence of sparse pebbles and some charcoal, mostly in the upper half. Several sand intercalations also appear within such units.

The palaeochannel's bed is cut into the terrace basal gravels to a maximum depth of about 2.45 m from the ground surface in transect A and to about 2.8 m in transect B, and roughly 3 m below bankfull level; it appears to have a roughly W-shaped section. The channel's width appears in both transects to be about 25 m. In transect A the bottom organic sediments fill the whole bed of the

channel, while in transect B they are present only in the right (South-East) half of it, the other half being filled with silty sand (though a small bed of organic-rich sand is present at the bottom of the 8 m core). The part featuring the organic-rich fill (likely the last to remain active) only spans about 15 metres in transect B. A reconstruction of the palaeochannel's cross-section along transect A can be seen in Figure 36; a similar reconstruction along transect B is enclosed in Figure 35.

The palaeochannel's width of around 15 to 25 metres is comparable to the Darwen's present width of 20 metres about; the palaeochannel's depth is 2.45 to 2.8 metres. The palaeochannel's fill features an organic-rich, clayey unit directly overlain by sand and silt similar to the surrounding overbank material. This suggests the channel was abandoned while the Cuerdale terrace deposition was still going on, and that it was buried by overbank sediments from the nearby active channels after a comparably short time with respect to the infill history of the Brockholes palaeochannel (see section 4.2.3.3 above), without a long phase of intermittent flooding that allowed the accumulation of peat.

The meander directly upstream survived until the XVIII Century, when it was filled up artificially (see section 2.3.5 above); its stratigraphy is likely visible in borehole 22 (Figures 13, 24c), and appears completely different from that observed in the core transects. Most of the stratigraphy here consists of the silty/clayey material used to fill the channel, and there is no trace of organic-rich fines at the bottom. Between the filling material and the underlying gravels

a bed of loose cobbles is reported; it could also have been dumped there, or it could represent channel bed sediments. GPR data, especially along transect A (Figure 13) could be consistent with the presence of a coarse channel bed unit distinct from the surrounding gravels. The cores, however, did not sample below the finer units, as the manual corer could not penetrate further after hitting the first gravelly or cobbly material, and there are no direct sedimentological data about what lies directly below the organic-rich units in the palaeochannel. The sequence in borehole 18 (Figures 13, 24c) doesn't seem to represent a channel fill, and more closely resembles what has been identified as type "B" sequences, particularly the one found in borehole 9, though its lower elevation sets it apart.

In the GPR diagrams (see section 4.2.5.1 above) the traces of former channel positions seem also to be visible (Figures 29, 30). The sequence observed in the 75 metres core in transect A (see Figures 26, 36), deeper and featuring two layers of sand and a unit of silty clay with plant materials, supports the existence of another smaller buried channel feature South-East of the bigger palaeochannel.

4.2.5.3. Evolution of the terrace

Very limited lateral changes seem to have occurred along the Ribble during the incision of the Walton Terrace and the deposition of the Cuerdale one; as a consequence, most of the Cuerdale Terrace fill lies within a very narrow area

following the course of the Walton stage floodplain, in which it is inset. One major avulsion, however, took place in the Fishwick Bottoms area (SD559287) before the incision of the Walton Terrace began. The Ribble abandoned its course across the middle of the Fishwick Bottoms, taking a course through Brockholes Terrace, along the path of the old compressed meander by the South valley edge. This could have given to the bend of the river bordering the Walton Flats a tendency to migrate North during or after the Walton Terrace incision, resulting (together with the Darwen's action, discussed below) in a locally wider new floodplain (the Cuerdale Terrace).

The only site where the course of the Ribble underwent major lateral change during the Cuerdale stage is at Balderstone Hall (see section 4.1.2.1 above and Figure 8). The downstream bend from Alston/Boot Farm, just upstream of Balderstone Hall, caused the Ribble to constantly migrate towards the North valley side from the Brockholes stage on. This apparently led to a constant tendency of the channel to migrate North, expanding the Lower House/Balderstone Hall meander and eroding the higher terraces and valley edge along its right bank while preserving those along its left one. The structure of the Lower House/Balderstone Hall area features now a series of concentric terraces, each one hugging the higher one on its North side, as the course of the river moved North.

The only other point where the Walton stage floodplain became wider is in the Walton flats. When the incision of the Walton Terrace occurred, the River

Darwen was still flowing across the site of the Roman town following an only slightly sinuous path. Subsequently, a series of four bends grew laterally into small meanders, widening the last part of the Darwen's floodplain and moving upstream the river's confluence with the Ribble. In the process the Darwen eroded part of the Walton Terrace, and with it large parts of the Roman remains. In Figure 39 a possible reconstruction is presented of the aspect of the Walton Flats area at the time of the Roman activity; symbols are same as in Figures 8-9.

These meanders did not survive until the present time. The present, nearly straight course of the last part of the River Darwen was partly cut artificially through a Walton Terrace neck (see sections 2.3.3.2 and 2.3.5 above); the original course formed a meander that is shown in Figures 9 and 13 as a palaeochannel. Another palaeochannel running across the Cuerdale Terrace in the North part of the Walton Flats, together with the Cuerdale Terrace area observed just across the Darwen (see Figure 9), suggests the meander was originally followed by another one of similar shape and size, the Darwen's confluence with the river Ribble being upstream of the present one.

An archaeomagnetic date (P. Gibbons, personal communication, 2000; LUAU 1996) on the Walton Flats silts, belonging to the Cuerdale Terrace, shows its deposition was taking place at 1400-1050 cal BP (AD 550-900). A Viking treasure (the Cuerdale hoard, found in 1840), provides an indirect confirmation of the terrace's age. The treasure was buried by Vikings in the body of the

terrace downstream of Cuerdale Hall (SD573295) most probably around AD 905 (Hunt 1997), close to the break of slope to the Walton Terrace above and not far from the present course of the Ribble – and likely from its course at that time, since it doesn't seem to have changed its position by more than a few metres. Its presence shows that by that time the terrace had been deposited; it also could suggest that the spot appeared safe enough at the time and that it could be easily reached from the sea.

The Roman activity phase lasted until the early IV Century AD (around 1700 BP) (Cumbria and Lancashire Archaeological Unit 1988); the erosion of the Walton Terrace (including the Roman site) cannot have begun until then. In the centuries between that time and Gibbons' archaeomagnetic date (see above) the Ribble and Darwen dissected their floodplain again, giving rise to the present Walton Terrace. This short time interval could likely account for the scarcity of significant lateral changes in the Ribble's course. As noted above, the last part of the Darwen's course underwent a lateral evolution with the growth of small meanders accounting for the removal of most of the Roman site; such meander growth needs not have entirely taken place before AD 550–900. Comparison of old maps shows the artificial straightening of the Darwen's upstream meander was performed between 1738 and 1786 (see Figures 3 and 4 and section 2.3.5 on page 63). The downstream meander had already disappeared in 1738, as it does not appear in Porter's map; the 1728 engraving reported by Hunt (1997) (Figure 5; see section 2.3.5 on page 63), however, seems to suggest that just 10 years before Porter's map the river Darwen still formed three bends before joining the

Ribble, though such a representation is not necessarily fully realistic. The buried meander's fill, as observed from the Walton Flats cores, suggests the abandonment happened naturally, or that even if the cut was artificial the dead meander was left to be filled up naturally by overbank silts.

4.2.6. More recent deposition

The small depositional units formed after the Cuerdale Terrace incision show great sedimentological variety in their observed sections. In some places the whole sequence is made up of fine, overbank-like silty sand, in others coarse sand and gravel are visible. The sedimentology varies widely over relatively short distances along the same bank, supporting the hypothesis of small-scale, locally-driven deposition (in channel beds, as channel bars or overbank) directly followed by incision.

Present river deposition is varied too; the observed mid-channel and side bars seem to be mostly sandy, while the point-bars can feature different sediment sizes. The channel's bed, where the Ribble does not flow on solid rock, seems to be gravelly and cobbly in most places. Boreholes 157 and 161 (Figure 22) from the M6 motorway (see Figure 13 and section 4.2.2.1 above) were drilled from a platform in the Ribble, and exemplify a possible stratigraphy of the Ribble's channel bed: under the sandy gravels at the top there can be gravelly clay and even silty sand. The sequences in the two boreholes, little more than a hundred metres apart, show the stratigraphy can be quite variable (the top gravel

varying from 0.5 to over 2 m in thickness). The presence (in borehole 157) of angular gravel suggests only the top layer of gravel could be channel-(re)deposited material, while the underlying sediments would be older and largely unaffected by channel reworking.

Modern artefacts found embedded in the late depositional units at Lower Magdell Bank, Osbaldeston Hall, Hothersall Hall and Sunderland Hall suggest their accretion went on until past the mid-Twentieth Century.

4.3. The Ribble terraces: general sequence of events

The Lower Ribble alluvial sequence apparently formed in a series of four depositional phases, each followed by a period of incision, forming a typical series of river terraces. No formation of purely erosional terrace surfaces has been observed, as a new depositional floodplain apparently formed after each phase of incision.

A possible reconstruction of the valley floor's aspect through the various stages of its development is provided in Figure 40a-e. Those valley and terrace edges that are still visible today and likely already existed at the time each figure refers to are drawn with a continuous line (the valley edges with the same symbol used in Figures 8-9); dashed lines are used in each figure to complete the terrace and valley sides along their likeliest position at the time. The areas corresponding to the different terrace surfaces are shown in the same shades as

in Figures 8-9. A possible course of the Ribble and of the lowermost part of the Darwen at each stage are also shown in each figure as dashed lines; where a river channel's position at the time appears to be confirmed by a surviving stretch of palaeochannel the course is drawn with a solid line. The thickness of both the dashed and solid line is meant to give an approximate idea of the relative likely width of the rivers' main channel.

4.3.1. Devensian Lateglacial and early Holocene

4.3.1.1. *The Ribchester stage*

The observations of possible residual fragments of an ancient terrace higher than the Ribchester one are too scarce to support its existence or offer any useful information about it, and its possible existence is not taken into consideration here. If such an older and higher terrace existed in the lower Ribble valley, anyway, the extreme scarcity of its possible surviving fragments show it would have been reworked almost entirely before or during the formation of the Ribchester floodplain.

The Ribchester Terrace formed therefore the first confirmed extensive alluvial plain of the lower Ribble. Though there are no direct dating controls for the Ribchester Terrace, we know it was deposited after Devensian Lateglacial incision of the valley through the glacial till, and was likely re-incised by the start of the Holocene. A possible reconstruction of the valley at the time of the

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Ribchester stage floodplain is shown in Figure 40a, where it is represented as continuously occupying the entire valley bottom. The valley was probably at most points narrower than at the present time, though it is not possible to know its exact width. Before the incision of the Ribchester Terrace, however, the Ribble had already started to erode the valley sides widening its floor, especially at some points such as the Fishwick Bottoms, Alston and likely Lower Hall/Bezza Brook. Other surviving valley bluffs from that stage suggest in their shape the carving action of a river bend and the existence of widening or migrating river meanders. GPR evidence could also suggest the existence of braided channels; the channel observed in the North Penwortham Lane GPR transect could be related to an earlier stage, before the valley widening occurred.

4.3.1.2. The Brockholes Stage

After the incision of the Ribchester Terrace, a new floodplain was deposited. Apparently the floodplain was initially rather narrow, flowing mostly lengthwise between the incised Ribchester Terrace or one or the other valley side, though the Lower Hall and Brockholes meanders were already present. Figure 40b shows a reconstruction of the possible aspect of the Ribble valley at the time; most of its edges were likely still the same as during the Ribchester stage, and only minor valley widening seems to have occurred, if at all.

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A phase of vertical stability followed the Brockholes Terrace deposition. During this period no net incision or aggradation occurred, but the Ribble had a vast amount of lateral activity, eroding and fragmenting a greater part of the earlier Ribchester Terrace. In several instances the river eroded the valley sides, widening the valley and forming confined meanders, some of which have been subsequently maintained. A reconstruction of the Brockholes floodplain towards the end of this phase is shown in Figure 40c. The whole process happened before 9000 cal years BP, at which time the Brockholes channel had reached its final position.

4.3.2. Early to mid-Holocene

4.3.2.1. *The Brockholes stage*

The phase of lateral development was ended between 9000 and 6900 cal years BP by a change in river activity that led to the short-cutting of meanders and caused an overall straightening of the Ribble's course; in some places a new course was cut through parts of the Ribchester Terrace, leaving abandoned stretches of the Brockholes floodplain. It is uncertain if this change coincided with or immediately preceded the start of the Brockholes Terrace incision phase, or if the incision began some time later. The river, anyway, ceased to have marked lateral activity, and generally maintained its new course until the incision started (compare Figure 40c with Figure 40d).

4.3.2.2. *The Walton stage*

Figure 40d shows a reconstruction of the Ribble valley after the deposition as a floodplain of the Walton Terrace and before its incision. There are no dates between the alluviation above the Higher Brockholes palaeochannel around 4700 cal years BP and Gibbons' (*personal communication*, 2000) date of 1400–1050 BP (AD 550–900) for the Walton Flats silts. The time of the aggradation of the Walton Terrace fill is not known; it could have occurred after ca 4700 cal BP, or it could be related to the alluviation at that time, having likely started sometime earlier. The deposition generally happened inside the trench of the Brockholes Terrace incision that in most places remained narrow. Some lateral activity did however occur at some places, during or after the floodplain's deposition, leading to its widening, for instance at the confluence of the river Darwen with the Ribble. Between the Brockholes and the Walton stages the width of the Ribble's channel increased, reaching a size comparable with the present time.

4.3.3. Bronze Age to Middle ages

4.3.3.1. *The Walton stage*

The period of the Bronze and Iron Age, up to the end of the Roman time, seems to have seen another phase of relative stability on the Ribble. The Walton floodplain had not yet been incised, but was apparently safe enough from floods to allow human settlement. Some channel shifts seem to have occurred,

possibly early during this stage, bringing the Ribble to (with few exceptions) its present course.

4.3.3.2. *The Cuerdale stage*

The Walton Terrace was incised after or at the end of the Roman age; at or before that time the Ribble's course underwent its last major change at Fishwick Bottoms, abandoning its mid-valley floodplain in favour of a path along the South valley edge. Within five or six centuries renewed aggradation had deposited a narrow floodplain, closely flanking the Ribble along most of its course. The only two exceptions are at Lower House/Balderstone Hall, where the meander continued to enlarge expanding its floodplain, and at the Ribble/Darwen confluence, with expansion of both the Ribble and Darwen floodplains at the expense of the Walton Terrace. A reconstruction of the Ribble valley at the end of the Cuerdale stage (X Century AD or later) is shown in Figure 40e. The reconstruction shown in Figure 39 (see section 4.2.5.3 above) refers to a time between Figure 40d and 40e.

4.3.4. Recent times

The time when the incision of the Cuerdale Terrace started is not known. The propensity to flooding of the Walton flats in centuries past does not really offer a clue, since the Ribble was and still is able to flood over not only the Cuerdale but also the Walton terrace, and in exceptional times can reach even higher. The

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cessation of frequent flooding on the Walton Flats is actually principally due to their confinement by embankments, and doesn't really provide information about the Cuerdale Terrace's status as an active floodplain. The deposition of the Cuerdale Terrace was the last generalised aggradational event on the lower Ribble, and since its incision began the overall net tendency seems to have been to downcutting more than to aggradation. Within this general trend, local deposition and re-incision occurred along the Ribble, especially in the upper reaches of the study area, until the present time.

5 – Discussion and conclusions

5.1. Discussion of salient events in the lower Ribble fluvial evolution

An overview of the depositional and erosional episodes leading to the formation of the lower Ribble sequence of alluvial terraces is illustrated in **Figure 41**. The regional climate change record is also shown in the figure. Schematic reconstructions illustrate the possible relationships between different terrace fills and the possible general aspect of the valley during various stages of its development.

5.1.1. Ribchester stage

The oldest river terraces observed in North-West England (see **section 2.1.2.2(b)** on page 30) are usually thought to be of Pleistocene age; it is plausible the age of the Ribchester Terrace can be set in the Pleistocene too. The terrace appears to be graded to an elevation of 8-9 m OD (see **Figure 7**) that has no association with local relative sea-level in the Holocene (see **Figure 2**). This behaviour, however, is consistent with the oldest terraces described by Johnson (1969) (see **section 2.1.2.2(b)** on page 30), also graded to a high base-level. The presence of active meanders (see **section 4.2.2.3** on page 119) is not inconsistent with a Pleistocene age: in the Nene basin, for example, frequent cross-bedding

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suggests channel migration in the Lateglacial (Bølling-Allerød) interstadial (Brown 1997). According to Tebbens *et al* (1999) meandering channels were also present on the River Maas (the Netherlands) during a long phase lasted from around 12 900 ¹⁴C BP (ca. 14 800 cal BP) to around 10 900 ¹⁴C BP (12 400 cal BP), between two phases of channel braiding. Thus a plausible age for the aggradation of the Ribchester Terrace would be during the Lateglacial (Windermere) interstadial, possibly around 14 000 cal BP.

5.1.2. Brockholes stage

The Brockholes Terrace was deposited before about 8900 cal BP (see section 4.2.3.4 on page 151), and after the Ribchester stage. The Mersey High Terrace (see section 4.2.2.3 on page 119) started aggradation before ca. 11 700 cal BP (Johnson 1969), and the Brockholes Terrace could be related to the same regional alluviation phase. The terrace's profile (see Figure 7) is consistent with the base-level of about 6 m OD the Mersey High Terrace seems to be graded to (see section 4.2.2.3 on page 119). The phase of incision that ended the Ribchester stage, prior to the deposition of the Brockholes Terrace, could therefore be located between ca. 14 000 and ca. 12 000 cal BP.

According to Johnson (1969) the deposition of the Mersey High Terrace was complete before ca. 8200 cal BP; Hooke *et al* (1990) consider the high terrace in the Dane catchment, likely equivalent to the Mersey High Terrace, to be of Younger Dryas age. Such an age is also plausible for the Brockholes Terrace,

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that had ceased its aggradation before about 8900 cal BP. Unlike the Mersey High Terrace, however, a major part of the Brockholes Terrace fill consists of fine-grained overbank sediments, suggesting a difference in sediment transport processes or sediment source.

In the Early Holocene times the Brockholes Terrace fill continues to be reworked, but no actual aggradation seems to take place. This phase, characterised by mobile channels and growing meanders, ends between ca. 8900 and ca. 6900 cal BP with major meander cut-offs; afterwards, the Ribble seems to assume a fixed channel pattern, with only a limited amount of lateral change. The aggradation of the Mersey High Terrace also stops by ca. 8200 cal BP. This change could be related to a climate shift to wetter conditions, recorded in the sites of Walton Moss, Bolton Fell Moss and Burnfoothill Moss (see section 2.1.2.1(b) on page 19) between ca. 8300 and 7800 cal BP.

Though a wetter climate, through an increased flood frequency and magnitude, could have favoured meander cut-offs, it does not seem to justify channel stability. Our evidence does not support stability being related to woodland cover either. Though mixed oak forest prevails from ca. 7900–7800 cal BP, trees are present in the region since earlier times, before 11 200 cal BP, and total woodland cover is established from 10 200–9800 cal BP (Hibbert *et al* 1971; Greig 1996; Harvey 1997; see section 2.1.2.1(c) on page 21). The Brockholes stage lateral activity phase (ending before ca. 8900 cal BP) actually takes place with woodland already prevailing in the region.

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Alnus pollen is abundant in the Ribble catchment prior to ca. 6900 cal BP (see section 4.2.3.5(c) on page 163); the rise of *Alnus* in the region (see section 2.1.2.1(c) on page 21) dates to around 7800 cal BP, shortly after the time proposed for the Ribble meander cut-offs and the start of deposition of unit 3 in the abandoned channel at Brockholes (see section 4.2.3.2(b) on page 135 and Figure 34) where high *Alnus* values are recorded. This shows that alder colonised the Ribble valley rather early; the terrain features, with abundance of oxbow lakes and wet ground, could have favoured its establishment.

The grey silty clay observed by the North-West corner of Higher Brockholes (see sections 4.2.3.2(b) on page 135 and 4.2.3.3(c) on page 148) is stratigraphically equivalent to unit 3 in Figure 34, and can be supposed to date to between ca. 8900 and 6900 cal BP too; it lies approximately at an elevation of 7.5 to 8 m OD. The Ribble is known to have historically been tidal to upstream of Brockholes (see section 2.3.3.1 on page 48). At the start of the possible time interval of deposition of the grey clay the relative sea-level, though rapidly rising, was still quite low, definitely below 0 OD and likely below -10 metres OD (see Figure 2a-b); by the middle of the interval, however, the mean high water level at spring tides had exceeded OD. The tidal funnelling effect needed for estuarine conditions to exist at Brockholes around 8900 cal BP would have had to account for an amplification of up to 17-18 m, but before 6900 BP the needed magnitude of the effect would have fallen below 7 m, comparable (though still larger) to the 5-6 m one expected by Zong and Tooley (1996) in Morecambe Bay (see section 2.1.1.2(b) on page 16). Though not proven, it is

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therefore possible that some estuarine conditions existed in the dead channel at Higher Brockholes shortly after its abandonment.

The date of ca. 6900 cal BP corresponds to a climate shift towards drier conditions (see section 2.1.2.1(b) on page 19), and to a sudden, though probably local, fall of woodland cover (see section 4.2.3.5(c) on page 163); the abundance of microscopic charcoal suggests fire was responsible for the event, though it offers no evidence to characterise it as wildfire or early clearance by Mesolithic populations (see sections 2.1.2.1(d) on page 23 and 2.3.1 on page 41). The abundance of bacterial sulphide spherules suggests the sudden accumulation of a relevant amount of dead organic matter that could also be related to the fire event. From around 6900 BP (see section 4.2.3.5(c) on page 163) the local conditions in Higher Brockholes are of prevailing grassland. Some minor wet climate shifts (with variations in groundwater abundance) during this phase could be reflected in the increase in aquatics and ferns in pollen zones C1 and C2 (see Figure 38c), the ferns (especially bracken) favoured by the open ground conditions. Woodland regeneration seems to have been hindered by the drier climate, since it seems to occur when conditions start to be consistently wetter again, around 5200 cal BP. The continuous presence of microscopic charcoal throughout the grassland phase could also suggest a Late Mesolithic/Early Neolithic frequentation of the site played its part, though it could also be interpreted as flash-fires occurring in the grassland until it was substituted by woodland.

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The pollen sequence ends when the peat is buried by renewed alluviation, around 4700 cal BP. The date corresponds with the start of a period of maximum wetness, with agreement of all the three raised bog records (see section 2.1.2.1(b) on page 19). It is consistent with an increased sediment production on the Bowland Fells (upstream in the Ribble catchment) and possibly with aggradation in Langdale (see section 2.1.2.2(b) on page 30), as well as anthropogenic woodland reduction recorded at Fenton cottage (see section 2.1.2.1(c) on page 21). On the River Dane the time seems to coincide with the start of lateral activity, though no aggradation is recorded (see section 2.1.2.2(c) on page 33).

5.1.3. Walton stage

There is no direct information about when the Brockholes Terrace was incised or when the aggradation of the Walton Terrace occurred, except that the aggradation must have been complete by the time the Roman occupation at Walton-le-Dale began, in the early II century AD (see section 2.3.3.2(a) on page 52). Considering the regional analogies (see section 5.1.2 above), a plausible hypothesis would be to suppose the aggradation to be ongoing around 4700 cal BP, during a major wet shift of the climate, and being related with the overbank deposition events occurring at Higher Brockholes at that time. Unlike the Dane, the Ribble would have shown only minor lateral activity, though not being completely laterally stable (see section 4.2.4.3 on page 177). The incision of the Brockholes Terrace, prior to the Walton Terrace aggradation, would in this case

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be framed between ca. 8900 and 4700 cal BP. The dates of ca. 6900 and 5800 cal BP correspond, respectively, to the establishment of stagnant, asphyctic conditions and to the end of permanently flooded conditions in the dead channel at Higher Brockholes. The first event seems to correspond with a major dry shift of the climate, visible in all three bog records considered (see section 2.1.2.1(b) on page 19); the second one, however, has no similar correspondence, and actually seems to occur during a marginally wetter period (see section 5.1.2 above and 4.2.3.5(c) on page 163). It would be plausible that the first event was climatically driven, while the second event happened in relation to a fall in the water table, related to fluvial incision. Terrace aggradation is recorded on the Bowland Fells at about the same time (see section 2.1.2.2(b) on page 30); such event could be compatible with incision in the lower reaches, if it represents sediment being stored in the upper catchment rather than transported downstream. It is still possible the incision of the Brockholes Terrace occurred earlier, during the previous major wet shift at the time of the meander cut-offs (between ca. 8900 and 6900 cal BP); such possibility could also account for the cessation of relevant lateral activity. The Walton Terrace aggradation, though ongoing at 4700 cal BP, could likely have started earlier (the wet shift starting around 5200 cal BP at least). This picture would also be consistent with the Neolithic material found in the Walton Terrace (see section 4.2.4.3 on page 177) actually being *in situ*, and could possibly also explain the “Mesolithic” findings, given the scarce characterization of periods and the cultural conservatism of Lancastrian prehistory (see section 2.3.1 on page 41).

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A major change between the Brockholes and Walton stages is the relevant increase in channel size. Such change could coincide with the passage from the Brockholes to the Walton stage (possibly around 5800 cal BP), having happened during or after the incision of the Brockholes terrace. However, no late Brockholes stage palaeochannels were observed, and the channel size increase could also be older. An option would be for it to happen between 8900 and 6900 cal BP, in correspondence with the meander cutoffs and cessation of lateral activity, likely with another major wet climate shift and possibly with the start of incision (see above). In such case, however, the ca. 5800 cal BP change in conditions in the abandoned channel would need another explanation. Whenever it happens the Ribble channel size increase finds no match in regional fluvial literature.

5.1.4. Cuerdale stage

The aggradation of the Cuerdale Terrace was ongoing at 1400–1050 cal BP (AD 550–900), and was likely complete by 1045 cal BP (AD 905) (see section 4.2.5.3 on page 190). The incision of the Walton Terrace cannot have occurred before AD 250–300, when activity at Walton-le-dale ceased (see section 2.3.3.2(a) on page 52), and must have occurred prior to AD 550–900. Both events could be related with increased deforestation and cereal cultivation recorded on the Bowland Fells (see section 2.1.2.1(d) on page 23), with increased runoff followed by increased sediment load, and anthropogenic woodland reduction recorded at Fenton cottage (see section 2.1.2.1(c) on page 21). The Cuerdale

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Terrace aggradation is also consistent with the aggradation of the Dane lower terrace, and also related to human influence (Hooke *et al* 1990; see section 2.1.2.2(b) on page 30); increased sediment production on the Bowland Fells and in Langdale, however, seem to occur later, after AD 1100.

It may be argued that the incision of the Cuerdale Terrace happened in the last 300 years by analogy with fluvial histories recorded on the Dane and Langden Brook (Harvey 1985; Hooke *et al* 1990; see section 2.1.2.2(c) on page 33). Unlike those streams, the Ribble did not have marked lateral activity in the latest centuries, and as a consequence it did not build a floodplain below the Cuerdale Terrace.

5.2. Comparison with other North British examples

Published fluvial studies in North-West England are scarce. In order to better characterize the lower Ribble in the context of Holocene fluvial history, it is necessary to compare it with fluvial records from adjacent regions.

5.2.1. Ribchester stage

Outside of North-West England most observed high, old terraces are also found or supposed to be of Pleistocene age (though in the second case it is often by mere analogy); they usually feature abundant coarse sediments and are often associated with high discharges. Examples are in upper Wharfedale at Kettlewell (Howard *et al* 1998) and in the Tyne basin at Farnley Haughs

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(Macklin *et al* 1992a), Lambley (Passmore & Macklin 2000) and Scotswood (Passmore *et al* 1992). Most studies, however, focus on later terraces, and published data about pre-Holocene terraces tend to be fragmentary.

5.2.2. Brockholes stage

Data about Early Holocene or Pleistocene/Holocene boundary terraces are also scarce. In the lower Tyne basin at Scotswood an erosional contact is thought to mark the Pleistocene/Holocene boundary (Passmore *et al* 1992). The body of the first Holocene unit is dated at ca. 6400–6250 cal BP; though undated at the base, the unit is thought on palynological grounds to have started being deposited around 7500 cal BP. In the Milfield basin (in the catchment of the River Tweed) Tipping (1998) reports the incision of Pleistocene-aggraded fluvial sediments occurring between 11 500 and 11 000 cal BP, followed by little activity throughout the Early Holocene, fluvial aggradation not occurring again until around 7500 cal BP. On the South Tyne at Lambley (Passmore & Macklin 2002) the incision of the highest terrace and the deposition of the second terrace are estimated to have occurred after ca. 11 500 cal BP, though there are no direct dates. The earliest Holocene deposition in Annandale (South-West Scotland) is recorded by Tipping *et al* (1999) as occurring after ca. 8100 cal BP.

Thus, the common pattern in the North and North-East seems to be of a relatively stable Early Holocene, up to about 7500 cal BP, following entrenchment occurring at the Pleistocene/Holocene boundary. Such a picture

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is different from that observed on the Ribble, where a likely Younger Dryas aggradation is not incised until well into the Holocene, with major lateral activity ongoing throughout the early Holocene. At a latitude closer to the Ribble's, on the River Ure near Ripon (North Yorkshire), the base of peat overlying a flood basin or backwater sequence is dated to around 10 800 cal BP (Howard *et al* 2000), suggesting a continuity at the start of the Holocene closer to the pattern of the Ribble than to the one of the Tyne and the Northern rivers.

The lateral activity that reworked large parts of the Brockholes Terrace fill is also not usual in Northern England. The preservation of the Ripon sequence (see above) suggests the Ure had little or no lateral activity in the Early Holocene, unlike the Ribble.

All Early Holocene or older terraces of known sedimentology in northern England are largely or totally composed of coarse sediments; the sedimentology of the Brockholes Terrace has no match. The earliest Holocene fine-grained terrace aggradation was observed on the Thinhope Burn (South Tyne catchment), starting at ca. 8700 cal BP (Macklin *et al* 1992b). The fine units observed on the river Ure (Howard *et al* 2000) were deposited before ca. 10 800 cal BP, but they relate to a flood basin or backwater facies, unlike the seemingly overbank sediments observed at Higher Brockholes (Plate 3). The only example of fine sediments being deposited at an older time is on the lowland reach of the River Aire at Beal (Macklin *et al* 2000), where fine aggradation has been going on since 12 000 cal BP or earlier. The fine sediments at Brockholes could only be

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explained by analogy with the River Aire at Beal by supposing that at the time of their deposition the Brockholes area had the characteristics of a lowland reach; this cannot have happened during the Early Holocene (see section 5.1.2 above).

There are no clear parallels to the vertical stability of the Ribble at the start of the Holocene, nor to the meander straightening occurring between ca. 8900 and 6900 cal BP. The cutoffs, however, could have happened in relation to a climate deterioration, possibly also accounting for the aggradation episodes occurring elsewhere around 7500 cal BP. Thus, it seems the Ribble responded to the same climatic trends as other rivers, though in a rather different way.

The same climatic episode could also be related to the channel size increase occurring between the Brockholes and Walton stages. Macklin *et al* (1992b) relate channel enlargement in upland Tyne basin to rainfall-driven increases in floods magnitude and frequency, and a similar process could have occurred on the Ribble, either between ca. 6900 and 8900 cal BP or after 5800 cal BP. However, no precise parallels of the Ribble event are found in adjoining regions.

5.2.3. Walton stage

A phase of incision is recorded between ca. 3300 and 2300 cal BP on different piedmont reaches East of the Pennines: at Snabdaugh (Passmore & Macklin

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1997; Moores *et al* 1999) and Farnley Haughs (Macklin *et al* 1992a) in the Tyne basin and on the River Swale at Catterick (Taylor & Macklin 1998; Macklin *et al* 2000); Incision in the same period could have occurred in the upland reach at Lambley (South Tyne) (Passmore & Macklin 2000; Passmore & Macklin 2002), as well as in the lowland Tyne reach at Scotswood (Passmore *et al* 1992; Passmore & Macklin 1997). By analogy, this would support the incision of the Brockholes terrace on the Ribble having occurred after ca. 4700 cal BP, and the deposition occurred at that date not being related with the Walton Terrace aggradation. Other piedmont examples, however, show a better agreement with the hypothesis of the incision occurring earlier (see section 5.1.3 above). At Brownchesters Farm on the Tyne (Moores *et al* 1999; Macklin 1999) incision is recorded around 7000 and 6000 cal BP, corresponding with the dates at ca. 6900 and 5800 cal BP on the Ribble. At Snabdaugh (Passmore & Macklin 1997; Moores *et al* 1999) incision is also recorded between ca. 7000 and 6000 cal BP.

Data matching with the deposition of the Walton Terrace show different kinds of agreement. In the upland Tyne basin at Lambley (Passmore & Macklin 2000; Passmore & Macklin 2002) there is deposition between after ca. 3200 cal BP and until ca. 1400 cal BP, though it is prevalently coarse-grained (unlike the Walton Terrace, but the difference could be related to the upland character of the Lambley reach). Both on the upland Cheviot Hills (Tipping 1992) and in piedmont Annandale (South-West Scotland) (Tipping *et al* 1999) deposition (including fine-grained sediments) occurs between 4000 and 5000 cal BP, in accordance with the ca. 4700 cal BP Ribble event supposed to relate to the

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Walton Terrace aggradation. Also in the lowland Swale reach at Myton-on-Swale (Macklin *et al* 2000) there is accordance, the onset of deposition being dated between 5800 and 5000 cal BP. A similar accordance is possibly found in piedmont Tyne reaches. Aggradation onset at Snabdaugh (Moore *et al* 1999) occurs after ca. 5600 cal BP, though the unit is newly incised after ca. 3500 cal BP (much earlier than the Walton Terrace). At Farnley Haughs (Macklin *et al* 1992a) a terrace unit is incised at about the same time, but the onset of its deposition is dated as early as ca. 6700 cal BP, and would be consistent with an earlier onset of the Walton Terrace aggradation; deposition starts again from around 2400 cal BP, possibly consistent with a late (post-4700 cal BP) onset of the Walton Terrace aggradation. At Brownchesters Farm (Moore *et al* 1999) several deposition episodes seemingly followed each other, separated by brief incision events; such episodes – during which overbank deposition could also have affected older terrace surfaces, as seems the case with the Higher Brockholes ca. 4700 cal BC event – could be in accord with the Walton Terrace deposition starting between ca. 6900 and 5800 cal BP, between ca. 5800 and 4700 cal BP and after ca. 4700 cal BP, though only one incision event seems to have occurred on the Ribble. Only coarse-grained deposition is recorded at Kettlewell in upper Wharfedale in the Mid-Holocene (Howard *et al* 1998); different dates would point to possible accordance with the Walton Terrace aggradation occurring at different times. Fine-grained deposition in the Milfield basin (piedmont Cheviot Hills) occurs from ca. 7500 to ca. 4600 cal BP (Tipping 1998), and would accord with an early onset of the Walton Terrace aggradation and only its culmination

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with the ca. 4700 cal BP episode; deposition from around 7500 cal BP seems to be a relatively common trend (see section 5.2.2 above). However, the Milfield Basin deposition undergoes a slightly coarser-grained phase between ca. 5400 and 4700 cal BP. According to Macklin *et al* (2000), fine-grained deposition generally occurs in the piedmont and lowland Yorkshire Ouse basin around 5500 and 4000 cal BP, respectively before and after the Ribble ca. 4700 cal BP episode.

5.2.4. Cuerdale stage

A date for the Cuerdale Terrace aggradation is known; time constraints from archaeology and dating (see section 4.2.5.3 on page 190) leave a relatively short interval within which the incision of the Walton Terrace can have occurred.

There are several examples of incision or deposition processes ongoing at times more or less closely corresponding to the Cuerdale stage on the Ribble. Overbank deposition interrupting peat growth occurred in upper Annandale (southern Scotland) (Tipping *et al* 1999) mostly from around 1500 cal BP (AD 450), slightly earlier than the Cuerdale Terrace date. In different sites the start of deposition is recorded at different times, but still broadly falling around the Cuerdale deposition date – from ca. AD 401 to ca. AD 540 to ca. AD 880 (this last date referring to coarse-grained aggradation in an upstream reach). At the site of Frenchland Burn the peat was not buried until later, but a limited amount of fluvial deposition occurred at 1500–1270 cal BP (ca. AD 565). In the

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upland Tyne reach at Blackett Bridge aggradation started around AD 400 (Passmore & Macklin 1997). In piedmont reaches of the Tyne basin post-Roman aggradation buried structures by the HABITANCUM Roman fort at West Woodburn on the River Rede (Passmore *et al* 1991), and was complete by ca. 1350 or 1300 cal BP (AD 600-650). At Haltwhistle (Passmore *et al* 1991; Passmore & Macklin 1997) a fine-grained unit ceased aggrading and was incised around AD 1200. At Brownchesters Farm (Moore *et al* 1999) an incision episode at ca. 1300 cal BP (ca. AD 650) marked the end of the aggradation of a terrace unit before another one started aggrading. At Kettlewell (upper Wharfedale, Yorkshire Ouse basin) the upper, fine-grained part of a terrace fill is dated 1305-1175 cal BP (AD 645-775), though its lower, coarse-grained part could be older (Howard *et al* 1998; Macklin *et al* 2000). Widespread aggradation in piedmont Ouse reaches, however, is only recorded from ca. AD 1420 (Macklin *et al* 2000).

In a number of other sites, Late Holocene aggradation that may be comparable to the Cuerdale Terrace aggradation on the Ribble occurred earlier, or - though ongoing at the same time as on the Ribble - had started at an earlier time. At different sites in the upland Cheviot Hills (Tipping 1992) coarse-grained deposition on terrace units or in lakes occurred between ca. 2200 and after 1700 cal BP. In parts of upper Annandale (southern Scotland) aggradation is recorded earlier than mentioned above, having started between 2000 and 3000 cal BP, though it tended to go on until the early centuries AD (Tipping *et al* 1999). Incision from ca. 1577 cal BP (AD 374) (Macklin *et al* 1992b) terminated a

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phase of slow aggradation that lasted since the Early Holocene on Thinhope Burn (upland Tyne basin), though new deposition was ongoing by 1161 cal BP (AD 788). At Bleagate (Passmore & Macklin 1997) an aggradation onset is recorded around 1700 cal BP (AD 250). At Lambley (Passmore & Macklin 2000; Passmore & Macklin 2002) a mostly coarse terrace unit aggraded between ca. 3225 and 1160 cal BP, though the authors possibly narrow the interval (by analogy with other Tyne sites) to 1880-1410 cal BP (AD 70-540). In the piedmont Tyne reach at Snabdaugh (Moore *et al* 1999) a terrace fill seemingly aggraded from ca. 2435 cal BP to 1000-690 cal BP (AD 950-1260); its finer parts were deposited from 1820-1520 cal BP (AD 130-430). On the lowland Tyne at Scotswood (Passmore *et al* 1992; Passmore & Macklin 1997) mostly fine-grained deposition is recorded from around 2450 up to 500 cal BP (ca. 500 BC-AD 1450).

Parallels to the incision of the Cuerdale Terrace and later events on the Ribble are not obvious: incision episodes are recorded at different times during the second millennium AD, intercalated with late deposition. On Frenchland Burn (upper Annandale, southern Scotland) overbank fines are accumulating since 715-576 cal BP (ca. AD 1205) (Tipping *et al* 1999). At Lambley (upland Tyne) (Passmore & Macklin 2000; Passmore & Macklin 2002) incision occurred before 840 cal BP (AD 1100), between 590 and 490 cal BP (AD 1360 and 1460), between AD 1750 and 1830 and before AD 1865; terrace aggradation occurred after each incision episode. On Thinhope Burn (Macklin *et al* 1992b) three more incision episodes separating the aggradation of terrace units occurred between 1161 cal

BP (AD 788) and ca. AD 1800; minor incision and deposition events followed in the last two centuries, with a different pattern in upstream and downstream reaches of Thinhope Burn. Periods of more frequent floods occur AD 1780–1820, 1840–1880 and 1920–1950. At Farnley Haughs (piedmont Tyne) two incision and deposition cycles took place up to the late XIX century AD; through the late XIX and the XX centuries AD two more cycles occurred (Macklin *et al* 1992a). At Snabdaugh (Moore *et al* 1999) three fills were deposited since the Middle Ages, the second of them dated at around AD 1350. Both at Snabdaugh and Brownchesters map evidence shows the channels have been laterally stable since the XIX century (Moore *et al* 1999). In the lowland Tyne reach at Scotswood two incision and deposition cycles occur (Passmore *et al* 1992); the first one before the early XVII century AD, the second one between the early XVII and late XIX centuries, when the fill is incised again in relation with dredging of the river channel downstream. No incision happens at Low Prudhoe during the XX century; measurements of sediment accretion rates (Macklin *et al* 1992c) showed generally high values (averaging 2.4 cm a⁻¹) with a wide variability, ranging from 7.0 to 0.3 cm a⁻¹ in different decades of the XX century.

In the upland Yorkshire Ouse basin general trends also vary during the last millennium (Macklin *et al* 2000). A phase of prevailing fine-grained deposition (seemingly not affecting piedmont reaches) occurs between AD 1015 and 1290; between AD 1205 and 1450 incision prevails in upland and piedmont reaches, while around AD 1420–1645 the trend throughout the basin is fine-grained

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deposition again. In upland Coverdale (in the Ure catchment) Merrett & Macklin (1998) report an overall trend of incision since the XVI century AD. The trend is interrupted between AD 1750 and 1800 when increased floods resulted in major increase in sediment supply and aggradation; a second period of increased floods between AD 1870 and 1910, however, resulted in channel incision. Recent general trends in upland Ouse reaches (Merrett & Macklin 1999) show an increase of flood frequency from AD 1750 onwards, to a maximum in the 1890s; a decline follows through the first half of the XX century, while a new rise occurs afterwards. The XIX century pattern is consistent with the one observed on Thinhope Burn (Macklin *et al* 1992b). A tendency to aggradation is recorded between ca. AD 1600 and 1800, driven by frequent floods. Incision prevailed afterwards, as floods and sediment supply declined. A smaller increase in floods during the second half of the XIX century only caused aggradation in mining areas. In the piedmont Swale reach at Catterick (Taylor & Macklin 1998) three entrenchment episodes, intercalated with deposition, occur between the XIV and XVI centuries, XVII and XVIII centuries and around AD 1750-1780; such trends are consistent with those observed on the Tyne by Passmore *et al* (1993). The lowland reaches of the Swale and Aire are less variable, both showing accelerated sedimentation in the first centuries after AD 1000 and showing few changes afterwards, especially during the last two centuries (Macklin *et al* 2000).

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Most authors see incision and deposition episodes in the last two millennia as responses to climate change, enhanced by human modification of the landscape such as woodland clearance, agriculture or mining (*e.g.* Macklin *et al* 1992a, Passmore *et al* 1992, Passmore *et al* 1993, Passmore & Macklin 2000), or as direct consequences of human action (*e.g.* Tipping 1992).

5.3. Comparison with nationwide trends

From the analysis of dated alluvial units occurrence through the Holocene general trends of fluvial activity over Britain have been reconstructed by Macklin & Lewin (1993), Macklin (1999) and most recently Macklin & Lewin (2003); though the possibility of a bias due to erosion of older alluvial units must be taken into account (Lewin & Macklin 2003), a pattern can be seen. In the work by Macklin & Lewin (2003) a selection has been performed from 346 published ¹⁴C dates on alluvial units in Britain in order to minimize possible bias from human interference and to maximize significance in dating changes in river behaviour. 14 major brief periods of flooding are identified through the Holocene, grouped in four clusters around 10 420, 8100–7520, 3940–1940 and 1070–400 cal BP.

The observations from the Ribble do not seem to match particularly well with these general British trends. The deposition of the Cuerdale Terrace, dated 1400–1050 cal BP (see section 4.2.5.3 on page 190), does not fall within any of Macklin & Lewin's (2003) flooding periods, though it occurs immediately

before the most recent one and could be related to its onset. The deposition episode dated ca. 4700 cal BP at Higher Brockholes, supposedly related to the aggradation of the Walton Terrace (see section 4.2.4.3 on page 177), has also no correspondence with British flooding periods. The 8100–7520 cal BP flooding period does not correspond with any dated or supposed alluviation on the Ribble; however, it falls within the ca. 8900–6900 cal BP interval during which meander cutoffs occurred there (see section 4.2.3.6 on page 165 and 5.1.2 above), and could be related to such events. The earliest Holocene flooding period, around 10 420 cal BP, does not seem to correspond to any major incision or aggradation event on the Lower Ribble, and occurs during or before a phase of prevailing lateral activity (see section 4.2.3.6 on page 165 and 5.1.2 above),.

5.4. Discussion of driving influences on Ribble fluvial evolution

5.4.1. Geomorphological and sedimentological factors

Local reach- or basin-specific factors have conditioned Holocene fluvial processes, though within the context of superimposed wider-scale deposition and erosion trends (Passmore & Macklin 2000). Deposition in the Early Holocene was generally conditioned by Pleistocene glacial or periglacial sediment availability (*e.g.* Howard *et al* 1998, Macklin *et al* 2000), and incision could occur when that supply was depleted (*e.g.* Taylor & Macklin 1997). Sediment supply from hill slopes to channels is a decisive factor in fluvial

tendencies to incise or aggrade (Macklin & Needham 1992, Merrett & Macklin 1999), and is itself conditioned by them (Merrett & Macklin 1999). An increase in runoff and floods can result in aggradation or incision with different sediment supplies (*e.g.* Macklin *et al* 1992a). The connectivity between sediment transport in different environments, together with variations in fluvial storage, is also crucial in controlling sediment fluxes from river systems to sea (Macklin *et al* 2000). Geomorphological and sedimentological factors contribute to condition local fluvial response to other environmental influences, enhancing variations in response between different sites (Passmore & Macklin 1997; Taylor & Lewin 1997; Macklin *et al* 2000).

Differences in Late Pleistocene and Early Holocene sediment transport and deposition are evident on the lower Ribble, with likely Younger Dryas abundant fine-grained deposition followed by vertical stability and lateral reworking. Such differences could be the consequence of a difference in sediment supply or transport from the catchment, accounting for the large quantity of fine-grained sediment input in the Ribble; the absence of Early Holocene incision could be related to the absence of a sudden depletion of the sediment supply, the sediment input decreasing gradually and/or not ceasing completely. The apparent coincidence between changes in sediment production on the Bowland Fells and aggradation on the lower Ribble (see sections 5.1.2 and 5.1.4 above), if a connection actually existed, could suggest an efficient sediment transport system.

5.4.2. Sea-level change

According to Schumm (1977) simple base-level changes can bring about complex responses in fluvial systems. A drop in base-level (typically sea-level) will result in erosion starting at the river's mouth and progressively extending upstream. Thus, upstream tributaries will undergo rejuvenation when the river downstream has already adjusted to the new base-level. This will result in aggradation, followed by secondary incision; such cycle can repeat several times. A base-level rise, on the other hand, will cause aggradation spreading upstream from the mouth (*backfilling*), without other consequences. The downstream reaches will be the only ones to be immediately affected by the rise. Both incision and aggradation in lowland reaches of the Tyne basin have been related, at least partly, to relative sea-level changes (Passmore *et al* 1992; Macklin *et al* 1992a). However, even lowland reaches can be out of the range of sea-level change influences (*e.g.* Macklin *et al* 2000). Incision and aggradation in piedmont reaches can therefore be expected to be directly affected by sea-level changes even more rarely.

Comparing the lower Ribble evolution with Holocene relative sea-level tendencies in the area (see section 2.1.1.2(b) on page 16) no obvious relations are visible. Actually, both the deposition event dated at ca. 4700 cal BP (tentatively correlated with the Walton Terrace aggradation) and the episode dated to 1400–1050 cal BP (AD 550–900, representing the Cuerdale Terrace aggradation) seemingly correspond with low or regressive relative sea-levels,

while at the times the incision of the Walton Terrace takes place (likely between AD 300 and 550, see section 5.1.4 above) a regressive sea-level trend is recorded as well as a brief transgressive episode. On the other hand, it could be possible an opposite influence existed: if the deposition episodes observed at Higher Brockholes and the Walton Flats also represented a higher rate of sediment delivery to the estuary, the regressive tendencies could actually have been favoured by increased estuarine sedimentation. The construction of the main fort at Kirkham, around AD 120 (see section 2.3.3.3 on page 57) seemingly falls in the last part of a regressive period (see section 2.1.1.2(b) on page 16), thus possibly corresponds with a relative sea-level minimum; such situation could have rendered navigation up the Ribble Estuary to Walton-le-Dale impractical, causing the need to arise for a different landing point outer along the estuary at Kirkham, as well as for a good road connection with the “industrial” facilities at Walton-le-Dale (the Dane’s Pad, see section 2.3.2 on page 45).

5.4.3. Climate changes

Climate is a major factor in the control of fluvial processes, though its importance was underestimated in the past (Macklin *et al* 1992a; Macklin & Lewin 1993; Macklin *et al* 2000). General correspondences between climate and fluvial activity have been confirmed repeatedly, with good agreement between periods of alluvial units clustering (see section 5.3 above) and climatic deterioration recorded in mire surface wet shifts (see section 2.1.2.1(b) on page 19) (Macklin 1999; Macklin & Lewin 2003). Increased fluvial activity seems to be

related to climatic transitions rather than to worse climate periods, though dating is often not precise enough to make secure linkings (Macklin 1999); nevertheless, British rivers seem to be very sensitive to modest but repeated changes in climate (Macklin & Lewin 2003). Climatic control of fluvial discharge and regime has been widely recognised in the Yorkshire Ouse (Macklin *et al* 2000) and Tyne (Passmore & Macklin 1997; Macklin *et al* 1992a; Macklin 1999) basins, with enhanced activity in correspondence to shifts to cooler or wetter climate. At local scale, the correspondence is visible in upland (Macklin *et al* 1992b; Passmore & Macklin 2000), piedmont (Macklin *et al* 1992a) and lowland (Macklin *et al* 1992c; Passmore *et al* 1992) reaches.

Apparent influences of climate change on the lower Ribble have already been discussed (section 5.1 above). Major activity episodes seem to occur at the start of major wet periods. In Early to Mid-Holocene, when sediment supply was likely lower, shifts to wetter, cooler climate are correlated with channel straightening (and possibly widening) and meander cut-offs; in Mid-Late Holocene shifts to wetter, cooler climate are correlated with deposition. A possible correlation between dry climate and river incision is not as clear.

5.4.4. Human influences

Anthropogenic and climatic influences are not necessarily competing factors in controlling Holocene fluvial activity (Macklin *et al* 1992a). Rather than directly influencing fluvial processes, however, human action on the landscape – as

woodland clearance, agriculture or mining activities – seems to affect their response to other factors, such as climate (Macklin & Lewin 1993). Human effects are more visible on lowland rivers, dominated by fine-grained sediments (Macklin 1999). The main consequence of human activities is actually an increase in runoff and fine sediment input in rivers. In the Early Holocene stability or incision are actually more common (Macklin & Lewin 1993). Between 5000 and 6000 cal BP only small-scale river alluviation in response to a wetter climate occurred, as Neolithic clearance was too small and local; only with the spreading of Bronze Age agriculture does widespread aggradation occur when climate deteriorates (Macklin & Lewin 2003). Two phases of anthropogenic aggradation, seemingly related directly to woodland clearance, were observed by Tipping (1992) in the upland Cheviot Hills; in most other studies, however, human action was found to mainly increase river responsiveness to climate. On the Tyne basin climate deterioration before ca. 4000 cal BP has slight effects on fluvial activity, whereas later (especially in the last 2000–2500 years) relevant river adjustments ensue to slight changes in climate (Macklin *et al* 1992a; Macklin *et al* 1992b; Macklin *et al* 1992c; Macklin 1999; Moores *et al* 1999; Passmore & Macklin 1997); some anthropogenic effects, however, could be visible since the Mesolithic (Passmore *et al* 1992). Similar effects are seen in the Yorkshire Ouse basin (Howard *et al* 1998; Merrett & Macklin 1999; Macklin *et al* 2000).

A possible effect of human action on the lower Ribble is visible as the massive woodland reduction recorded at Higher Brockholes around 6900 cal BP (see

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section 5.1.2 above), though the episode was probably localised and does not seem to have had relevant influence on fluvial processes. Some minor woodland clearance seems to be recorded in the pollen sequence from Higher Brockholes just before its interruption by alluviation around 4700 cal BP (see section 4.2.3.5(c) on page 163). The correspondent increased sediment production in the catchment (see section 5.1.2 above) is not specifically characterised as anthropogenic (Harvey & Renwick 1987); anthropogenic fluvial activity (due to woodland clearance), however, is recorded by Tipping (1992) in the same period or slightly after on the Cheviot Hills (see above and section 5.2.4 above), and analogous events could have occurred on the Bowland Fells. The aggradation of the Cuerdale Terrace at 1400–1050 cal BP (AD 550–900) appears more clearly related with anthropogenic factors (see section 5.1.4 above).

5.5. Conclusions

5.5.1. Summary

A cut and fill sequence of four river terraces exists on the lower reach of the river Ribble; possible traces of an older terrace are tenuous. The first terrace (Ribchester Terrace), rich in coarse sediments, was likely deposited in the Lateglacial interstadial. The second one (Brockholes Terrace) features abundant fine sediments, and seems to date to the late Pleistocene (Younger Dryas), and

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is not incised again for most of the early Holocene. The early Holocene is characterised by a phase of lateral channel activity occurs, the river still being vertically stable; the phase ends with channel cut-offs, after which lateral activity is more limited. Both the timing of the terrace's deposition and incision and its sedimentology are atypical. The third and fourth terraces are both prevalently fine-grained; the former (Walton Terrace) likely dating to the mid-Holocene and being incised at the end of the Romano-British period; the latter being deposited before AD 1000 and incised again in the last few centuries.

5.5.2. Synthesis

Regional or extra-regional parallels seem to broadly exist for most Holocene events recorded on the Ribble. No events, however, are visible in all the sites used in the comparison. It is concluded that local and regional differences in factors affecting river behaviour and its response are too marked to allow a fine-scale correlation. Sensitivity to climate changes, influenced by human action and other local factors, seems to be confirmed on the Ribble, where major changes in fluvial activity apparently coincide with the onset of wetter/cooler climate conditions. Relative sea-level changes do not show any marked influence on fluvial processes; on the contrary, an influence of river sediment input on local transgression and regression in the estuary could be possible, though it is not proven.

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Major discrepancies between the Ribble and the most commonly observed regional and extra-regional fluvial trends occur at the end of the Pleistocene and in the first half of the Holocene. Relevant fine-grained aggradation occurs at an early time, most likely in the Younger Dryas period, when the usual trend is of coarse-grained aggradation of reworked glacial and periglacial materials. No incision occurs at the beginning of the Holocene, which rather is characterised by vertical stability and major lateral reworking that seems to occur at least in part at a time when woodland cover would be expected to prevail onto floodplains. The reasons for these differences are not known; they could be possibly due to some different (finer) sediment supply, unique to the Ribble catchment. If this is true, likely such sediment supply was also depleted at a later time than happened in other basins, allowing vertical stability rather than incision throughout the Early Holocene. Sediment depletion at the Early-Mid-Holocene transition could have caused the Ribble to respond to a wetter/cooler climate shift with meander shortening and possibly channel enlargement and/or incision rather than with alluviation.

Nothing is proven about the Walton-le-Dale roman settlement, also due to the very small portion of surviving original ground that was still accessible to survey. What observations and considerations can be made would support the possibility of some naval traffic reaching Walton-le-dale in the very first part of its occupation (early II century AD), as well as a possible change of conditions (increased fluvial sediment input and silting up of the inner estuary channel) preventing navigation in later times. The settlement's occupation does not seem

to end completely until the early IV Century AD; the erosion by the Ribble and Darwen of most of the settlement's ground likely mainly occurs after that time, though its onset – if between the mid-III and early IV Centuries – could have played a part in accelerating the town's abandonment.

5.5.3. Further research

Most of the issues examined in this study could be usefully carried on. The structure of the four terraces and their relationships have only been generally described; in particular, direct dates for the Ribchester and Walton Terraces could be sought in order to improve the lower Ribble chronology. Pollen analysis from other Brockholes Terrace palaeochannels could better explore the valley floor vegetation in the Early to Mid-Holocene, and ascertain whether the Higher Brockholes site is typical or atypical; for this purpose, the peat at the foot of Flashers Wood (SD638341) would be a promising choice. Sediment provenance analysis for the Brockholes Terrace overbank fines could provide information on their origin and ascertain possible sediment supply differences in respect to other river basins; with the same purpose, research could be extended to the reaches beyond Ribchester, in order to find out the extent to which the Ribble terrace fills maintain their characteristics upstream. Finally, sedimentological and stratigraphical research could be carried out on the Ribble estuary, especially in the Dow Brook valley South of Kirkham (SD438318) and close to the Roman site there, where previous research was interrupted by the foot & mouth disease outbreak before results could be obtained. At the site

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some organic/minerogenic sediments intercalations had been found, possibly suggesting relative sea-levels at a higher elevation than had been previously recorded in the area.

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Figures, tables and plates

Table 1 – radiocarbon essays

DATE CODE	SAMPLE TYPE	¹⁴ C ENRICHMENT (% MODERN ±1σ)	C CONTENT (% BY WEIGHT)	δ ¹³ C _{PDB} ‰ ±0.1	CONVENTIONAL AGE (YEARS BP ±1σ)	CALIBRATED AGE (CAL YEARS BP, MAX RANGE AT 2σ)
AA-48971	<i>Quercus</i> tree wood	48.76±0.35	47	-24.8	5770±57	6723-6411
AA-48972	leaf and wood debris	44.40±0.29	2.7	-28.6	6522±53	7560-7319
AA-48973	leaf-rich peat	37.78±0.27	1.9	-28.5	7819±58	8929-8430
AA-48974	leaf-rich peat	46.51±0.40	4.7	-29.1	6149±70	7248-6801
AA-48975	peaty laminae in clayey silt	31.96±0.16	1.5	-26.9	9163±40	10474-10221
AA-48976	clayey silt with organic inclusions	42.44±0.23	1.1	-26.5	6885±44	7790-7613
AA-49826	organic-rich silty clay	36.74±0.27	1.6	-27.9	8043±59	9228-8658
AA-49827	organic-rich clay	38.87±0.29	2.6	-28.3	7591±60	8453-8217
AA-49828	organic-rich clay	35.32±0.29	2.4	-28.4	8361±66	9526-9135
AA-49829	organic-rich silty clay	46.98±0.33	2.2	-28.6	6068±56	7157-6749
AA-49830	organic-rich silty clay	52.97±0.36	41	-31.6	5104±54	5985-5726
AA-49831	peat	53.36±0.36	42	-31.1	5046±55	5916-5654
AA-49832	peat	60.27±0.38	10	-29.1	4067±51	4813-4418
AA-49833	layer of organic material in silt	59.08±0.43	2.3	-28.5	4228±58	4869-4573

(see figures 10 and 12 for sample locations)

Figure 2a - Holocene sea-level changes in North-West England (after Tooley 1978)

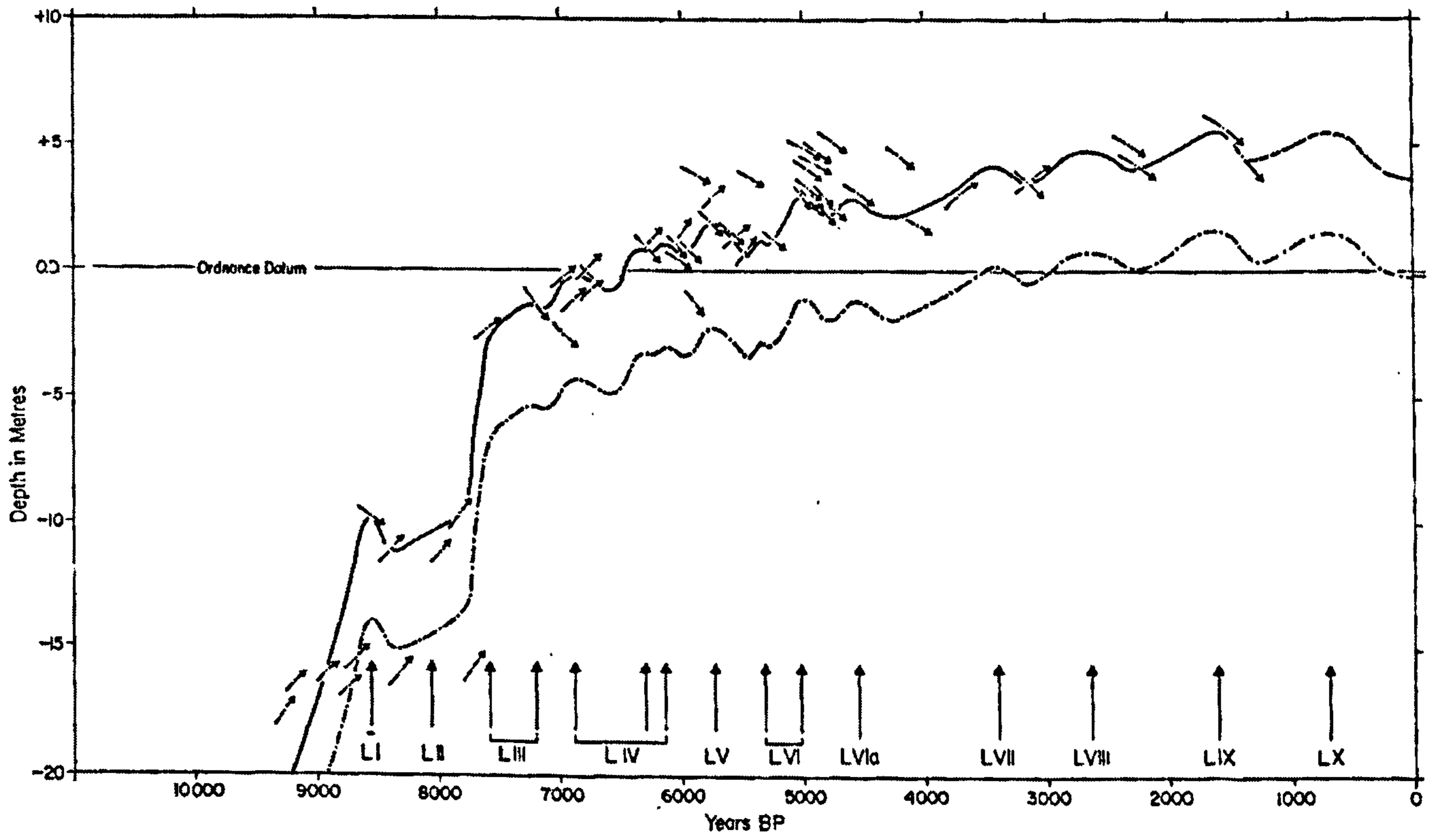


Figure 2b - Holocene sea-level tendencies in North-West England (after Tooley 1982)

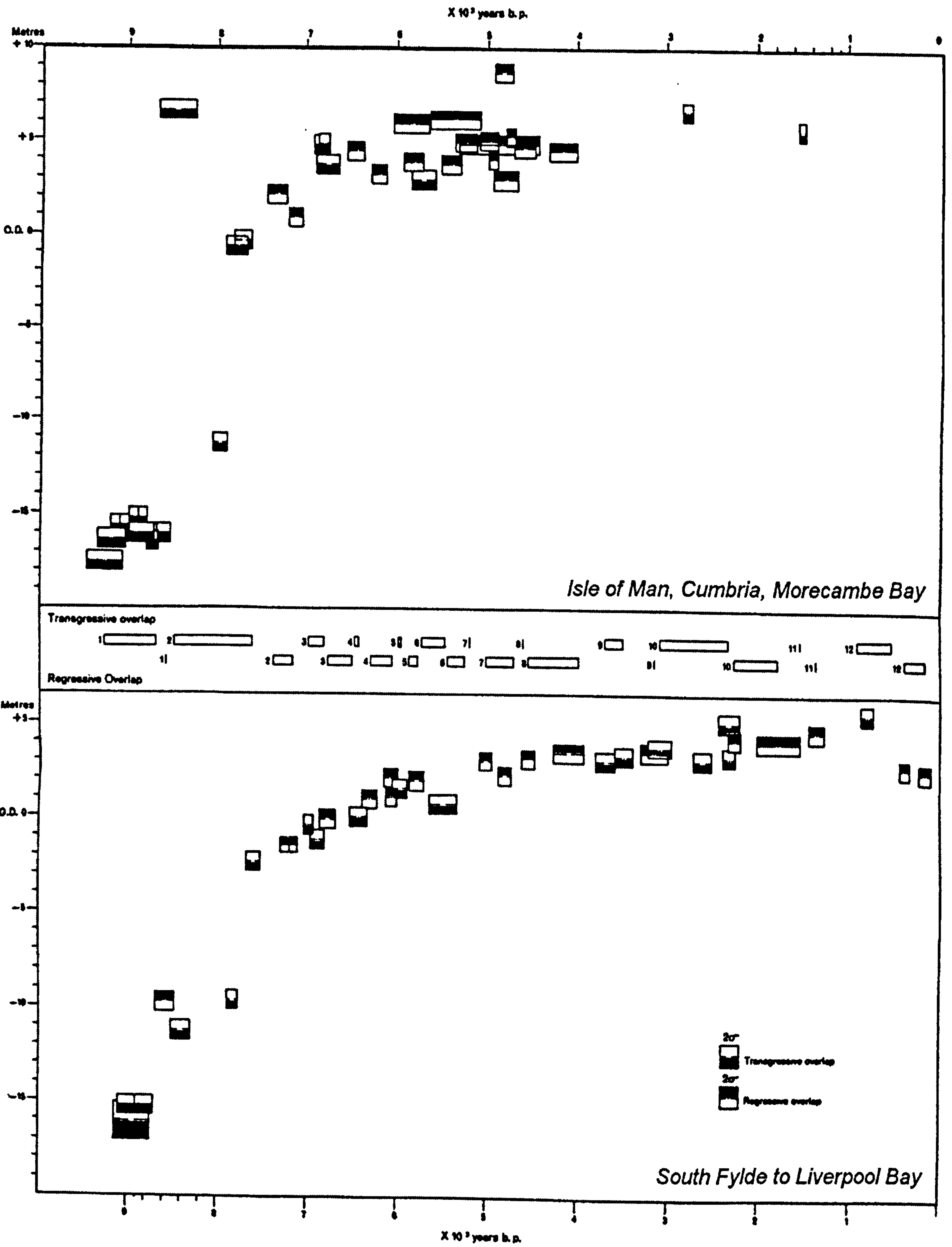


Figure 3

B - reconstruction of the confluence area according to C. Hardwick (1856)

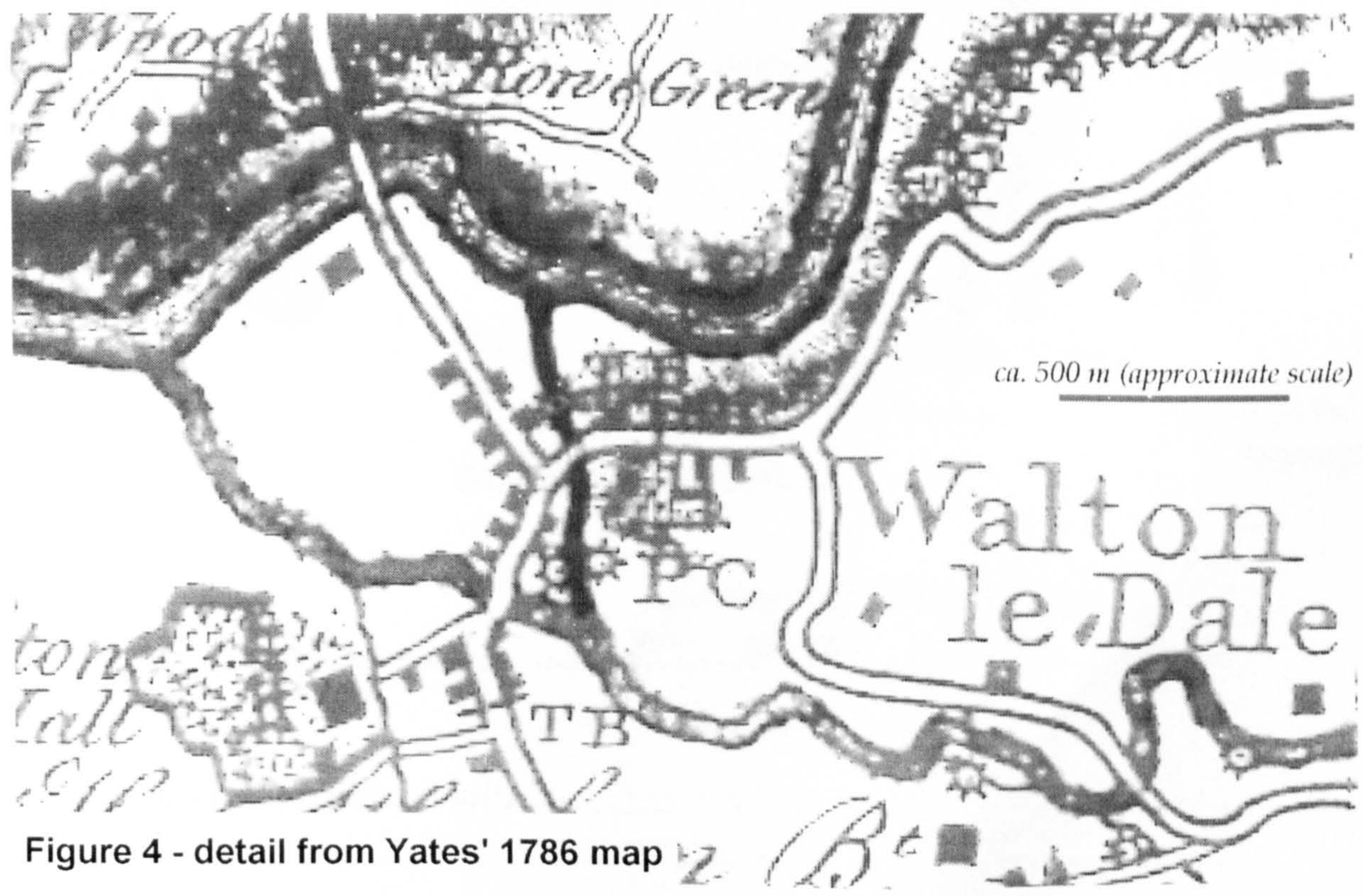
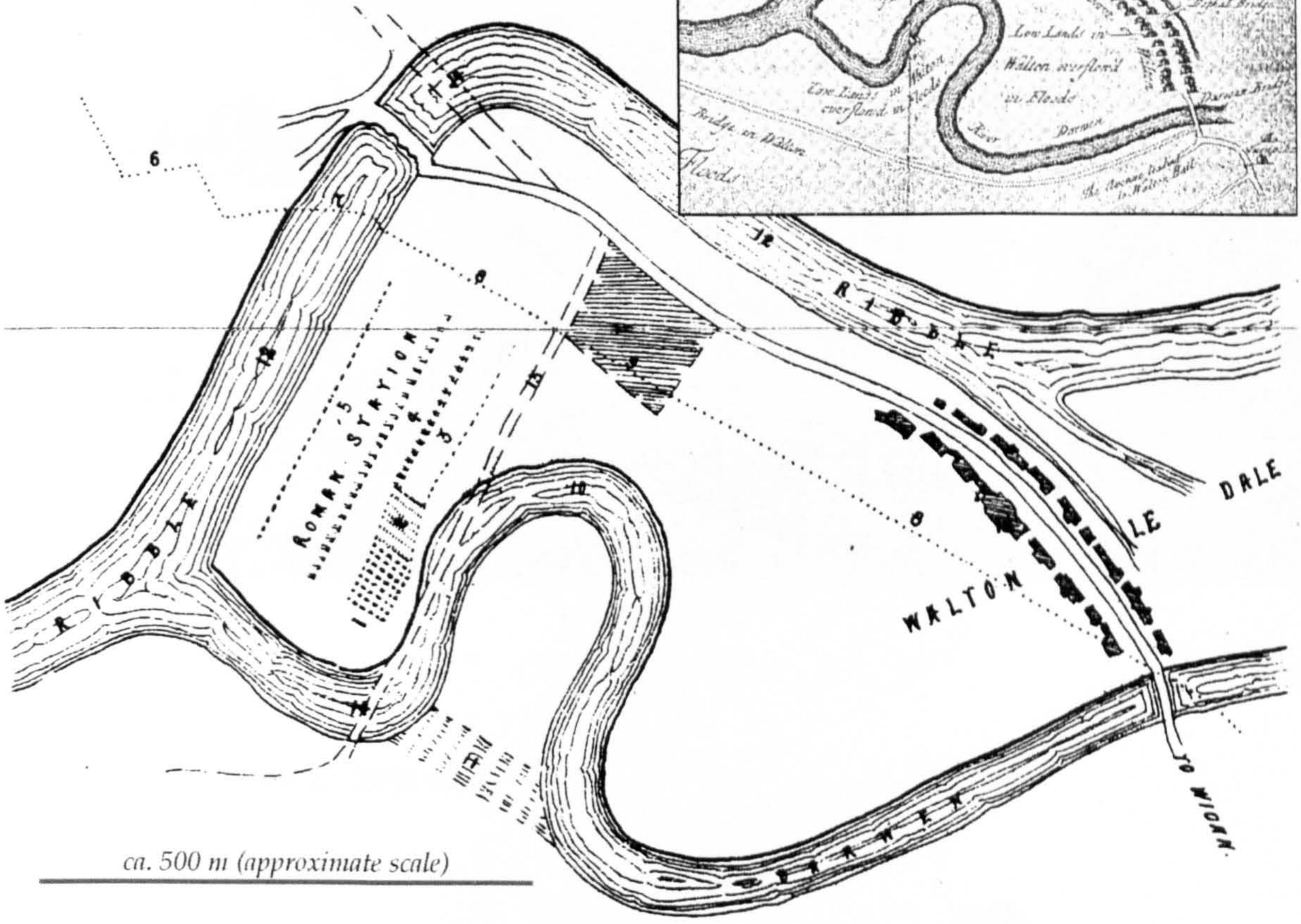
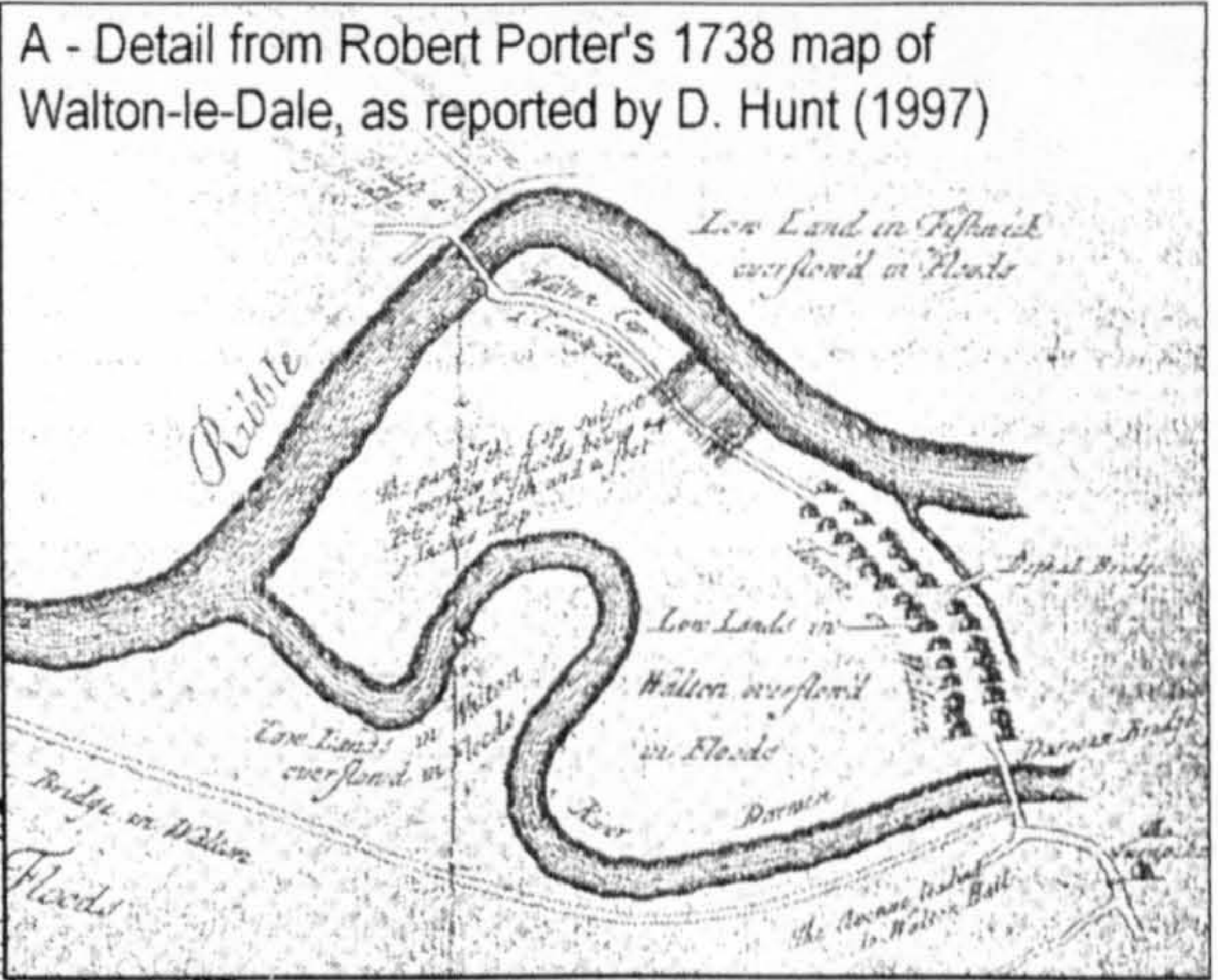


Figure 4 - detail from Yates' 1786 map

Figure 5 - 1728 engraving by S. & N. Buck depicting the Walton Flats and Darwen/Ribble confluence, as reported by D. Hunt (1997)

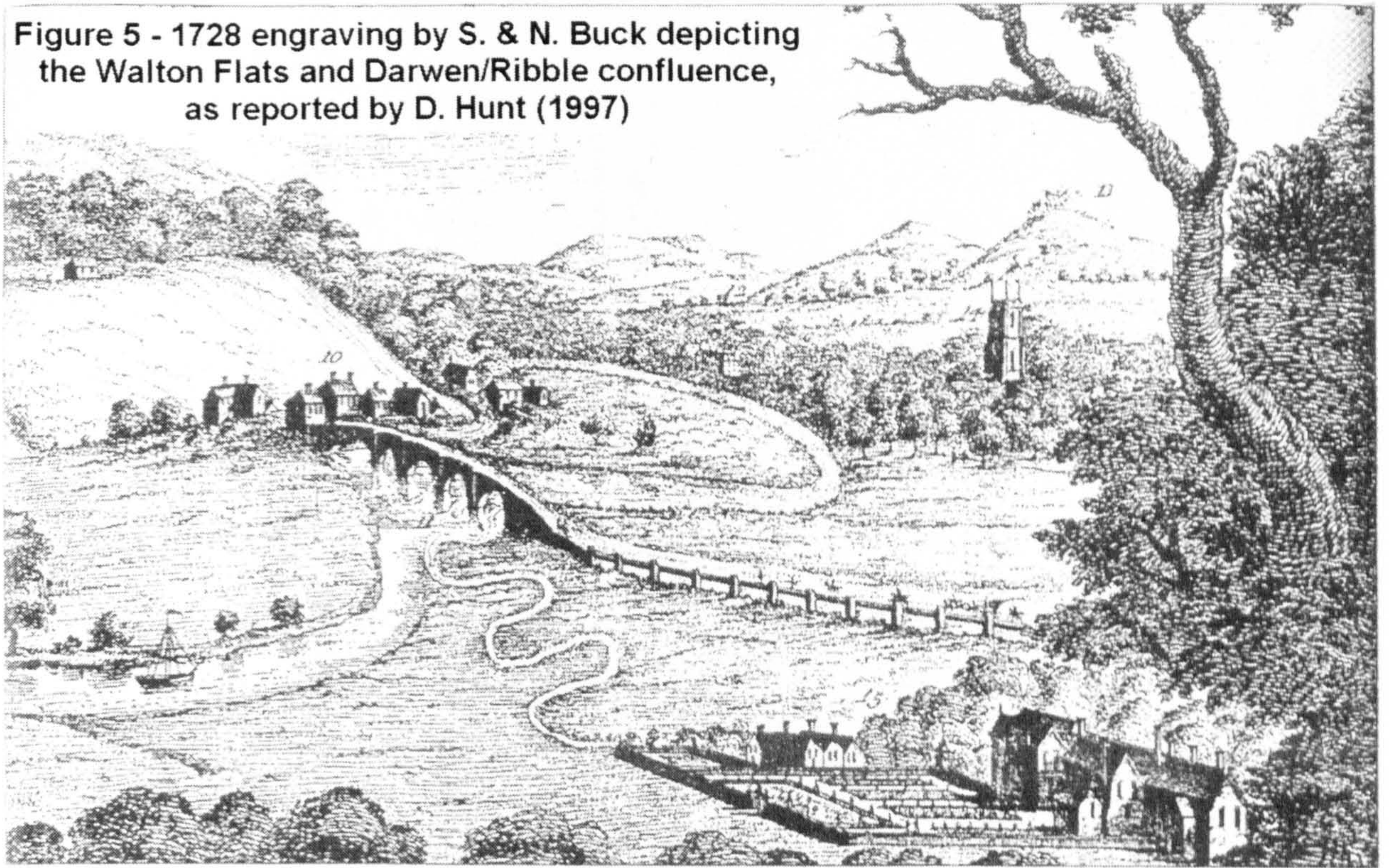


Figure 6 - scheme of GPR use

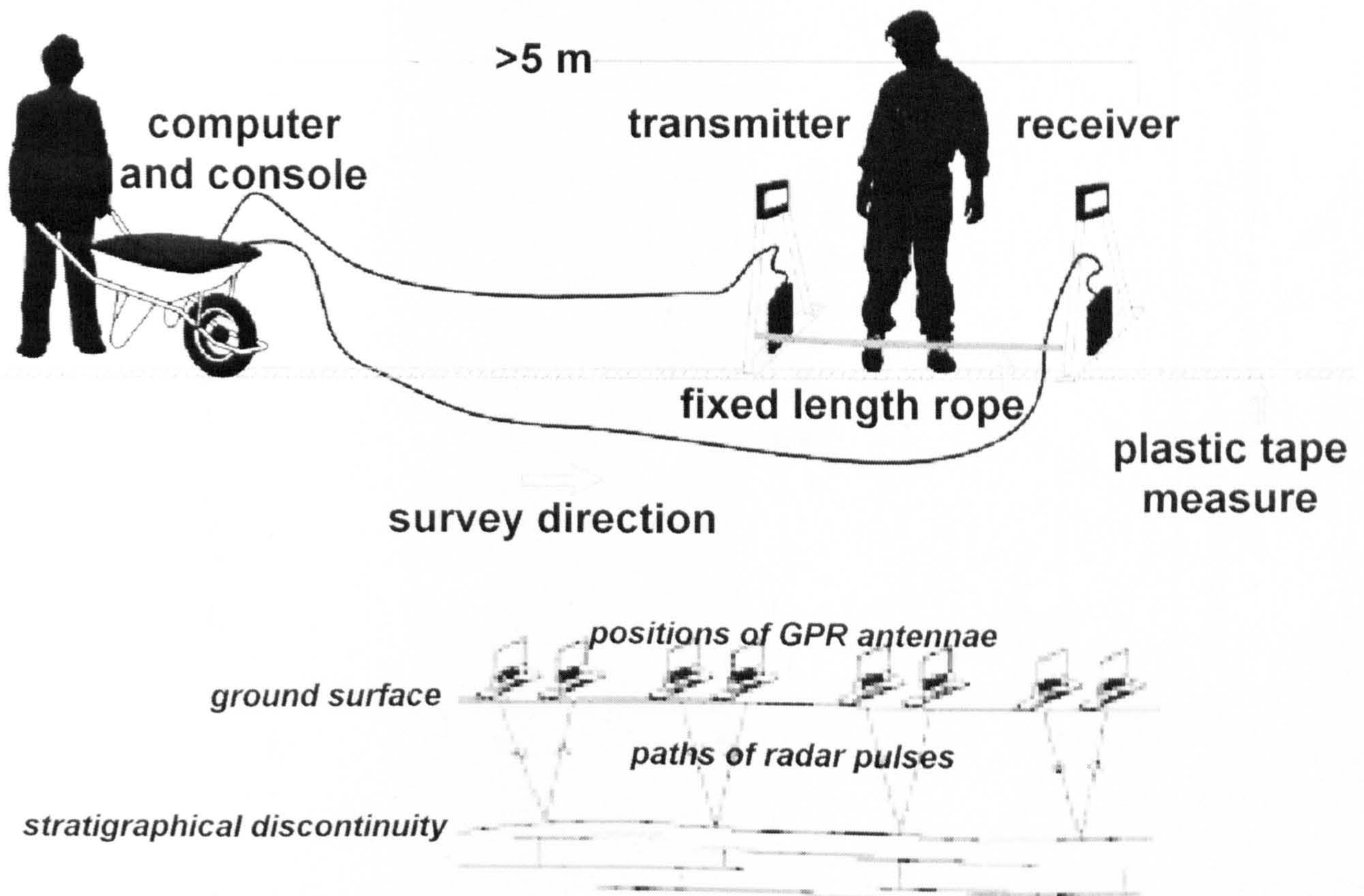


Figure 7 - long profile of the terrace surfaces

(see Figure 1 for site locations)

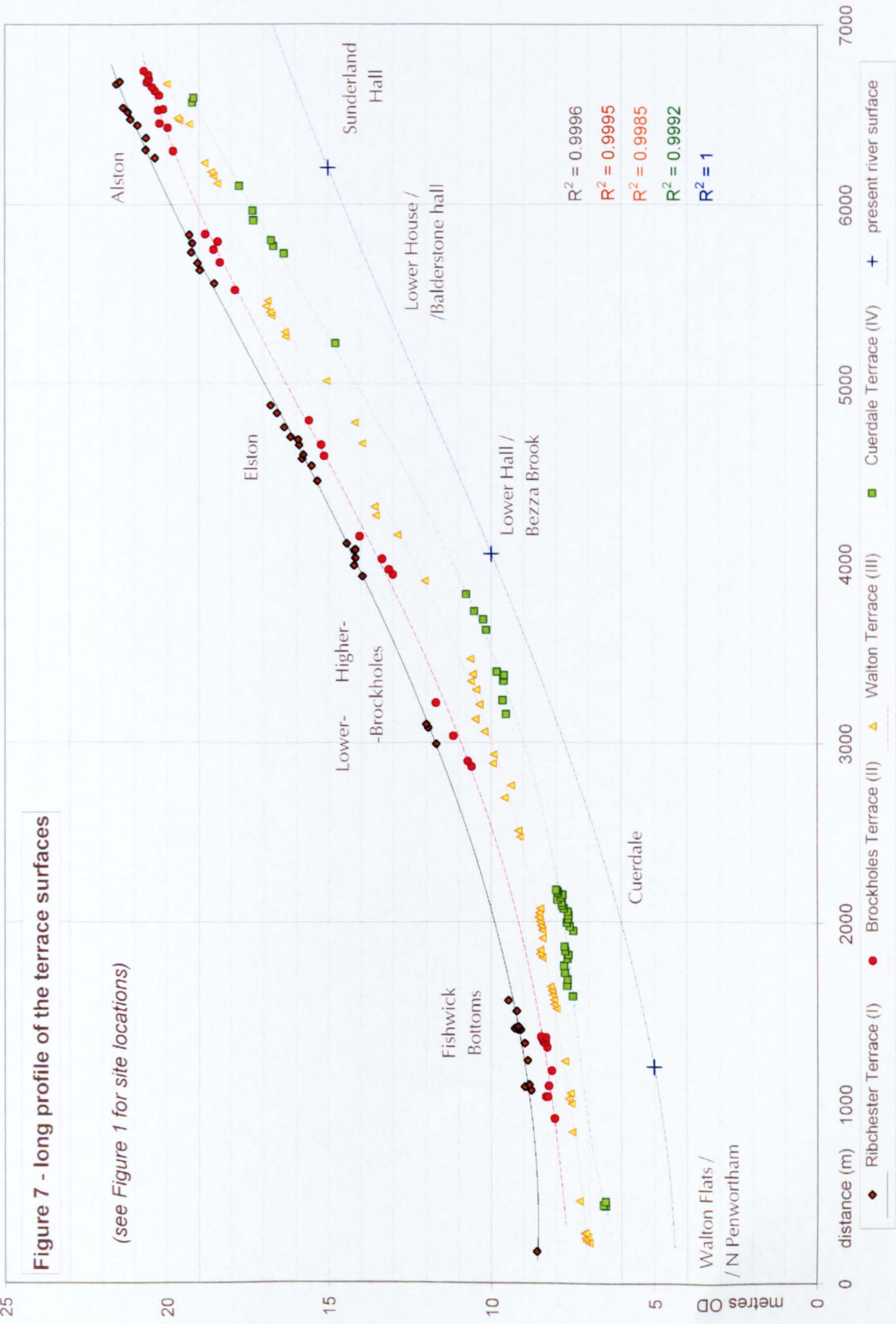
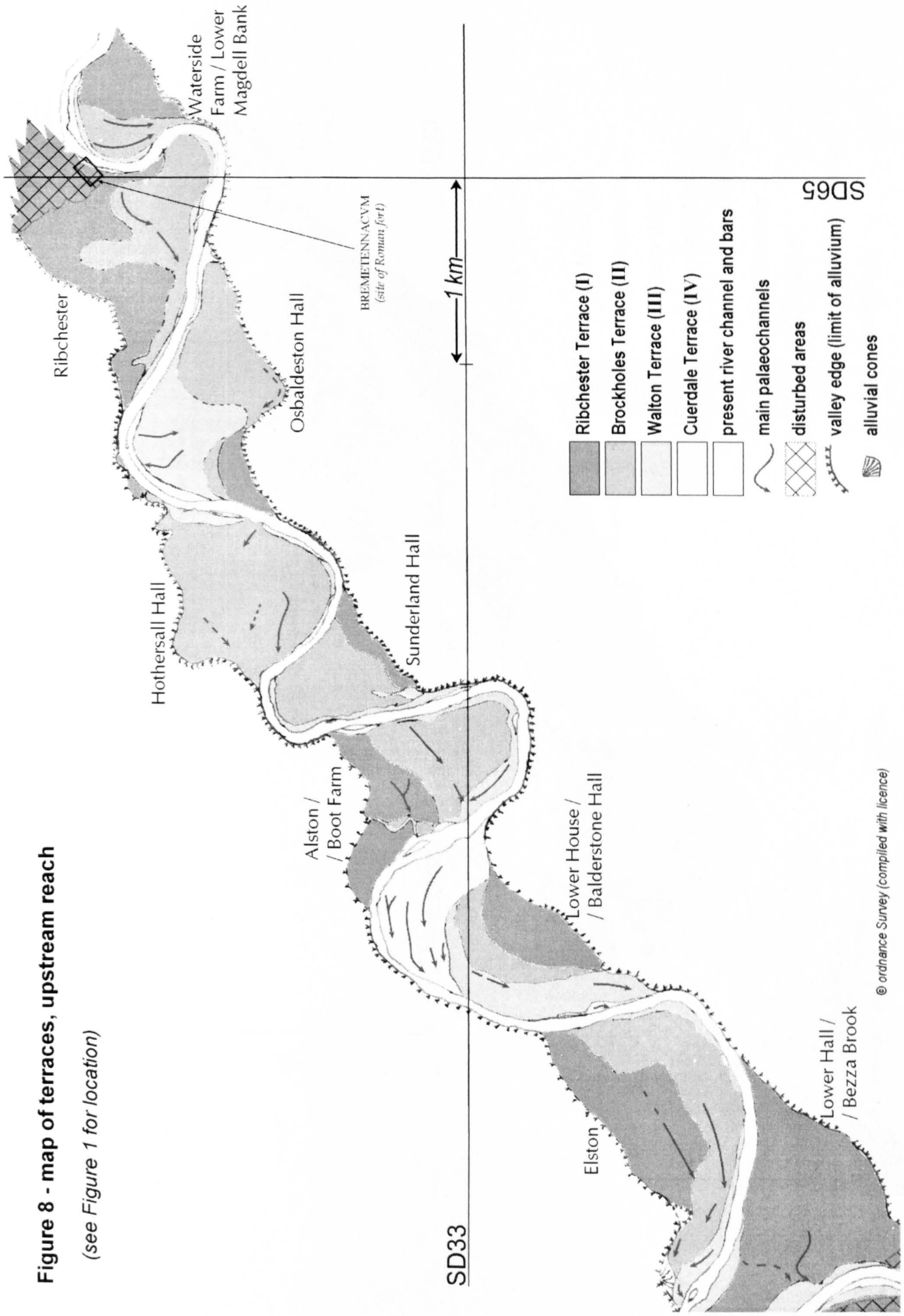


Figure 8 - map of terraces, upstream reach

(see Figure 1 for location)



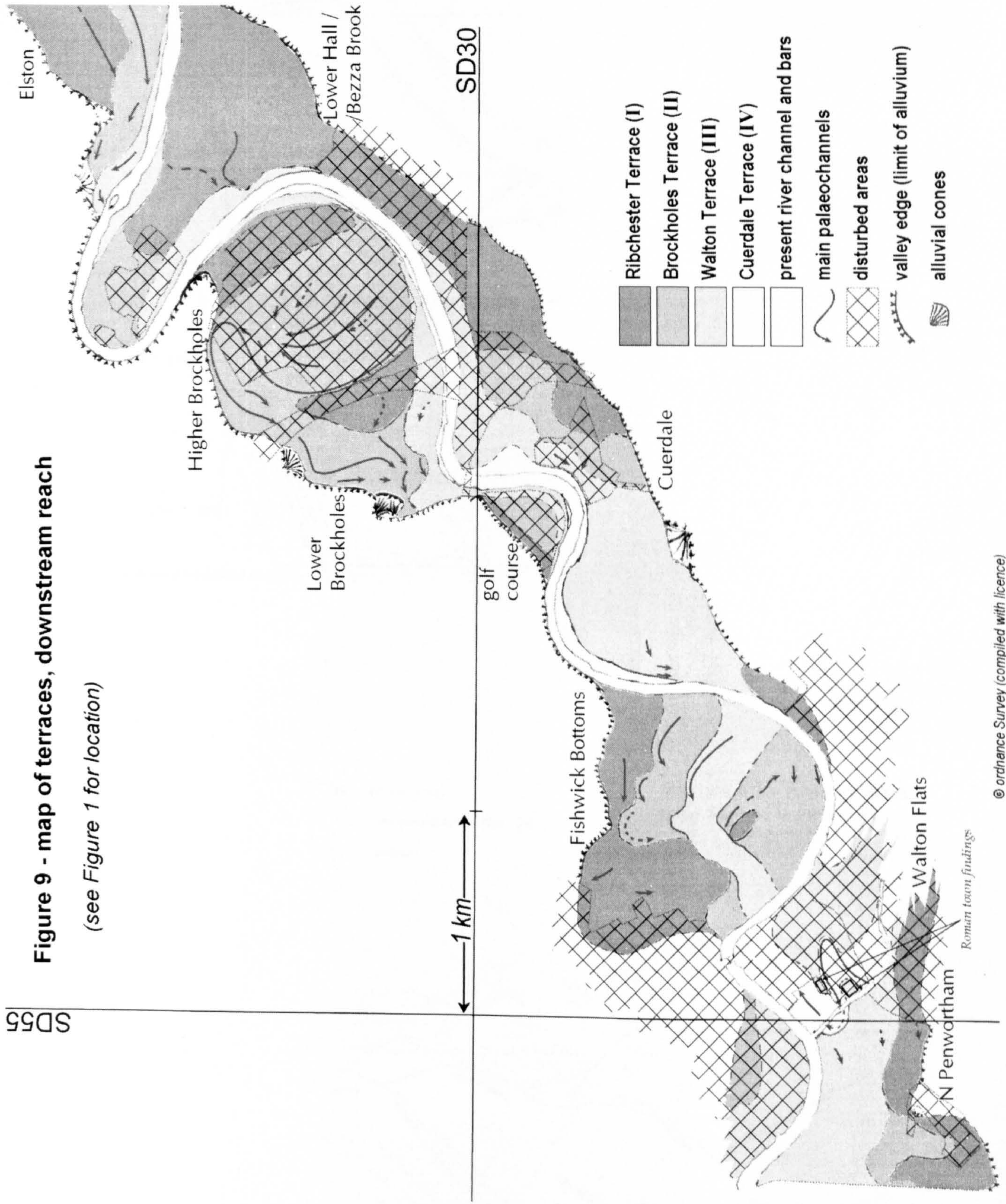
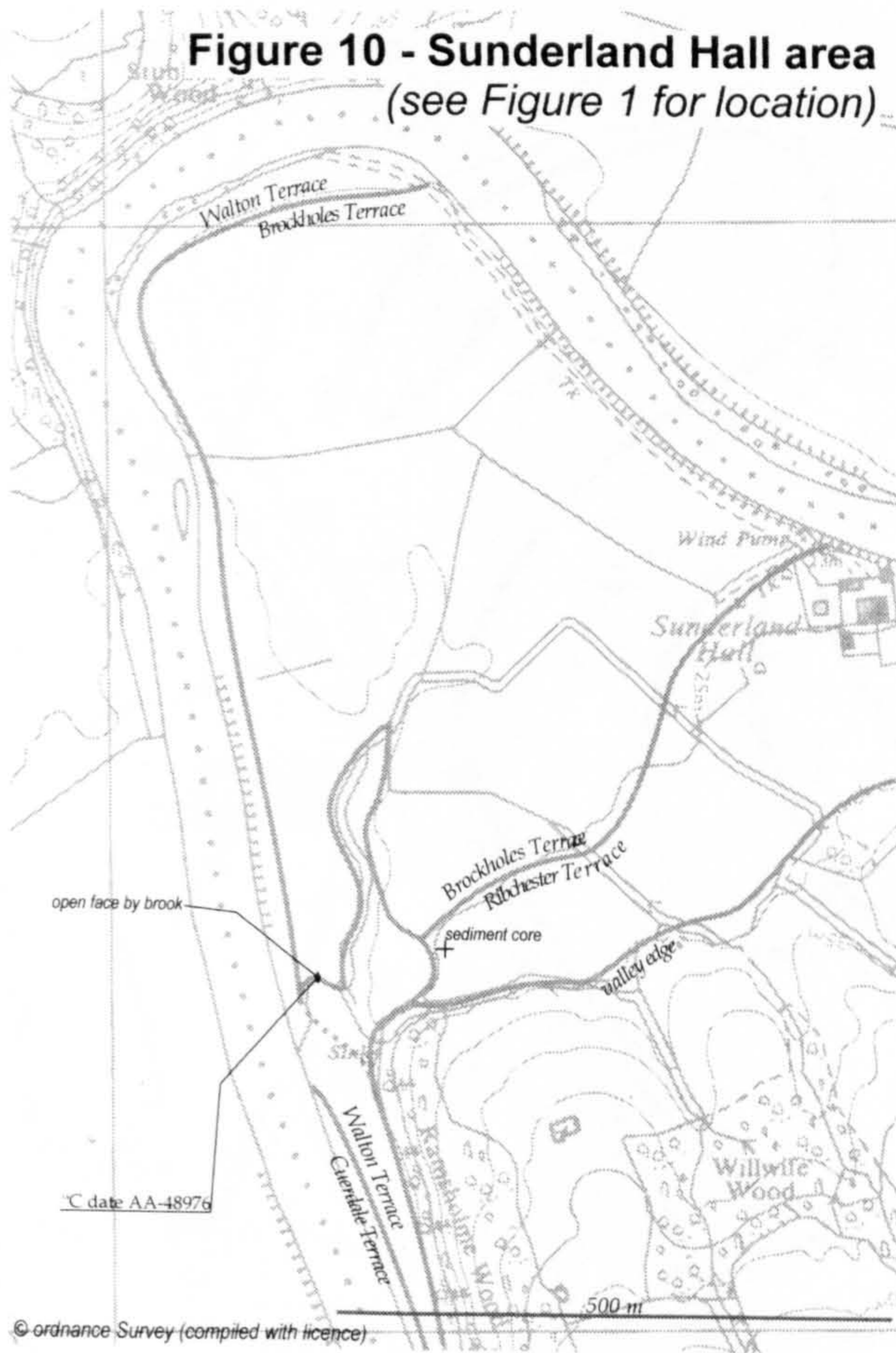


Figure 9 - map of terraces, downstream reach

(see Figure 1 for location)

Figure 10 - Sunderland Hall area
(see Figure 1 for location)






-  palaeochannel
-  (unconfirmed) terrace edge
- 26+  borehole

Figure 11 - Elston area
(see Figure 1 for location)

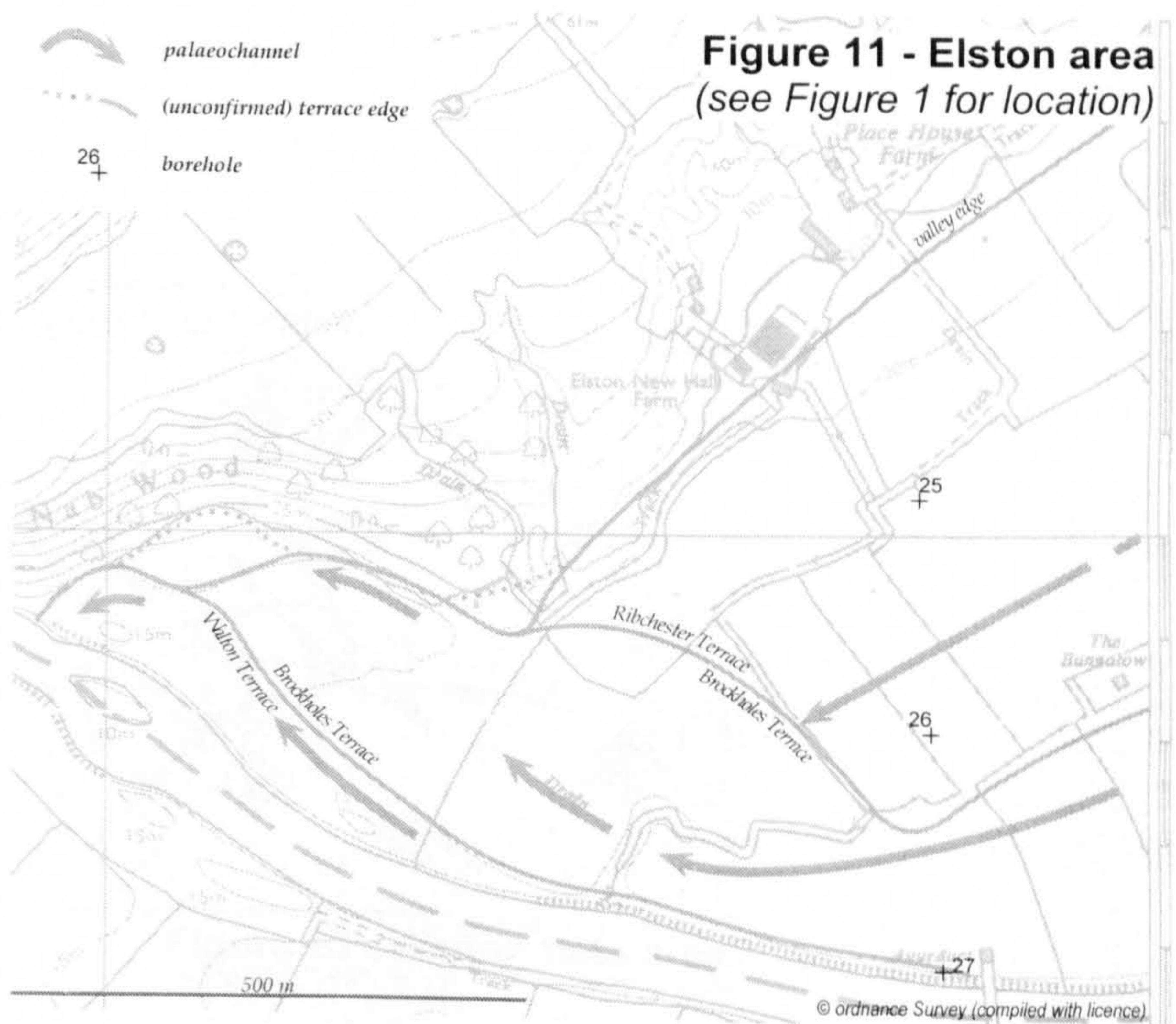


Figure 12 - Brockholes area
(see Figure 1 for location)

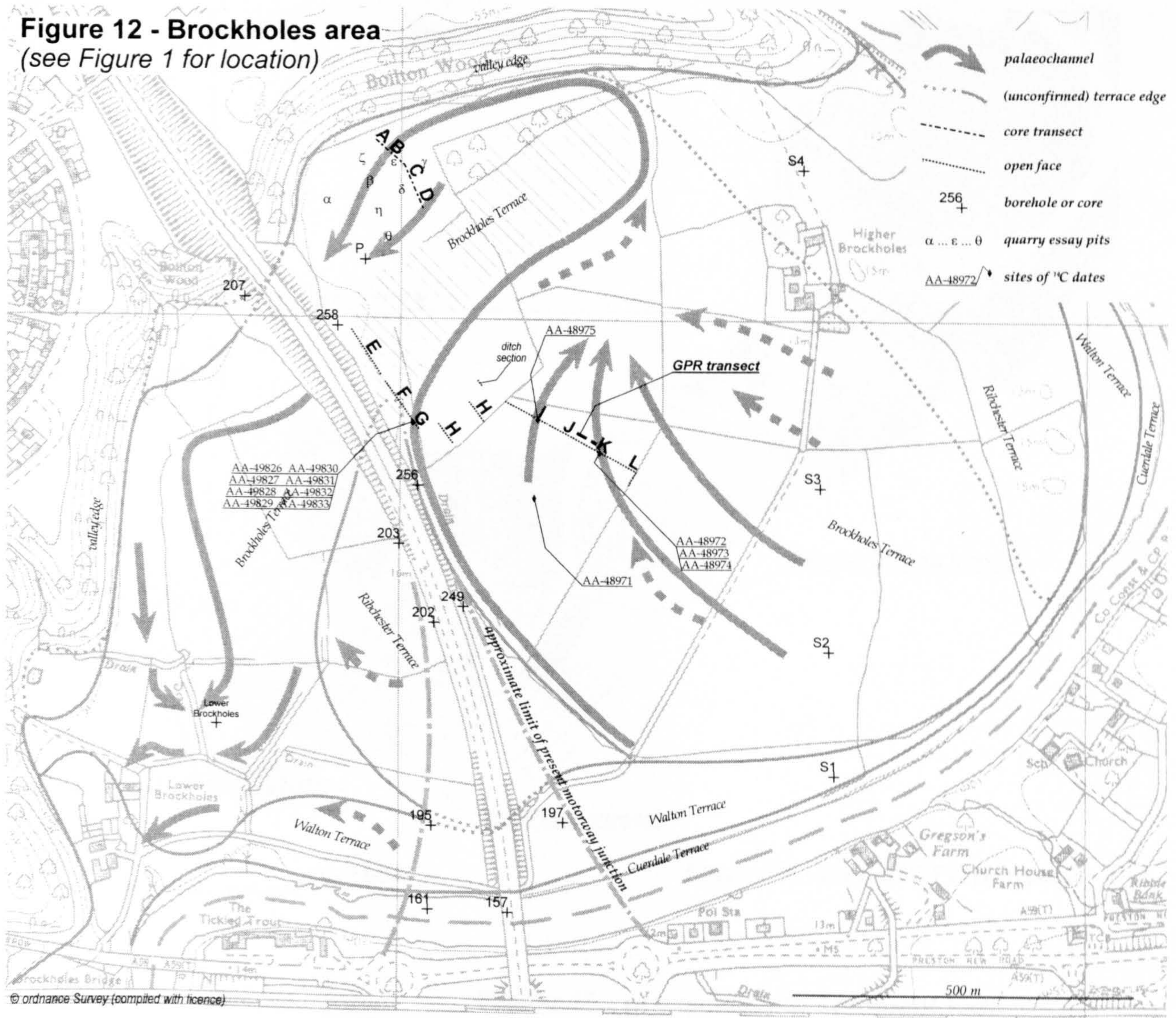
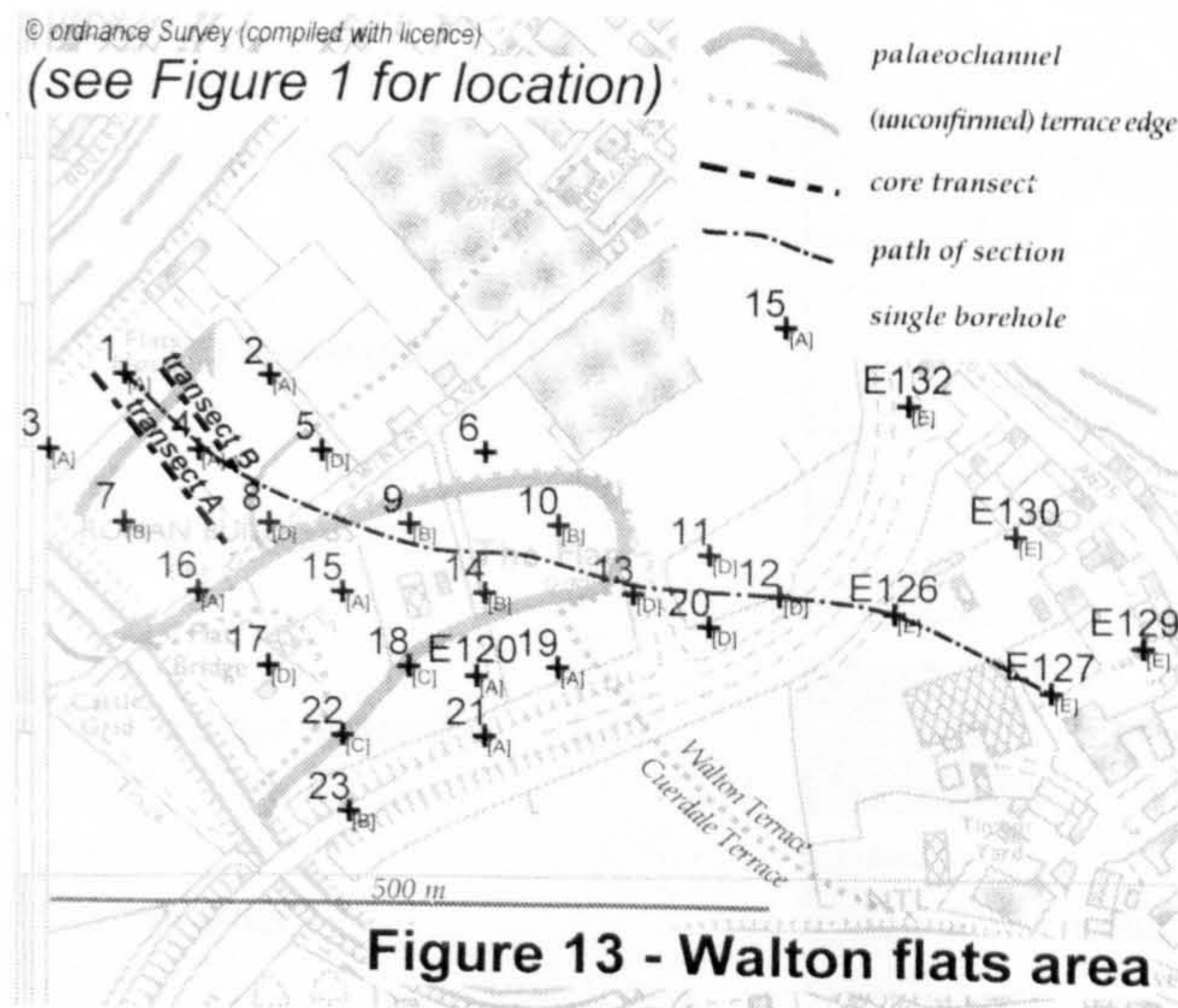


Figure 13 - Walton flats area
(see Figure 1 for location)



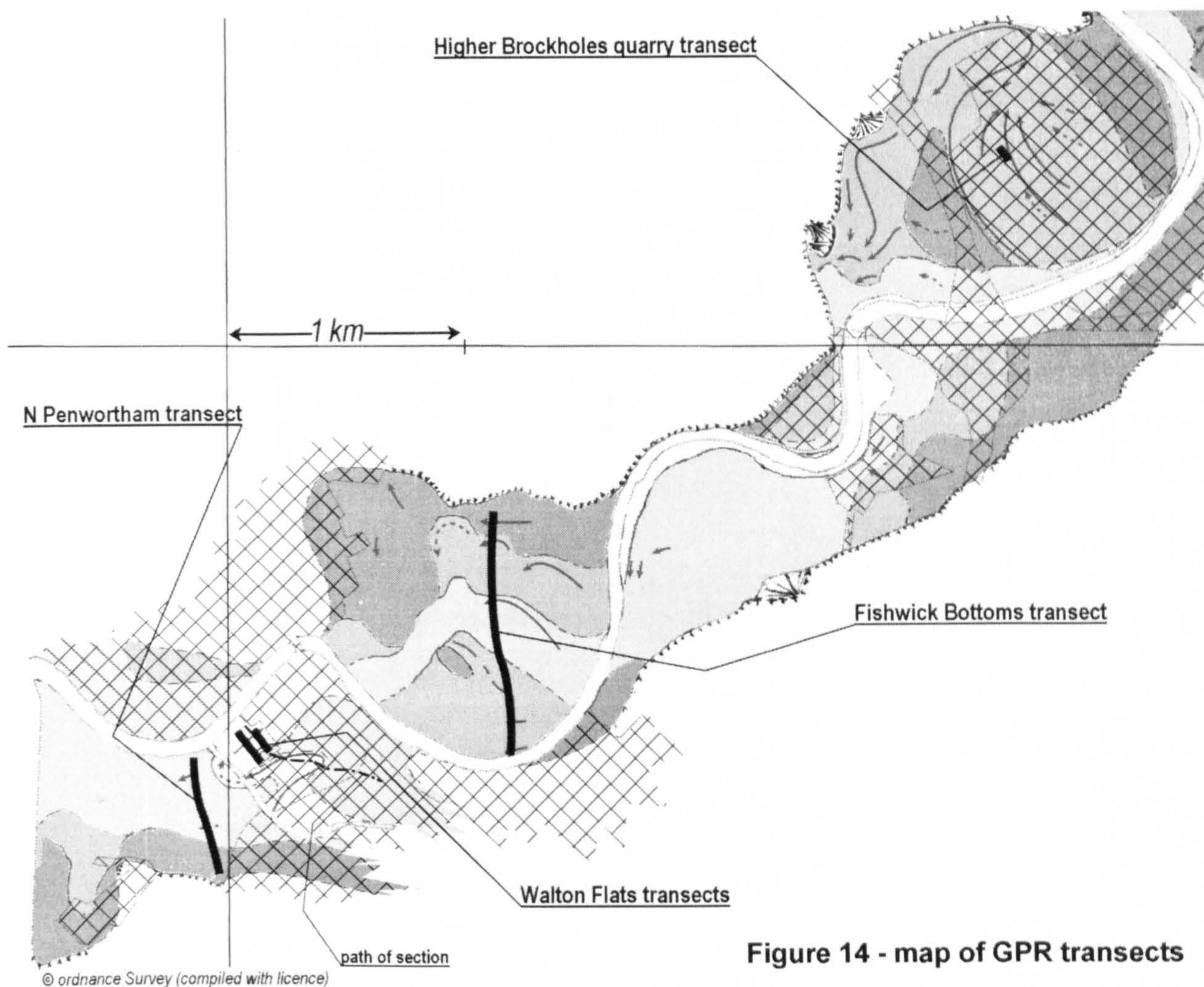


Figure 14 - map of GPR transects

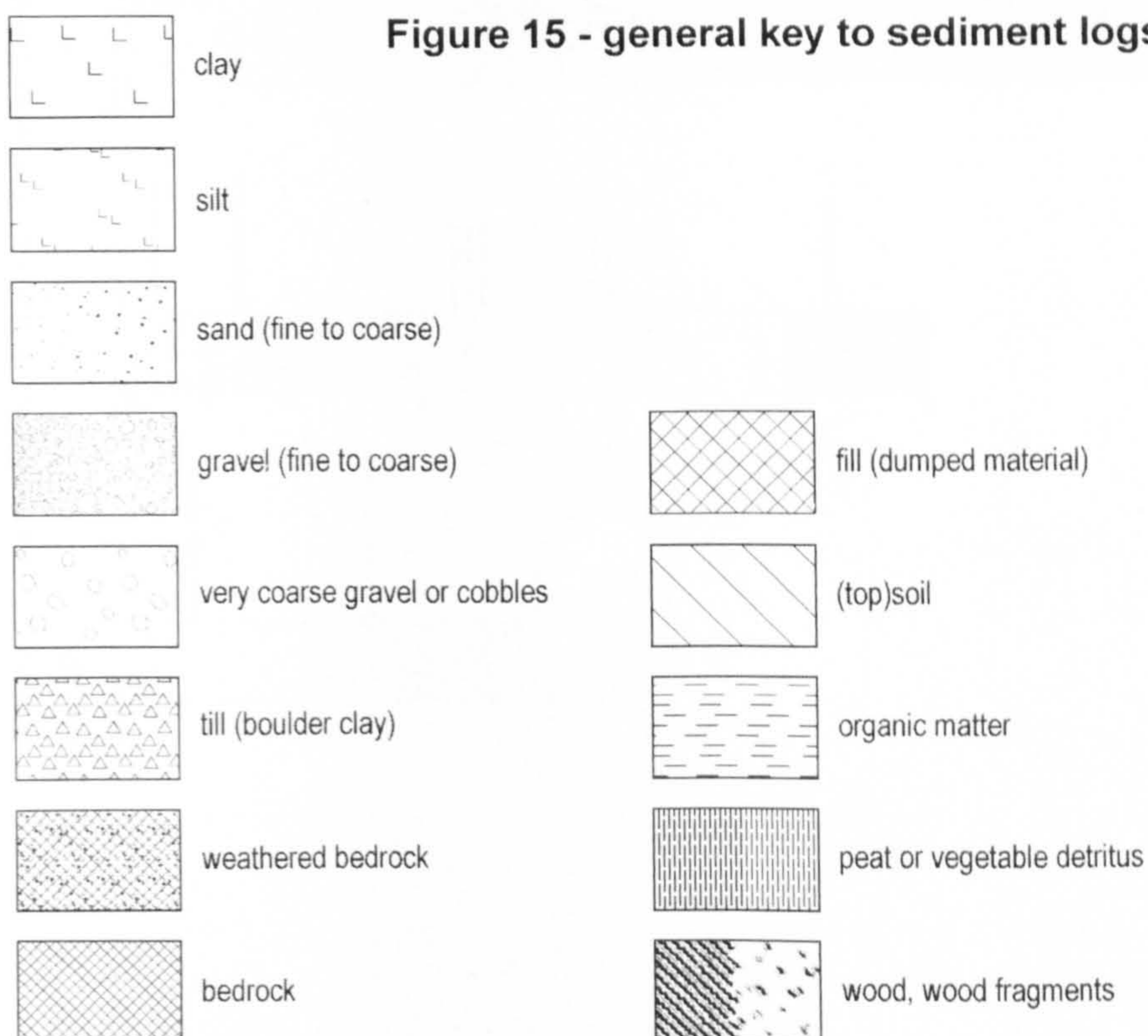


Figure 16 - sediment logs from Elston and Sunderland Hall

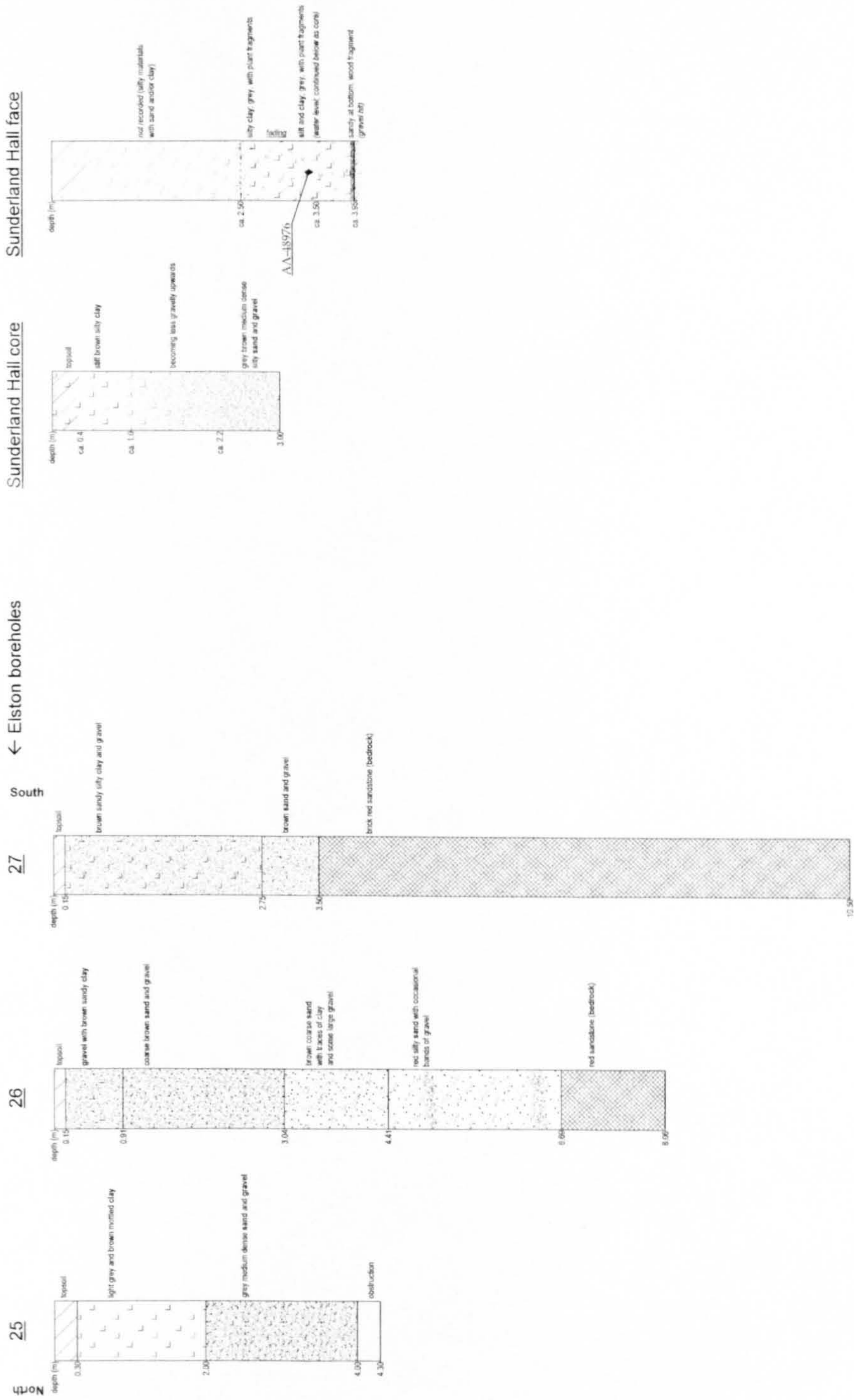


Figure 17 - core transect through ponds in NW corner of Higher Brockholes

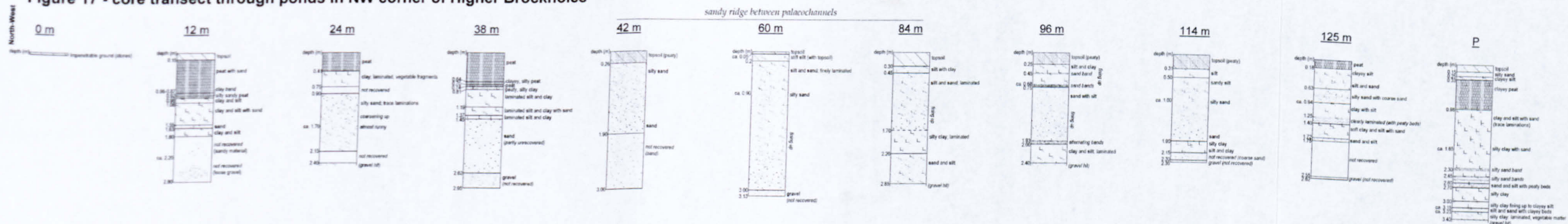


Figure 18 - Lower Brockholes quarry essay pits

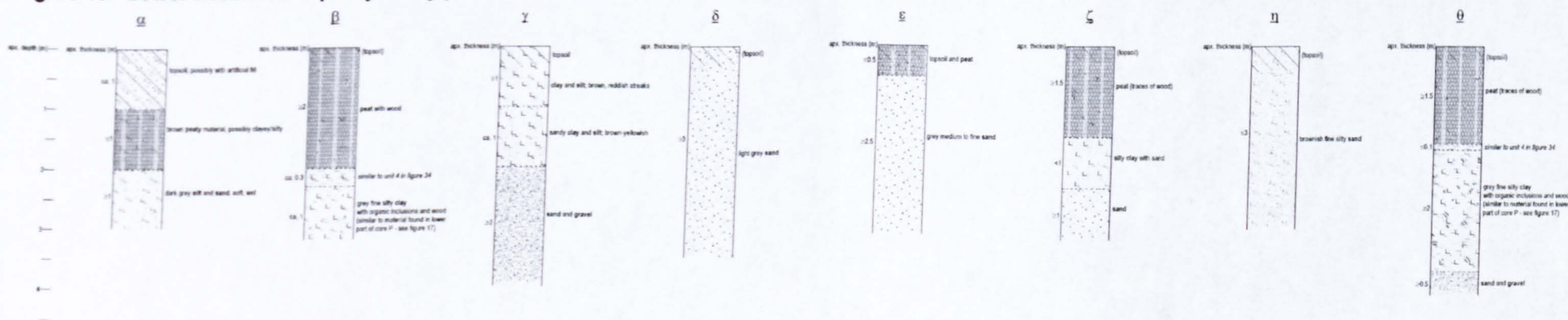
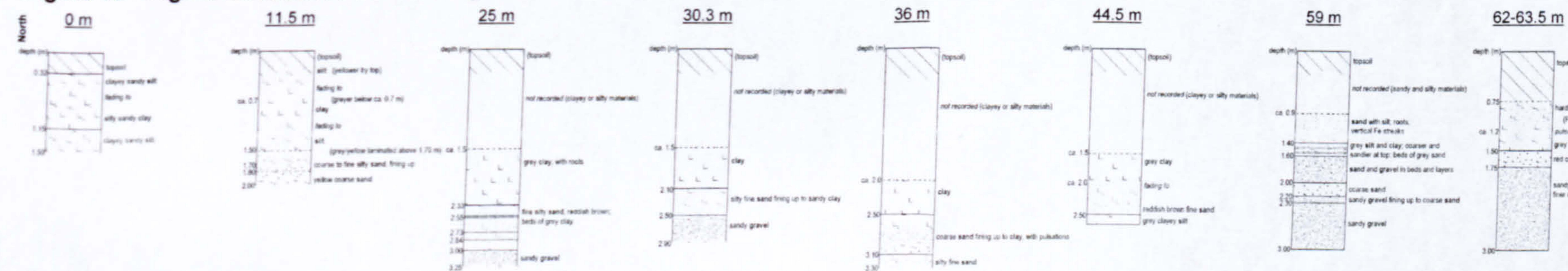


Figure 19 - Higher Brockholes NW face logs



palaeochannel logs

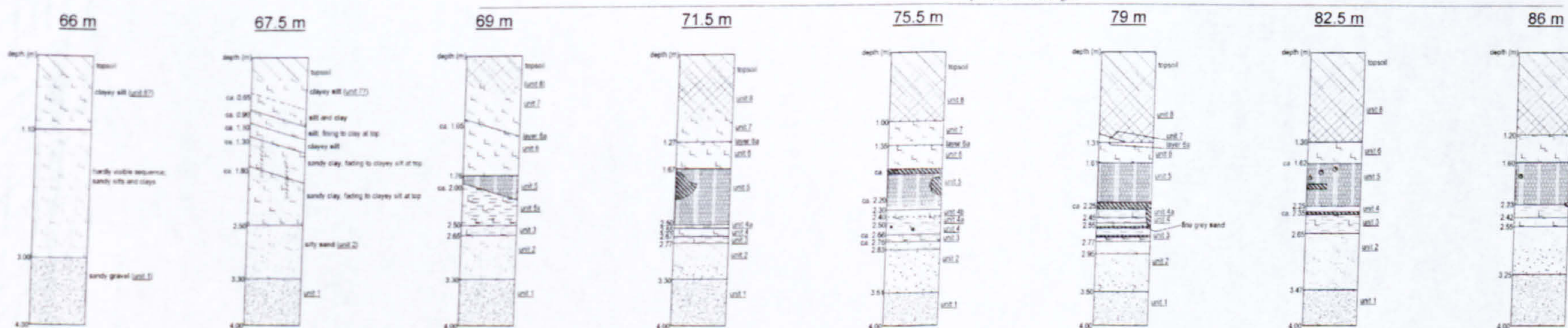


Figure 20 - a: ca. 185 m from South end

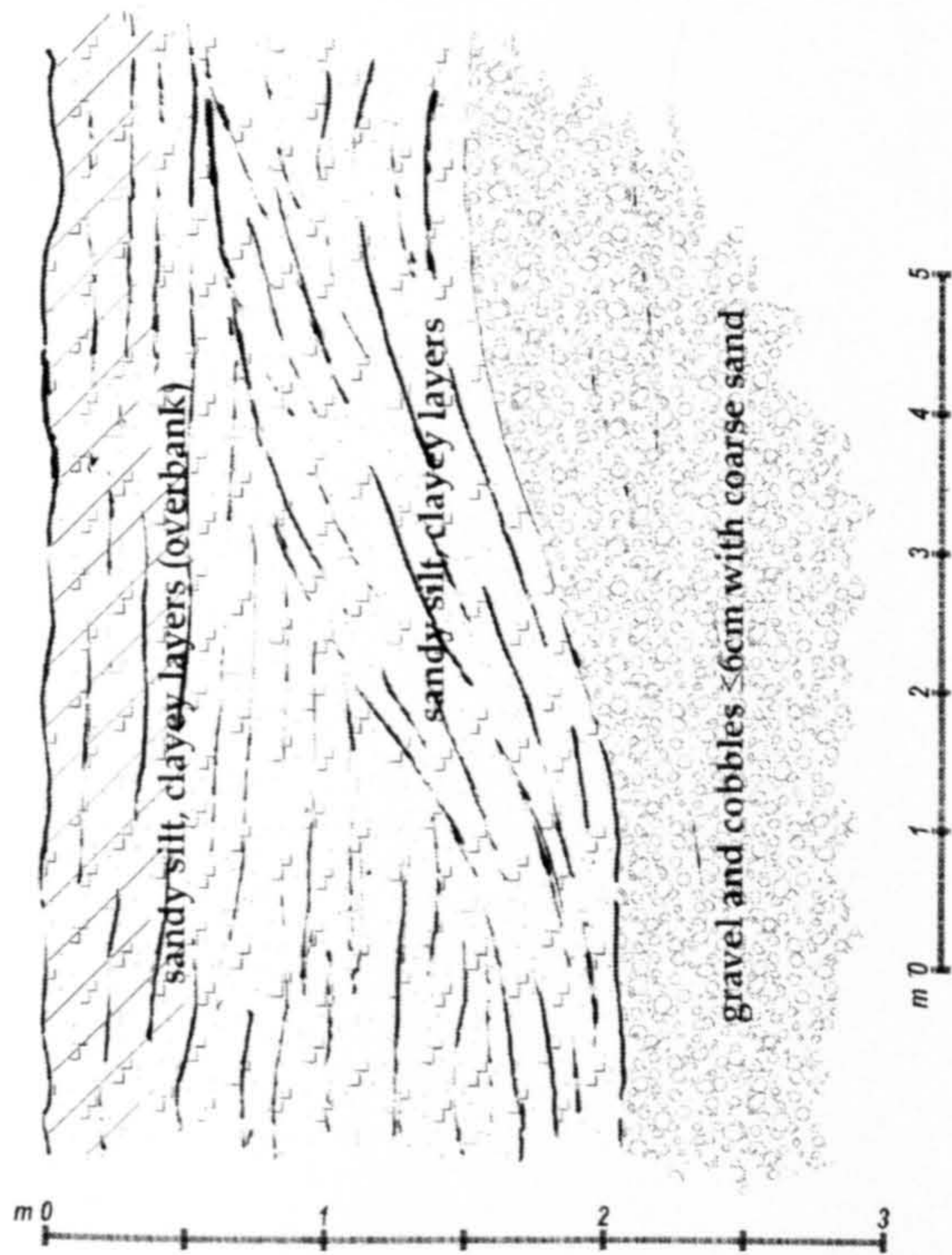


Figure 20 - b: ca. 160-170 m from South end (at I in figure 12)

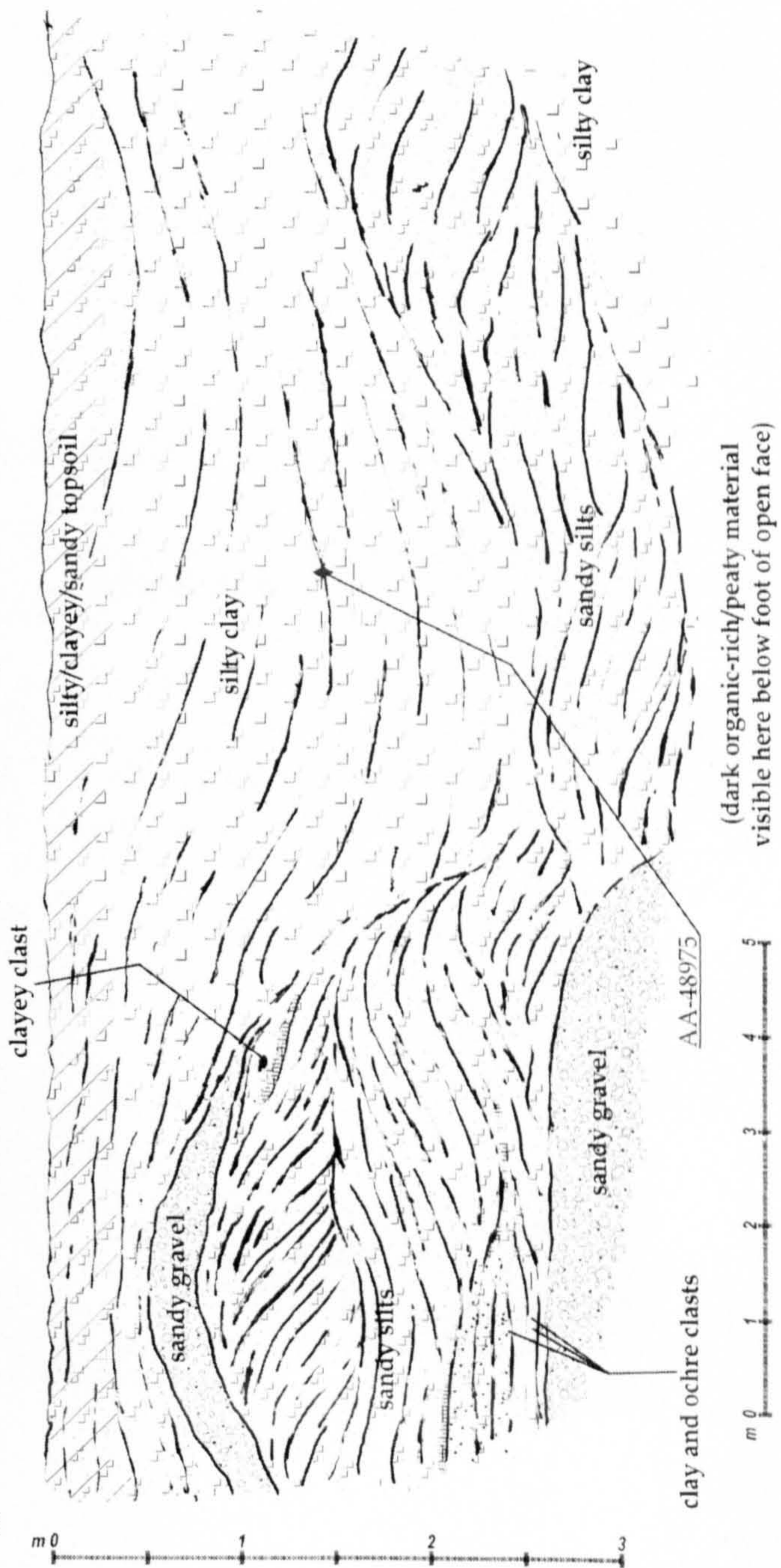


Figure 20 - c: ca.55 m from South end (at K in figure 12)

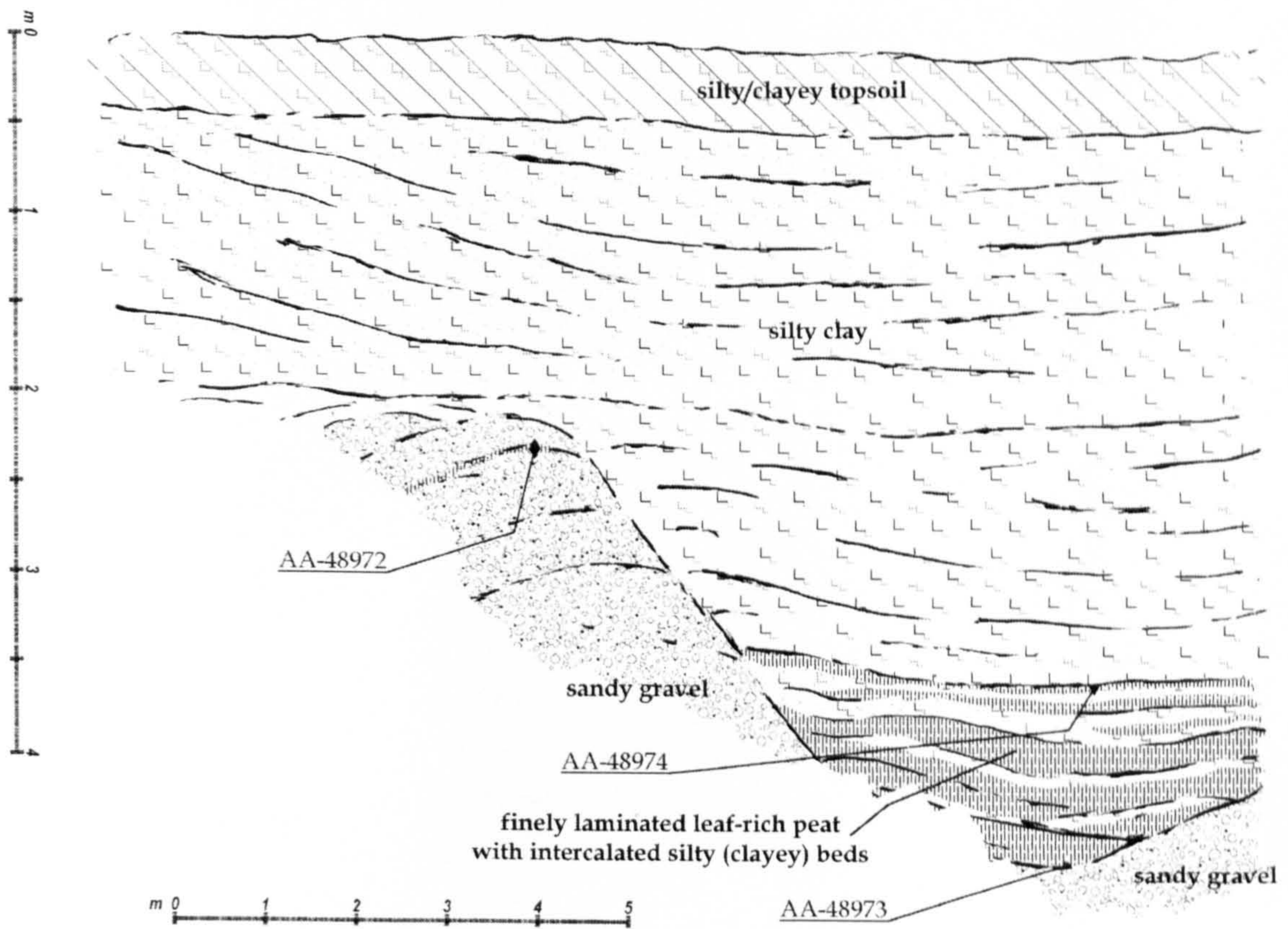


Figure 21 - Higher Brockholes SW face logs

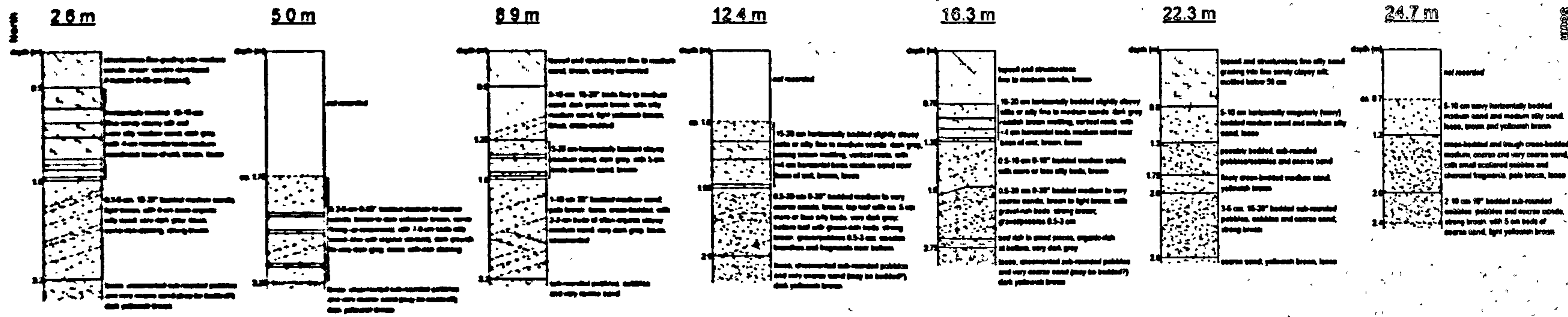


Figure 23 - boreholes across Brockholes quarry

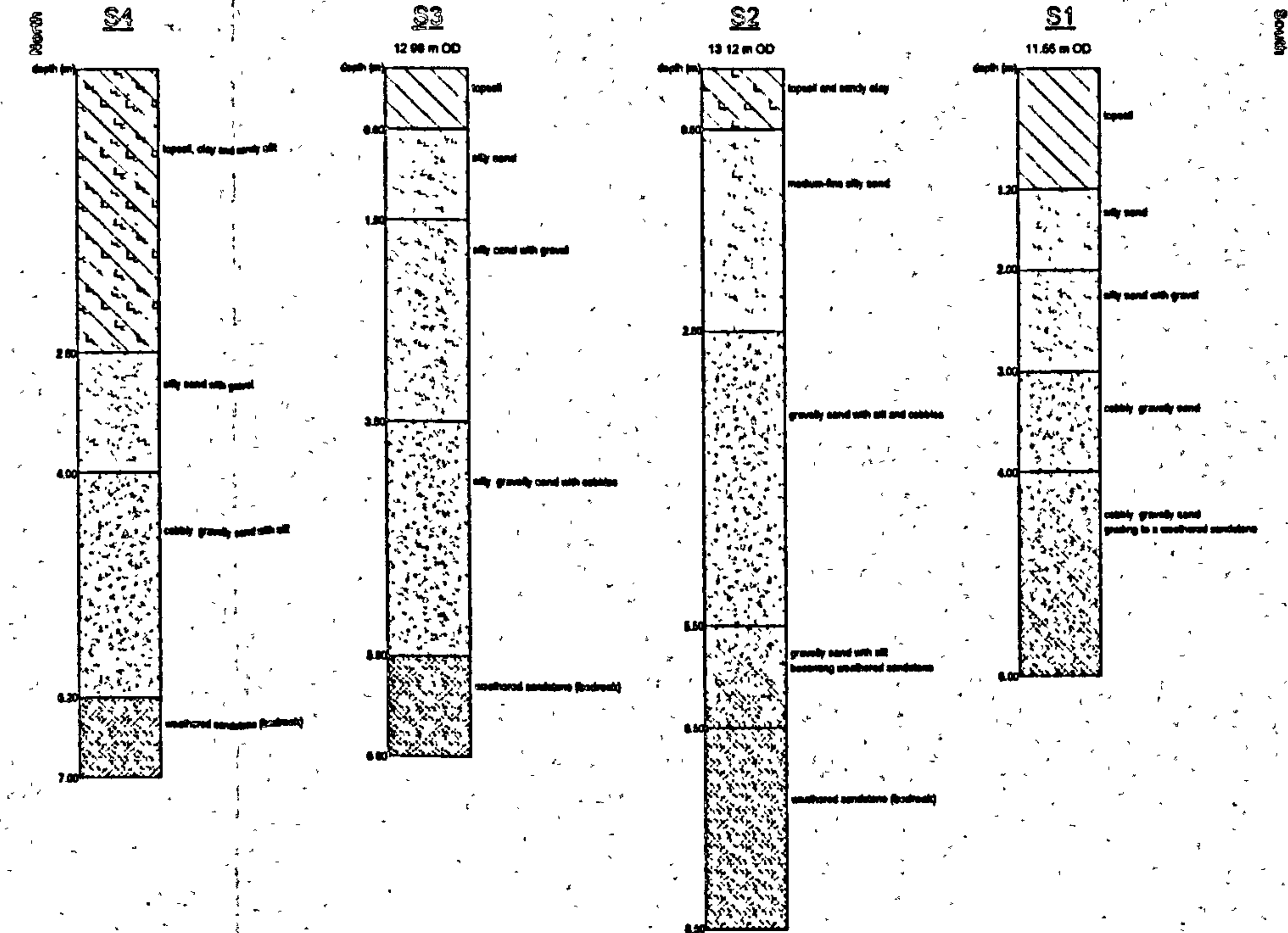


Figure 22 - boreholes from M6 motorway works, Brockholes area

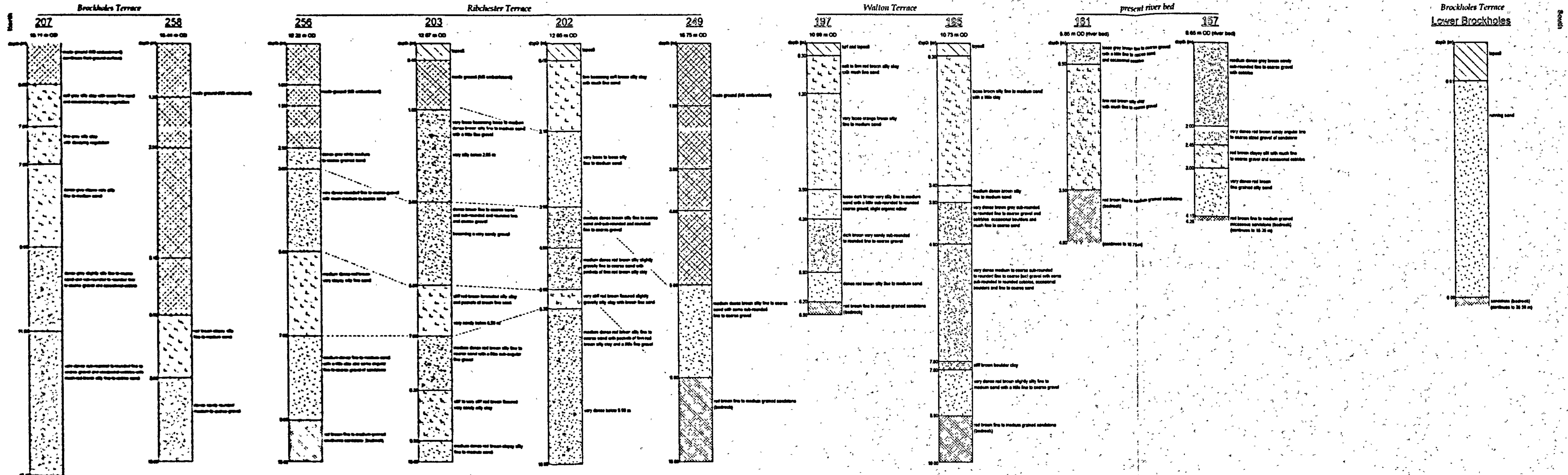


Figure 24a - Walton Flats 1981 boreholes

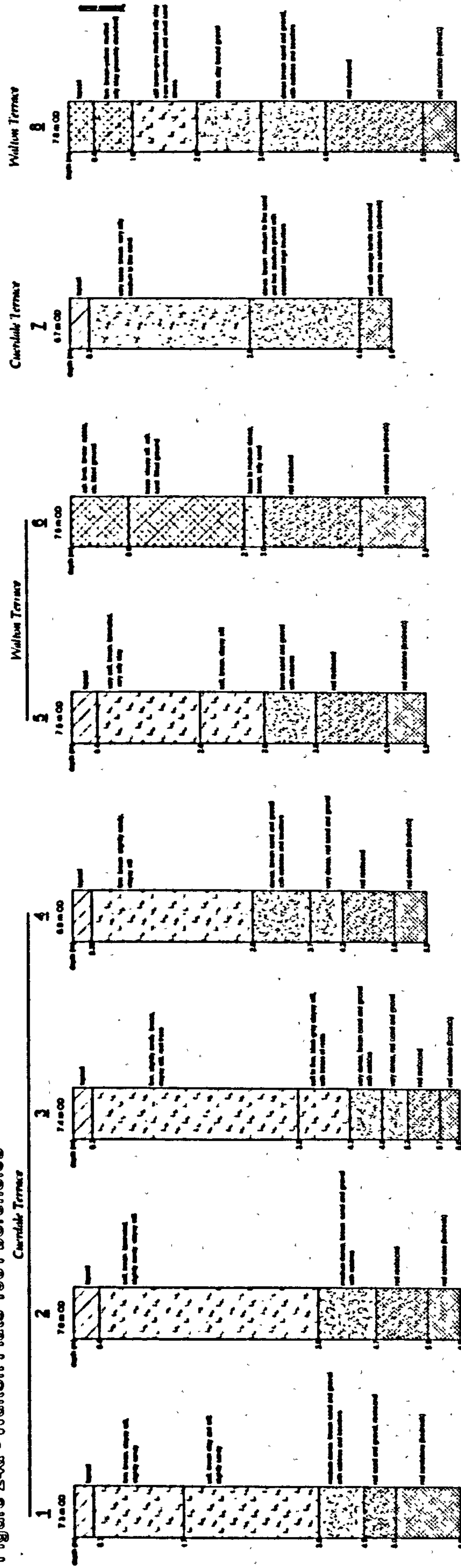


Figure 24b - Walton Flats 1981 boreholes (continued)

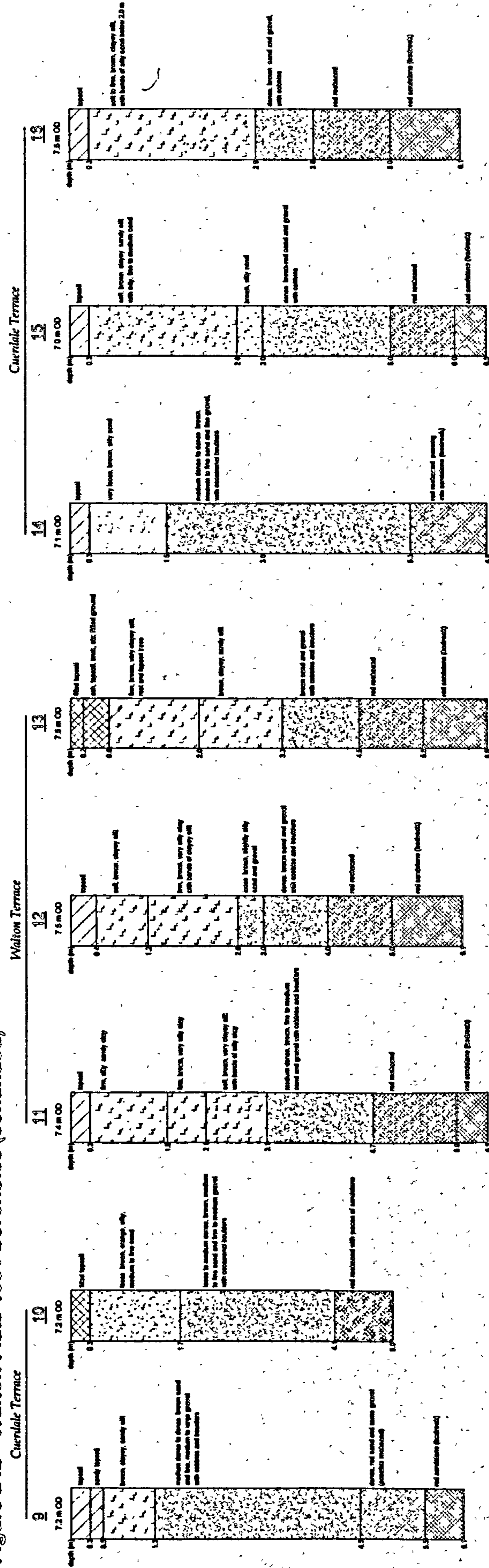


Figure 24c - Walton Flats 1981 boreholes (continued)

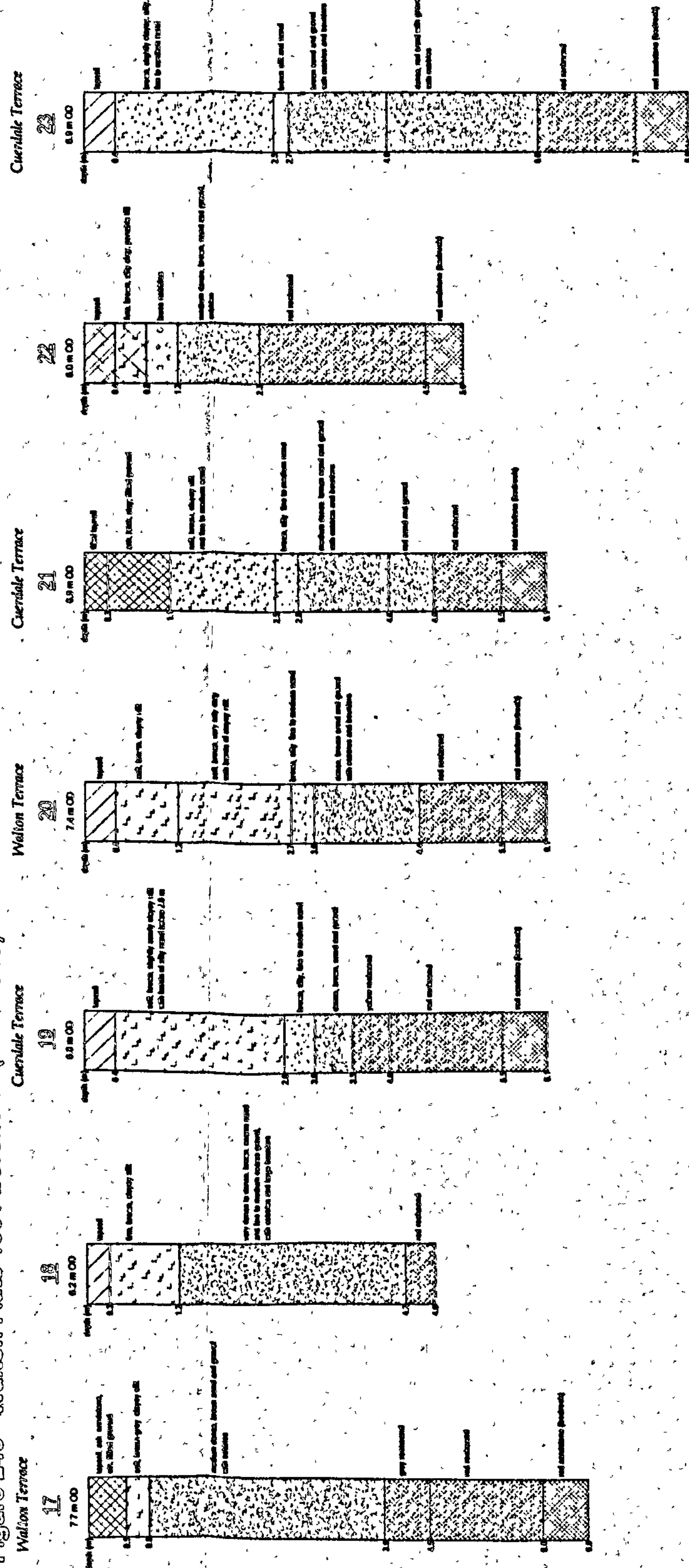


Figure 25 - Walton Flats 1975 boreholes

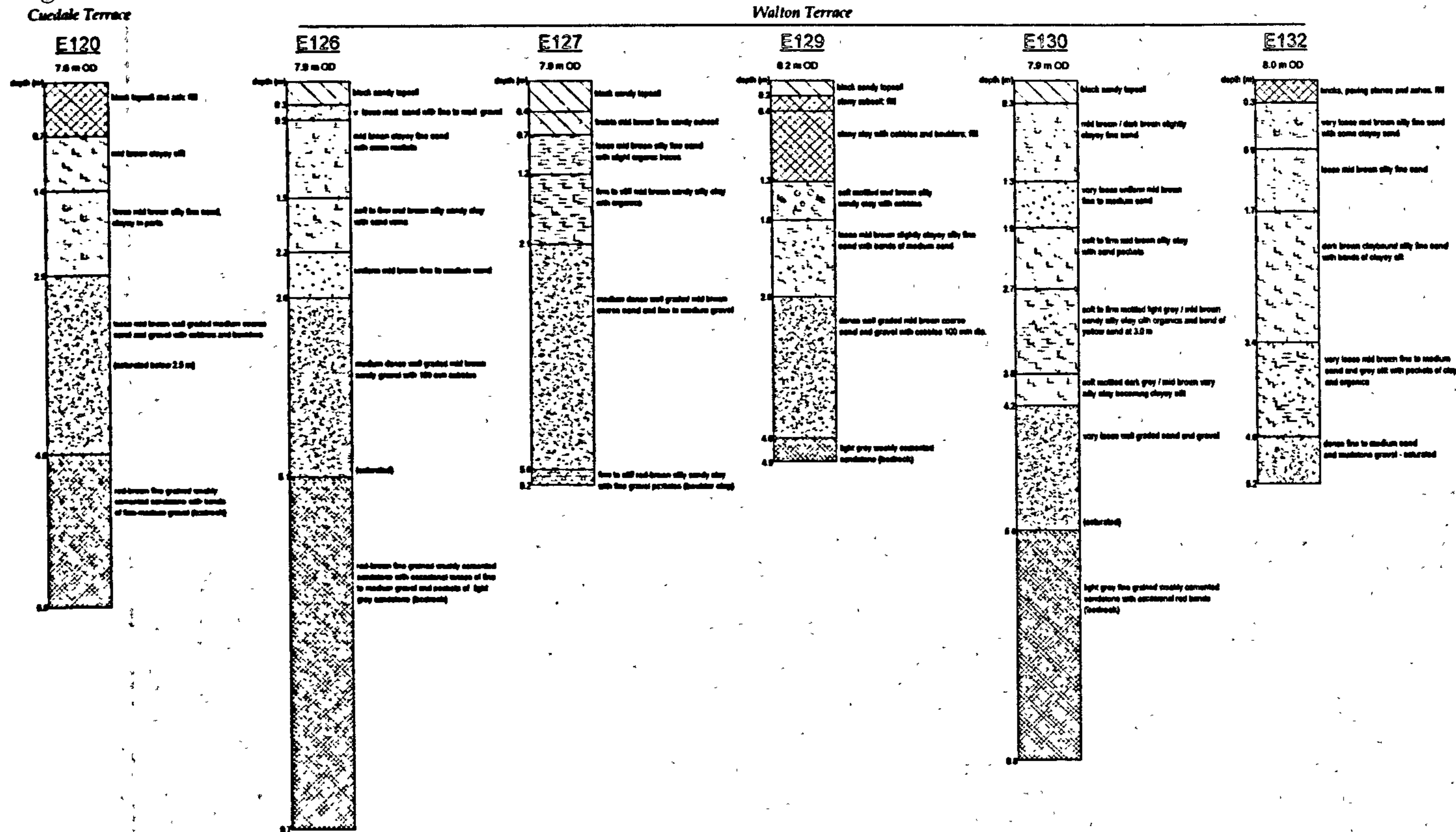


Figure 26 - Walton Flats SW core transect (A)

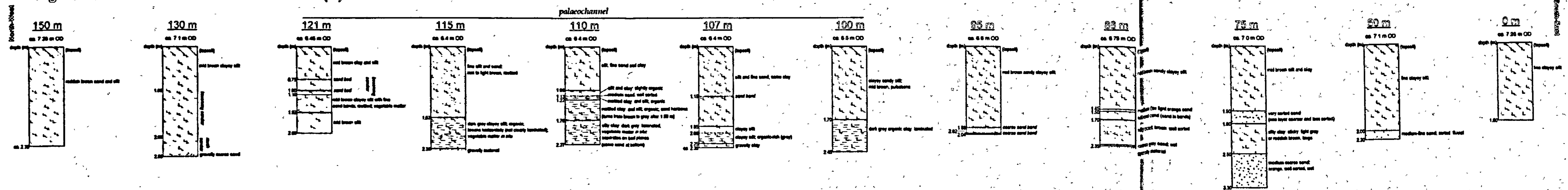
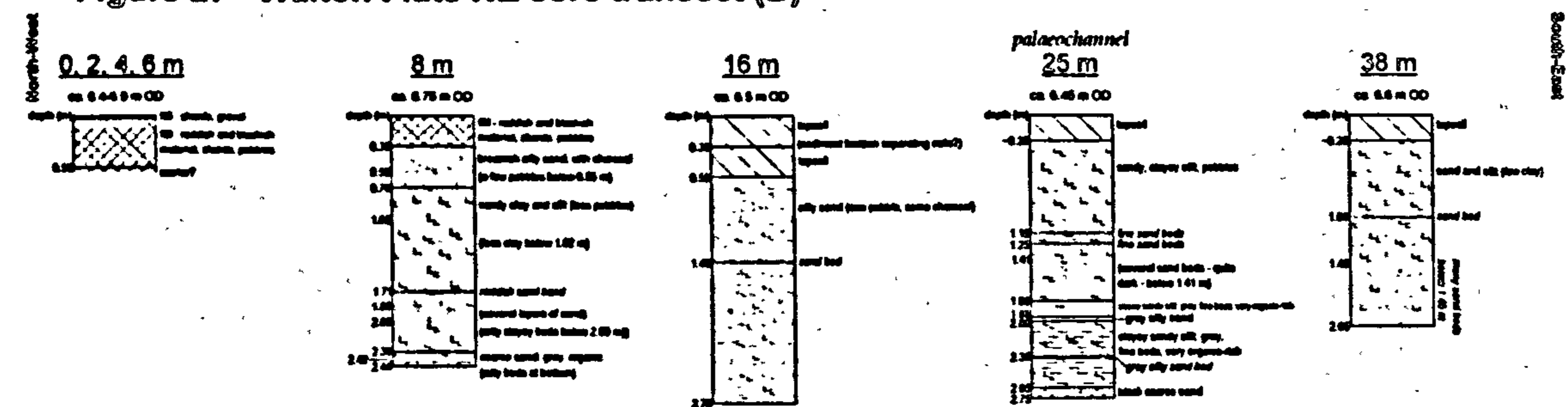


Figure 27 - Walton Flats NE core transect (B)



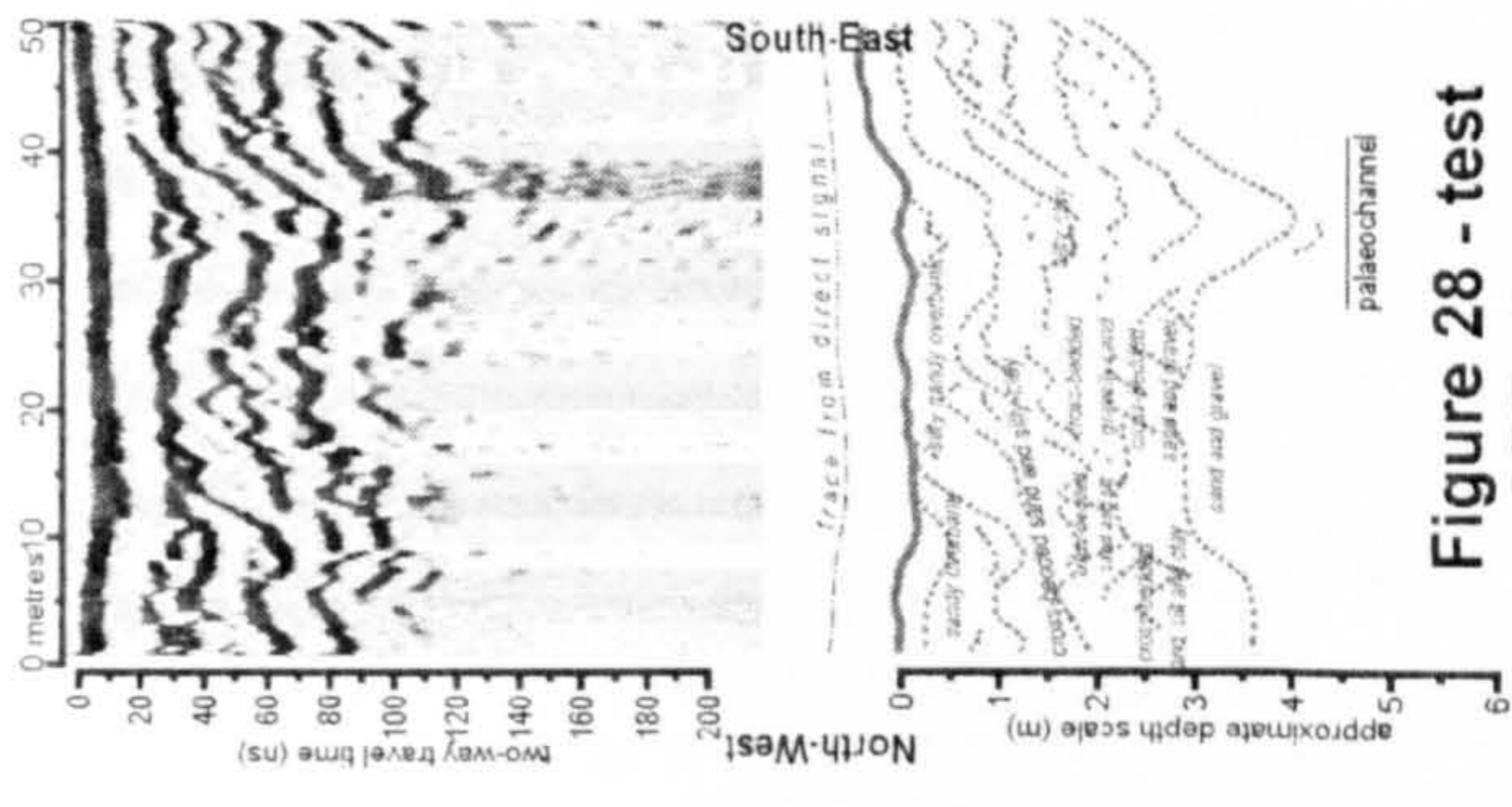


Figure 28 - test GPR diagram

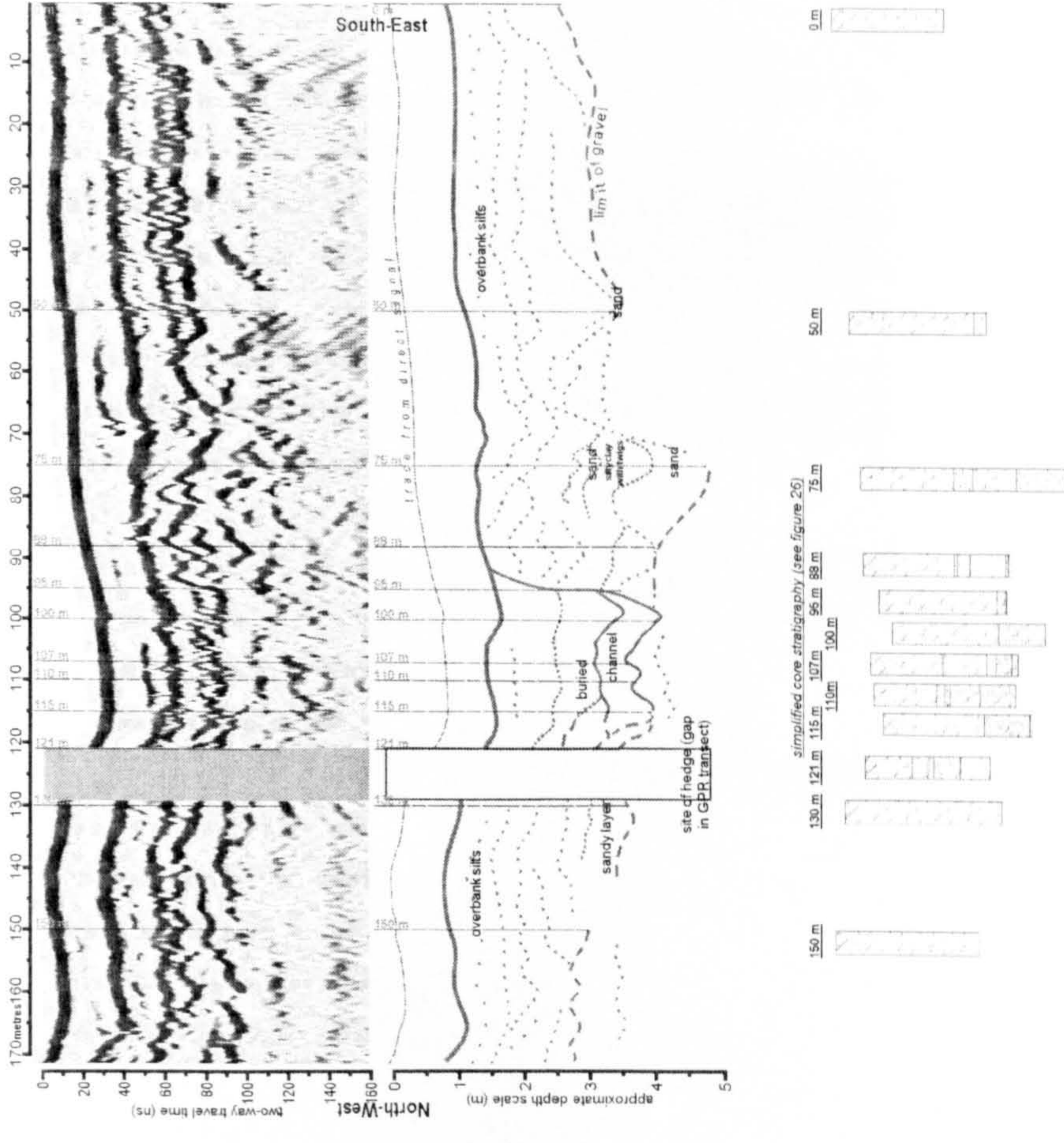
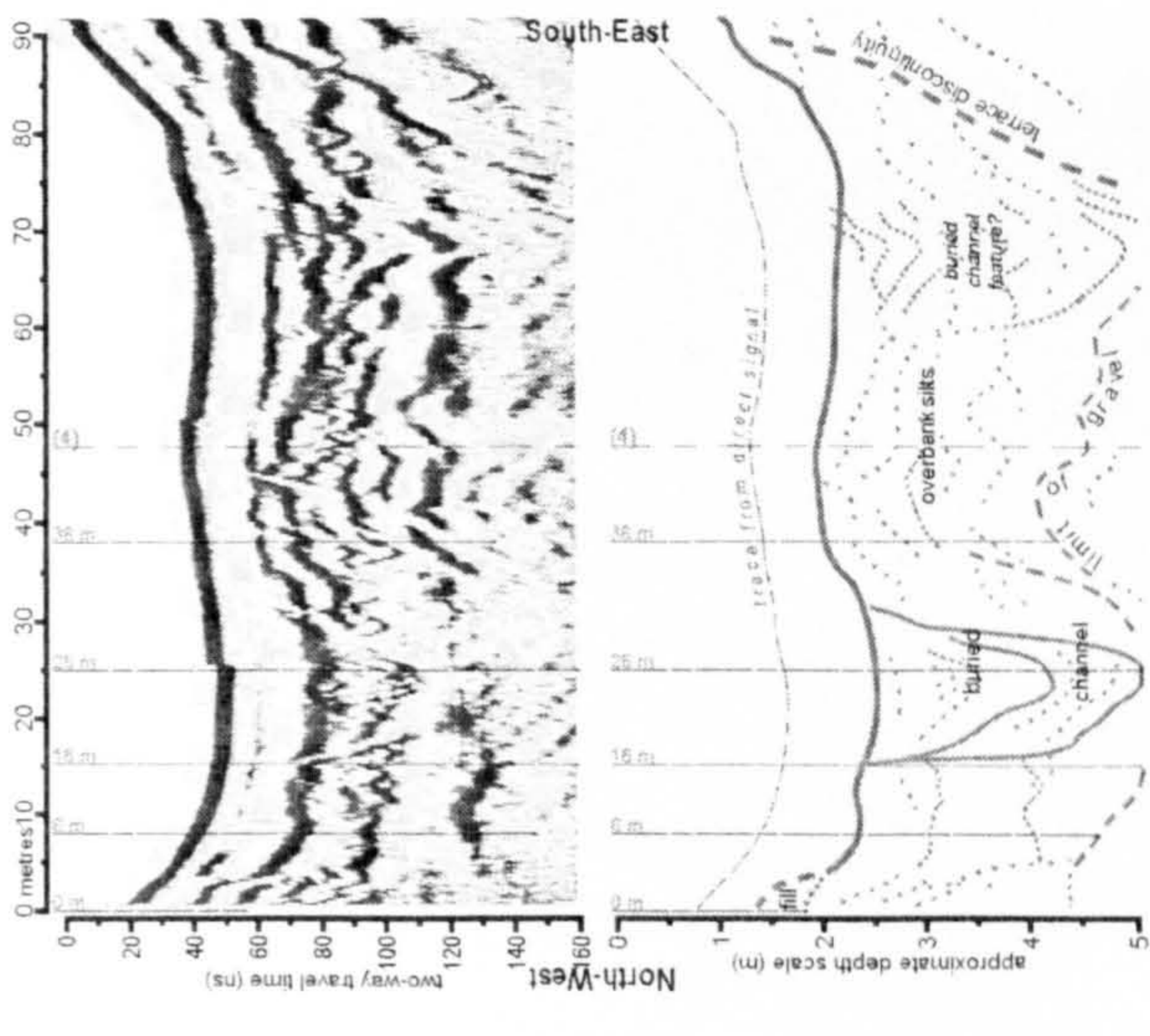
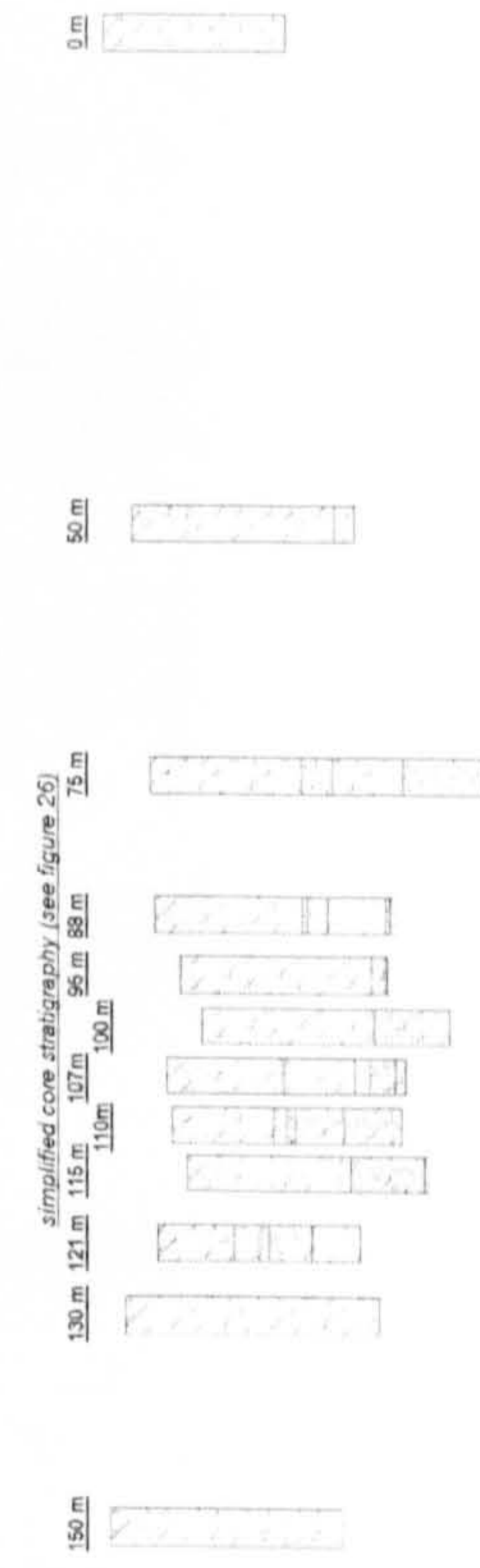


Figure 29 - Walton Flats GPR diagram A



simplified core/borehole stratigraphy (see figure 24 a and 27)

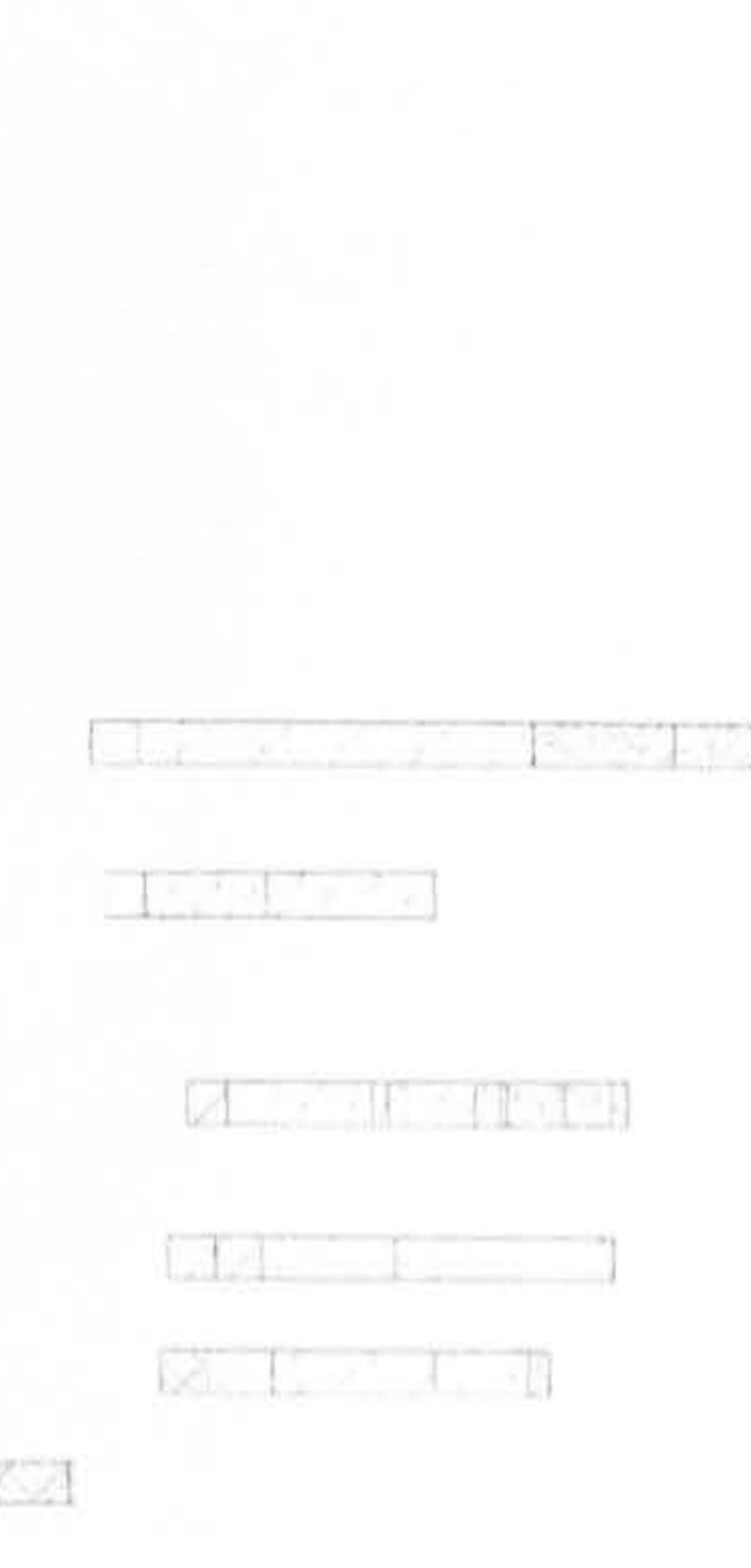


Figure 30 - Walton Flats GPR diagram B

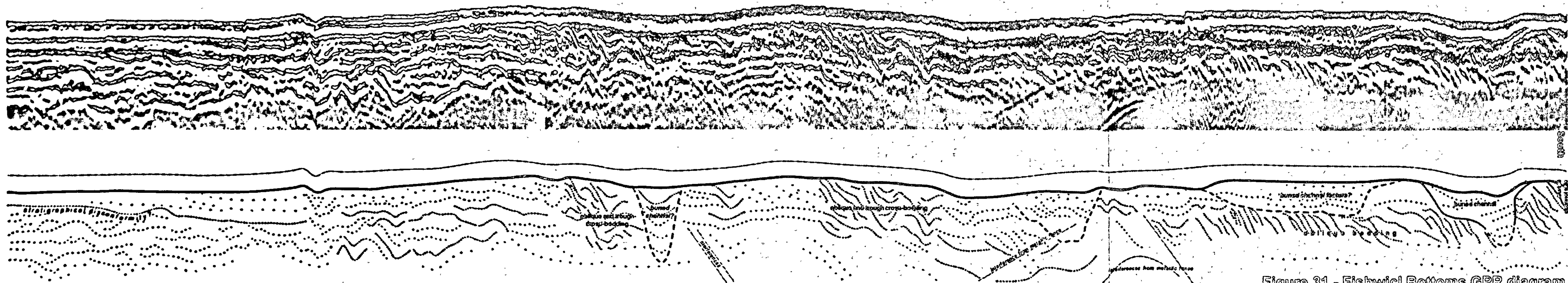
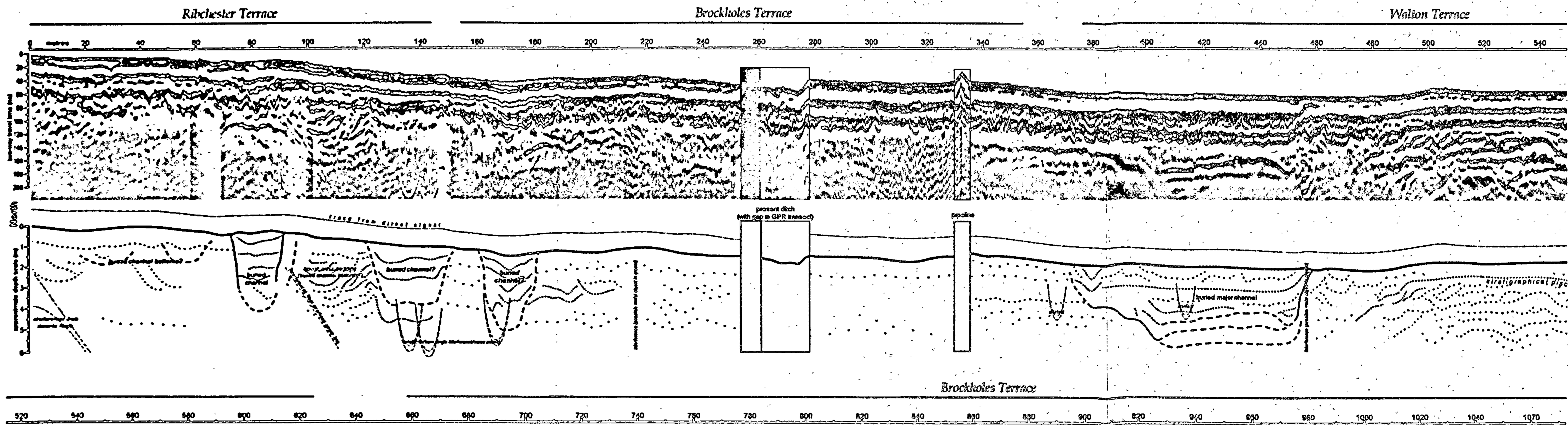


Figure 31 - Fishwick Bottoms GPR diagram

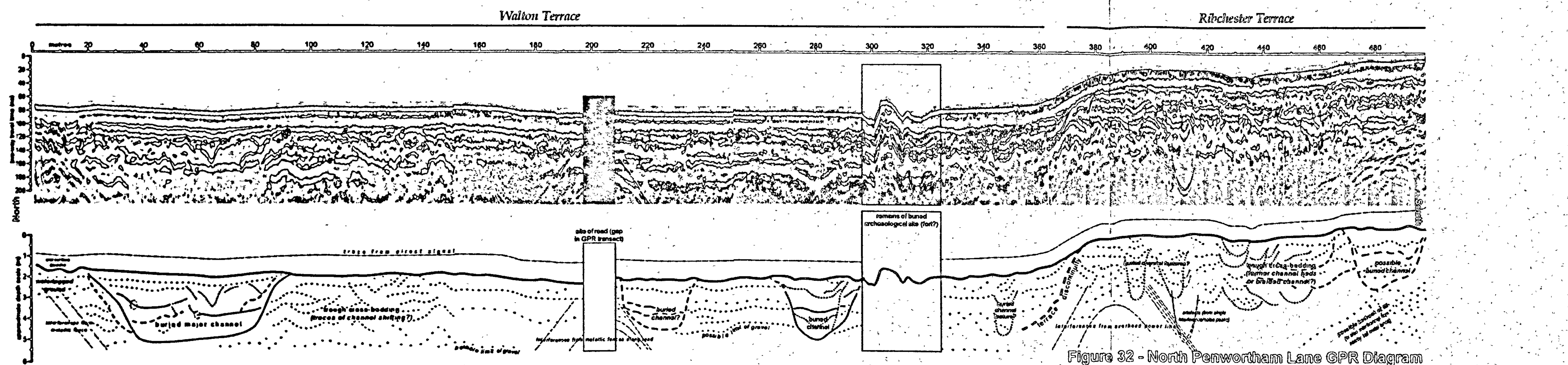


Figure 32 - North Penwortham Lane GPR Diagram

Figure 33 - Section through Higher Brockholes area

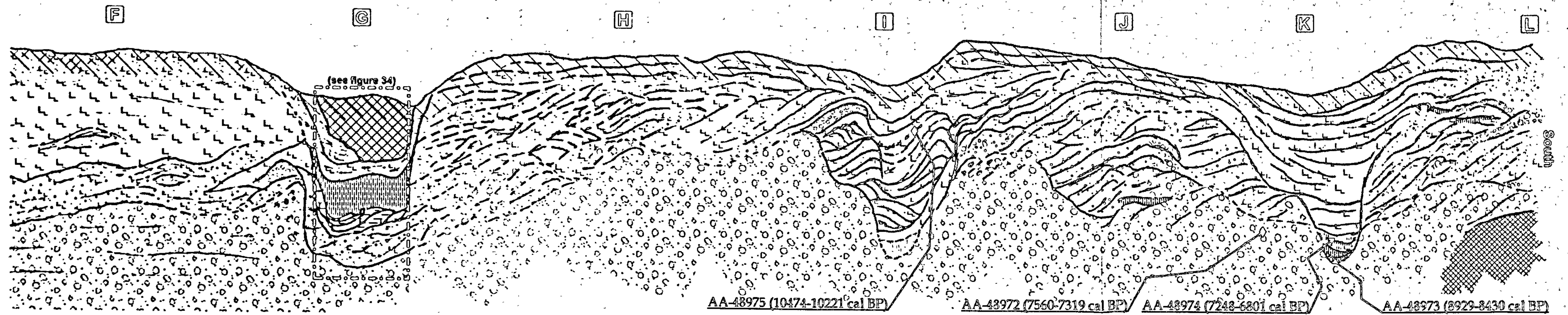
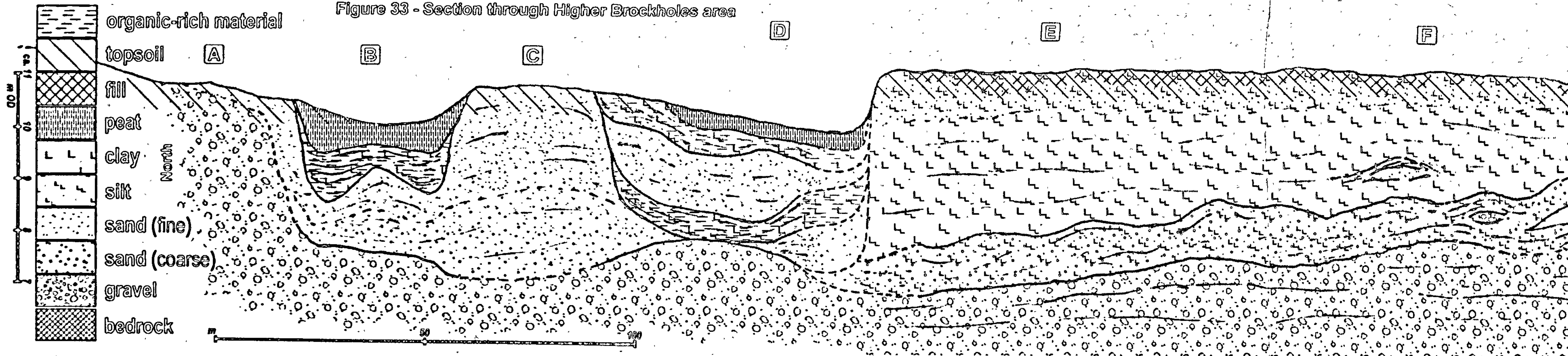


Figure 34 - palaeochannel section at Higher Brockholes

- North**
- 1 - fine to coarse gravels with sand (main basal unit in area)
 - 2 - fine to coarse grey to brownish sand and silt, with various bedding and grading
 - 3x - bedded dark grey clay and silt with detrituous beds
 - 3 - very finely laminated dark greyish clay with organic content, small beds of vegetable matter and twigs
 - 4 - slightly silty clay, finely bedded, very soft, unctuous, cream-yellowish; highly reducing environment
 - 4a - similar to unit 4, but oil grey and more organic; not as much reducing
 - 4b - same as unit 4
 - 5x - brownish silty clay, very organic-rich
 - 5 - peat, more or less massive or finely bedded, leafy, quite detrituous; rich in large tree branches and trunks; clayey at bottom
 - 6 - grey silt and clay with iron-reddish mottling; stiff, crumbly
 - 6a - extensively consistent thin organic-rich layer between units 6 and 7
 - 7 - clayey silt, similar to unit 6
 - 8 - artificial fill; hard silty material, rich in irregular stones
 - w - wood branches and trunks

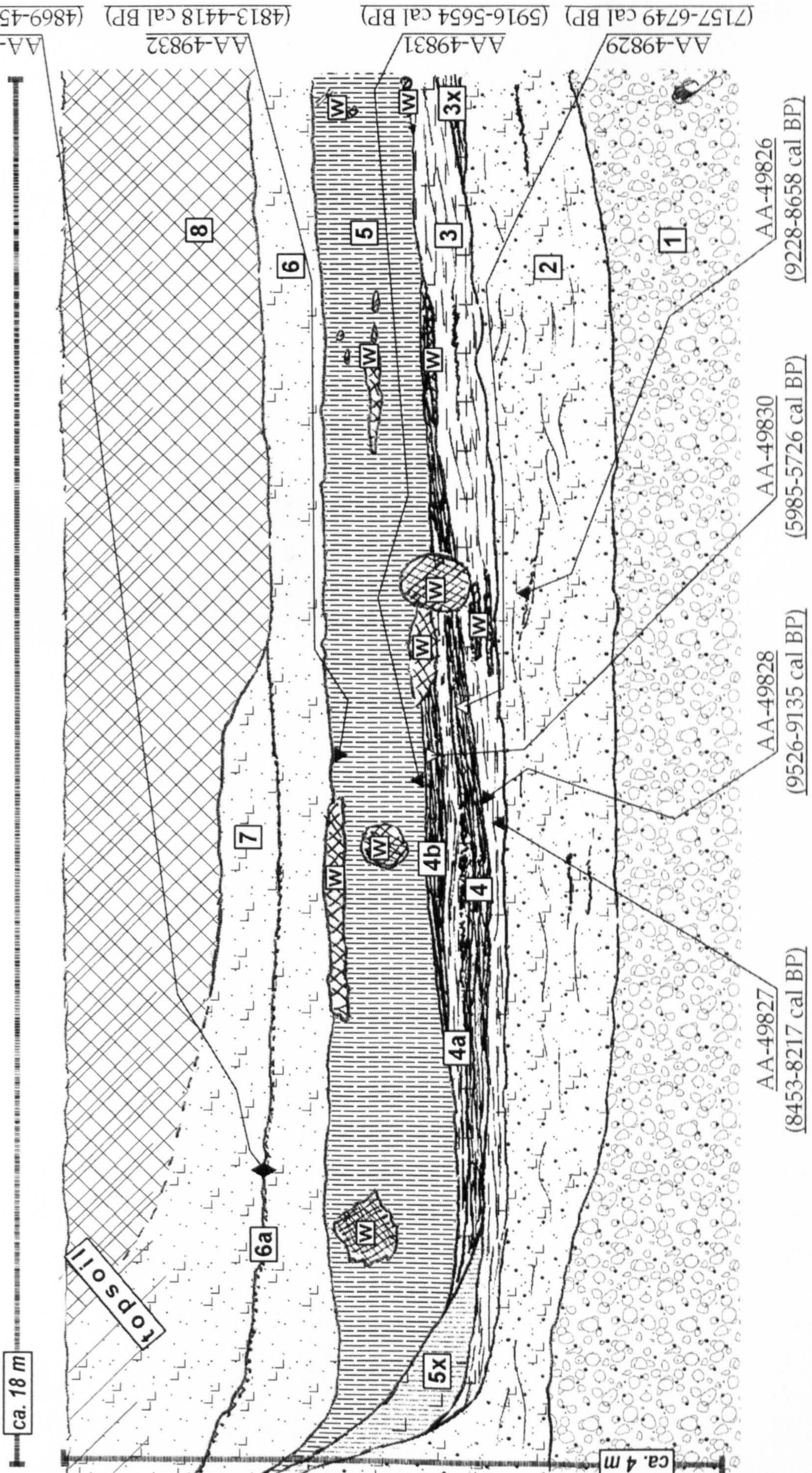
South

AA-49833 (4869-4573 cal BP)

AA-49832 (4813-4418 cal BP)

AA-49831 (5916-5654 cal BP)

AA-49829 (7157-6749 cal BP)



AA-49827 (8453-8217 cal BP)

AA-49828 (9526-9135 cal BP)

AA-49830 (5985-5726 cal BP)

AA-49826 (9228-8658 cal BP)

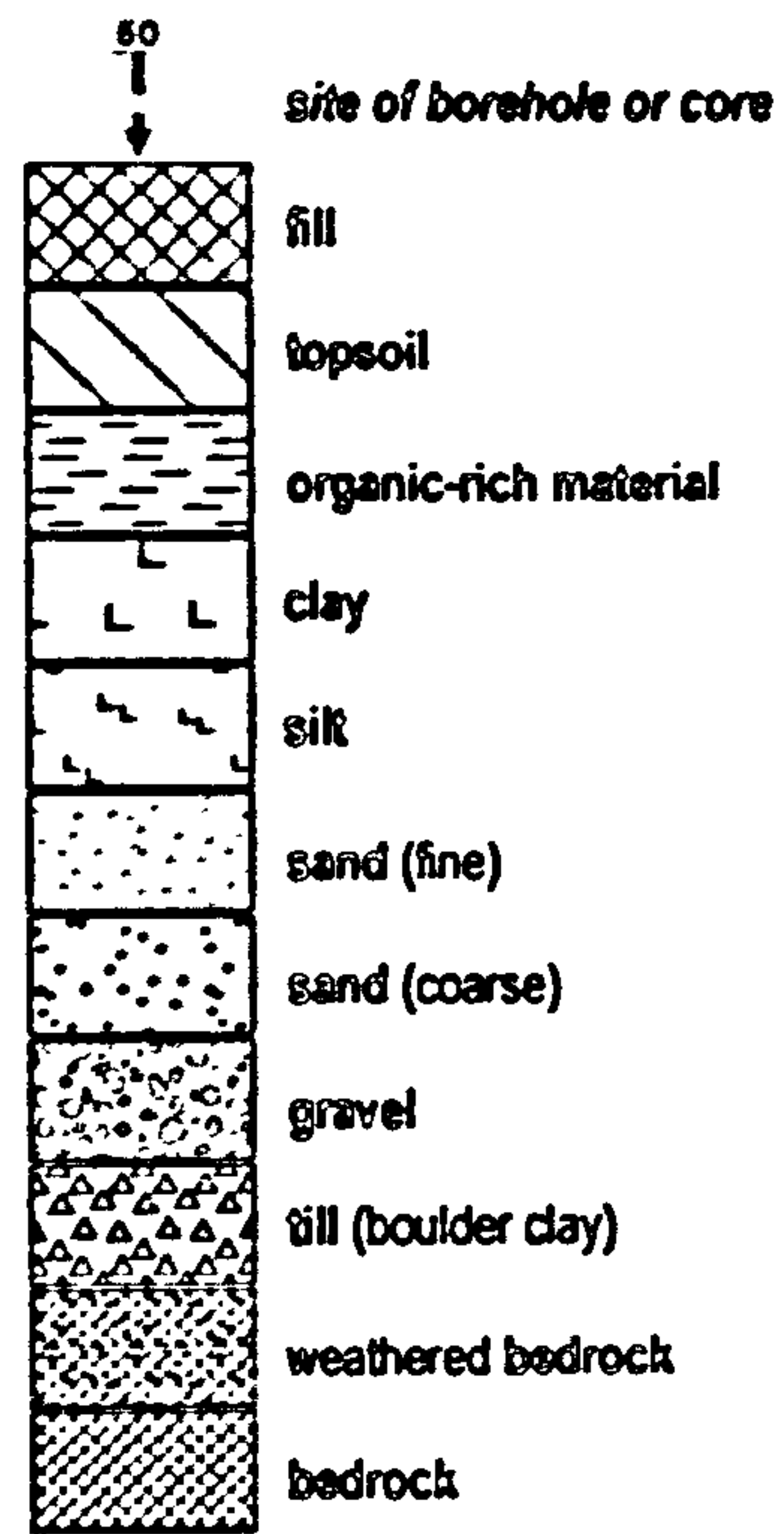


Figure 35 - Section through Walton Flats area

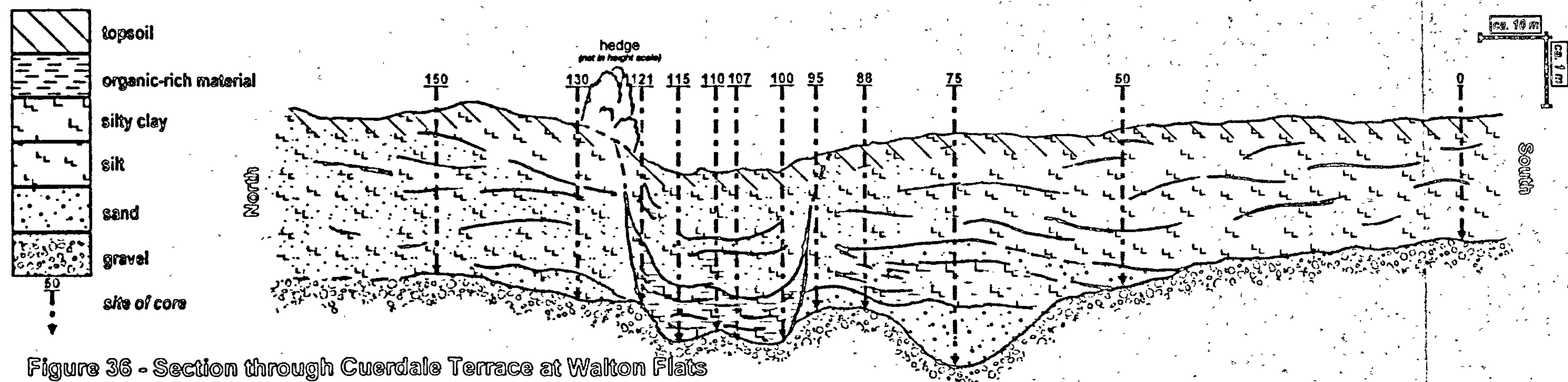
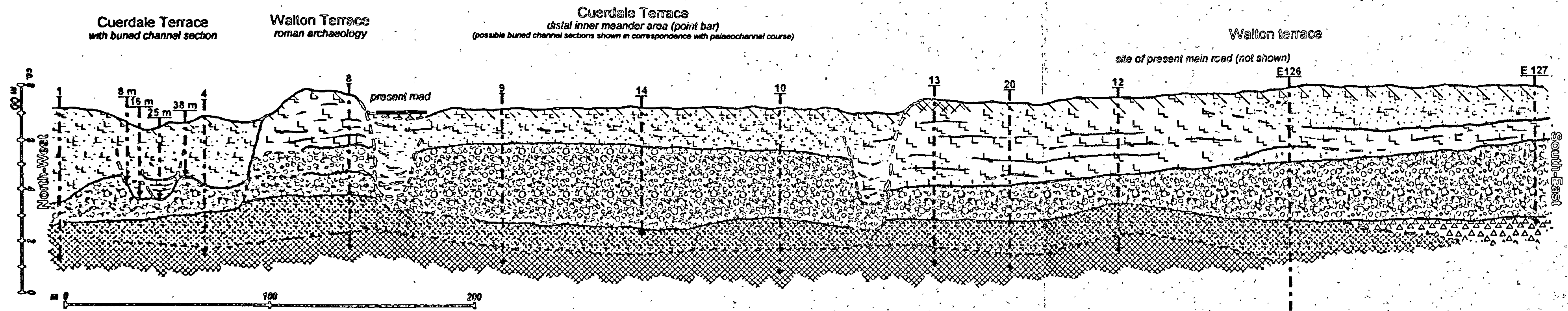
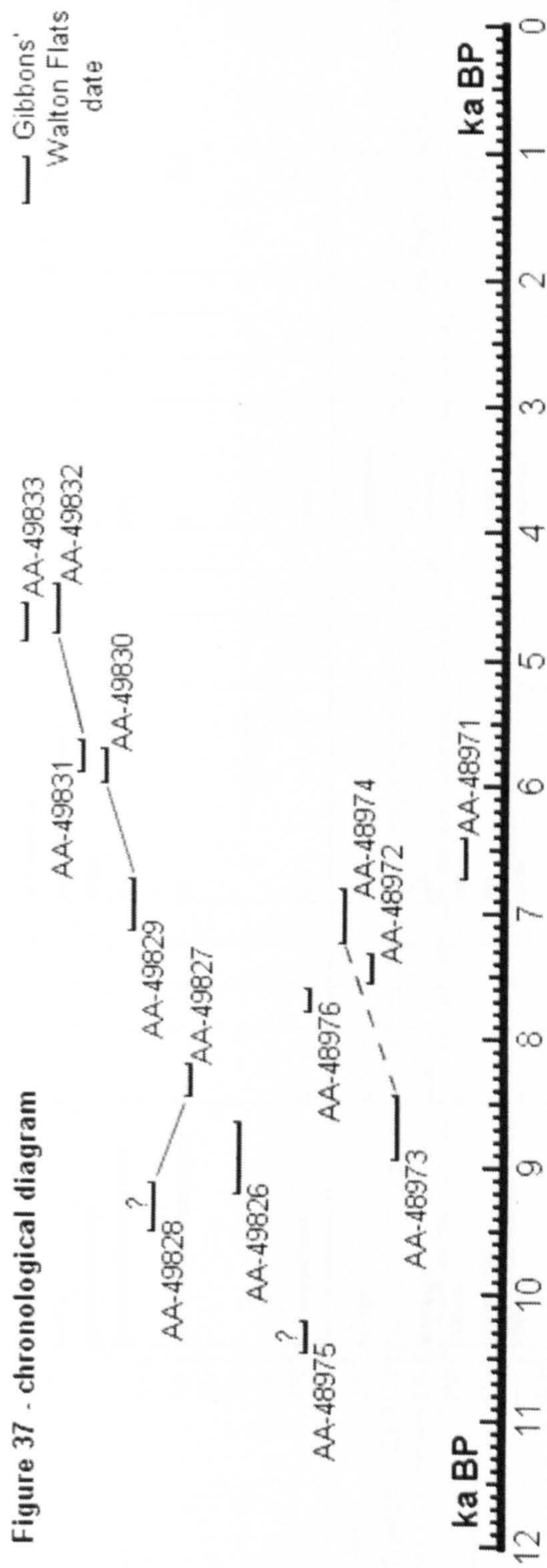


Figure 36 - Section through Cuerdale Terrace at Walton Flats

Figure 37 - chronological diagram



(linked dates are from top and bottom of same unit)

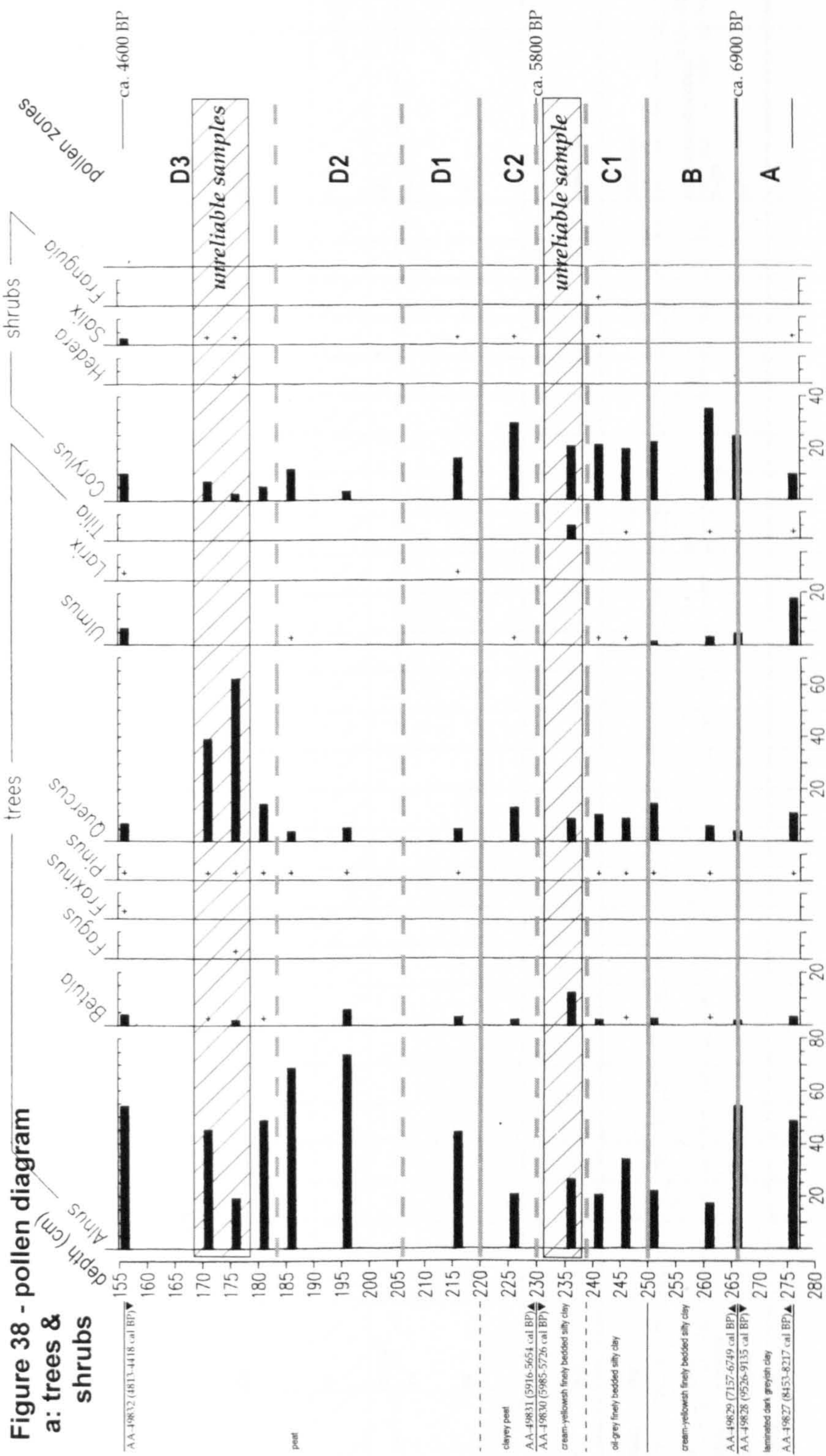


Figure 38 - pollen diagram
b: herbs, aquatic, spores

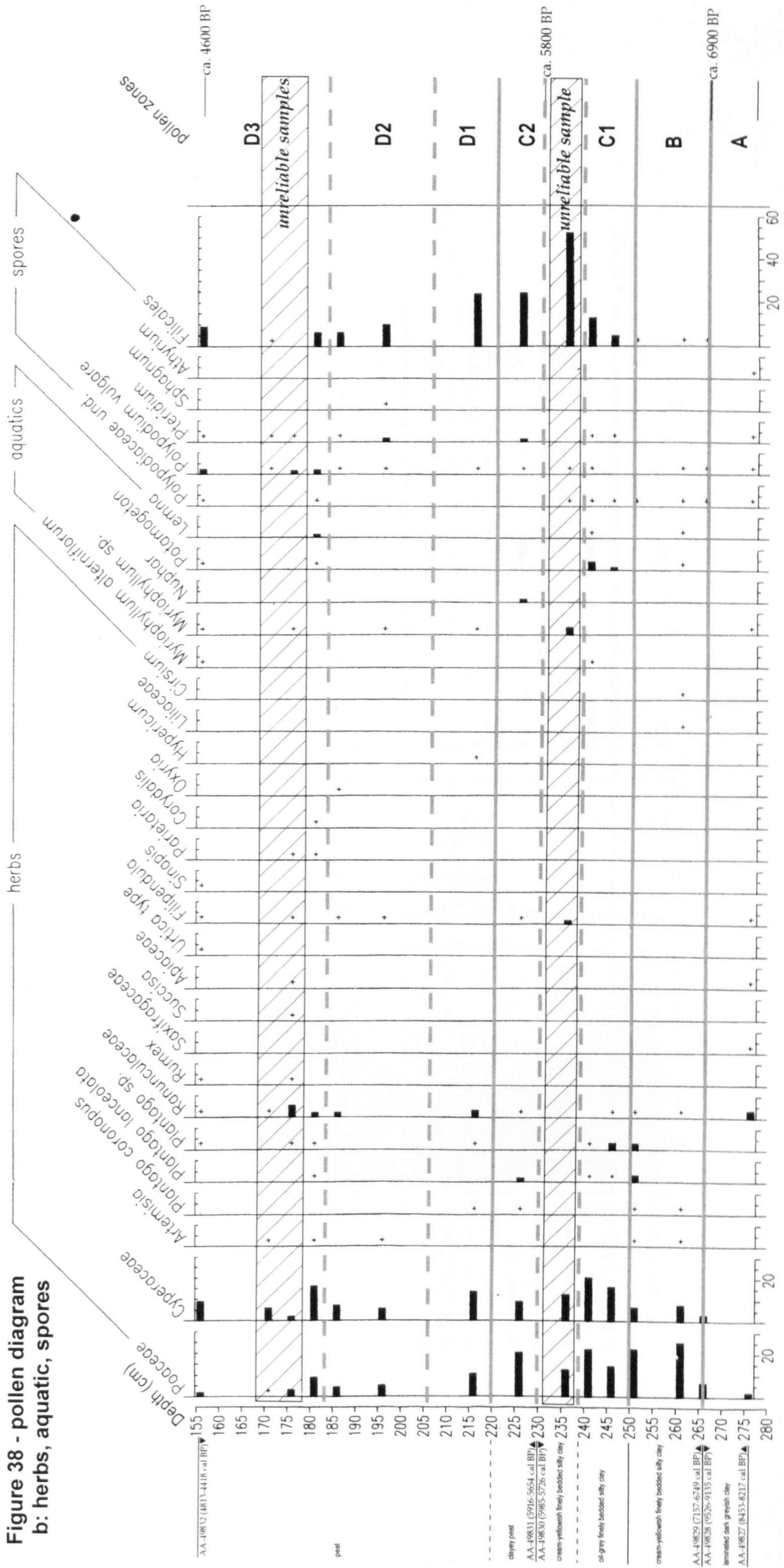
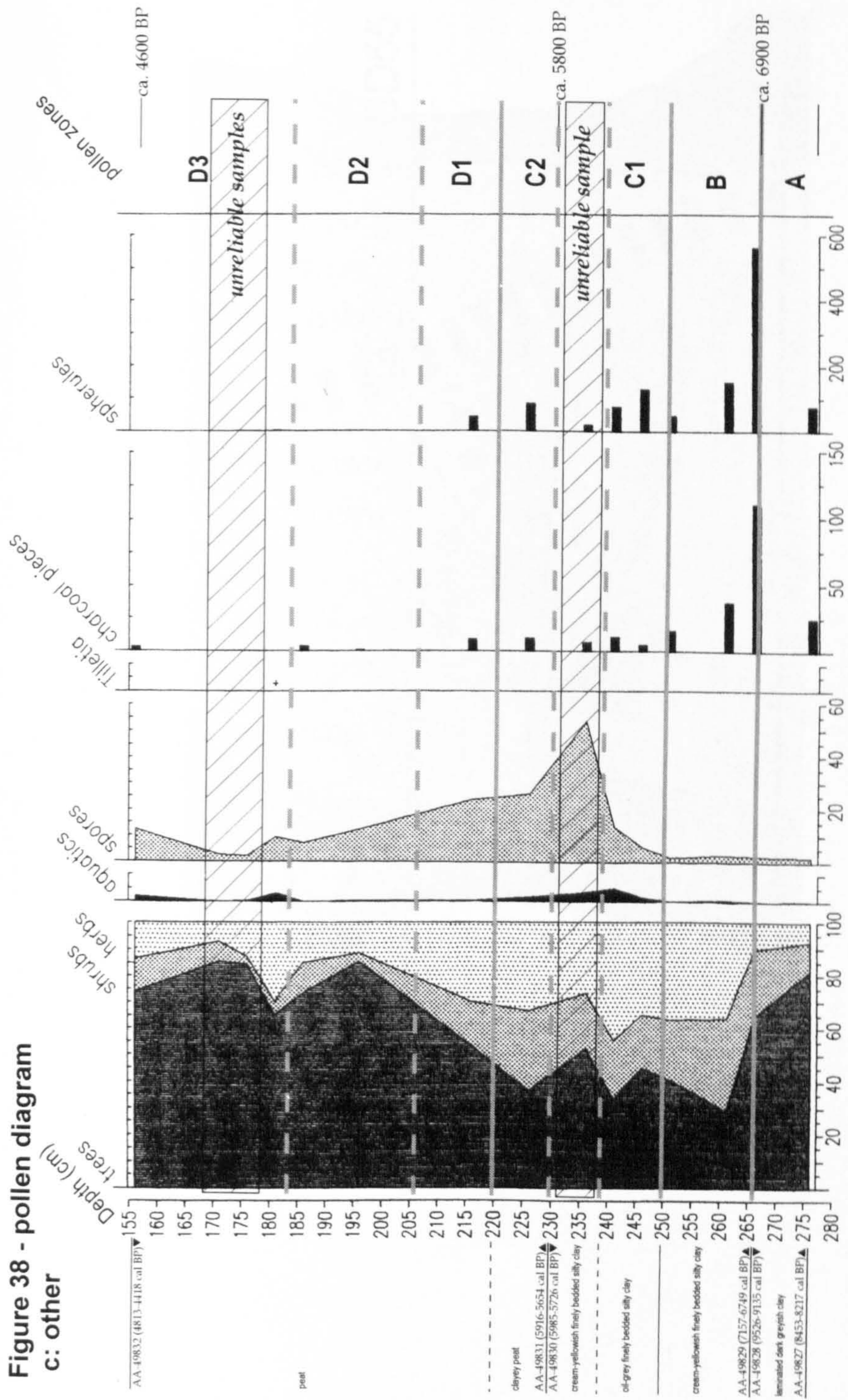


Figure 38 - pollen diagram
c: other



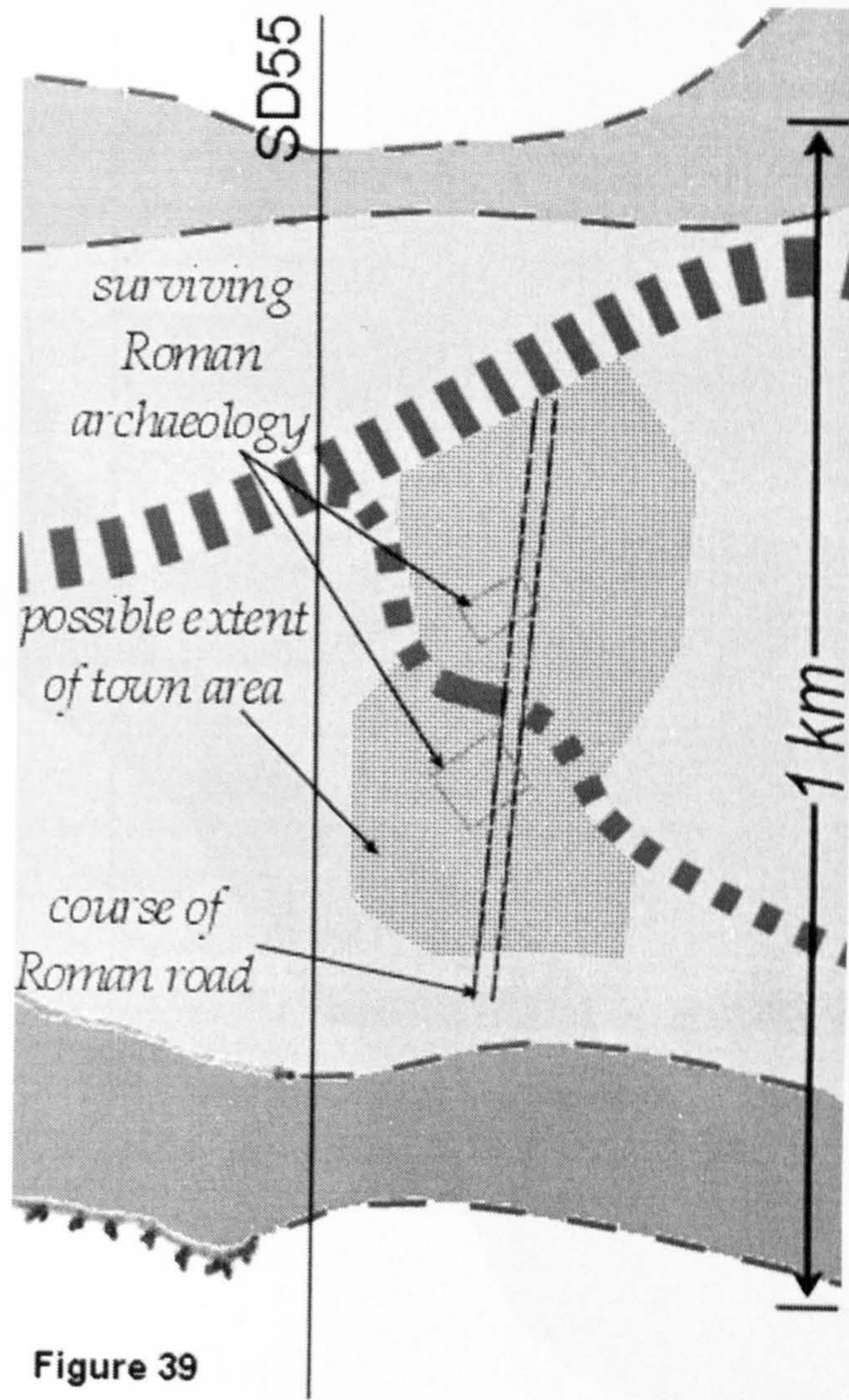


Figure 39

**Figure 40 - Reconstruction of the valley in the past
a: Ribchester stage floodplain**

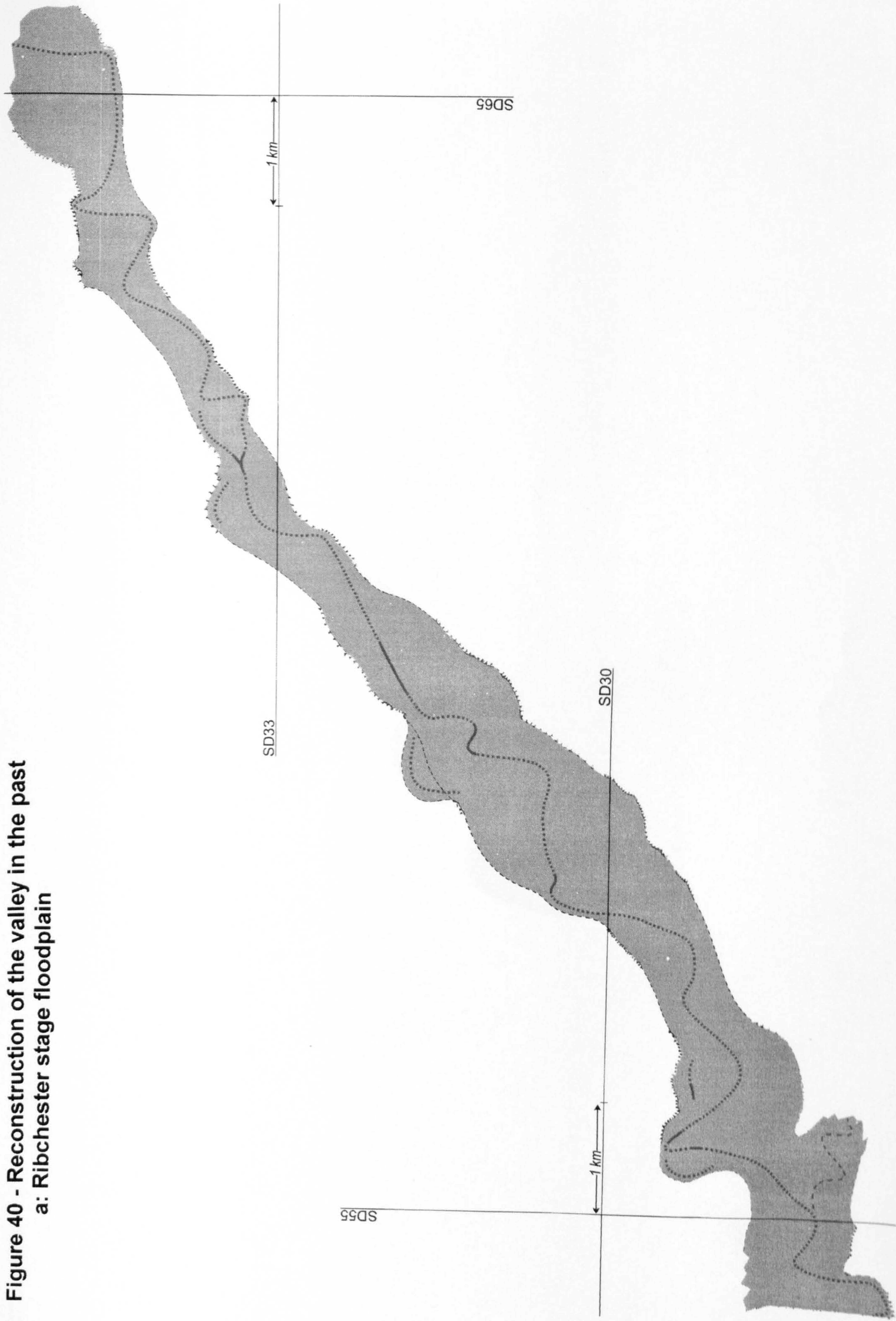


Figure 40 - Reconstruction of the valley in the past
b: Brockholes stage floodplain

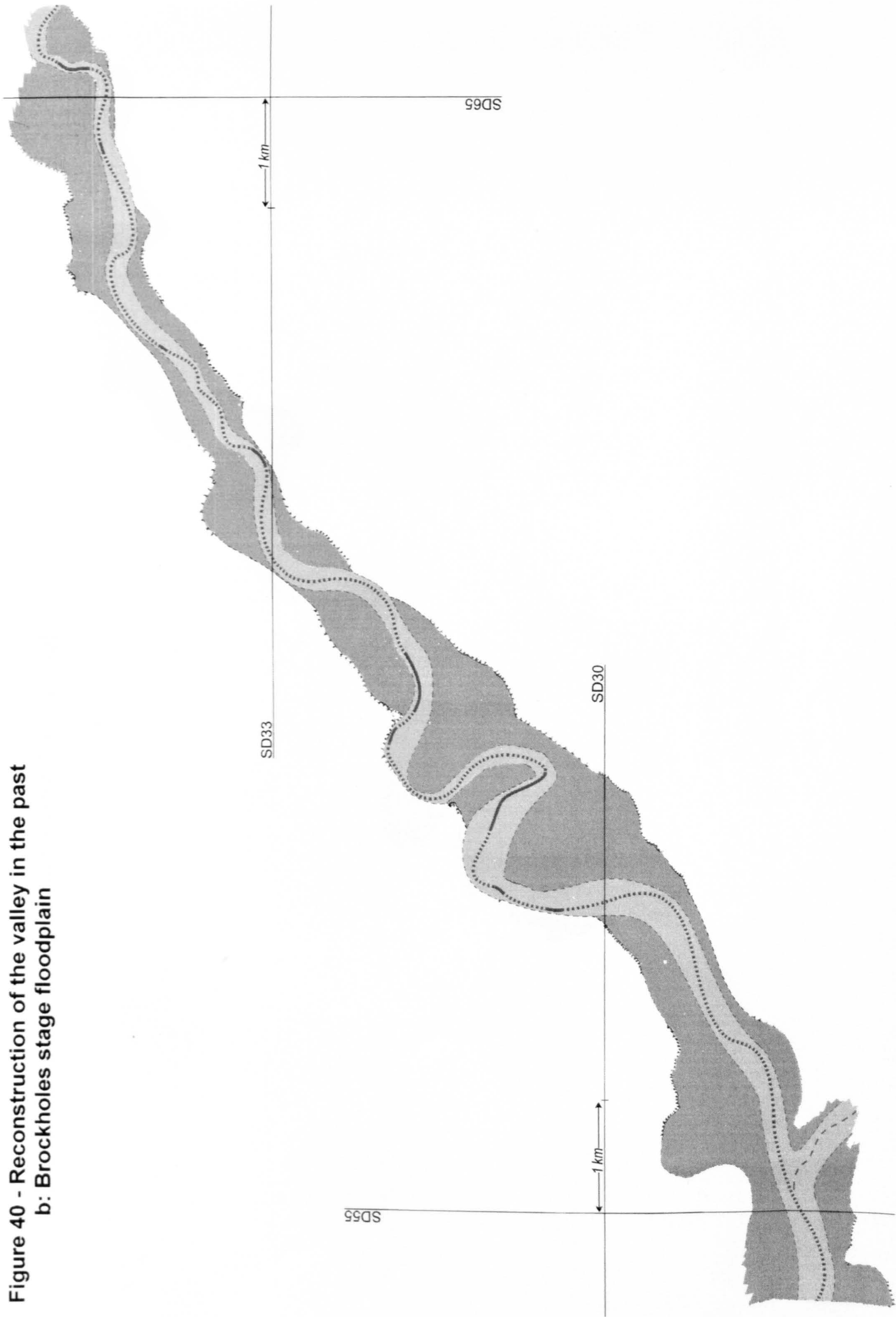


Figure 40 - Reconstruction of the valley in the past
c: Brockholes stage floodplain (after lateral reworking)

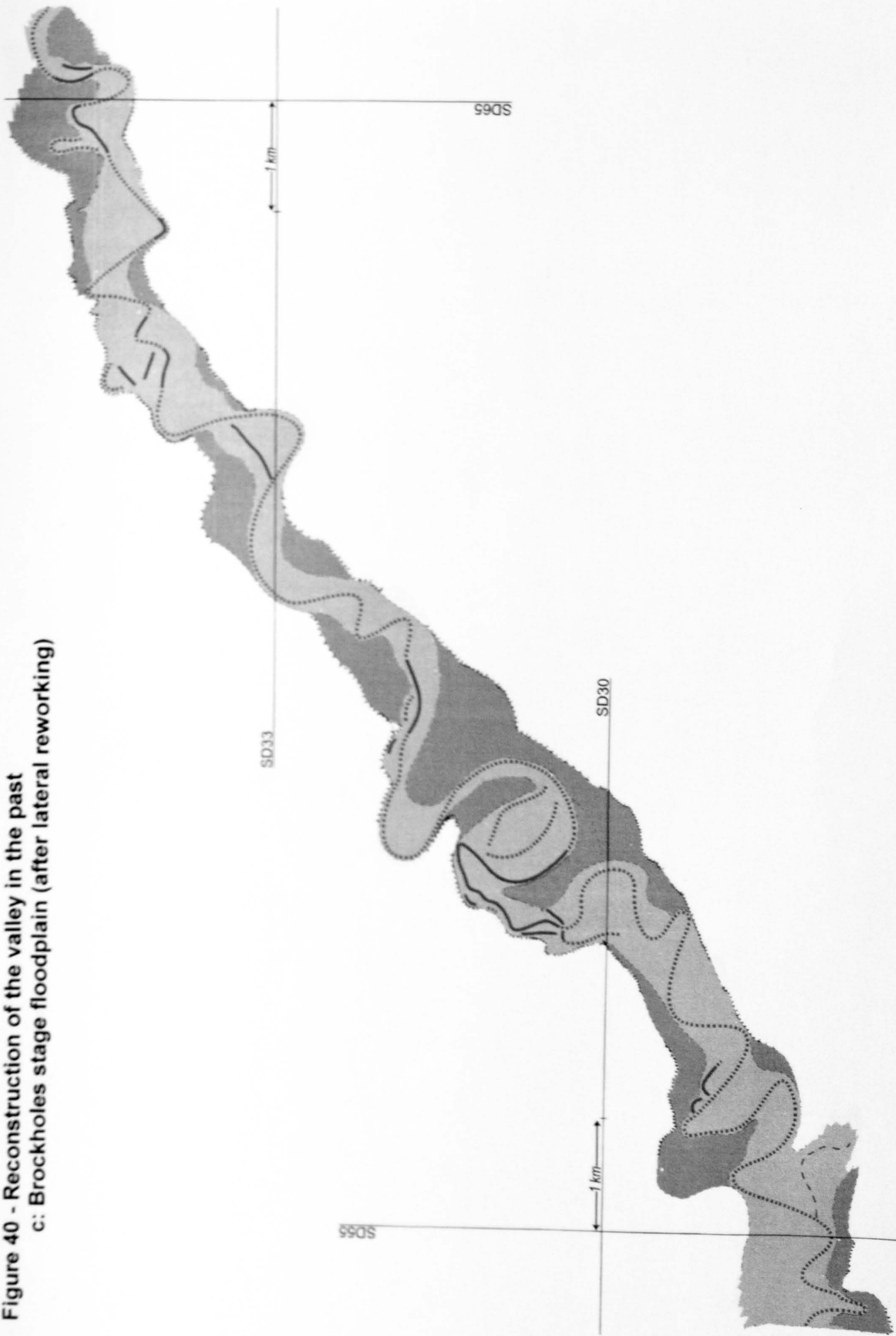


Figure 40 - Reconstruction of the valley in the past
d: Walton stage floodplain

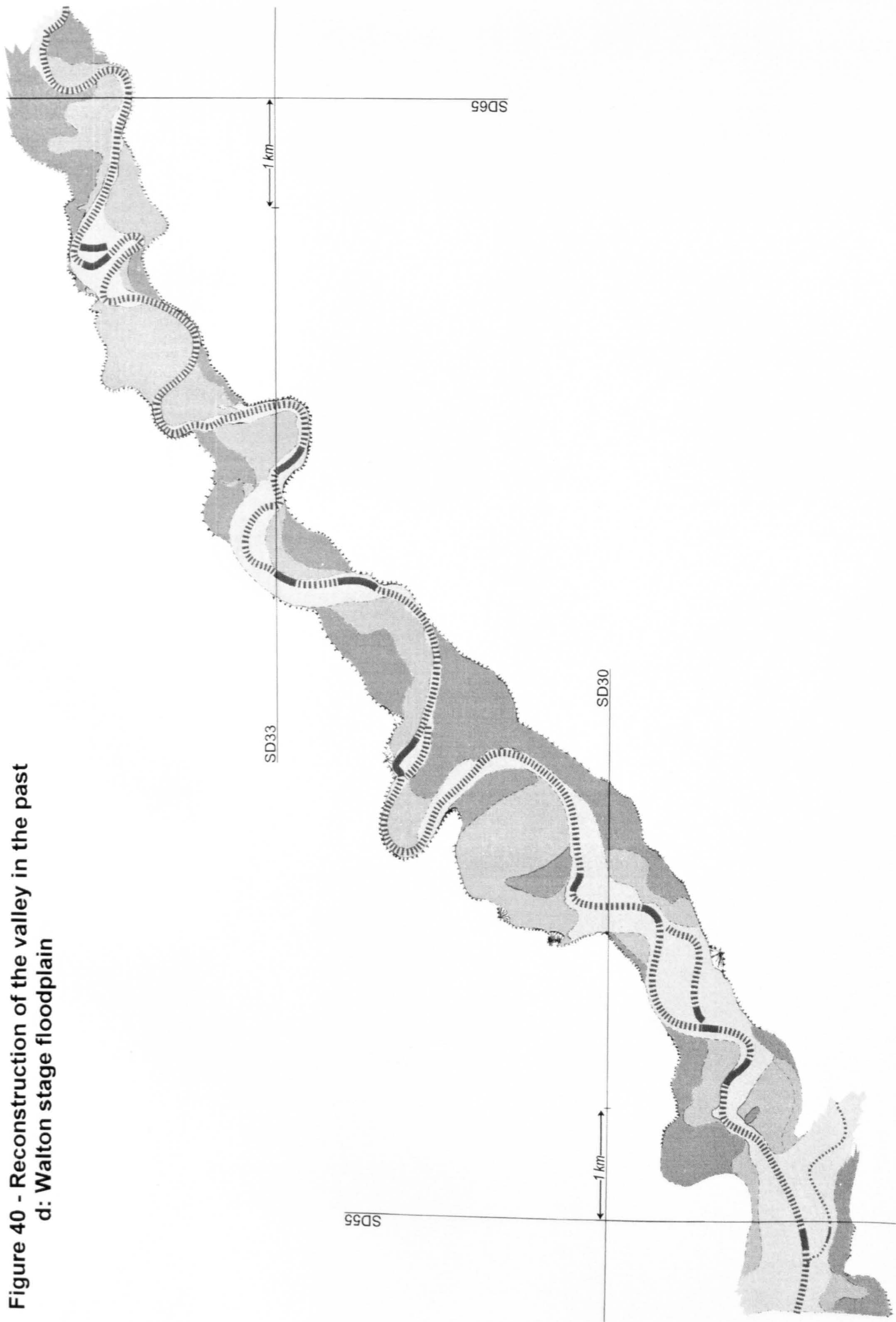


Figure 40 - Reconstruction of the valley in the past
e: Cuerdale stage floodplain

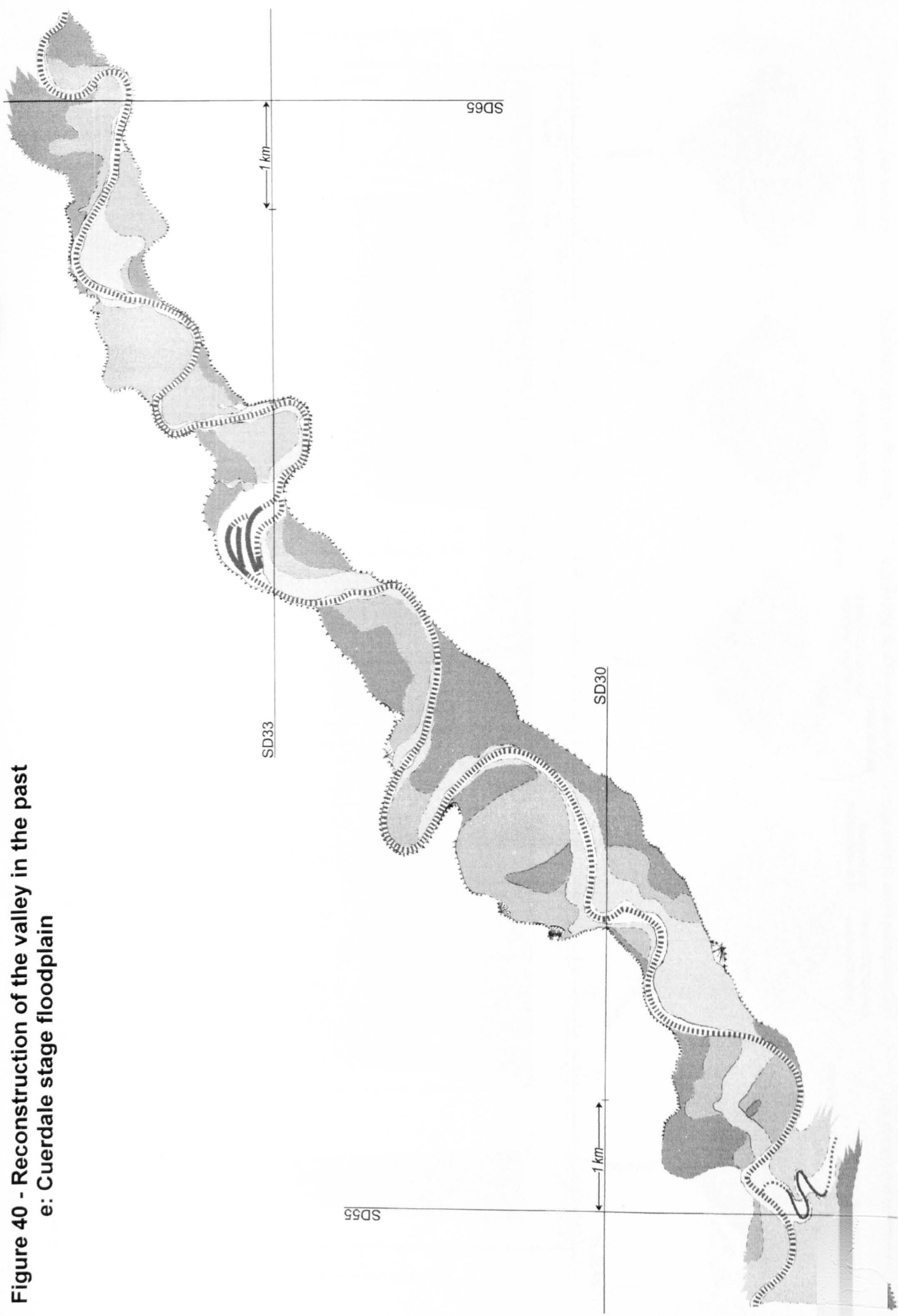
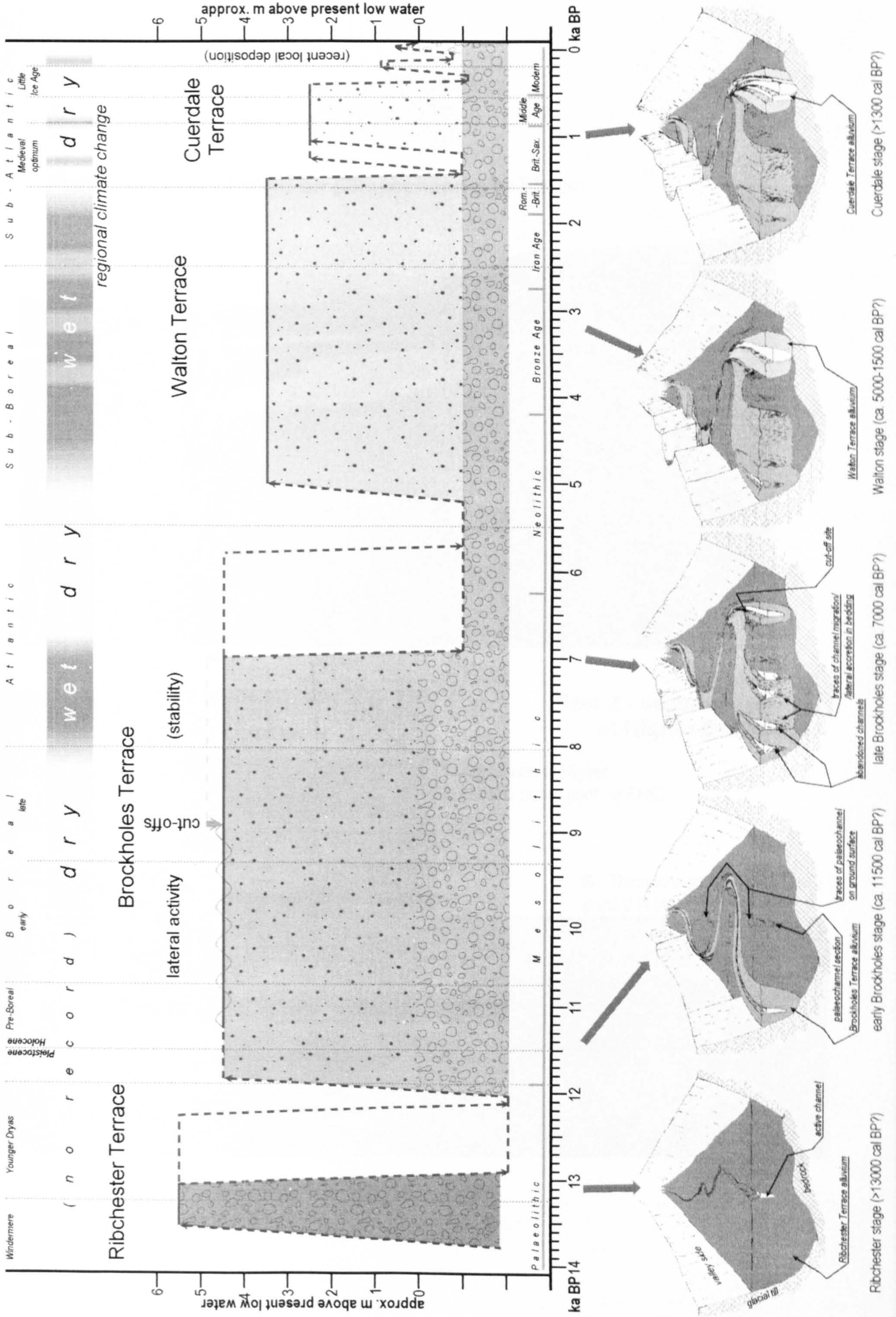


Figure 41 - timeline of events



Ribchester stage (>13000 cal BP?)

early Brockholes stage (ca. 11500 cal BP?)

late Brockholes stage (ca. 7000 cal BP?)

Walton stage (ca. 5000-1500 cal BP?)

Cuerdale stage (>1300 cal BP?)

Plate 1 - seasonal pond on palaeochannel at Elston

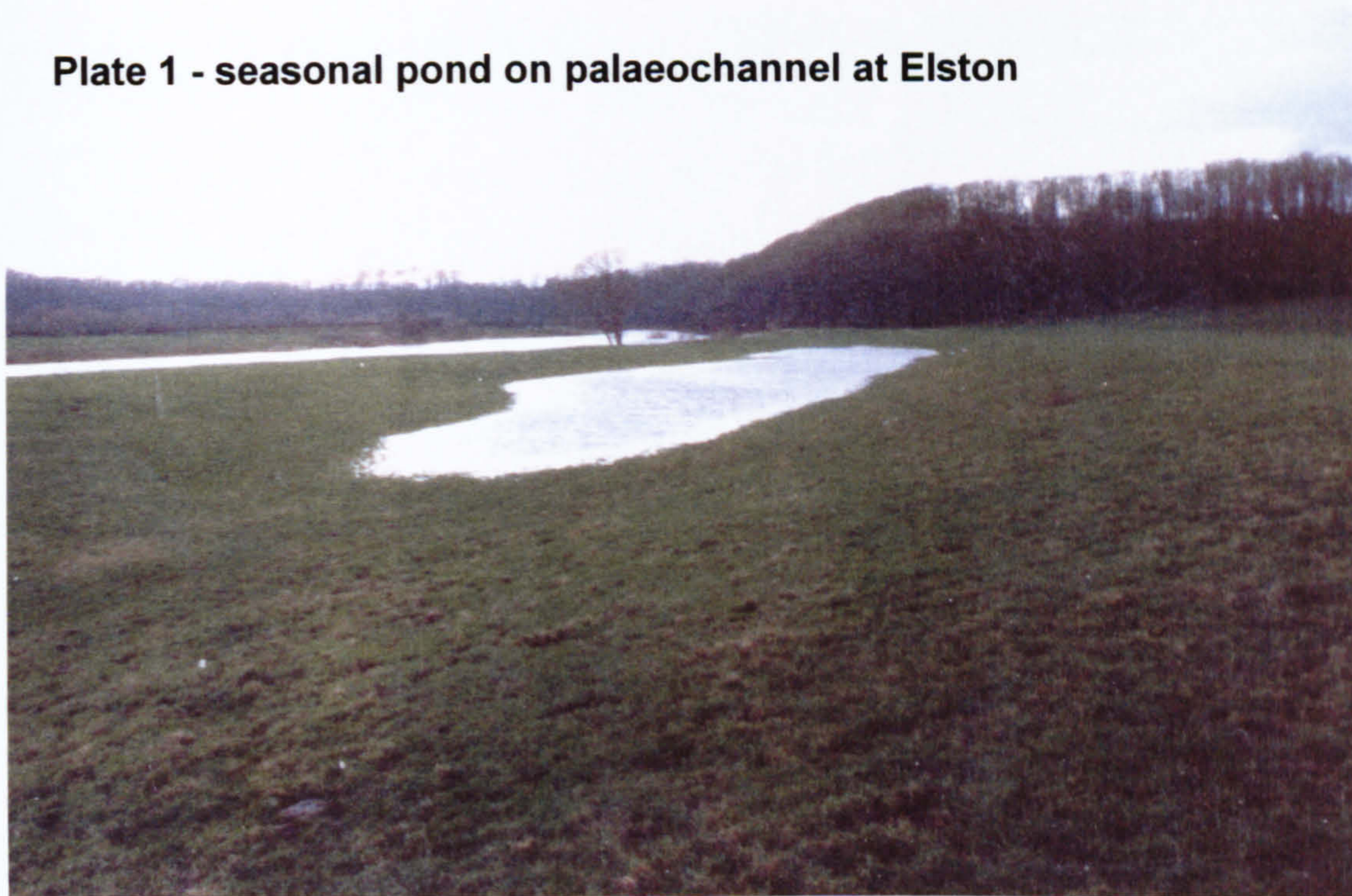
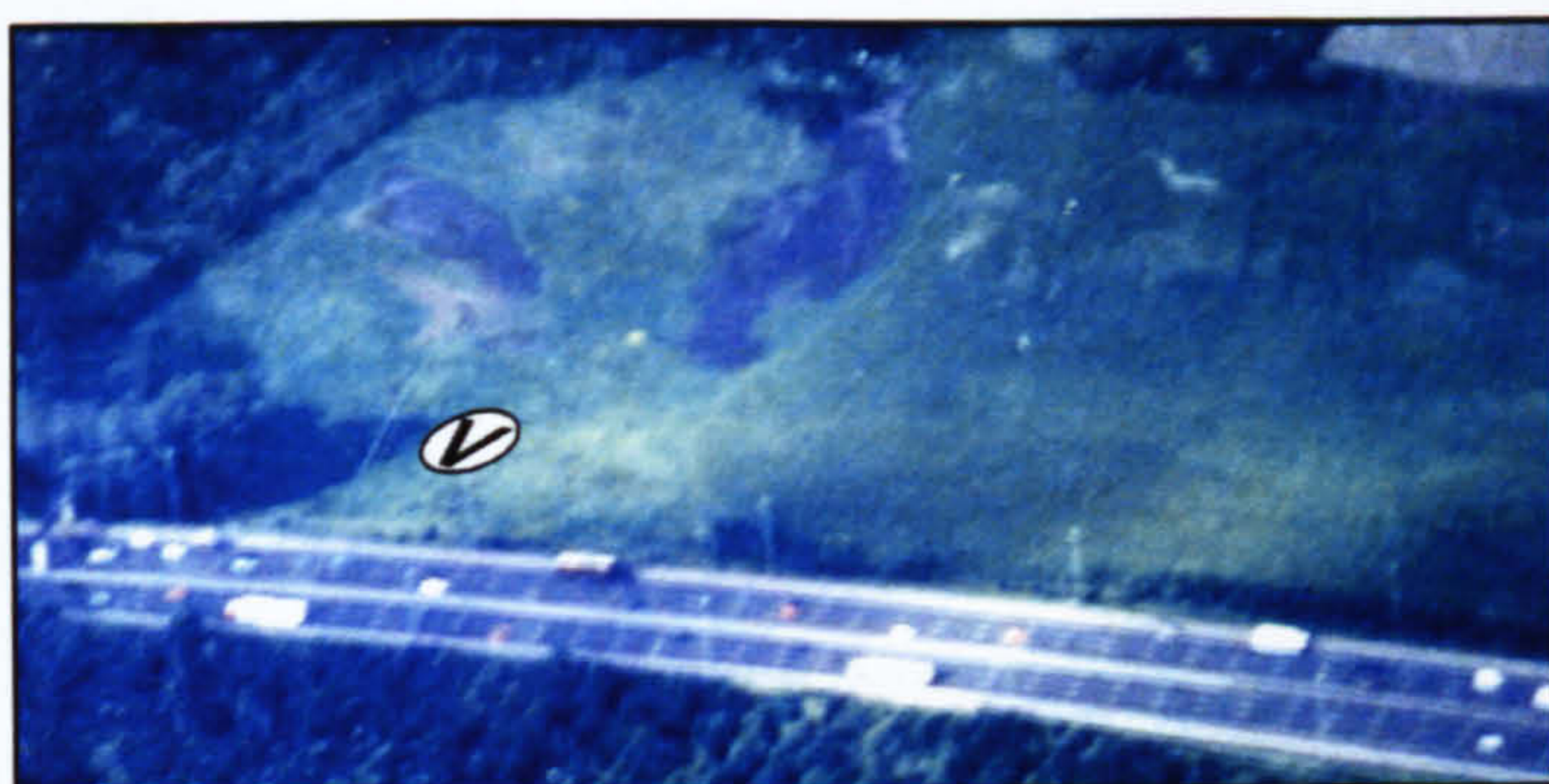


Plate 2 - seasonal ponds at Higher Brockholes



A - Aerial view of Higher Brockholes ponds (looking ENE)

B - The ponds as seen from about point V in (A), at ground level.



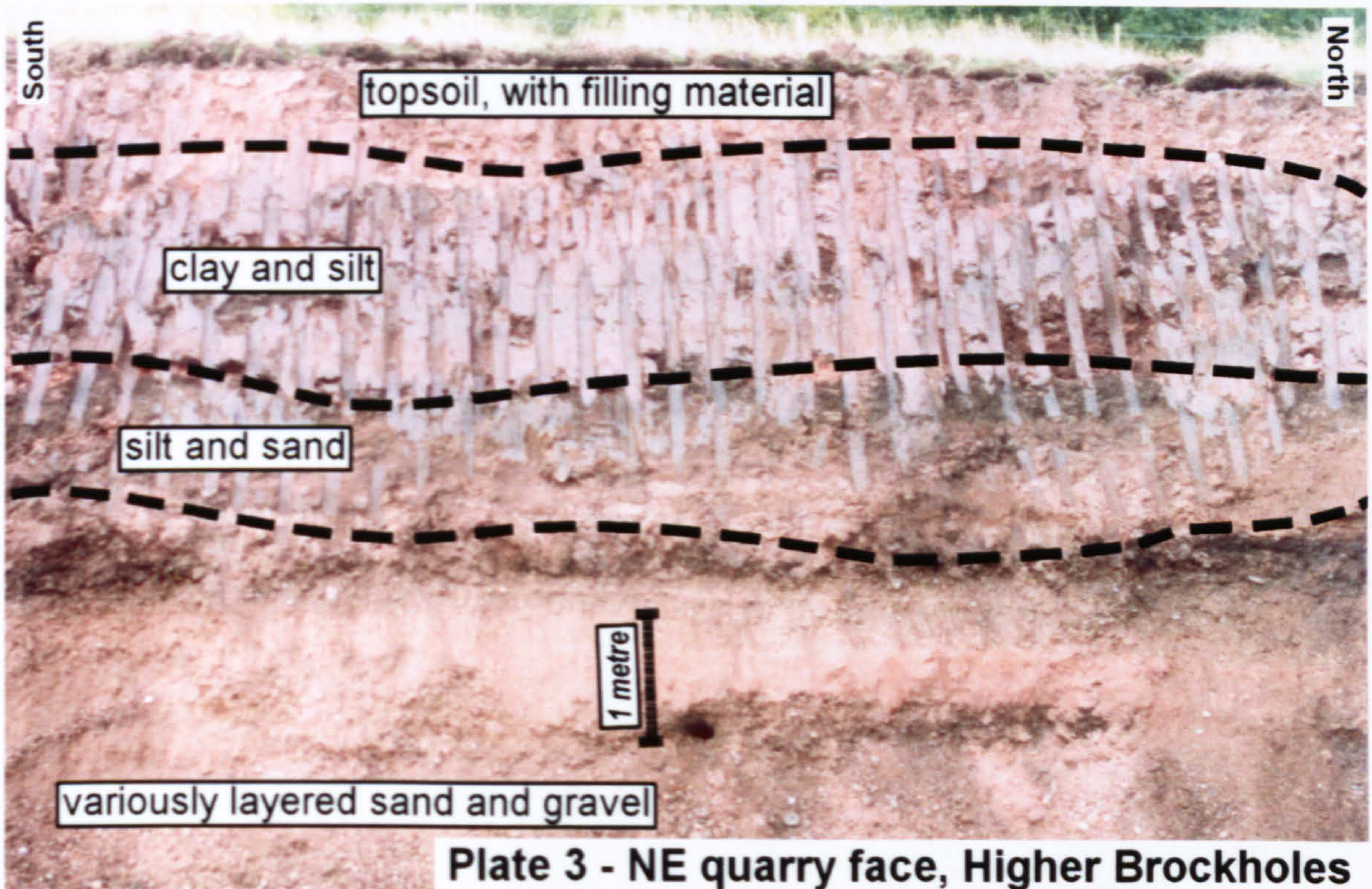


Plate 3 - NE quarry face, Higher Brockholes



Plate 4 - SW quarry face, Higher Brockholes

Plate 5 - buried ditch section at Higher Brockholes

- 1 - beds of black organic peaty material
- 2 - very peaty silty sandy clay
- 3 - peat, with embedded wood branches and pieces and hard clay clasts
- 4 - artificial fill (compact sandy silt with interspersed stones)
- a - scree from bank (bedded grey sand mixed with stones)

