5. THE LANDSCAPE: A HERITAGE RESOURCE

5.1 GLACIAL HISTORY OF THE RIBBLE BASIN

5.1.1 ***Introduction:*** compared to lowland Cheshire, the Welsh Borderland and the Pennine uplands, the lowland plain of Lancashire, flanking the Ribble Valley, has attracted little recent attention from researchers with interests in Pleistocene history. This largely reflects the paucity of sediment exposure, the subdued relief and lack of well-defined landforms, and the degree of urbanisation. The adjacent Pennine uplands, in contrast, have received much attention, with research focusing on ice sources, ice-flow patterns and drumlin fields (Rose and Letzer 1977; Johnson 1985; Mitchell 1991). The mapping presented here is the result of a comprehensive re-evaluation of the geomorphology of the Lancashire plain, using LiDAR and NextMAP elevation datasets, supplemented with field mapping.

5.1.2 During the Pleistocene, the region was probably glaciated on several occasions, judging by the oxygen isotope curves that have been produced from deep marine sediments (Fig 60), which reflect variations in global ice volume, and show up to 50 cold glacial episodes during the last 2.5 million years (Shackleton *et al* 1995). The magnitude of these cold phases increases markedly during the last 1.0 million years, especially during Marine Isotope Stage (MIS) 12, known as the Anglian Glaciation and the most extensive to have affected the British Isles. Significant glacial episodes also occurred during MIS 6 and 8, the Saalian glaciations of Europe, with glacial diamicts associated with the MIS 6 glaciation identified in the English Midlands (Maddy 1999). There is little evidence for these glaciations in north-west Britain (Thomas 1999), largely because the most recent glaciation, the Devensian (MIS stages 4, 3 and 2, Fig 61), has either removed or buried much of the sediment deposited by them.

5.1.3 The Devensian cold stage spans the period 75,000 to 11,500 years ago and evidence from both marine sediments and Greenland ice cores show repeated fluctuation of temperature and ice volume throughout the period (Johnson 1985). The repeating cycles of fluctuating temperature are called Bond cycles and last between 15,000 and 10,000 years (Fig 62), with the colder phases associated with bands of ice-rafted debris in marine sediment profiles produced by increased discharge of icebergs into the North Atlantic. These iceberg discharge episodes are called Heinrich (H) events (Fig 62). Recent work (Bowen *et al* 2002), suggests that a highly mobile and climatically sensitive ice sheet existed in the British Isles throughout much of the Devensian, with an early glacial maximum position reached in Heinrich event H4 before 38,000 years ago, and a Late Devensian maximum limit in H2 around *c* 24,000 years ago (Fig 61). The H2 episode was followed by extensive deglaciation and then a rapid advance or surge to the H1 limit *c* 17,000 years ago, at which time the ice front connected eastern Northern Ireland, the Isle of Man and Cumbria (Fig 62) (Thomas *et al* 2006). The significance of this history is that the glacial landforms and sediments of lowland Lancashire and the Ribble basin almost certainly reflect glacial processes during advance to H2, re-advance during H1 and subsequent retreat.

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5.1.4 In north-west England, ice radiated out from centres in Scotland, the Lake District and the northern Pennines to coalesce and move southwards. The Irish Sea Ice-stream (ISI), from source areas in Scotland and the Lake District, moved on-land and southwards through the Cheshire and Shropshire lowlands, reaching maximum limits near Wolverhampton (Fig 63). Ice cover and penetration was extensive in the northern Pennines, but ceased at Burnley, south of which the Pennine hills formed a significant ice barrier and were as a result largely ice-free (Crofts 2005). During the latter stages of the Devensian, as the ice-sheets reduced in extent, local ice source areas become increasingly important, moderating ice-streams within the main British and Irish Ice-sheet (BIS). The Ribble area was potentially affected by three significant ice-streams: first, an eastern Irish Sea Ice-stream (ISI) that crossed lowland south Lancashire, Cheshire and southwards towards Shropshire; second, a south Lake District Ice-stream (SLDI), radiating south out of the Lake District and passing across lowland Lancashire; and a third that radiated off the northern Pennines ice-divide southwards and then bifurcated eastwards down Wharfedale and Airedale and south-westwards down Ribblesdale (Fig 63). The division of the south Pennine Ice-stream (SPIS) into strands feeding the Ribble and Aire has contributed to the complexity of ice-flow indications shown by the morphometry of the drumlin field in the Craven lowlands around Skipton (Rose and Letzer 1977; Johnson 1985).

5.1.5 The earliest description and interpretation of the Pleistocene deposits of lowland Lancashire were undertaken in the late nineteenth century by Binney (1852) and De Rance (1875; 1877a), who utilised the, at the time, excellent coastal exposure at and north of Blackpool (Fig 64). The investigations of De Rance (1877a) are summarised with full illustrations by Wilson and Evans (1990), and provide considerable detail on the composition of the Kirkham end moraine complex (Gresswell 1967a), which stretches in a broad arc from Preston to the coast at Blackpool (Fig 65). Wilson and Evans (1990) and Aitkenhead *et al* (1992) provide further detail of the stratigraphy of the Kirkham moraine from borehole evidence along the M55 and M6 motorways (Figs 66, 67). Considerable care must be taken in correlating glacigenic units because growing numbers of studies (*cf* Thomas *et al* 2004; Thomas and Chiverrell 2006) show that, during retreat from H2 limits, the margins of the ISI were highly dynamic and the retreat was punctuated by minor re-advance and snout oscillation. This tends to produce a complex stratigraphy and geomorphology, often with a basal lodgement till, lain down under the ice possibly during the main advance (H2), but overlain by complicated sequences of glaciofluvial outwash sands and gravels, upper glacial diamicts produced by minor re-advance or snout oscillation, and other lithologies including glaciolacustrine muds. Often these sequences are accompanied by repeated ice-marginal moraine systems, separated by inter-morainic sandur troughs or fans generated by minor marginal oscillation during retreat.

5.1.6 Binney (1852) and De Rance (1877a) devised a tripartite scheme (Fig 64) for the glacial deposits of the Blackpool area. Although currently unfashionable, the scheme is a useful summary of the overall sequence, but it does not capture the complexity implicit in the probable history of ice retreat. ‘The Lower Boulder Clay’, hereafter the Lower Diamict, occurs at the base of the sequence overlying the bedrock which lies up to some 20-30m below OD. Lithologically, this lower diamict is composed of materials originating from the Lake District for the most part, with occasional chalk flints and Jurassic erratics. Overlying the lower diamict is a sequence of sands and gravels ('The Middle Sands' of De Rance (1877a)), varying in thickness by up to 25m. Sand tends to be considerably more dominant than gravel, although this balance varies at a local scale. These sands and gravels are glaciofluvial deposits lain down in a pro-glacial setting, probably during retreat. They are overlain by 'the Upper Boulder Clay', hereafter termed Upper Diamict, which varies spatially both in terms of thickness and inter-digitation with glaciofluvial sands and gravels. The broad lower diamict - sands - upper diamict sequence occurs widely across the region and has been interpreted in varying ways. Binney (1852) and De Rance (1877b) viewed the lower and upper diamicts as being lain down by floating sea ice during two cold episodes, with the sands reflecting a marine transgression and deeper waters. Tiddeman (1872), however, devised the concept of a terrestrial icesheet and argued that the two diamicts represented two separate ice advances, a view subsequently supported by later workers. In the 1980s, however, this consensus was challenged by Eyles and McCabe (1989), who argued that during the Last Glacial Maximum (LGM) ice advanced down the Irish Sea basin when the floor was isostatically depressed. During subsequent deglaciation, re-flooding of the depressed basin to relative sea levels as high as 100m OD triggered rapid drawdown and ice-sheet collapse. Consequently, most of the glacigenic sediment deposited below this height was reinterpreted as glaciomarine, including those around the Lancashire and Lake District coasts. Most subsequent work around the basin (Scourse *et al* 1991; McCarroll 1995; 2005) has rejected this model and a consensus view again sees the deposits as principally of terrestrial origin.

5.1.7 Sedimentary and geomorphic evidences of the last deglaciation are characterised by widespread evidence of ice-marginal oscillation and minor re-advance. Implicit in understanding the depositional environments, stratigraphy, and geomorphology associated with deglaciation is the recognition of re-advance. The geomorphology, sediment exposure and borehole records from the Ribble area shed new light on the glacial history of the region and in particular the sequence of environmental changes during deglaciation from the H2 maximum.

5.1.8 ***The Glacial Geomorphology and Geology of the Ribble Valley:*** the Fylde lowlands and Ribble Valley contain a broad suite of landforms and sediments that were formed largely by sub- and pro-glacial processes (Fig 65). Large areas of the lowlands, and the marked topographic bench between 50m and 75m OD in the Lower Ribble Valley, are of low relief, and form a relatively featureless subglacial diamict plain, formed by basal deposition under relatively thick ice conditions when the ice margin was some distance south of the region. The main subglacial landforms are the swarms of drumlins (*Section 3.11.24*) occurring on the interfluve between the Ribble and the head of Airedale, between Hellifield and Skipton, and in lowland Lancashire flanking the River Wyre south of Fleetwood (Fig 65). The orientation of drumlins in the Hellifield-Skipton cluster indicates two directions of ice movement: south-eastwards down the Ribble Valley and east and south-east into Airedale. The orientation of the drumlin field south of Fleetwood confirms the expected north to south ice-flow direction. Relatively little exposure has been seen but Wilson and Evans (1990) describe a section near the mouth of the Wyre that comprised glacial diamict containing an erratic suite of Lake District-derived lithologies. Other exposed sites, together with borehole evidence (see Wilson and Evans 1990 for further details) (Fig 66), reveal complicated sequences of diamict, and sands and gravels, within some of the drumlin forms. The only other subglacial landform type within the region is a series of esker ridges that include those north of Garstang near the M6 motorway (Fig 65) and the ridges that diversify the 150-80m OD bench on the Ribble and Hodder north of Clitheroe (Fig 68). These ridges have a relief of 25-19m above an uneven plain or bench that limited exposure suggests is composed of stiff clay-rich diamict and stiff laminated lacustrine clays. The ridges themselves are better drained than the surrounding plain, and very limited exposure and animal burrows show they are composed of rounded gravels, which is suggestive of fluvial processes. The morphology and apparent composition are suggestive of eskers. Three or four kilometres to the west, Aitkenhead *et al* (1992) identified a series of ridges, on the north flanks of the Ribble intermittently between the Hodder confluence and Longridge, also as esker/kame mounds. The latter group of landforms includes features that display a fairly conclusive delta fore-set sequence in a former gravel pit at Hurst Green (Fig 68).

5.1.9 The most substantial ice-marginal landforms in the region are the extensive array of elongated low ridges that extend from the foothills of the Bowland Fells east of Preston to the coast north of Blackpool. These ridges, collectively termed the Kirkham End Moraine by Gresswell (1967a), was remapped during this project and comprise a sequence of parallel ridge forms with an amplitude of relief of 15-35m extending over some 10km north to south (Fig 69). The ridges are diversified by numerous depressions and water-filled basins identified as kettleholes (Wilson and Evans 1990), formed by disintegration and melt of marginal dead-ice. The ridges are often separated by narrow, flat-floored channels, sometimes pitted with small kettleholes, running parallel to moraine crests and formed by deposition in marginal sandur troughs constrained by the moraine ridges. Other, larger channel systems, such as the Skippool Channel (Wilson and Evans 1990), cut right through the moraine complex and represent fixed-position drainage outlets from the retreating margin of the icesheet.

5.1.10 Unfortunately, the exposures described by De Rance (1877a) are no longer visible owing to engineering works to protect the coastline around Blackpool. The De Rance section drawings (Fig 64), redrawn from Wilson and Evans (1990), however, match some of the critical indicators of repeated re-advance defined by Thomas and Chiverrell (forthcoming), which were:

1. Unconformities with breaks in sedimentation, incision or erosion;
2. Large-scale deformation in the underlying sediments;
3. Down-ice termination of subglacial diamict at the location of the ice-margin;
4. Down-ice passage across the ice-margin from subglacial to pro-glacial facies, usually into pro-glacial upper fan sandur sediments, ice-front alluvial fans, debris flows, or ice-contact lacustrine sediments;
5. Upward coarsening from distal to proximal pro-glacial facies as a response to increased proximity to the re-advancing ice-margin;

6. The occurrence of large moraine structures or ridges providing there is supporting stratigraphic evidence;

7. The recognition of packages of repeating sequences of sediment-landform assemblage in a down-ice direction.

5.1.11 Obviously, there are large moraine ridges present throughout the Kirkham complex meeting criterion 6. However, supporting stratigraphic evidence is limited to descriptions of the coastal sections at Blackpool (Fig 64), the M55 borehole sequence (Wilson and Evans 1990; Aitkenhead *et al* 1992), which for part of its length is oblique to the strike of the moraine ridge crests and so shows an up-ice sequence (Fig 67), and the north/south M6 boreholes, also an oblique sequence.

5.1.12 The borehole and section evidence (Figs 64, 66) show that the altitude of the top of the basal diamict undulates in a manner similar to that produced by subglacial deformation by ice over-ride in many other locations around the Irish Sea basin. There is insufficient exposure and detail is typically lacking from borehole records to assess the other sedimentological criteria for re-advance. The lower diamict is not currently exposed and it is impossible to discern from the borehole sequence the nature and extent of deformation. The glaciofluvial sands and gravels appear to thicken in the inter-moraine areas (Figs 64, 66). In terms of a depositional model, the sequence appears to be one of the basal diamict deposited as a lodgement till during ice advance, followed by ice retreat and coincident deposition of outwash sands and gravel. The series of moraine ridges (Fig 69) signifies that ice retreat was punctuated by oscillations of the ice-margin. Between the moraine ridges, substantial ice front sandur reflect the major outwash channels, for example the Skippool Channel (Fig 69), and perhaps produced the thicker sequence of sands beneath the M55/A585 interchange (Figs 66, 67).

5.1.13 Towards the eastern end of the M55 and southern end of the M6 borehole sequences, there is evidence for a further depositional environment with thick, *c* 15m, sequence of glaciolacustrine laminated clays (Figs 66, 67). These deposits thin-out and disappear to the west and have been over-ridden by the upper diamict. The diamict appear to overlie and inter-digitate with the glaciolacustrine muds (Fig 67), and so both must pre-date or be contemporaneous with the marginal oscillations associated with formation of the Kirkham moraine.

5.1.14 Evidence for glaciolacustrine environments are widespread further upstream within the Lower Ribble and Hodder, with stiff laminated clays present in boreholes and exposures in the Vale of Chipping and the Hodder and Langden Brook valleys (Fig 65). During deglaciation, it appears that the Bowland Fells became free of ice relatively early, perhaps not unexpected given the limited altitude and source areas as the BIS down-wasted and returned to local ice-stream control. Borehole investigations also have revealed over 9m of laminated lacustrine clays in the upper Hodder, near Burholme Bridge (Fig 65; Aitkenhead *et al* 1992). Boreholes sunk, in this study, to investigate the fluvial gravels of the Lower Ribble system, have revealed a sequence of thick laminated clays that were not penetrated near the aqueduct at Whalley in the lower Calder. Laminated clays also underlie the flat ground surrounding the esker ridges north of Clitheroe (Fig 68). In summary, within the Lower Ribble Valley evidence for

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lacustrine environments extends from just east of Preston, upstream in the Lower Ribble and Calder, in the Vale of Chipping, and throughout much of the Hodder at least upstream as far as Langden Brook. This lake may have varied considerably both in size and water depth throughout its existence, but essentially the key controlling feature was the damming mechanism across the Lower Ribble Valley east of Preston and the western edge of the Vale of Chipping (Fig 65). Throughout its existence, the lake would have received ice- and snow-meltwaters from the Bowland Fells and from the retreating Ribble glacier.

5.1.15 The evidence for an extensive ice-dammed lake also provides a different context for the interpretation of the extensive sand and gravel deposits on the north flanks of the Ribble intermittently between the Hodder confluence and Longridge (Fig 65). These features have been interpreted as esker/kame mounds (Aitkenhead *et al* 1992), and the higher of these features probably are kames formed against the margins of the glacier. However, the delta fore-set sequence displayed in a former gravel pit at Hurst Green suggests a different depositional setting, and lends further credence to identification of a substantial water body in the Lower Ribble during deglaciation (Fig 68). The fore-set sequence occurs at altitudes up to 65m OD and is locally buried by bottom-set laminated clays, which shows that the water levels were dynamic and highly variable, a characteristic of ice-dammed lakes. The limited exposure available suggests the presence of an ice-marginal delta, and brings into question the nature of the deposits that form this bench at 150-80m OD in the Lower Ribble. It is also possible that the ridges north of Clitheroe are a mixture of pro-glacial sub-aqueous fan and subglacial esker forms produced as the margin of the Ribble glacier retreated eastwards (Fig 68).

5.1.16 Further up the Ribble, between Hellifield and Settle (Fig 65), the extensive flat low-lying floodbasin, currently occupied by a tortuously meandering/anastomosing Ribble, is also underlain by thick sequences of laminated clays containing drop-stones, which reflect the presence of a lake at *c* 130m OD in the Upper Ribble. This pro-glacial lake probably reflects a local overdeepening of the valley floor, but may also have been dammed by moraines and the Ribble/Aire drumlin field, with the current Ribble channel excavated later during Late-Glacial times (Dean 1950).

5.1.17 ***The Pleistocene Evolution of the Ribble Valley:*** the earliest evidence for Pleistocene environments in the region is the basal diamict, a lodgement till smeared over the bedrock of the Lower Ribble. Borehole evidence shows the rockhead is some 20-25m below OD and the Pleistocene sediment fill in places is over 50-60m in thickness. This lodgement till was probably emplaced during the advance of the BIS to limits in the English Midlands *c* 24,000 years ago (Fig 70). Much of the glacial geomorphic and sedimentary evidence relates to the sequence of environmental changes on retreat of the ice margins from that maximal limit. The following palaeogeographical reconstructions attempt to put this evidence base into context and present a deglacial environmental history.

5.1.18 That the Lower Ribble Valley, Vale of Chipping, much of the Hodder and Calder comprised a large ice-dammed lake during deglaciation is beyond question; the implications of this are that the Ribble glacier was in a state of retreat earlier than the ice-streams issuing from the Lake District and Scotland

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(Fig 71). This may reflect the comparatively low altitude and small ice source area of the southern section of the Pennine ice-field north of Settle (Fig 63). There is no information about the timing of this sequence of events, owing to the failure of OSL dating of the Hurst Green deltaic sediments (*Section 3.7.17*). Given that glaciolacustrine deposits appear to underlie much of the Lower Ribble and up the Hodder to Burholme Bridge (Fig 65), it does appear that the Bowland Fells had become ice free and the Ribble glacier was substantially in retreat whilst the eastern ISI and the SLDI may still have been in comparatively advanced positions, at least as far south as the rock-ridge that extends west to Skelmersdale (Fig 71). Ice-marginal positions for the Ribble glacier during retreat eastwards expanding this ice-dammed lake are provided by the deltaic/glaciofluvial sands and gravels exposed between Hurst Green and Longridge. The esker ridges north of Clitheroe may also be a mixture of pro-glacial sub-aqueous fan and subglacial esker lain down as the margin of a Ribble glacier retreated eastwards (Fig 68). High level (90-120m OD) glaciofluvial gravels on either side of the Calder 2-3km upstream of Whalley are also candidate deltaic deposits. Eventually retreat northwards of the eastern ISI and SLDI ice-front would have allowed drainage of this lake system and perhaps encouraged some of the incision producing the reach that the contemporary Ribble occupies.

5.1.19 The Kirkham moraine complex is an extensive feature of some magnitude, with no obvious parallels down-ice until the moraine ridges of south Cheshire are reached at Whitchurch (Fig 63), and little else in the up-ice direction until the Lake District. The geomorphology and limited stratigraphic data suggest the Kirkham moraines were the product of repeated ice-marginal oscillation, with tills over-riding the glaciolacustrine deposits east of Preston. The probable subglacial deformation in the lower diamict, the number of moraine ridges, and stratigraphy tentatively identified from the borehole and previously described section exposures (De Rance 1877b), can all be interpreted as reflecting a re-advance episode. Two palaeogeographical models are put forward here to explain the sequence of events, although they are somewhat tenuous and end members of a spectrum of possible stories.

5.1.20 The first palaeogeographical model (Fig 72) has the SLDI at or near the Kirkham moraine complex during the existence of the Ribble ice-dammed lake, with the EISI, further advanced as far south as the rock-ridge at Skelmersdale, providing the damming mechanism. In this context, the curvature of the Kirkham moraine and the north/south aligned moraine ridge to the south of the Ribble extending towards Skelmersdale mark the join between two ice-streams. As such, the Kirkham moraine is at least, for part of its length, an example of an inter ice-stream moraine complex, as is the continuation of the moraine ridge form south of the Ribble towards Skelmersdale. The diamict drape over glaciolacustrine deposits east of Preston can then be explained as debris flows off the ice margin over bottom-set laminated clays. It also would explain some of the inter-digitation between glaciolacustrine clays and sand and gravel units (Figs 66, 67), with outwash sands and gravels from the nearby ice margin impinging upon the lake.

5.1.21 The second model (Fig 73) entails the SLDI, after retreat from an ice-damming position across the Lower Ribble (Fig 71), advancing rapidly in a surge also

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responsible for subglacial deformation and the production of the drumlins south of Fleetwood and between Kendal and Lancaster. A corollary of this rapid ice advance could be the advances to Heinrich event 1 (H1) limits identified in north-east Ireland and on the Isle of Man (Bowen *et al* 2002). This ice-sheet geometry would require more rapid retreat of a marine-based eastern ISI than the terrestrial SLDI. Glaciers and ice-streams typically retreat more rapidly with a water-contact margin. This theory is largely underpinned by an attempt to link the retreat sequence to major ice-advance episodes, which is not necessary because the pulsed process of ice margin retreat is more than capable of producing substantial recessional moraine complexes. However, the curvature of the Kirkham moraine does encourage the identification of the SLDI as the dominant ice source area. Unfortunately, much of the geomorphology required to assess the westward continuation of ice-marginal moraine limits is currently on the seabed of the Irish Sea.

5.1.22 After the ice-marginal oscillations associated with the production of the Kirkham moraine, the BIS appears to have gone into terminal decline, with rapid ice wastage and marginal retreat denoting the transition to the warm conditions of the late-Glacial interstadial, the Windermere Interstadial of Great Britain. In Lancashire, this is evidenced by the complete Windermere interstadial to Holocene stratigraphic sequences at Haweswater (Marshall *et al* 2002; Jones *et al* 2006) and in the kettleholes of the lowland Lake District, which show the region was ice-free by 15,500 years ago. During the latter stages of the deglaciation and during the climate changes associated with the colder late-Glacial stadial (Loch Lomond Stadial, *c* 12,500 to 11,500 years ago) event, the Ribble probably continued to incise and aggrade fluvial terraces within the current reach. The Ribble basin is at too low an altitude for glaciation to have occurred during the cold phases of the late-Glacial interstadial and stadial climate oscillations, but it would have experienced a colder snowmelt-affected fluvial regime prior to the ultimate warming into the Holocene, 11,500 years ago.

5.2 FLUVIAL GEOMORPHOLOGY AND SEDIMENTOLOGY

5.2.1 This section describes the results of geomorphological, sedimentological and geochronological studies aimed at elucidating the nature and timing of Post-Glacial landform development in the Ribble catchment. At the outset of this work, it was anticipated that Post-Glacial fluvial development would follow broadly the general evolutionary model outlined in *Section 2.2:* Late glacial to early Holocene landscape instability and valley filling; early to middle Holocene stability and fluvial incision; heightened fluvial dynamics due to human–induced sediment supply episodes during the later Holocene, with the potential for spatial and temporal variability on a wide range of scales. In order to understand fully the sequence of fluvial landform development, detailed mapping and sediment studies were carried out at four study reaches within the Lower Ribble, Calder, Upper Ribble, and the Hodder sub–catchments. Within each study reach, the strategy was to characterise the geomorphology of all river terraces and to ascertain the timing of channel abandonment at one or more palaeochannel site on each river terrace. For the Lower Ribble, a multi-site approach was adopted, thus allowing the investigation of within-reach differences in fluvial development. Additional hillslope alluvial fan studies were also carried out in the Upper Ribble headwaters, with the aim of improving an understanding of the timing of hillslope erosion in the catchment and characterising the coupling relationship between hillslope and fluvial-system response.

5.2.2 ***The Lower Ribble Valley:*** the surface geomorphology and sub–surface sedimentology of the Lower Ribble Valley has been studied in detail at three meander bends, located at *c* 2km intervals along a *c* 7km reach of the river upstream from the M6 motorway (Brockholes, Lower House Farm and Osbaldeston Hall). Figure 74 provides an overview of the river terrace surfaces and their surface palaeochannels, mapped by DEM analysis and field survey. This also shows the height–range diagram, demonstrating the downstream correlation between mapped terrace surfaces. The terrace sequence consists of four main surfaces (T1 highest to T4 lowest), together with more localised deposits representing the modern floodplain (T5); meandering palaeochannels are well-defined and occur on the surfaces of Terraces T2 to T5. The subsequent sections present the geomorphology, sedimentological investigations and geochronological control obtained for each of the three detailed study reaches.

5.2.3 ***Brockholes:*** this site is dominated by deposits relating to Lower Ribble Terrace T2, but much of the geomorphology and sedimentological evidence has been obliterated by sand and gravel extraction. The geomorphological map for the site (Fig 75), discerned from oblique aerial photography and detailed survey undertaken in the 1980s by Tilcon Ltd prior to mineral extraction at Higher Brockholes, highlights an evolutionary sequence of surface palaeochannels, representing the north-east to south-west scroll-bar mode of lateral channel migration, leading to the development of a major, fully preserved, meander loop. Inner parts of the scroll-bar may have included areas of the T1 river terrace, but it has not been possible to verify this, given the subsequent 25 years of mineral extraction. Stratigraphic investigations were undertaken by Chiti (2004), as part of his PhD research at the University of Stirling, and by Gearey and Tetlow (2006) as part of site investigations conducted by Birmingham Archaeo–Environmental for a site of proposed sand and gravel extraction at Lower Brockholes to the west of the M6 motorway.

5.2.4 The location of the study sites is shown on Figure 75; Chiti's sites (ie C1 to C4) relate to the lateral migration of the scroll-bar system and to the later development of the main meander loop, while Gearey and Tetlow's sites also encompass the main meander loop (ie site G1) but also include a site (ie G2) relating to a later channel stage. In total, 16 radiocarbon dates have been obtained from analyses carried out by NERC Radiocarbon Laboratory (sites C1 to C4) and Beta Analytic (sites G1 and G2 (Table 21). These dates (Fig 76) constrain the timing of successive channel abandonment events at sites C4, C2/3 and C1, and upper fill dates representing the late stage of sediment filling within the main palaeo-meander loop.

Region	Location and nature of radiocarbon dated sites	Dated materials	^{14}C Years BP	Calibrated Years
Higher	Suite of radiocarbon dates obtained by Bernado Chiti (2004)			
	East of the M6. Ribble Terrace 2			
	Main palaeochannel loop: C1 Basal sand	Organic clay	8043±59 (AA-49826)	7172-6709 cal BC
	Main palaeochannel loop: C1 Basal flood silt/clay	Plant remains in silt/clay	7591±60 (AA-49827)	6593-6271 cal BC
	Main palaeochannel loop: C1 Top of basal silt/clay (A)	Plant remains in silt/clay	6068±59 (AA-49829)	5208-4837 cal BC
	Main palaeochannel loop: C1 Top of basal silt/clay (B)	Plant remains in silt/clay	8361±66 (AA-49828)	7572-7193 cal BC
	Main palaeochannel loop: C1 Base of peat (A)	Peat	5104±54 (AA-49830)	4037-3773 cal BC
	Main palaeochannel loop: C1 Base of peat (B)	Peat	5046±55 (AA-49831)	3960-3711 cal BC
	Main palaeochannel loop: C1 Top of peat	Peat	4067±51 (AA-49832)	2864-2473 cal BC
	Main palaeochannel loop: C1 Alluvium above peat	Organic layer in alluvium	4228±58 (AA-49833)	3002-2621 cal BC
	1st scroll-bar palaeochannel: C2 mid palaeochannel fill	Peaty layer	9163±40 (AA-48975)	8531-8286 cal BC
	2nd scroll-bar palaeochannel: C4 base palaeochannel fill	Leaf-rich peat	7819±58 (AA-48973)	6982-6481 cal BC
	2nd scroll-bar palaeochannel: C4 mid palaeochannel fill	Leaf-rich peat	6149±70 (AA-48974)	5299-4912 cal BC
	2nd scroll-bar palaeochannel: C4 mid palaeochannel fill	Leaf + wood detritus	6522±53 (AA-48972)	5611-5371 cal BC
	Sunderland Hall			
	Plant detritus towards base of alluvium	Organic layer in alluvium	6885±44 (AA-48976)	5878-5673 cal BC
Lower	West of the M6. Ribble Terrace 2 (Gearey and Tetlow 2006)			
	Main palaeochannel loop northern edge (G1) Top peat	AMS wood	4430±40 (BETA-213393)	3331-2922 cal BC
	Main palaeochannel loop northern edge (G1) Base peat	Radiometric peat (humic)	4070±60 (BETA-213394)	2867-2473 cal BC
	Main palaeochannel loop closest to river (G2) Top peat	Radiometric peat (humic)	2500±50 BETA-213392)	791-416 cal BC
	Main palaeochannel loop closest to river (G2) Base peat	Radiometric wood (humic)	5330±70 (BETA-213391)	4331-3994 cal BC

Table 21: Radiocarbon dates for the Brockholes meander, Lower Ribble (Chiti 2004; Gearey and Tetlow 2006)

5.2.5 The stratigraphy at site C1, on the main palaeo-meander loop, consists of basal channel gravels and sands overlain by *c* 3m of flood-laminated silty-clay channel fill deposits, within which has developed a well-humified, wood- and leaf-rich peat horizon (Fig 77). A similar sequence of sediments was also recorded at sites G1 and G2, also within the main palaeo-meander and subsequent inner meander bend scroll-bar channel fills respectively. The stratigraphy at sites C2 to C4, located on the earlier scroll-bar channels, consists of basal channel gravels overlain by bed/bar form silty-sands that fine up to a silty-clay fill; once again, a thin peat is intercalated within the clayey-silt fill (Fig 78).

5.2.6 The geochronology relating to the sequence at site C1 is established by the following radiocarbon dates: a date of 7172-6709 cal BC (8043±59 BP; AA-49826); from organic-rich silty-clays in sands near the base of the palaeochannel fill, 7572-7193 cal BC (8361±66 BP; AA-49828) and 6593-6271 cal BC (7591±60 BP; AA-49827), from organic-rich layered silty-clays at the base of the channel fill; a date of 5208-4837 cal BC (6068±59 BP; AA-49829) from the middle of the same unit; two statistically consistent measurements ((T'=0.6; ν=1; T'(5%)=3.8; Ward and Wilson 1978; 3960-3711 cal BC (5046±55 BP; AA-49831) and 4037-3773 cal BC (5104±54 BP; AA-49830), come from the base of the overlying peat, with a further date from the top of the peat of 2864-2473 cal BC (4067±51 BP; AA-49832). A further, slightly older, date was obtained from overlying flood-laminated silty-clay alluvium 3002-2621 cal BC (4228±58 BP; AA-49833). At G1, the organic peat unit above the palaeochannel gravel/fill contact provided bottom and top age-reversed mid–Holocene dates of 2867-2473 cal BC (4070±60 BP; BETA-213394; basal age) and 3331-2922 cal BC (4430±40 BP; BETA-213393; upper age). As Beta-213393 was a piece of unidentified wood it only provides a *terminus post quem* for the top of the peat unit as it could be affected by an unknown age-at-depth offset. At site G2, the sediment geochronology relating to the youngest channel set within the main palaeo-meander bend was established, with a date of obtained from the base of the peat unit above the channel gravel/fill, 4331-3994 cal BC (5330±70 BP; BETA-213391) and a date from the top of the peat of 791-416 cal BC (2500±50 BP; BETA-213392).

5.2.7 The model (Fig 76) shows good agreement between the radiocarbon results and stratigraphy ($A_{overall}$=84.8%) and provides an estimate for the date at which the main palaeochannel appears to have been abandoned, becoming a backwater channel of shortly before 7150-6750 cal BC (8043±59 BP; AA-49826). The later inset meander bend may have been an active channel as late as 3970-3780 cal BC (combining AA-49830 and AA-49831), when an extensive peat unit formed throughout the length of the palaeo-meander loop; inundation and flooding of the terrace continued until at least 3002-2621 cal BC (4228±58 BP; AA-49833), possibly as late as 791-416 cal BC (2500±50 BP; BETA-213392).

5.2.8 The morphological sequence suggests that channel fills linked with the scroll-bar system, located on the eastern limb of the terrace (see Fig 75), should pre-date the fills associated with the main meander and youngest meander loops, as outlined for sites C1, G1 and G2. However, radiocarbon dates of 5299-4912 cal BC (6149±70 BP; AA-48974) obtained from the top, and 6982-6481 cal BC (7819±58 BP; AA-48973) from the bottom of the palaeochannel fill at site C4 (Fig 78) are similar in age to those obtained from the main loop. At site C2/3 (Fig 78), the peat intercalated within the clayey-silt fill has been dated to 8531-8286 cal BC (9163±40 BP; AA-48975), older than the basal ages obtained from the adjacent palaeochannels.

5.2.9 One of the strengths of the radiocarbon dating in this current study was the use of paired dates targeting identified plant macrofossils to secure chronologies for fluvial settings where there is a high likelihood of reworked organic materials circulating through the system. Discrepancies between dates obtained on humic acid and humin fractions and even differing macrofossils from the same horizon highlight the wisdom of this approach. It also avoids potential problems associated with dating 'heartwood', which can be 200-300 years older than living tissue in extant trees. The radiocarbon dating at Brockholes was not subject to the same rigour; however, the generally strong correspondence between the radiocarbon ages obtained from the base of the Brockholes palaeochannel fills suggests that fluvial incision below Terrace T2, and the subsequent abandonment of the T2 channels, probably occurred at some time between 7150-6750 cal BC and possibly as late as 3970-3780 cal BC. Organic-material-dominated sedimentation, fed by regular discharge from the main channel, could have persisted for some time after initial abandonment, with the

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meander loop operating as a cut-off or oxbow lake. The remaining ages suggest that Terrace T2 remained susceptible to flood inundation and overbank sedimentation until at least *c* 2820-2570 cal BC.

5.2.10 ***Lower House Farm:*** geomorphological mapping of the Lower House Farm meander identified a complete four-stage suite of main Ribble river Terraces T1 to T4, together with additional minor fragments of modern floodplain (T5) present locally along the edge of the modern channel (Fig 79). Evidence for near surface sediment-filled palaeochannels was found for all terraces except T1. Despite more subdued palaeochannel definition than at Brockholes, channel and terrace-edge plan-forms for Terraces T2-T5 suggest meandering patterns similar to the modern river. The locations of coring sites used to characterise sub–surface sediments at the Lower House Farm meander are given in Figure 79, and the core logs are provided in Figure 80. The stratigraphic sequence observed in core LH/C1/T1, taken from the highest and oldest river terrace (T1), shows a thick basal unit of stratified sands and gravelly sands, interpreted as the product of deposition within a braided river regime during cold climate (Late-Glacial stage) conditions. The sands were sampled for OSL dating, but the analyses failed due to the unsuitable properties of the sand quartz fraction for OSL dating.

5.2.11 At the Lower House Farm meander palaeochannels provided the opportunity to secure data on the rates of change within Terraces T3 and T4. Samples from three cores were dated from Terrace T3 and two from Terrace T4, with the geochronology provided by 13 radiocarbon dates(Table 22 and Fig 81). The cores (Fig 80) display fining up sequences consisting of: (1) basal channel gravels; (2) overlying normally graded sandy (proximal/overbank) flood beds; (3) iron mottled, bioturbated silty clay (backwater) flood laminations. The thickness of the flood–deposits increases from T3 to T4.

Feature	Lab code	Sample details	Materials	$\delta^{13}C$ (‰)	^{14}C date	Cal. yrs 2σ range
Terr 2	SUERC-10667	LH T2 C2 0.90-1.00m (B)	wood, *Alnus* sp	-28.3	2280±35	403-209 cal BC
Terr 2	OxA-15687	LH T2 C2 2.00-2.10m (A)	wood, *Alnus* sp	-27.7	2232±28	387-205 cal BC
Terr 2	SUERC-10648	LH T2 C2 2.00-2.10m (B)	root fragment, unidentified	-27.7	1480±35	cal AD 467-650
Terr 3	OxA-15743	LH T3 C4 2.62-2.61m (A)	wood, *Alnus/Betula* sp	-25.4	3814±34	2454-2140 cal BC
Terr 3	SUERC-10652	LH T3 C4 2.62-2.61m (B)	wood, *?Prunus* sp	-25.4	3725±35	2201-2035 cal BC
Terr 4	OxA-15882	LH T4 C5/6 0.88-0.93m (A)	soil, humic acid	-25.1	8185±45	7324-7070 cal BC
Terr 4	OxA-15689	LH T4 C5/6 4.33-4.43m (A)	wood, *Prunus spinosa*	-25.7	1739±27	cal AD 239-383
Terr 4	SUERC-10666	LH T4 C5/6 4.33-4.43m (B)	wood, *Alnus* sp	-29.8	1770±35	cal AD 135-378

Table 22: Radiocarbon dating from Lower House Farm, Lower Ribble Valley

5.2.12 The sequence at Terrace T3 was recorded within two palaeochannels (three core sequences), with palaeochannel progression, going from the topography, probably moving from north to south across the terrace. Four samples were

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submitted for dating from core LH T2 C2. The two samples (387-205 cal BC (2232±28 BP; OxA-15687) and cal AD 467-650 (1480±35 BP; SUERC-10648)) from the base of the sequence of coarse to medium sand flood laminations overlying channel gravels gave statistically inconsistent results (T'=274.8; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and thus this deposit would appear to contain material of vastly different ages. The same is also true for the samples cal AD 990-1160 (982±31 BP; OxA-16513) and 403-209 cal BC (2282±35 BP; SUERC-10667) from 0.9-1.0m, within the uppermost sandy flood deposits just below the switch to silt and clay laminations (ie the last major flood event to affect the channel) (T'=777.5; ν=1; T'(5%)=3.8; Ward and Wilson 1978). In both cases the latest two dates from LH T2 C2 provided the best estimates for the age of their deposits, of cal AD 990-1160 (982±31 BP; OxA-16513) and cal AD 530-650 (1480±35 BP; SUERC-10648). Further upstream within this palaeochannel, a single sample was submitted from core LH T2 C3, which dated to 770-400 cal BC (2462±31 BP; OxA-16357) at the top of 1.3m of flood-laminated deposits overlying channel gravels. From core LH T3 C4, two measurements of 2454-2140 cal BC (3814±34 BP; OxA-15743) and 2201-2035 cal BC (3725±35 BP; SUERC-10652) obtained on samples from the organic detritus, within a thick sandy gravel floor layer 0.40m above the underlying channel gravels, are statistically consistent (T'=3.3; ν=1; T'(5%)=3.8; Ward and Wilson 1978). Two measurements from near the top of a sequence of coarsely bedded sands dated to cal AD 710-940 (1197±30 BP; OxA-16410 (0.161-0.159m)), and cal AD 690-882 (1229±29 BP; OxA-16358; (0.17-0.162m)), provide a date for the later stages of a major flood inundation and also provide an estimated latest date at which the terrace was abandoned.

5.2.13 Cores from two parallel scroll-bar palaeochannels on Terrace T4 were dated (LH T4 C5/6 and LH T4 C7/8). The two basal samples from T4 C5/6, dated to cal AD 239-383 (1739±27 BP; OxA-15689) and cal AD 135-738 (1770±35 BP; SUERC-10666), are statistically consistent (T'=0.5; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and thus provide a date for the basal flood layer above the underlying channel gravels. The humic fraction from an organic-rich soil towards the top of a sequence of coarse to medium sand flood laminations produced a date of 7340–7060 cal BC (8185 ± 45 BP; OxA-15882). This is clearly far too early and once again highlights the problematic nature of dating AMS-sized bulk samples and of 'old carbon' reworking within a fluvial system. It suggests that radiocarbon dates should only be obtained from plant macrofossils that have been identified with some veracity. At LH T4 C7/8 in a different palaeochannel, one basal sample yielded a radiocarbon date of 767-417 cal BC (2477±31 BP; OxA-16359) and thus provides a date for the basal flood layer above the underlying channel gravels. The model shown in Fig 81a shows good agreement between the radiocarbon results and stratigraphy ($A_{overall}$=85.4%). Two measurements have been excluded from this model; OxA-15882, for the reasons outlined above, and SUERC-10648, which was an unidentified root fragment that was clearly intrusive (Table 22).

5.2.14 The model shown in Fig 81b shows the basal dates from Terraces T3 and T4 and thus allows an estimate of the date of abandonment of T3 and the start of incision of T4 (Event 3/4). The overall index of agreement in this model is poor ($A_{overall}$=4.8%) because the radiocarbon results and stratigraphy are not in agreement. Two samples have low individual agreement values (OxA-16359;

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A=18.1% and OxA-15687; A=0.3%), because it is not possible to evaluate which of these measurements is incorrect, although arguments for questioning the reliability of both are plausible. As OxA-16359 is a single measurement from core C7/8, it is not possible to confirm its reliability with respect to other results from this sequence and the statistically inconsistent dates from the base of T2/C2 highlight the problems of the reworking of organic material. Both dates are from roundwood samples from basal contexts within palaeochannel sequences on different terraces, and the relative order is reversed with the younger sample, OxA-15687, from the older terrace, T3. Given the problems identified above, it has been proposed that alternate models should be produced; in the first (Fig 82, Top) OxA-16359 has been excluded, and in the second (Fig 82, Middle) OxA-15687 has been excluded. Both models show good overall indices of agreement ($A_{overall}$=99.7%) and provide estimates for the switch from T3 to T4 of 310 cal BC - cal AD 280 (Event 3/4 (1); (Fig 82, Top) and 2100-640 cal BC (Event 3/4 (2); Fig 82, Middle).

5.2.15 In summary, at Lower House Farm there is no chronological control for Terraces T1 and T2. For Terrace T3 the radiocarbon dating framework is a little contradictory, but it appears that older channels were being abandoned from 2440–2140 cal BC, prior to eventual abandonment by incision in either 310 cal BC - cal AD 280 or 2100-640 cal BC (Fig 82, Bottom). There followed incision and subsequent aggradation, culminating in the formation of Terrace T4, which in turn was being abandoned after cal AD 230–390.

5.2.16 ***Osbaldeston Hall:*** geomorphological mapping within the Osbaldeston Hall meander identified the presence of Lower Ribble Terraces T2 to T5, each displaying numerous meandering surface palaeochannels (Fig 83). Sub–surface sediment cores were extruded from Terraces T2, T3 and T4, with the coring locations shown on Figure 83. The geochronological framework for terrace development was established from a total of 16 radiocarbon dates obtained from ten stratigraphic horizons (Table 23; Fig 84).

Feature	Lab code	Sample details	Materials	$\delta^{13}C$ (‰)	^{14}C date	Cal yrs 2σ range
Terr 1	OxA-15712	OS T1 C1 1.18-1.20m (A)	wood fragment *cf Alnus/Corylus, Salix/Populus* sp	-28.5	875±31	cal AD 1041-1225
Terr 1	SUERC-10653	OS T1 C1 1.18-1.20m (B)	leaf fragments	-27.2	905±35	cal AD 1036-1210
Terr 1	OxA-15690	OS T1 C1 2.66-2.68m (A)	wood, *Alnus* sp	-28.4	1596±27	cal AD 411-540
Terr 1	SUERC-10654	OS T1 C1 2.66-2.68m (B)	twig, unidentified	-29.4	1550±35	cal AD 424-584
Terr 1	SUERC-10655	OS T1 C1 2.96-2.94m (B)	twigs, *Rubus* and *Sambucus*	-27.1	1630±35	cal AD 343-537
Terr 1	OxA-15686	OS T1 C1 3.60-3.42m (A)	wood, *Alnus* sp	-28.3	1690±26	cal AD 258-413
Terr 1	SUERC-10656	OS T1 C1 3.60-3.42m (B)	wood, unidentified	-28.7	1720±35	cal AD 242-405
Terr 2	OxA-15708	OS T2 C2 3.43-3.33m (A)	*Alnus* scales and seeds	-25.5	1497±38	cal AD 435-645
Terr 2	SUERC-10657	OS T2 C2 3.43-3.33m (B)	buds and twigs	-27.4	1435±35	cal AD 563-658
Terr 3	OxA-15707	OS T3 C3 0.81-0.76m (A)	leaf fragments	-27.5	422±29	cal AD 1427-1617
Terr 3	SUERC-10658	OS T3 C3 0.81-0.76m (B)	twigs, unidentified	-29	340±35	cal AD 1467-1641
Terr 3	OxA-15685	OS T3 C3 2.50-2.40m (A)	unidentified. bark	-30.3	397±25	cal AD 1439-1620

Feature	Lab code	Sample details	Materials	$\delta^{13}C$ (‰)	^{14}C date	Cal yrs 2σ range
Terr 3	SUERC-10668	OS T3 C3 2.50-2.40m (B)	wood, *cf Salix/Populus*	-26.6	375±35	cal AD 1444-1634

Table 23: Radiocarbon dating from Osbaldeston Hall, Lower Ribble Valley

5.2.17 Core OS/C1/T1, taken from the Flashers Wood palaeo-meander bend, river Terrace T2, yielded a basal cohesive diamict, a stiff clay matrix supporting angular, shattered and lithologically diverse rock fragments, interpreted as lodgement till deposited under the base of an ice sheet during the last (Devensian) glacial episode. This was overlain by a *c* 2m thick unit of sandy flood bed deposits, in turn buried by a *c* 1.5m thick accumulation of well-humified peat; clast-supported gravels, regarded as diagnostic of channel lag deposits, were not present and it appears the channel bed was locally sand-dominated. Cores taken from Terraces T3 and T4 show typical fining-up-style palaeochannel fill sequences, consisting of: (1) basal channel lag gravels; (2) sandy graded flood beds; (3) iron-stained (bioturbated) laminated silty clays (Fig 85).

5.2.18 The sequence of samples from core OS T1 C1 on Terrace T2 is given below; however, the lack of identifiable organic material at the base of the fluvial sequence precluded the possibility of establishing the timing of initial filling at the coring site. Duplicate samples, dated to cal AD 258-413 (1690±26 BP; OxA-15686) and cal AD 242-405 (1720±35 BP; SUERC-10656) from towards the top of active channel-bedded sands, provided a *terminus post quem* for the later stages of channel sedimentation and aggradation of the fluvial deposits associated with Terrace T2. These are statistically consistent (T'=0.5; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could therefore be of the same actual age. The sample dated to cal AD 343-537 (1630±27 BP; SUERC-10655) came from the lowermost flood deposits within a sequence of organic sand and coarse sand flood layers. It potentially provides a date for channel and terrace abandonment, although these horizons may not be the base of the fluvial sequence. The two measurements, cal AD 424-584 (1550±35 BP; SUERC-10654) and cal AD 411-540 (1596±27 BP; OxA-15690), were from the base of a 1.5m thick peat sequence overlying organic-rich sand and coarse sand flood layers. They are statistically consistent (T'=1.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could therefore be of the same actual age. The measurements, cal AD 1041-1225 (875±31 BP; OxA-15712) and cal AD 1036-1210 (905±35 BP; SUERC-10653), from the top of the same peat deposit, below flood-laminated silts and clays, are also statistically consistent (T'=0.4; ν=1; T'(5%)=3.8; Ward and Wilson 1978).

5.2.19 For Terrace T3, chronological information is available from two palaeochannels sampled from cores OS T2 C2 and OS T2 C4. Two samples were submitted from OS T2 C4, which were dated to cal AD 1327-1444 (515±29 BP; OxA-16360), from organic debris within the basal flood layer of a palaeochannel overlying channel gravels, and cal AD 570-655 (1436±29 BP; OxA-16361) from a flood horizon towards the top of the flood sequence in the uppermost coarse sand flood laminations (0.15-0.145m) below the switch to sand, silt, and clay laminations. Statistically consistent radiocarbon results (T'=1.4; ν=1; T'(5%)=3.8; Ward and Wilson 1978; cal AD 435-645 (1497±38 BP; OxA-

15708) and cal AD 563-658 (1435±35 BP; SUERC-10657) came from the base of the flood bed sequence in core OS C2 T4. Higher up the sequence, towards the top of the flood-laminated palaeochannel fill deposits, organic debris from a flood layer has been dated to cal BC 165 - AD 21 (2049±30 BP; OxA-16362).

5.2.20 In the case of Terrace T4, four samples were submitted from a core (OS T3 C3) taken through a back-terrace palaeochannel on Terrace T4. The two dated samples, cal AD 1439-1620 (397±25 BP; OxA-15685) and cal AD 1444-1634 (375±35 BP; SUERC-10668), which were from organic detritus within a sandy gravel floor layer towards the base of flood-laminated deposits and the underlying channel gravels, are statistically consistent (T'=0.3; ν=1; T'(5%)=3.8; Ward and Wilson 1978). Statistically consistent results (T'=3.2; ν=1; T'(5%)=3.8; Ward and Wilson 1978; cal AD 1427-1617 (422±29 BP; OxA-15707) and cal AD 1467-1641 (340±35 BP; SUERC-10658)) were also obtained from the two samples submitted from within the upper flood layers, just below the switch to silt and clay laminations.

5.2.21 The model (Fig 84) shows good overall agreement between the radiocarbon results and stratigraphy ($A_{overall}$=73.6%). Two measurements have been excluded from this model, OxA-16360 and OxA-16362. OxA-16360, a monocotyledonous fragment, is clearly much younger than any other material dated from Terrace T3 and seems to be intrusive. OxA-16362 is probably older material reworked as a result of the flooding event recorded in core OS C2 T2. The model provides an estimate for the final abandonment of C1 and Terrace T2 of cal AD 290-480 (Event abandonment; Fig 84) and probably cal AD 340-430. It suggests abandonment of C3 and Terrace T4 occurred in cal AD 1460-1610 (Event 4/5; Fig 84) and that the flooding recorded in the channel-fill was short lived but intense, resulting in *c* 2m of deposition.

5.2.22 Figure 86 summarises the main events at Osbaldeston Hall. The model provides an estimate for the abandonment of T2 of cal AD 350-600 (Event 2/3; Fig 86). The chronological control for Terrace T2 is young compared to other sites in the Lower Ribble Valley and an alternative interpretation is that the samples from the deepest contexts in core OS T1 C1 are in fact 0.175m above the basal sand-dominated channel fill, rather than from towards the top of the active channel-bedded sands, as suggested above. This alternative interpretation would thus mean that OxA-15686 and SUERC-10656 only provide a *terminus ante quem* for abandonment of the OS T1 C1 channel and Terrace T2 before cal AD 240-390. It is not considered likely that the surface-laminated silty-clays in this palaeochannel reflect active channel flooding; they are more likely to reflect localised inundation from the hillslope gullies that drain the adjacent Flashers Wood slopes (Fig 83). For Terrace T3 the currently available data suggest abandonment by incision around cal AD 630-1460 (Event 3/4; Fig 86). There followed incision and subsequent aggradation, culminating in the formation of Terrace T4, which in turn was being abandoned here in cal AD 1460-1610 (Event 4/5; Fig 86).

5.2.23 ***Lower Ribble Valley - Summary:*** field investigations carried out at the three meander bends in the Lower Ribble Valley lead to the following summary (Fig 87), which can be interpreted to discuss the implications of this history for sediment transition and the controls upon fluvial development during the Holocene.

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- *Terrace T1:* this is a late Devensian-stage surface (height *c* 10m above the modern Ribble) that aggraded after a phase of either pro-glacial outwash or pro-glacial lake drainage driver incision into the glacial deposits of the Lancashire coastal plain. The T1 fluvial environments were probably those of cold stage multiple-channel braided rivers, depositing thick inorganic sands and gravels. Unfortunately, it was not possible to date these sands using OSL methods owing to problems with the quartz. The Lower Ribble T1 terrace clearly post–dates the Ribble-lake deglaciation stage, and may be the correlative of high terrace present on the northern flanks of Ribble estuary to the south of the Kirkham moraine at the exit from the Kirkham channel (Fig 69).
- *Terrace T2:* a cycle of cut and fill (depth *c* 6m) led to the formation of Terrace T2 (height 7-8m), the deposits of which are characterised by inorganic reddish sands and gravels, mostly reworked Permo-Triassic bedrock. The late stage of T2 development involved a meandering channel regime. Palaeochannel fill sediments reflect the fact that the channel and probably terrace abandonment occurred after cal BC 7150-6750 with the later stages of flood inundation as recently as *c* cal AD 1.
- *Terrace T3:* a second cycle of cut and fill (depth *c* 5m) led to the formation of T3 (height *c* 5-6m), which is characterised by meandering channels and thick deposits of fine-grained alluvium, locally overlying gravels at depth. Channel fills signify channel abandonment and migration after either 2100-640 cal BC or 350-150 cal BC at Lower House Farm and cal AD 485-710 at Osbaldeston Hall. The chronology suggests post–T2 incision was prior to either 2100-640 cal BC or 310-150 cal BC, with flood inundation of the terrace continuing until after at least *c* cal AD 630-1460. These findings appears to reveal temporal differences in surface and palaeochannel abandonment between meander reaches separated by less than 4km.
- *Terrace T4:* a third cut and fill cycle (depth 4-5m) accounts for T4 (height 4-5m), which is again characterised by fine-grained alluvium and surface meandering channels. The chronology points to post-T4 incision before *c* cal AD 230-390, with flood inundation continuing until at least *c* cal AD 1460-1610.
- *Floodplain:* locally inset deposits forming 3-4m of flood-laminated alluvium reflect limited incision and subsequent aggradation between *c* cal AD 1460-1610 at Osbaldeston Hall. The dating at Lower House Farm only provides a *terminus post quem* for abandonment of Terrace T4 at after cal AD 230–390.

5.2.24 ***Sediment budget implications:*** valley filling (T1), which has not been dated, but probably occurred during the late Devensian, was followed by a period of incision. An aggradation then took place in the early Holocene (T2), followed by a major incision and phase of palaeo-meander abandonment after *c* 7150-6750 cal BC. During the incision episode, sediment transmission to the Ribble estuary was potentially high. The incision into T1 and subsequent aggradation of T2 is estimated to have affected *c* 25% of the valley floor. The last 5000 years have involved heightened dynamism in the fluvial system, with successive incision/aggradation cycles forming Terraces T3 to T5. The T2/T3 transition is spatially time transgressive, but reflects incision broadly constrained to *c* 3970-3780 cal BC based on abandonment dates for T2 palaeo-meanders and the oldest basal ages for T3 palaeochannel fills of *c* 2100-640 cal BC at Lower House Farm. The T3/T4 transition is also spatially time transgressive, but broadly reflects incision *c* 2100 cal BC - AD 280, with continued flood inundation locally as recently as after *c* cal AD 1460-1610. The aggradation associated with T4 occurred at some point before *c* cal AD 230-390, with local channel migration as recently as cal AD 1460-1610; the T4/floodplain incision/aggradation cycle is a feature of the last 400-300 years. The timing and extent of each of these cycles appears to vary on a reach scale, but given the proximity to the coast of these Lower Ribble sites, it is likely that periods of incision involved high downstream sediment transmission to the estuary. However, the lateral continuity of the terrace surfaces between the Lower Ribble Valley and the estuary implies downstream sediment transmission may also have been high during valley aggradational phases.

5.2.25 ***The Lower Calder Valley:*** the Lancashire Calder, rising in the Pennines, is one of the three substantial headwater tributaries of the Ribble. The geomorphology and sedimentology of the Lower Calder Valley was investigated along a 4-5km study reach between the Ribble confluence and upstream of Whalley. Terrace and palaeochannel mapping around the Whalley viaduct (Fig 83) and height–range information (Fig 89) identified a suite of four main terraces: T1 (*c* 7m above the modern stream); T2 (*c* 5.5m); T3 (*c* 4m); and T4 (*c* 2m). The height/range diagram indicates that at least one additional, lower fluvial terrace (T5/T6, *c* 1m) occurs locally upstream and downstream from the study reach. In general, the Calder river terrace sequence appears to be similar to that described for the Lower Ribble Valley. Figure 88 demonstrates that river terrace preservation (spatial extent) reduces with increasing terrace height, and thus age. For example, the highest terrace (T1) occurs only in the form of isolated remnants, whereas the valley floor is dominated by the lower terraces, T3 and T4. This suggests that, in addition to long-term fluvial incision, lateral channel migration processes played an important role during the later stages of floodplain evolution.

5.2.26 Preserved palaeochannels are limited to the lower river terraces, T3 and T4 (see Fig 88). Terrace T3 is dominated by deep meandering palaeochannels (meander bend m1) that are clearly visible both within and beyond the study reach, with the meander bend at Bushburn Bridge demonstrating that the later stages of Terrace T3 development involved scrolling channel/bar modes of channel change (Fig 90). Incision below Terrace T3, and subsequent aggradation to level T4, involved an initial switch to a lower sinuosity channel pattern, but this was followed by channel avulsions over time, leading to the development of a meandering course similar to that of the modern river.

5.2.27 The meanders of the Calder immediately downstream from Whalley on either side of the A59 bridge provided the opportunity to secure data on the rates of change within Terraces T1-T4. The locations of coring and bank section sites used to characterise subsurface sedimentology are given in Figure 88. The geochronology relating to the development of Terraces T1-T4 has been established from a total of 20 dates obtained from 12 stratigraphic horizons

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(Table 24). The stratigraphic logs (Figs 91, 92), reveal both the broad age–stratigraphic consistency of the terrace formation chronology and the high degree of temporal agreement yielded by the comparison of paired sets of radiocarbon dates.

Feature	Lab code	Sample details	Materials	$\delta^{13}C$ (‰)	^{14}C date	Cal yrs 2σ range
Terr 1	OxA-15883	CAL/C5 1.12-1.17m	Sediment, humin fraction	-28.2	7685±50	6631-6445 cal BC
Terr 1	OxA-15884	CAL/C5 1.12-1.17m	Sediment, humic acid	-27.5	7315±40	6241-6070 cal BC
Terr 1	SUERC-10644	CAL/C5 1.61-1.56m (B)	bud scales	-26.9	9365±40	8751-8495 cal BC
Terr 1	OxA-15749	CAL/C5 1.70-1.75m (A)	wood, *Salix/Populus*	-26.9	9450±45	9114-8618 cal BC
Terr 1	OxA-15709	CAL/C5 2.50-2.45m (A)	wood, unidentified twig	-26.8	9955±50	9666-9294 cal BC
Terr 1	OxA-15710	CAL/C5 2.50-2.45m (A)	wood, unidentified twig	-27.1	9935±50	9657-9288cal BC
Terr 1	SUERC-10645	CAL/C5 2.50-2.45m (B)	unidentified seeds	-27	9985±40	9741-9318 cal BC
Terr 2	OxA-15745	CAL/C6 1.03-1.09m (A)	*Alnus* catkins/seeds	-27.8	4965±34	3895-3655 cal BC
Terr 2	SUERC-10646	CAL/C6 1.03-1.09m (B)	twigs, *Corylus* sp	-29.4	4925±35	3775-3646 cal BC
Terr 2	OxA-15746	CAL/C6 3.12-3.07m (A)	*Alnus* catkins	-26	4909±35	3766-3640 cal BC
Terr 2	SUERC-10647	CAL/C6 3.12-3.07m (B)	*Corylus* shells	-27.3	4900±35	3763-3638 cal BC
Terr 3	SUERC-10665	CAL/C4 2.33-2.45m (B)	wood, bark unidentified	-27	2840±35	1116-913 cal BC
Terr 3	OxA-15744	CAL/C4 0.93-0.80m (A)	wood, *Salix* sp	-28.9	1237±27	cal AD687-875
Terr 3	SUERC-10664	CAL/C4 0.93-0.80m (B)	wood, *Alnus* sp	-26.8	1315±35	cal AD 653-773
Terr 4	OxA-15684	CALD peat 0-0.02m (A)	wood, twig fragment	-30.5	1398±27	cal AD 604-666
Terr 4	OxA-15711	CALD peat 0.24-0.26m (A)	wood, *Alnus* sp, twig	-28.2	1283±30	cal AD 661-779
Terr 4	SUERC-10643	CALD peat 0.24-0.26m (B)	leaf fragments	-28.6	1315±35	cal AD 653-773
Terr 4	SUERC-10662	CALD Bank 0.90-1.00m (B)	wood, *cf Alnus/Corylus*	-26.6	830±35	cal AD 1058-1272
Terr 4	OxA-15688	CALD Bank 1.73-1.84m (A)	wood, *Alnus* sp	-27.9	1506±27	cal AD 438-631
Terr 4	SUERC-10663	CALD Bank 1.73-1.84m (B)	wood, *Alnus* sp	-28.1	1520±35	cal AD 432-611

Table 24: Radiocarbon dating from near Whalley, Lower Calder Valley

5.2.28 The sediments underlying Terrace T1 (core CAL/C5) show a basal grey minerogenic clay rhythmite, interpreted as a deglaciation stage glaciolacustrine deltaic bottom-set style of deposit. The rhythmite gives way to a peaty alluvium, the upper part of which contains two discrete layers formed of sandy flood beds, in turn buried by bioturbated laminated silty clays, indicative of low-energy flood deposition. The base of core CAL/C6 (river Terrace T2) yielded the same basal glaciolacustrine deposit, overlain by a 2m thick fluvial unit of normally graded, organic-rich, sandy/gravelly overbank flood layers; once again, the upper *c* 1m of the core consists of finer, laminated fluvial silty clays. The thickness of the T1 and T2 sand and gravels, the main aggregate mineral resource contained in the lower Calder, is relatively thin compared to that in the Lower Ribble Valley. Unlike the Terrace T1 and T2 sites, core CAL/C4 (Terrace T3) and bank sections CAL/BS and CAL/PEAT (Terrace T4) were sampled at palaeochannel infill settings. Core CAL/C4 shows a transition from basal cohesive glacial diamict to coarse channel gravel, and an upward transition to laminated clayey silts, reflecting a change from in-channel to backwater-style sedimentation. At river bank exposures of Terrace T4, two sites were sampled from 25-50m of laterally continuous river bank exposure (Fig 93). The base of the sequence consists of cohesive glacial diamict, giving way to *c* 500mm of peaty alluvium, overlain by *c* 1m of organic-rich, sandy flood layers, and capped by a unit of finer-grained, clay/silt flood laminations. The two sampled sections recorded slightly different depositional sequences; while at CAL/BS there was an organic-rich flood laminated alluvium, at CAL/PEAT, the equivalent unit, there was a floodplain/backchannel peat deposit.

5.2.29 For Terrace T1, two samples were submitted from the base of a 0.75m thick peat sequence that overlay finely laminated glaciolacustrine rhythmites in CAL/C5. Replicate measurements on an unidentified twig, of 9666-9294 cal BC (9935±50 BP; OxA-15709) and 9657-9288 cal BC (9955±40 BP; OxA-15710), are statistically consistent (T'=0.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and thus allow a weighted mean to be calculated (*c* 7945 cal BC). These two measurements, together with a collection of aquatic seeds dated to 9741-9318 cal BC (9985±40 BP; SUERC-10645), are also statistically consistent (T'=0.6; ν=2; T'(5%)=6.0; Ward and Wilson 1978) and could thus be of the same actual age. A single sample, dated to 9114-8618 cal BC (9450±40 BP; OxA-15749), comes from the top of the 0.75m thick peat sequence at 0.175-0.17m. The sample dated to 8751-8495 cal BC (9365±40 BP; SUERC-10644) came from the basal flood layer that overlies the 0.75m thick peat sequence, and is the first evidence for active channel sediment transport to affect this fluvial surface. Measurements on the humic and humin fractions of a buried soil from the top of a 0.45m thick sequence of flood-laminated rich sands, buried beneath 0.75m of fine-grained silty alluvium (the last active channel sediment transport prior to alluvial overbank style flooding), are not statistically consistent (T'=33.7; ν=1; T'(5%)=3.8; Ward and Wilson 1978). The upper two dated horizons were from the base of the silty-clays and constrain the end of peat accumulation and the last flood inundation to *c* 6640-6060 cal BC.

5.2.30 Four samples were submitted from core CAL/C6 taken from a back-terrace channel on Terrace T2. The two measurements, dated to 3766-3640 cal BC (4909±35 BP; OxA-15746) and 3763-3638 cal BC (4900±35 BP; SUERC-10647), from organic detritus within the basal flood layer that overlies a thick sequence of glaciolacustrine rhythmites, are statistically consistent (T'=0.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could therefore be of the same age. Statistically consistent results were also obtained from two samples from an organic-rich silty clay palaeosoil towards the top of the sequence of laminated coarse to medium sand flood deposits, and probably reflect the last major flood to affect the channel: 3895-3655 cal BC (4965±34 BP; OxA-15745) and 3775-3646 cal BC (4925±35 BP; SUERC-10646) (T'=0.7; ν=1; T'(5%)=3.8; Ward

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and Wilson 1978). As all four measurements from core CAL/C6 are statistically consistent (T'=2.1; ν=3; T'(5%)=7.8; Ward and Wilson 1978) it suggests that channel C6 was only active for a very short period of time and experienced a short-lived period of rapid flood-generated sedimentation *c* 3900-3630 cal BC.

5.2.31 Core CAL/C4 was taken from a back-terrace palaeochannel, which was probably one of the earliest to be both abandoned as the active channel and cease being affected by flood inundation on Terrace T3. A single sample (SUERC-10665) was submitted from organic detritus within the basal flood layer at the base of a sequence of coarse sand flood to basal channel gravel deposits. The two measurements, dated to cal AD 653-773 (1315±35 BP; OxA-15744) and cal AD 687-875 (1237±27 BP; SUERC-10664), from near the top of the flood sequence of the palaeochannel fill (0.93-0.8m), are statistically consistent (T'=3.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978).

5.2.32 For Terrace T4, the exposed sediment sequence (Calder T4 – Bank and Peat) was sampled using stream-cut exposures in the banks of the Calder at Whalley. The Bank Section profile is from the centre of the palaeochannel and shows a basal diamict overlain by coarse fluvial gravels lain down in a channel setting. These in turn are overlain by laminated organic-rich layers of sand, silt and clay. The sequence represents a number of floods inundating an abandoned channel. Two samples were submitted from the basal flood layer overlying channel gravels; the results, cal AD 432-611 (1520±35 BP; SUERC-10663) and cal AD 438-631 (1506±27 BP; OxA-15688), are statistically consistent (T'=0.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978). A single sample, dated to cal AD 1058-1272 (830±35 BP; SUERC-10662), came from the upper flood layer of a series of flood laminated alterations between flood sands and slack water silts and clays. The nearby Peat Section targeted a 0.26m thick peat that overlies bar form gravels. The two samples from the base of the peat, dated to cal AD 602-667 (1399±28 BP; OxA-16356) and cal AD 604-666 (1398±27 BP; OxA-15684), are statistically consistent (T'=0.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978), as are the two samples from the top (T'=0.5; ν=1; T'(5%)=3.8; Ward and Wilson 1978; cal AD 653-773 (1315±35 BP; SUERC-10643) and cal AD 661-779 (1283±30BP; OxA-15711)).

5.2.33 The model shown in Figure 92 shows good agreement between the radiocarbon results and the stratigraphy of the individual sequences ($A_{overall}$=85.4%) and provides the basis for the Calder terrace model shown in Figure 94, that estimates the dates of terrace abandonment/incision events.

5.2.34 The field investigations and geochronological analyses carried out in the Lower Calder Valley contribute to the following summary, which reflects the interpretation and discussion of the implications of this geomorphic history for sediment transmission and the controls upon fluvial development during the Holocene.

- *Terrace 1:* this is a late Devensian surface which aggraded to 7m above modern base level after incision into glaciolacustrine bottom-set deposits. The fluvial setting is likely to have been a cold-stage braided system. Section exposures and borehole surveys (not shown), reveal 1-2m of sands and gravels, with localised scour into the underlying muds. Again, attempts to OSL date these sands have proven

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unsuccessful. However, post-T1 incision is estimated to have occurred in 8580-3720 cal BC (Event 1/2; Fig 94). Terrace T1 appears to be a correlative of Lower Ribble Terrace T1.

- *Terrace 2:* a cycle of cut and fill (depth *c* 3m) is responsible for the formation of Terrace T2 (height relative to the current river *c* 5.5m). Its development involved meandering channels, and post-T2 incision is estimated at *c* 3660-1030 cal BC (Event 2/3; Fig 94).
- *Terrace 3**:*** a further cut and fill (depth *c* 2.5m) cycle led to the formation of Terrace T3 (height relative to the current river *c* 4m), with the deposits composed of fine-grained alluvium. The terrace surface displays meandering channels, fills having been dated between 970 cal BC and cal AD 490 (Event 3/4), with flood-generated sedimentation continuing in Terrace T3 palaeochannels until at least cal AD 650-890.
- *Terrace 4:* a further cut and fill (depth *c* 2m) cycle led to the formation of Terrace T4 (height relative to the current river *c* 2.5m), with deposits composed of fine-grained alluvium. The terrace displays meandering palaeochannels, fills spanning *c* cal AD 430-1270. The chronology reflects a pre–T4 incision before *c* cal AD 430-620, with flood aggradation until at least cal AD 1150-1270, and probable subsequent incision and abandonment of Terrace T4 after cal AD 1460-1610.
- *Floodplain:* locally inset deposits, consisting of *c* 1.5m thick flood-layered alluvium, reflect a limited incision and subsequent partial aggradational since cal AD 1460-1610 (Event 4/5).

5.2.35 ***Sediment budget implications:*** strong links exist between the geomorphological sequences in the Lower Calder and Ribble Valleys, with the valley filling (T1) not dated but probably dating to the late Devensian, after which there was a period of incision. A further phase of incision follows the early Holocene aggradation of Terrace T2 *c* 8580-3720 cal BC. Between them, these substantial incision and aggradation phases are estimated as having affected *c* 25% of the Calder Valley, and promoted accelerated downstream sediment transmission. Heightened dynamism of sediment movement has characterised the last *c* 4-3000 years. The switches from T2/T3 and T3/T4 reflect cut and fill cycles estimated to have occurred in 3660-1030 cal BC and 970 cal BC-cal AD 490 respectively. The T4/floodplain transition is a feature of the last *c* 500 years. The implications of this for sediment transfer downstream are phases of heightened supply downstream during the incision episodes. Sediment transmission may have also been high during aggradation phases, given the lateral terrace continuity.

5.2.36 ***The Upper Ribble Valley:*** a stretch of the valley floor to the south of Settle is unique in the context of the entire Ribble catchment system and is recognised as such by Natural England (English Nature 1999). There, the valley forms an almost flat-lying basin some 1km in width and 5km (Fig 95). Fluvial geomorphology and sedimentology was investigated to a preliminary degree within the northern part of the basin, some 1km to the south of Settle.

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5.2.37 A geomorphological map of the study area (Fig 95) suggests the presence of four main terraces (T1-T4), but at this stage it is not possible to identify linkages with the terrace sequences identified downstream because of the number of nick-points and presence of local base-level control that exists between this reach and the Lower Ribble system. Terrace T1 is present only as isolated fragments towards the margins of the valley and does not display evidence for surface palaeochannels. Field observations identified smooth morphological contacts between T1 and bounding alluvial fan surfaces, suggesting a Late-Glacial cold-stage origin for this feature. Terraces T2 and T3 dominate the valley floor, while T4, the youngest terrace, represents recent accelerated sedimentation due to flooding activity within flood embankments built during the nineteenth and twentieth centuries.

5.2.38 The most striking geomorphological feature of the site is the abundance of palaeochannels preserved in the surface morphology of Terraces T2 and T3 (Fig 95). The channels of T2 form an intricate, interconnected network, for which two competing environmental interpretations may be proposed: (1) low-energy anastomosing systems; (2) high-energy braided systems. The channels preserved upon T3 are clearly different, consisting of numerous cut-off meandering courses that seem to represent the natural form of the river in this flat reach prior to flood embankment and channel protection.

Feature	**Lab code**	**Sample details**	**Materials**	**$\delta^{13}C$**	**^{14}C date**	**Cal yrs 2σ range**
Terr 2	OxA-15880	LB T2 C2 0.83-0.86m	peat, humic acid	-27.7	3524±33	1939-1752 cal BC
Terr 2	OxA-15881	LB T2 C2 0.83-0.86m	peat, humin fraction	-28.3	4158±34	2880-2628 cal BC
Terr 2	OxA-15878	LB T2 C2 0.98-0.95m	peat, humic acid	-28.2	3780±34	2334-2047 cal BC
Terr 2	OxA-15879	LB T2 C2 0.98-0.95m	peat, humin fraction	-28	4149±36	2879-2621 cal BC
Terr 3	SUERC-10672	NH T3 C6 1.86-1.9m (B)	wood, *cf Salix/Populus*	-28.8	670±35	cal AD 1271-1394
Terr 3	SUERC-10673	NH T3 C6 2.75-2.79m (B)	wood, *Ulmus* sp	-27.9	5935±35	4907-4721 cal BC

Table 25: Radiocarbon dating from Settle, Upper Ribble floodbasin

5.2.39 Sub–surface sediment studies were conducted at seven palaeochannel coring sites on Terrace T2 at Littlebank Farm (Fig 96) and at two palaeochannel coring sites on Terrace T3 at New House Farm (Fig 97). The general lack of datable organic material at these sites restricted the number of radiocarbon dates to eight, constraining an understanding of the development of Terraces T2 and T3 to a limited extent (Table 25).

5.2.40 Several of the cores taken from Terrace T2 yielded a basal unit of coarse channel gravels that are buried by a thin (<1m) unit of laminated, low-energy flood deposits. Locally, a thin organic peat has developed between the gravels and the flood deposits, while some of the other coarser deposits may represent archaeological detritus from the remains of farming settlements. At a single site, coring was able to penetrate through the basal gravels, revealing an underlying unit of grey minerogenic clay rhythmite, interpreted as representing deposition

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in a pro-glacial lake environment. The coarse nature of the channel gravels tend to support the idea that the Terrace T2 palaeochannel morphology was inherited from a high-energy (ie braided) rather than low-energy (ie anastomosing) fluvial setting. The relationship with the underlying lake deposit suggests that this braided river system or sandur developed during a cold climate glacially-fed or nival (snowmelt) regime during the Devensian deglaciation. Cores extruded from Terrace T3 show the same basal unit of glaciolacustrine clay rhythmite, but there these stiff laminated clays are overlain by thicker (*c* 3m) palaeochannel fill deposits, showing fining up sequences consisting of: (1) basal channel gravels; (2) overlying high-energy sandy flood bed deposits; (3) a fine-grained, low-energy flood-generated clay/silt lamination cap.

5.2.41 Two samples were submitted from core LB T2 C2 on the Terrace T2 of the Upper Ribble flood-basin terrace sequence at Littlebank Barn (Fig 98). The basal sample (0.95-0.98m) comprised a compacted well-humified peat that overlay coarse channel gravels. Measurements on the humic acid of 2334-2047 cal BC (3780±34 BP; OxA-15878) and humin fraction of the peat are not statistically consistent (T'=54.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978). The same is also true for the humic acid (1939-1752 cal BC (3524±33 BP; OxA-15880)) and humin fraction (2880-2628 cal BC (4158±34 BP; OxA-15881)) measurements from the upper layers of the same compacted peat layer (0.83-0.86m) underlying laminated flood silts from the latter stages of flood inundation of Terrace T2 (T'=179.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978).

5.2.42 Providing an accurate chronology from radiocarbon dating of organic (peat) samples is problematic (Blaauw *et al* 2004; Kilian *et al* 1995; 2000; Shore *et al* 1995), and even more so if bulk AMS samples are involved. The humin (alkali and acid insoluble organic detritus) comprises the actual organic detritus and is not necessarily homogeneous, so when measured by AMS the smallest contamination can have a large effect (this is to some extent alleviated by radiometric dating of large (>250g) size samples). Humic acids (alkali soluble and acid insoluble matter), are the *in situ* products of plant decay. Although they are produced *in situ* and imply a stability to the ground surface, they can be mobile in groundwater, both vertically and horizontally (Shore *et al* 1995), but their mobility is probably limited. Therefore, they cannot be relied upon always to date accurately the horizon from which they were sampled. However, unlike the humin fraction, humic acids are homogeneous, as they are alkali soluble, and therefore can usually be more reliably dated by AMS.

5.2.43 Two samples were submitted from core NH T3 C6, a mid-terrace palaeochannel on Terrace T3 of the Upper Ribble flood-basin terrace sequence at New Hall Farm (Fig 98). The basal wood sample dated to 4907-4721 cal BC (5935±35 BP; SUERC-10673) came from organic material within thick sandy flood laminations just above the erosive contact with stiff glaciolacustrine clays. The upper sample of cal AD 1271-1394 (670±35 BP; SUERC-10672), came from near the top of a 1m thick sequence of coarse to medium sand flood laminations, and just below the switch to sandy silt and clay laminations. The results suggest that the date of channel abandonment (NH T3 C6) and the abandonment of Terrace T3 was some time after 4907–4721 cal BC (5935±35 BP; SUERC-10673).

5.2.44 The present work at best represents a preliminary assessment of a rare fluvial environment. Tightly meandering and anastomosing flood-basin fluvial settings of this nature are unusual in upland Britain, hence the site's listing as an SSSI, Long Preston Deeps SSSI. It has been beyond the scope of the current study to undertake a comprehensive assessment of the basin, but a limited chronological constraint for Terraces T2 and T3 has been established; furthermore, the propensity for regular flooding and the abundance of palaeochannel sites suggests the locality offers considerable potential for future geomorphic and palaeoecological research to reconstruct the history of the basin in greater detail and particularly to look at variations in flooding during the mid to late Holocene.

5.2.45 ***The Hodder Valley:*** the Hodder river system in the Bowland Fells provides a well-defined record of geomorphic activity during the Holocene, but until this present research had been poorly dated (Harvey and Renwick 1987; Miller 1991). Harvey and Renwick (1987) identified a four-stage terrace sequence at Burholme with considerable activity after 3310-2700 cal BC (4320±80 BP; WIS-1613).

5.2.46 Geomorphological mapping and sediment investigations in the Hodder Valley were conducted along a *c* 1.5km reach where the river flows south around a large meander bend at Burholme Farm. There, height range analysis and mapping identified a clear four-stage river terrace staircase (Fig 99). Again, comparison with the sequences obtained downstream must be contemplated with caution, owing to local base-level control between this reach and the Lower Ribble Valley. The lowermost terrace, T4, exhibits complex surface morphology, suggesting a time-transgressive sequence, and has thus been sub–divided into four sub-terrace units. Only a limited number of palaeochannel forms have been identified within the reach, and these depict clearly meandering plan-forms on the surfaces of Terraces T3 and T4, with little palaeochannel definition on Terraces T1 and T2.

5.2.47 Several cores were taken from Hodder Terraces T2, T3 and T4 (see Fig 99 for core locations), but only six of these, on Terraces T3 and T4, yielded sediments suitable for fluvial reconstruction and dating. Core stratigraphies are presented in Figure 100, in addition to a previously existing result (Harvey and Renwick 1987), a date of 3331-2679 cal BC (4320±80 BP; WIS-1613), for an unidentified piece of wood from Terrace T2, provides a *terminus post quem* for the overlying channel fill.

5.2.48 Core BUR 3/2, taken from a palaeochannel located on Terrace T3, consists of basal channel gravels and a fining-up sequence of fluvial flood deposits, and *c* 1m thick accumulation of well-humified peat. Three samples were submitted from core BUR 3/2, a back-terrace palaeochannel that was thought to be the earliest that was both abandoned as the active channel and ceased being affected by flood inundation. The basal sample gave a date of cal AD 607-666 (1395±25 BP; OxA-16350) and came from organic detritus from within the basal flood layer of a palaeochannel fill overlying channel gravels. A dated sample of cal AD 136-337 (1779±30 BP; OxA-16370) came from the base of a 1m thick peat in the palaeochannel, and a further dated sample cal AD 673-663 (1255±28 BP; OxA-16349) came from the top of the peat layer and the base of the uppermost flood-laminated silts and clays.

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5.2.49 The only other datable organic materials were obtained from Terrace T4, and were from the base of rather thin (ie < 2m) fining-up palaeochannel fill. The core on terrace segment T4(c), a large palaeomeander, yielded sufficient materials for radiocarbon dating. A single sample, dated to cal AD 1042-1218 (888±29 BP; OxA-16369), came from the basal flood layers of a palaeochannel fill on Terrace T4, overlying channel gravels.

5.2.50 The model shown in Figure 101 shows good agreement between the radiocarbon measurements and stratigraphy ($A_{overall}$=98.1%), although OxA-16350 has been excluded as it may represent contamination of material from higher up the sequence. It is, though, considered less likely that the date obtained from monocotyledonous remains within the *in situ* peat deposits is incorrect.

- *Terrace T1:* the highest terrace, standing some *c* 15m above the modern river bed, is clearly of Late-Glacial age with very mature surface soils and a strong surface field relationship with valley-bounding solifluction deposits.
- *Terrace T2*: a palaeochannel, regarded by Harvey and Renwick (1987) as part of Terrace T2, contains an organic fill suggesting channel abandonment before 3310-2700 cal BC (4320±80; WIS-1613), and so was used to constrain the terrace to the early Holocene, before 3310-2700 cal BC. Mapping in this study suggests, however, that this palaeochannel may in fact be part of the later stages of the evolution of Terrace T2.
- *Terraces T3:* a core was obtained from Terrace T3, which targeted a palaeochannel 1-2km downstream from the Harvey and Renwick (1987) site. They identified their palaeochannel as Terrace T3, but in the light of the present work this was revised to a palaeochannel associated with Terrace T2. The dates obtained for Terrace T3 are difficult to interpret. The lack of agreement between the radiocarbon age of samples and their stratigraphic position suggests that some of the dated material is either too old or too young for its context (ie residual or intrusive). The monocotyledonous leaves from the base of the peat (OxA-16370) are probably the most taphonomically secure of the three samples as they probably represent *in-situ* plant material. The onset of channel abandonment of Terrace T3 is therefore estimated to have occurred in cal AD 250-1150 *(*Event 3/4; Fig 102).
- *Terraces T4:* Harvey and Renwick's (1987) two-stage (low terrace and floodplain) sequence has also been revised into four phases, of which the earliest yielded no datable material. Phases 4b and 4c form an extensive terrace surface, on which a large palaeo-meander loop was either the latest phase of T4b or a discrete terrace in its own right. The results (*Sections 5.2.48-9*) provide a date for this palaeochannel fill and secure the onset of channel abandonment at Terrace T4b of cal AD 1030-1220.

5.2.51 ***Headwater alluvial fans:*** within the fluvial system, particular sub-environments have long been regarded as more susceptible to human impact. The inception of alluvial fans at the base of gully networks incised into the drift-mantled hillslopes of upland north-western Britain have long been attributed to human activity (Harvey *et al* 1981; Harvey and Renwick 1987; Harvey 1996; Harvey and Chiverrell 2004; Chiverrell *et al* 2006). Geomorphic changes on hillslopes can be crucial in terms of affecting sediment transfer and budgets within a river system. Tributary junction alluvial fans at the outlet zone of discrete gully systems are settings where the geomorphic responses are closely coupled to hillslope processes (Harvey 2002). Considerable evidence exists for late Holocene slope instability (after cal AD 950) throughout the Solway Firth - Morecambe Bay region, encompassing the Bowland Fells, Howgill Fells, Lake District and Southern Uplands of Scotland (Chiverrell *et al* 2006).

5.2.52 The episodes of increased gullying and alluvial fan accumulation often coincide or pre-date downstream valley floor alluviation, which may occur as a response to high sediment availability. Radiocarbon dating of alluvial fans and associated hillslope gully systems (Harvey and Renwick 1987; Chiverrell *et al* 2006) has identified three phases of heightened erosion. The first phase is dated to between *c* 2900 cal BC and cal AD 100, and probably spanned *c* 600 BC-cal AD 100 (*c* 2500-1900 BP). The second, more extensive, phase is dated at four sites to *c* cal AD 650-1240 (*c* 1400-800 BP), and produced either new extensive gullies or reactivated pre-existing ones. At a number of sites there are more recent, lower fan surfaces reflecting a third gullying phase, which, although undated, probably relates to the last 500 years. The increased transfer of sediment to the Hodder headwaters may be a contributing factor to the downstream aggradation of the Lower Ribble Terraces, T3 and T4. However, little is known regarding hillslope responses in other headwater areas of the Ribble catchment, such as the Yorkshire Dales.

5.2.53 The work conducted by Harvey and Renwick (1987) and Chiverrell *et al* (forthcoming) in the Bowland Fells of Lancashire, within the Hodder catchment, has elucidated the chronology of hillslope gullying and associated fan/cone accumulation at four study sites (see Fig 103; Table 26). These results constrain the timing of episodic hillslope gullying to after *c* 850–150 cal BC and after *c* cal AD 550-1150 (Fig 104). Thus, it seems possible that increased transfer of sediment to the Hodder headwaters may have been a contributing factor to the downstream aggradation of Lower Ribble Terraces T3 and T4. However, little is known regarding hillslope responses in other headwater areas of the Ribble catchment, such as the Yorkshire Dales.

Region	**Location and nature of radiocarbon dated sites**	**Dated materials**	**^{14}C Years BP**	**Cal yrs 2σ range**
Bowland Fells	Langden Valley (Harvey and Renwick 1987; Miller 1991)			
	Langden Castle Fan - soil buried beneath fan gravel	*Betula* remains	980±70 (WIS-1611)	cal AD 898-1214
	Fiendsdale Fan - organic soil underlying fan gravel	*Betula* timber	1970±70 (WIS-1612)	166 cal BC-cal AD 213
	Little Hareden Fan - organic clay overlying fan gravel	*In situ Betula*	2000±70 (WIS-1615)	201 cal BC-cal AD 137
	Little Hareden Fan - soil buried beneath fan gravel	*In situ Betula*	1020±70 (WIS-1616)	
	Lower Langden - base of organic fill in a gully	Wood remains	1780±70 (WIS-1628)	cal AD 879-1206

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Region	Location and nature of radiocarbon dated sites	Dated materials	^{14}C Years BP	Cal yrs 2σ range
	Main river terrace - base of overlying peat	*Betula* remains	4680±80 (WIS-1614)	cal AD 84-403
				3646-3125 cal BC
	Upper Langden Fan - top of soil buried beneath fan gravel	Humic fraction	1450±50 (SRR-3340)	
				cal AD 443-668
	Upper Langden Fan - base of soil buried beneath fan gravel	Humin fraction	1650±60 (SRR-3340)	
				cal AD 255-540
	Dunsop Valley (Harvey and Renwick 1987)	Humic fraction	3390±60 (SRR-3341)	
	Whittendale Fan - beneath fan gravels	Humin fraction	3970±70 (SRR-3341)	1878-1528 cal BC
				2839-2210 cal BC
	Hodder Valley (Harvey and Renwick 1987)	Wood remains	1200±70 (WIS-1627)	
	Base of channel fill on the low river terrace	Wood remains	4320±80 (WIS-1613)	cal AD 675-975
				3331-2679 cal BC

Table 26:Radiocarbon dates relating to gully/fan development, Bowland Fells, Lancashire (after Chiverrell et al *forthcoming)*

5.2.54 Understanding hillslope geomorphic changes throughout a catchment is crucial, because of the erosional importance and spatial/temporal variability of anthropogenic activity (farming intensity and woodland clearance). The main phase of hillslope instability in the Forest of Bowland has been linked to Norse (cal AD 700-1000) and medieval (cal AD 1100-1240) rural population and agricultural expansion in north-west England (Winchester 1987; 2000). What few alluvial fan dates that are available for the Yorkshire Dales suggest earlier Romano-British and Anglo-Saxon phases of activity, in Wensleydale (Chiverrell *et al* forthcoming) and Wharfedale (Howard *et al* 2000). At present the dataset is too small for a rigorous assessment of this hypothesis; however, spatial differences in the pattern and timing of increased delivery of sediment from upland hillslopes between the Hodder and Upper Ribble would be important for understanding evolution and environmental sensitivity of the catchment geomorphic system.

5.2.55 In order to improve the spatial representivity of hillslope erosion sites within the Ribble catchment, geomorphic mapping and sedimentological studies have been carried out, as part of the present study, at the Cam Beck (Ribble)–Oughtershaw Beck (Wharfe) watershed, in an area with a stronger record of Roman influence (Cam High Road) and Anglo-Saxon woodland clearances than in other parts of the catchment. This work identified ten coupled alluvial fan and gully settings where exposures showed organic deposits (peat and soils) underlying alluvial fan gravels. The geomorphology and sedimentology of the area is summarised in Figure 105. In order to understand the timing of alluvial fan development at the end of gully networks incised into the hillslopes of the Upper Ribble, samples were submitted from nine alluvial fan sites at the Cam Beck (Ribble) and Oughtershaw Beck interfluve (see Table 27; Fig 106). As the samples all come from organic-rich peat deposits buried beneath alluvial fan gravels, they only provide a *terminus post quem* for increased gullying and alluvial fan progradation. However, the results do suggest that hillslope instability at the Cam Beck (Ribble) and Oughtershaw Beck interfluve is for the most part very recent, during the last 500 years, which corresponds to the most recent phase identified in other areas (Fig 107), for example, the Bowland and Howgill Fells (Chiverrell *et al* forthcoming). Two of the sites, Oughtershaw Beck alluvial fans 8 and 6, provide evidence for earlier instability with alluvial fan progradation and coincident gully incision constrained to after cal AD 780-990 (1138±30 BP; OxA-16372) and after 1500-1390 cal BC (3170±31 BP; OxA-16353) respectively. Whilst these only provide a *terminus post quem* for increased gullying and alluvial fan progradation the timings broadly coincide with phases of hillslope instability in the wider North West (Fig 107) during the Iron Age and into the Romano-British period at 800 cal. BC-cal AD 250 and during the period cal AD 700-1250 (Chiverrell *et al* forthcoming).

5.2.56 ***Synthesis: catchment geomorphology and environmental change:*** research on the fluvial development of the Ribble basin was underpinned by a number of fundamental questions regarding the Post-Glacial development of landform assemblages. These questions were:

(1) What was the history of valley floor and hillslope evolution in the Ribble basin?

(2) To what extent does this fluvial history reflect response to major extrinsic environmental changes, such as changing sea (base) level, climate and land cover?

(3) Is there evidence for space–time variability in catchment landform development that may signal the role of the fluvial system in filtering or transmitting the geomorphic effects of environmental change?

(4) To what extent does the Ribble catchment represent a coupled slope–channel sedimentary system?

5.2.57 A synthesis is provided of the main geomorphological findings, and these questions addressed through comparisons between the dated geomorphic archives and other available records of Post-Glacial environmental change for north-west England (see *Section 5.2.44*).

5.2.58 Figure 108 shows a chronological model for the sequence in the Ribble, including evidence from the reaches in the Calder and Hodder systems. They show broadly consistent timings of valley incision and aggradation activity that fit the anticipated evolutionary model of river–floodplain development (*Section 2.2*), consisting of: a) late glacial to early Holocene aggradation (Calder Terrace T1; no dated Lower Ribble equivalent, but probably T1) related to the reworking of abundant glacigenic sediments under a cold climatic regime and a sparsely vegetated landscape; b) prolonged valley floor stability from the early to Mid Holocene, a time of climatic improvement and forest invasion; c) heightened rates of vertical and lateral instability during the late Holocene period of cultural expansion.

5.2.59 However, the geochronological data also provide evidence for subtle between-reach differences in the timing of valley geomorphic responses. For example, there appears to have been a significant lag in the timing of incision into T2

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deposits and the ending of aggradation between reaches. This evidence appears to show lag times that reflect early aggradation in downstream reaches and a possible upstream transmission of this early Post-Glacial switch from an incising to aggrading regime. Figure 109 compares the general model of Ribble catchment aggradation and incision with modelled evidence for changes in relative sea level in the region through the Post-Glacial period (after Tooley 1978; Shennan *et al* 2006). A period of rapid sea-level rise, from *c* 400 cal BC-cal AD 800, correlates with the incision between T1 and T2 in the Lower Ribble. It seems likely that incision below the level of Late-Glacial Terrace T1 deposits occurred earlier at locations closer to the coastline, such as the Lower Ribble reach, than in upstream reaches such as the Calder. There is some evidence from the radiocarbon geochronology that the formation of Terrace T2 was represented by a long period of dynamic lateral channel migration between *c* 6000 cal BC and 3000 cal BC, (*Section 5.2.3*), whilst upstream in the Calder, aggradation to T2 occurred somewhat later, *c* 3000 cal BC, and was apparently relatively short lived. Both the nature and spatial pattern demonstrated in this early Holocene fluvial response is consistent with the anticipated upstream progressive transmission of the switch from incision to aggradation, perhaps forced by the reduced channel gradient and high-base-level produced by relative sea-level rise. A further contributing factor to fluvial change during the early Post-Glacial period is that vegetation colonisation would have reduced sediment availability from *c* 9500 cal BC, perhaps also encouraging a switch from an aggrading to incising regime, with reduced sediment also encouraging greater lateral channel migration (Miall 1996). There seems little evidence in the fluvial geomorphology for the later Holocene that can be linked with base-level changes, perhaps not surprising given that sea level has remained relatively stable, falling only slightly over the past 5000 years.

5.2.60 In order to assess the role of cultural activity, particularly vegetation change, as an agent of fluvial-system change, the timing of Terrace T2 to T5 aggradation phases has been compared to Holocene pollen records from the Craven lowlands in the Upper Ribble catchment (Bartley *et al* 1990). Changes in vegetation cover, involving significant reductions in tree cover and increasing open-ground species, appear to register periods of human–induced landscape disturbance *c* 3750-1260 cal BC, and particularly *c* cal AD 650. It is reasonable to expect that such periods were characterised by enhanced soil erodability, raising the potential for increased slope channel sediment delivery and, in downstream environments, sediment overload and aggradation within the fluvial system. The earliest of these events during the Neolithic period clearly post-dates Terrace T2 and probably can be discounted as a factor contributing to the aggradation. However, the timing of the later Bronze Age / Iron Age and early medieval disturbance phases corresponds quite closely to the onset of aggradation leading to the development of Terraces T3 and T4.

5.2.61 Human-induced vegetation change has been postulated as being a major driver of late Holocene hillslope gullying across upland Britain, including in the Bowland Fells of Lancashire (S*ections 2.2.6 and 5.2.54*). Indeed, very close agreement exists between the timing of post-Bronze Age vegetation changes, the timing of hillslope gullying phases in the Bowland Fells, and the timing of episodic aggradation in the Ribble catchment (Fig 110). These associations provide a picture whereby late Holocene valley aggradation appears to have been strongly related, or coupled, to changes in sediment availability and supply on hillslopes, triggered by deforestation and changing land use. The effects of changing sediment supply from the headwaters to mid-reaches, and then downstream, clearly will have lagged responses downstream as the sediments are cycled through phases of deposition and re-mobilisation, for which there is limited evidence in the geochronology for Terraces T3 and T4. Transmission is a key issue that must be considered when discussing sediment flux through river systems, because sediment cycling and temporary storage are critical components of the sediment conveyer that rivers provide (Lang *et al* 2003). The timing of both palaeochannel and terrace abandonment clearly varies between meander loops separated by 4-5km, which shows that geomorphic change that appears to produce a staircase of river terraces is time transgressive within a broad temporal envelope that encompasses each phase of aggradation.

5.2.62 Sediment supply is not the only factor driving the system, and the periods of Ribble aggradation leading to the development of Terraces T3 and T4 were also, however, synchronous with hydro–climatic deterioration in north-west England (Fig 111) and it therefore seems likely that the late Holocene fluvial system was also highly responsive to the combination of climatic and anthropogenic environmental change (Coulthard *et al* 2005). Significantly, this apparent in-phase relationship between climatic forcing and sediment response is only apparent during the last 3000 years. It is thus possible that human activity, by increasing the connectivity between the catchment slopes and channel systems, has heightened the sensitivity of the Ribble fluvial system to centennial scale hydro-climatic variability.

5.3 Vegetation History of the Ribble Basin and an Assessment of the Palaeobotanic Potential of the Valley

5.3.1 ***Pollen assessment from Flashers Wood, Osbaldeston, Lower Ribble Valley:*** a rapid pollen assessment was carried out from a buried peat deposit in a palaeo-meander bend, from Terrace T2, at Flashers Wood, Osbaldeston Hall, in the Lower Ribble Valley (SD 6438 3441). Six subsamples were assessed for their potential for further analysis (Table 28).

5.3.2 Pollen was plentiful and well preserved in all the samples from 2.92-2.94m. Two dates from near the base of the peat (2.68-2.66m) suggest that it started to form between cal AD 484 and cal AD 582 (combined dates of cal AD 424-584; 1550±35.BP; SUERC-10654 and cal AD 411-540; 1596±27 BP; OxA-15690) and was reflooded between cal AD 1103 and cal AD 1257 (combined date of cal AD 1036-1210; 905±35 BP; SUERC-10653 and cal AD 1041-1225; 875± 31 BP; OxA-15712) in the early medieval period. Therefore, the pollen from Flashers Wood will provide a record of the land use relating to this little understood period.

5.3.3 The pollen assemblage at a depth of 2.10-2.12m, towards the base of the peat, suggests that an open carr woodland with alder was growing in the wetter areas, with some hazel scrub on the drier ground away from the river and some areas of grassland. The relatively high values of fern spores suggest that the woodland was quite open. Although the alder carr and hazel scrub continued to be important the increasing values of herb pollen, of which grass pollen is the most significant, suggest that grassland became more prevalent, with some possible cereal cultivation at a depth of 1.75-1.76m.

5.3.4 The upper two samples (at depths of 1.20-1.22m and 1.22-1.24m) were dominated by willow (*Salix*) and alder (*Alnus glutinosa*) pollen, suggesting that willow and alder were growing close to the site before it was reflooded between cal AD 1103 and cal AD 1257 (combined date at a depth of 1.20-1.18m of cal AD 1036-1210 (905±35 BP; SUERC-10653), and cal AD 1041-1225 (875± 31 BP; OxA-15712)). The pollen sub-samples by this time had large amounts of willow pollen rather than alder, although the latter was present. Hazel was also frequent but other trees were not well represented. It is likely that the willow and alder carr, growing on or near to the site, was filtering other pollen types from the pollen assemblage.

Depth in metres		**1.20-2**	**122-4**	**175-6**	**186-8**	**210-12**
Trees and shrubs %		90.1	79.2	46.3	52.1	61.9
Herbs %		6.1	17	43.5	37.8	21.2
Ferns %		3.8	3.8	10.2	10.1	16.8
Trees						
Alnus glutinosa	Alder	25.2	23.6	16.7	11.8	24.8
Betula	Birch	0	0.9	0	1.7	2.7
Corylus avellana-type	Hazel-type	6.1	8.5	19.4	30.3	23.9
Fraxinus excelsior	Ash	0.8	0	0	0.8	0
Pinus sylvestris	Pine	0	0	0	0	0.9
Quercus	Oak	1.5	0.9	7.4	5.9	5.3
Salix	Willow	55	42.5	2.8	0.8	3.5
Ulmus	Elm	0.8	0	0	0.8	0
Shrubs						
Hedra helix	Ivy	0	1.9	0.9	0	0.9
Herbs						
Asteraceae	Daisy family	0	0	0	0.8	0
Brassicaceae	Cabbage family	0	0	0	0	0.9
Capsella-type	Shepherd's purse	0	0	0	0	0.9
Cerealia-type	Cereal-type	0	0	0.9	0	0
Cyperaceae	Sedges	0.8	1.9	12	6.7	3.5
Filipendula	Meadowsweet	0.8	1.9	13	0	2.7
Plantago lanceolata	Ribwort plantain	0	1.9	3.7	0	0
Plantago undifferentiated	Plantains	0	0	0	2.5	0
Poaceae	Grasses	3.1	1.9	10.2	13.4	8
Potentilla-type	Cinquefoil	0	0	0.9	0	0
Ranunculus	Buttercups	0.8	0	0	0.8	0
Rubiaceae	Bedstraw family	0.8		0	4.2	0
Rumex	Sorrel	0	0	1.9	2.5	2.7
Succisa pratensis	Devil's bit scabious	0	0	0	0	0.9
Undifferentiated herbs		0	1.9	2.8	1.7	0.9
Ferns						
Dryopteris filix-mas	Male fern	0	0	0	2.5	0
Dryopteris	Bukler ferns	0	1.9	0	0	0
Polypodium	Polyploid ferns	1.5	0	1.9	3.6	1.7
Pteridium aquilinum	Bracken	0	0	3.7	1.7	3.5
Pteropsida	Ferns	2.3	0.9	4.6	1.7	10.1
Thelypteris palustris	Marsh fern	0	0.9	0	0.8	0.9

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Depth in metres		1.20-2	122-4	175-6	186-8	210-12
Pollen sum		131	106	108	119	113
Sphagnum	Bog moss	0	0	0	0.8	1.7
Aquatics						
*Typha angustifolium-*type	Lesser bulrush	0	0	8.3	1.7	1.7
Indeterminates		0	5.7	9.3	2.	14.2
Charcoal		0	0	6.1	0.8	88.6
Exotics		18	40	68	73	46

Table 28: Pollen assessment of peat deposits from Flashers Wood, Osbaldeston. Pollen values are calculated as a percentage of the total land pollen and fern spores. Charcoal values are expressed as a percentage of the pollen sum plus charcoal

5.3.5 ***Discussion:*** the date of the peat deposit, when considered with the considerable potential for further palynological analysis at Flashers Wood, makes it an extremely significant resource for recording the vegetational history of this area of the Lower Ribble Valley in the early medieval period. The increase in local woodland, although related to the history of the River Ribble, may reflect a reduction in anthropogenic activity, or conversely the flooding of the peat may be associated with increased activity later in the early medieval period. The regional pollen diagrams from Fenton Cottage (Middleton *et al* 1995) and Fairsnape Fell (Mackay and Tallis 1994) both record some woodland regeneration at this time. The assessment has demonstrated that the palynological analysis of the deposits from Flashers Wood has a very high potential to record vegetational changes in the post-Roman period. This is made more important because of the proximity of the site to the important Roman settlement of Ribchester, which is in an area where there is very limited previous palaeoecological work or available sites that are suitable.

5.3.6 ***Assessment of the Palaleoecological Potential of the Lower Ribble Valley:*** it is difficult to describe adequately the palaeoecology of the Lower Ribble Valley because there are only two sites within the study area that have provided evidence, both from Brockholes, near Preston (Chiti 2004, 155-66; Gearey and Tetlow 2006; Fig 112). An organic fill of a palaeochannel was dated to 7572-7193 cal BC (8361±66 BP; AA-49828) to 2864-2473 cal BC (4067±51 BP; AA-49832). It therefore only provides a record of vegetational change from the middle and later Mesolithic and the early Neolithic period. The pollen data suggest that a woodland of alder/elm/oak and hazel (*Alnus*/*Ulmus*/*Quercus* and *Corylus*) was growing in the catchment of the Lower Ribble around 7572-7193 cal BC (8361±66 BP; AA-49828). A little after 5208-4837 cal BC (6068±56 BP; AA- 49829), there is evidence of a grass/sedge community developing at the site, associated with an increase in microscopic charcoal particles, perhaps indicating that the woodland may have been destroyed by fire. Chiti (2004, 164) suggests that this burning event may have accelerated the formation of an oxbow lake as the channel became abandoned, forming a backwater. The presence of sulphide spherules, which indicate decomposition of organic matter (Wiltshire *et*

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al 1994), are thought to indicate a rapid change from an aquatic to terrestrial environment.

5.3.7 The open vegetation continued sometime after 3960-3711 cal BC (5046±55 BP; AA-49831), when the pollen data suggest that there was a regeneration of an alder/oak and hazel woodland. Woodland dominated the landscape up to 2864-2473 cal BC (4067±51 BP; AA-49832), when the site reflooded. A generally wooded environment, with oak, hazel and alder, at 3331-2922 cal BC (4430±40 BP; Beta-213393) is also suggested from a recent assessment at Brockholes (Gearey and Tetlow 2006).

5.3.8 Apart from these two studies, the only evidence comes from the pollen studies of the lowland mosses of north Lancashire (Middleton *et al* 1995), south-west Lancashire (Middleton *et al* forthcoming), Greater Manchester (Hall *et al* 1995) and Merseyside (Cowell and Innes 1994) and the uplands of the Bowland Fells (Mackay and Tallis 1994) and Anglezarke (Bain 1991; Howard-Davis 1996; OA North in prep). These studies suggest that towards the end of the last glaciation there was a temporary amelioration of the climate, before a return to colder conditions in Late Devensian III. As the climate started to ameliorate after this cold phase in the early Holocene, which is dated at Knowsley Park, Merseyside (Cowell and Innes 1994), to before 8715-8301 cal BC (9280±80 BP; GU-5246) and at Red Moss, Greater Manchester (Hibbert *et al* 1971), to 10,027-8656 cal BC (9798±200 BP; Q-924), a tundra-like vegetation developed over much of the landscape. This was replaced by an open plant community rich in herbs and shrubs, such as juniper (*Juniperus*), birch (*Betula*) and crowberry (*Empetrum*), a low ericaceous shrubs found today in upland areas of Britain. Birch and juniper gradually formed a scrub before hazel woodland developed over much of the north-west of England. This hazel expansion has been dated at Knowsley Park, Merseyside (Cowell and Innes 1994), to 8599-8249 cal BC (9160±80 BP; GU-5245) and at Red Moss, Greater Manchester (Hibbert *et al* 1971), to 8429-7588 cal BC (8880±170 BP; Q-921). Pine gradually expanded with the hazel before the more thermophilous deciduous species of oak and elm and later alder, at *c* 5500 cal BC formed a dense woodland.

5.3.9 Throughout this early part of the Holocene, which corresponds to the Mesolithic period, there are frequent records of charcoal in the peat but it is not possible to say definitively whether this charcoal originated from natural wildfires or as the result of anthropogenic activity. These burning episodes are often associated with temporary small-scale clearance of the woodland, as recorded at Brockholes (Chiti 2004). Early evidence of possible arable cultivation is also recorded in pollen diagrams from south-west Lancashire and north Merseyside (Middleton *et al* forthcoming; Cowell and Innes 1994).

5.3.10 More generally, anthropogenic activity was recorded in pollen diagrams from the early Neolithic period, for example at Fenton Cottage, in the Fylde (Middleton *et al* 1995; Wells *et al* 1997), and at sites in south-west Lancashire (Middleton *et al* forthcoming). This activity was followed by periods of regeneration and short-term clearance throughout the Neolithic and Bronze Age. There is only limited pollen evidence for cereal cultivation in the Bronze Age, although areas of grassland are likely to have been present before woodland regenerated in the early Iron Age. However, cereal pollen and an increase in other anthropogenic indicators was recorded in a peat deposit associated with a

Late Bronze Age human skull 1212-843 cal BC (2845±65 BP; AA-28733; Huckerby 2001). Major clearance activity is only recorded in the Late Iron Age, for example at Fenton Cottage (Middleton *et al* 1995; Wells *et al* 1997), and continues into the Roman period, when it was followed by two brief episodes of woodland regeneration before the relatively treeless landscape that we know today started to develop a little before cal AD 1048-1281 (820±50 BP; GU-5142). The pollen diagrams from south of the Ribble record a similar picture, as does that from Red Moss (Hibbert *et al* 1971).

5.3.11 The chronological length of the pollen record is limited by the date of peat inception in the uplands, with the earliest peat forming in the Mesolithic period, at 5711-5563 cal BC (6720±35 BP; SUERC-4550), on the higher fells of the Forest of Bowland (OA North in prep). The peat gradually spread downslope in the Neolithic period, accelerating in the Bronze Age (Bain 1991;OA North in prep), with peat initiation being recorded as late as 732-379 cal BC (2365±40 BP; SUERC-4507) (ie in the Iron Age) at Site 3 in the Forest of Bowland (OA North in prep). Again, as in the lowlands, the pollen record is of regional vegetational change rather than local. There is evidence in the uplands of a major clearance of woodland in the Iron Age (Mackay and Tallis 1994) similar to that in the lowlands (Middleton *et al* 1995; Wells *et al* 1997). This clearance continued into the Roman period and was followed by a period of regeneration before further anthropogenic activity in the early medieval period. Today, the landscape is mainly treeless, although small areas of woodland survive in the valleys. There is also evidence for cereal cultivation in the uplands.

5.3.12 ***Summary:*** throughout the Late Devensian and the Holocene, the palaeoecology of the Lower Ribble Valley is likely to have been similar to that recorded in the coastal lowlands of north-west England, although local edaphic factors will have influenced individual sites. The open landscape of the Late Devensian and early Holocene will have gradually become more wooded, as birch and juniper scrub succeeded the open herbaceous plant communities. This scrub would in turn have been replaced by dense hazel woodland, with increasing numbers of pine and then oak and elm trees. As the climate became wetter, alder would have invaded the heavier damper soils close to the River Ribble. In other parts of Lancashire, Merseyside and Greater Manchester, small areas of this mixed deciduous woodland were temporarily cleared from the late Mesolithic period onwards, with periods of woodland regeneration. More extensive clearance probably took place in the late Iron Age and Roman period, followed by periods of alternating woodland regeneration and clearance before the cleared landscape we know today came into being sometime after cal AD 1048-1281 (820±50; GU-5142;Middleton *et al*1995; Wells *et al* 1997).

5.4 EVOLUTION OF THE LANDSCAPE: SYNTHESIS AND NEEDS FOR FUTURE RESEARCH

5.4.1 The landscape of Lancashire reflects the cumulative impacts of override by ice, subsequent retreat clearly punctuated by repeated oscillation of the ice margin, and possibly a substantial ice advance episode associated with the Kirkham moraine complex, the most substantial glacigenic landform in lowland Lancashire. During deglaciation there was a period when the decoupling of different ice-streams produced ice-free conditions in the Lower Ribble Valley,

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the Loud and the Hodder, with an extensive ice-dammed lake blocked in by ice east of Preston and fed by waters draining the retreating Ribble glacier. The work undertaken for this project has only begun to scratch the surface of the complicated deglacial history of lowland Lancashire, and compared to surrounding regions, Cheshire, Cumbria and the Pennines, glacial research has lagged, with little occurring since the early pioneering work of (1877b). Poor exposure admittedly constrains what can be achieved in terms of future research, but the use of quality elevation datasets, field mapping and extensive borehole coverage offers considerable potential to advance understanding of the glacial history in this region, which would be research of some significance, given a current academic focus on ice-stream behaviour during deglaciation, and, from an applied research perspective, the association between the Kirkham moraine complex and quantities of high-grade sand and gravel mineral.

5.4.2 Much of the project focused on the fluvial development of the Ribble and its tributaries, and redressed a gap in fluvial geomorphic research in Britain. The Ribble has a suite of five river terraces, including the modern floodplain, which reflects the cumulative response of the river system to the impacts of base-level change, early Holocene landscape recovery from the last glaciation, cultural change and variations in climate during the Holocene. The broad sequence in the Lower Ribble is:

- T1: a late Pleistocene high terrace aggraded until undated incision during the early Holocene, triggered by a combination of gradual landscape stabilisation and relative sea level, forced lower base levels;
- T2: this aggraded during the early Holocene, 8000-4000 cal BC, with significant lateral channel mobility, perhaps related to reduced long profile gradient and a higher base level, as mid-Holocene sea-level optimum conditions were achieved *c* 6000 cal BC. The subsequent incision is constrained to *c* 4000-15000 cal BC.
- T3: this aggraded *c* 1500-200 cal BC and potentially reflects increased sediment transfer to the fluvial system in response to cultural impacts on the landscape during the Bronze and Iron Ages. This episode also coincides with increased climatic wetness identified in peat records *c* 1600 and 300 cal BC (Charman *et al* 2006). The correspondence with the peat record is engaging but it must be stressed that high magnitude events (floods) are critical events in the development of fluvial geomorphic and sedimentary sequences, with significant geomorphic work possible in single flood events (Wells and Harvey 1987; Macklin and Lewin 1993). Peat records do not possess the resolution or ecological/ environmental response to rainfall events to provide a comparator record for flooding. Climatic factors, particularly high-magnitude flood events, both contribute to produce erosion and increased sediment flux, but the late Holocene reduction in woodland cover and increased agricultural activity caused a change in the baseline conditions that produced a landscape more susceptible to geomorphic processes. Geomorphic modelling scenarios (Coulthard *et al* 2000) support this view, showing an order of magnitude increase in the response of the fluvial system when increases in rainfall and decreases

in tree cover occur in combination. The incision that followed T3 is broadly secured to the period 300 cal BC-cal AD 200.

- T4: this aggraded *c* cal AD 200-100 and potentially reflects increased sediment transfer to the fluvial system in response to cultural impacts on the landscape during the late Romano-British period and onwards into the medieval period. Much of this geomorphic activity coincides with more extensive gullying in headwater reaches in cal AD 80-250, and cal AD 700-1250, and so reflects increased efficiency of sediment delivery to the fluvial system in an increasingly cultural landscape. Again, climate and floods are the agents affecting flow in the fluvial system, and have mediated this increased transmission of sediment. The incision that followed T4 is broadly secured to the period after cal AD 1460-1610.
- T5: the modern floodplain has aggraded during *c* cal AD 1460-1610, although more detailed interpretation of historical maps may clarify the chronology for this episode and the behaviour of the current river system.

5.4.3 Unfortunately, there has been little research on the alluvial history of the other westwards-draining river systems in north-west England with which to compare the detailed record for the Ribble. There has been research within the Irthing tributary of the Eden, where Cotton *et al* (1999) identified a suite of seven river terraces, with the sequence secured by two radiocarbon dates for the base of peat-filled palaeochannels in Terrace T4 of 2470-1930 cal BC (3750±80 BP; Lab code N/A) and Terrace T5 of cal AD 1400-1620 (460±50 BP; Lab code N/A). Terraces T1-T3, clearly, and Terrace T4, probably, pre-date 2470-1930 cal BC and would be late Devensian or early Holocene in age. Terrace T5 deposits aggraded between 2470-1930 cal BC and cal AD 1400-1620, and Terraces T6-T8 post-date cal AD 1400-1620, both of which could be the result of gullying in the uplands and the greater availability and cycling of sediment within the lowland catchment. There are similarities to the Ribble in the Eden, with late Pleistocene higher terraces, a main phase of sediment accretion during the mid-Holocene, and then numerous cut and fill cycles during the culturally impacted history of the last 3000-2000 years. There are up to three river terraces within the Lune Valley (Harvey 1985; Chiverrell *et al* forthcoming), but unfortunately there is no geochronological control available for the lower two terraces and the modern floodplain, other than that they are of Holocene age. Further south still in the Dane, Cheshire, Hooke *et al* (1990) identified a late Pleistocene high terrace and middle terrace, constrained to before 3250-3050 cal BC, but in catchment perhaps wooded until relatively recently, since little subsequent aggradation occurs until the late Holocene, in the last 800-400 years.

5.4.4 To the east of the Pennines a much greater quantity of geomorphic research has been undertaken, which has addressed the tributaries of the Yorkshire Ouse, and the Rivers Tees, Wear and Tyne (Howard *et al* 2000; Macklin *et al* 1992; 2005). For example, the geomorphic sequence in the middle reaches of the Wharfe (Howard *et al* 2000) also comprises late Pleistocene high terrace (T1), a mid-Holocene aggrading T2, 3650-340 cal BC, with two younger terraces, T3 and T4, during the last 1500 years, which Howard *et al* link with increasing cultural impact on the landscape. The pattern of geomorphology varies considerably within and between both reaches and rivers, with, at Thinhope Burn in the upper Tyne Valley, comparative stability through most of the Holocene, 6350 cal BC-cal AD 350, after which two cycles of cut and fill have produced terracing that is a function of increased erodibility of the landscape and increased sediment supply from the hillslopes, probably due to human activity, but also, critically, substantial flood events triggering change in the fluvial system (Macklin and Lewin 1993). It is beyond the scope of this report to undertake a comprehensive response to geomorphic change across north-east England (Macklin 1999; Macklin and Lewin 2003), but there are clear parallels between what is recorded in the geomorphology of the Ribble Valley and what is present elsewhere.

5.4.5 The research for this project demonstrates the value of comprehensive investigation of the geomorphic record in fluvial systems and highlights how it contributes to understanding the evolution of our landscape. Critical for ALSF-funded research, both the glacial and fluvial geomorphology provide prime resources of sand and gravel mineral aggregates, and so an enhanced understanding of their distribution and character is of benefit to the mineral extractive industries. The comparative lack of this type of investigation in the region has been highlighted; the geomorphologies of the Rivers Lune, Wyre and Eden are at present a relatively blank canvas that warrants investigation to complete the picture of the geomorphic development of north-west England. In the light of probable continued exploitation of these landforms and sediments for mineral extraction, the development of an improved understanding of the geomorphic history and its links with the cultural heritage for these regions remains an important objective, to some extent addressed in the case of the Lower Ribble, but there remains considerable potential in future research of this nature to fill gaps that remain for the Ribble, for instance, the Kirkham moraine and Ribble floodbasin, and particularly for the other river systems across north-west England.

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