ALSF AGGREGATE EXTRACTION IN THE LOWER RIBBLE VALLEY

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SUMMARY

This report presents the results of the ALSF Ribble Valley Aggregate Extraction project, which was a study of the aggregate and archaeological potential of the Lower and Upper Ribble Valley; the study area originally extended between Preston, in Lancashire and Settle in the Craven District of North Yorkshire, although during the course of the project more emphasis was placed on a study of the Lower Ribble Valley and the results are presented in ths report. The work was undertaken between May 2005 and December 2006 as a joint project between the University of Liverpool Geography Department and Oxford Archaeology North (OA North), and was funded by the Aggregates Levy Sustainability Fund (ALSF) under the overall management of English Heritage. The responsibility of the project was split such that the University of Liverpool undertook the geological and geomorphological elements of the project whilst OA North undertook the archaeological elements, and the palaeobotanical elements were undertaken jointly.

The geomorphological objectives of the project were to collate evidence on all past and present aggregate extraction, produce revised estimations and mapping of suitable resources for future extraction, and produce mapping of present and future geomorphological change. The archaeological objectives were to collate evidence for all archaeological activity and, by the means of an exhaustive survey of LiDAR, aerial photography, field survey and other methods, find new archaeological sites and assess the potential for sites within areas of potential extraction. The data were assimilated into a GIS system, which was integral to the project, and the archaeological data and geomorphic data were subject to spatial analysis to provide an assessment of the areas of greatest potential for each element. A final objective was to integrate these two strands and assess the potential impact of aggregate extraction or geomorphological change on the archaeological resource.

The University of Liverpool has produced an extensive re-mapping of the available aggregate reserves and geology within the study area. This has led to an assessment demonstrating that substantial reserves are available, but many are difficult to extract, given the environmental and statutory constraints. Mapping geomorphological change within the study area has demonstrated a considerable degree of change within the Upper Ribble Valley both of erosion and deposition, but less within the Calder and Hodder Valleys. Change within the Lower Ribble Valley appears to be mainly restricted to sedimentation. Future geomorphological change, based on a model of increased winter rainfall, is likely to intensify this pattern, with increased erosion in the Upper Ribble Valley and increased sedimentation in the Lower Ribble.

A survey of the archaeological resource using LiDAR and aerial photography was extremely successful, identifying new sites and improving classification of those already identified. Collating the enhanced resource and examining its location in relation to environmental and topographic factors, such as slope and distance to water, suggested considerable potential for buried archaeology within the study area. When superimposed upon the mapping of geomorphological change and aggregate extraction suitability within the GIS, there appeared to be areas where both known and potential buried archaeology could be under threat.

Recommendations have been made about further work within the region, following on from the discovery by the University of Liverpool of considerable mineral reserves in the Kirkham area, and the potential for the use of hard geological sources for aggregate in the Craven District of North Yorkshire.

1. INTRODUCTION

1.1 AGGREGATE EXTRACTION BACKGROUND

1.1.1 The Britain of the twentieth and twenty-first centuries is one that has been and is being subject to enormous change, be it from the expansion of urban centres, the improvement of its transport infrastructure, the reinvigoration of its industries, or even the pursuit of environmentally friendly solutions to our power crisis through wind farms. Change invariably entails construction, and construction almost always requires large amounts of aggregate, for road and building foundations, for tarmac, for concrete, or for mortar. Aggregate is relatively cheap to extract but costly to transport and so the development needs of an area require local sources of aggregate. The North West has seen a major upsurge in the scale of its developments, the city centre of Manchester has been extensively revamped, and now Liverpool, for some time the poorer cousin, is having its centre extensively remodelled; the current Paradise Street Development is currently the largest in Europe.

1.1.2 There is a recognised need for new sources of aggregate, and Lancashire County Council has commissioned studies (Entec UK Ltd 2005; Geoplan Ltd 2006) to identify areas for the future provision of high-quality mineral aggregates and high-grade sand (as a naturally accepted standard) in particular. These reports will eventually be incorporated into the *Lancashire Minerals and Waste Local Plan* (LCC 2006), identifying new Areas of Search. Policy 48 of the current adopted plan makes provision for release in 2006 of additional land for the extraction of 3.2 million tonnes of high-grade sand. The policy identifies three Areas of Search for aggregate: (1) the Lower Ribble Valley within the boroughs of Preston and south Ribble, with the others nearby; (2) north and west of Preston extending across the Fylde to the Wyre valley; and (3) the Leyland-Chorley area south of the Ribble but outside the West Pennine Moors. Notwithstanding the current provision for further extraction (landbank), it has been acknowledged that the current reserves of high-grade sand in the county will be exhausted towards the end of 2006, hence the motives behind the recent sand and gravel surveys (Entec UK Ltd 2005; Geoplan Ltd 2006).

1.1.3 This insatiable demand for sand and gravel comes into conflict with the aim to preserve the country’s archaeological heritage, as river gravels, a common source of mineral aggregates, provide good, well-drained agricultural land and so have attracted considerable settlement activity throughout the millennia in which man has occupied this part of Britain. While these sand- and gravel-rich areas may contain a rich archaeological resource, since this is buried, such a resource is not necessarily documented, with incorporation in the county’s Historic Environment Record, so there is an issue of the identification of the remains. The landscape itself has also considerable heritage value and the landform sequence contributes significantly to knowledge of environmental history and also an appreciation of the landscape. In any case, increasing an understanding of the archaeological resource through the planning process may typically provide for its excavation and preservation by record, but rarely does it provide for its actual preservation, which is the preferred option of the archaeological community (embodied within *Planning Policy Guidance* 16

(PPG 16). There is therefore a need to pre-empt the planning process and work with the sand and gravel extraction community to ensure that areas selected for such extraction do not include a significant archaeological resource.

1.1.4 English Heritage (EH) and the Aggregate Levy Sustainability Fund (ALSF) have sought to address the issue across the country by undertaking an extensive programme of research into areas where there is a potential sand and gravel mineral resource, coupled with research into areas of archaeological potential. The programme will result in the provision to the sand and gravel community of guidance on those areas that have enhanced potential for aggregate extraction, but which have a reduced archaeological potential.

1.2 CONTRACT BACKGROUND

1.2.1 As part of this ALSF programme, EH, acting on behalf of ALSF, invited Oxford Archaeology North (OA North) and the Department of Geography, University of Liverpool, to submit a joint tender for a programme of investigation into the potential impact of sand and gravel extraction on the archaeological resource of the Ribble Valley, in Lancashire and North Yorkshire (Fig 1). A project design was prepared by OA North and University of Liverpool Geography Department (2005) in accordance with a brief by English Heritage (2004), and following discussions with Peter Iles (Specialist Advisor (Archaeology) Lancashire County Council Environment Directorate), and Dr Susan Stallibrass, EH Scientific Advisor for the North West, and EH personnel. The project design provided for an investigation of the geology and geomorphology of potential areas of sand and gravel, undertaken by the Department of Geography, University of Liverpool, and for an investigation into the archaeological resource of the valley, undertaken by OA North. The project design was submitted in March 2005 and the project was commissioned in the same month.

1.3 THE RIBBLE VALLEY STUDY AREAS

1.3.1 The Ribble is the largest river system in Lancashire, covering some 1320km^2. The catchment extends from the headwaters of the Hodder in the Forest of Bowland to the headwaters of the Ribble in the western Yorkshire Dales. The current drainage network reflects the region’s glacial legacy, with aggressive erosion perhaps accentuated by glacial meltwaters capturing the Hodder headwaters at the expense of the formerly westward-draining Loud Valley, and the Ribble headwaters at the expense of the eastward-draining Aire (Wharfdale) (Harvey 1985; 1997) (Fig 2). Carboniferous Limestones in the Ribble Valley, Carboniferous coal measures in the Calder Valley, and Carboniferous sandstones and gritstones in the Hodder Valley form the bedrock geology of the catchment headwaters (BGS 1991). Downstream the drainage basin is for the most part underlain by Carboniferous sandstone, gritstone and limestone before the Ribble flows across Permian and Triassic sandstones in the Lancashire lowlands downstream of Ribchester.

1.3.2 The study areas were selected so as to concentrate on areas of greatest soft aggregate (sand and gravel) mineral potential, to follow on from the *Lancashire Minerals and Waste Local Plan* (LCC 2006), which targeted the Post-Glacial river terraces of the Ribble as a principal Area of Search. The present study defined two areas, the first comprising the river terraces of the Lower Ribble, between Preston and Sawley, and the second a substantially smaller area, to examine the terraces of the Upper Ribble, to the south of Settle, North Yorkshire (Fig 1).

1.3.3 ***Proposals for a Variation to the study area:*** once the programme was underway it became clear that the region included other areas and types of potential mineral aggregate. The project design (2005) provided only for areas of potential sand and gravel mineral within the region, and the study areas were defined accordingly. The landbank provision for crushed rock mineral aggregate is of greater duration than that for reserves of sand and gravel mineral (LCC 2006); furthermore, utilisation of new areas for crushed rock is typically achieved by expansion of existing sites. Consultation with the North Yorkshire County Council Minerals Officer (Chris Jarvis) and the North Yorkshire County Archaeologist revealed, however, that the *North Yorkshire County Council Minerals Plan* (1997) included a large area of search for crushed rock mineral aggregate. The reason for the discrepancy is that, in Craven District and the Yorkshire Dales National Park, hard aggregate, particularly magnesian limestone, is the dominant local mineral aggregate extracted. At present, the worked sources of aggregate are all limestone quarries within the Yorkshire Dales National Park, but it is North Yorkshire County Council and Yorkshire Dales National Park Authority policy to discourage further extraction of minerals in the National Park, and any applications for new quarries or extensions to existing quarries within the National Park will be rejected. In place of that, the *Minerals Plan* (NYCC 1997) has identified a search area for aggregate extraction between Long Preston and Skipton, bordered to the north by the National Park boundary and to the south by the Lancashire County boundary. The geology of this area is predominantly of Carboniferous mudstones and limestones (NYCC 1997), of which the mudstones have no potential for mineral extraction, but includes areas of limestone which have considerable mineral potential. It is inevitable that, as the existing quarries hit their planning boundaries, there will be a move to new quarry sites outside the National Park, which have good road communications, appropriate mineral reserves, and these will inevitably be within the *Minerals Plan* (NYCC 1997) Area of Search.

1.3.4 This project has focused on the sand and gravel aggregate, because that is the current need in Lancashire, but for other areas within the region, particularly the Craven lowlands, crushed rock is the principal source of aggregate. Accepting this aspect of local mineral extraction and the defined Area of Search in the *North Yorkshire County Council Minerals Plan* (NYCC 1997), there was a recognised need to extend the area of study for the present project to include other areas of potential aggregate extraction, particularly hard geology sources. As a consequence of this, a variation was proposed to extend the study area of the *Ribble Valley ALSF Aggregate Extraction Project* to encompass the *North Yorkshire County Council Minerals Plan* Area of Search (NYCC 1997), which would have encompassed an area between Skipton and Long Preston. In the event, the funding for a variation was not available in 2006/7 but there was some possibility that the funding would become available in 2007/8. In the meanwhile, analysis of the Upper Ribble dataset has been undertaken as far as possible, but not so as to require reworking if a variation is approved.

1.3.5 ***Remit of Present Report:*** while extensive work has been undertaken on the areas of soft aggregate in North Yorkshire, it was recognised that this study is substantially incomplete if it does not incorporate the areas identified by the *North Yorkshire County Council Minerals Plan* (NYCC 1997). It was therefore agreed with English Heritage that the work on the Upper Ribble should not be reported on at this stage, and that instead this should await the decision on funding in 2007/8. The present report, therefore, examines the archaeology and geology of the Lower Ribble study area in Lancashire, but also examines the sand and gravel mineral potential over a broader area to highlight potential zones of mineral and to inform future research of this nature within the wider region.

1.4 AIMS OF THE PROJECT

1.4.1 The Ribble Valley ALSF Aggregate Extraction Project has provided baseline data to assess the potential impact of aggregate extraction in the Lower Ribble Valley upon the archaeological and palaeoenvironmental resource, in accordance with Objective 2 of the Aggregates Levy Sustainability Fund (English Heritage 2005a). The following aims, defined in the *Project Design* (OA North and University of Liverpool 2005), have provided the foundations for the present project:

- to produce data that contributes to the needs of both planners, the minerals industry, and curators, and the archaeological community at large;
- to improve understanding of the quality, quantity and distribution of sand and gravel mineral aggregate within the region;
- to establish the effect that extraction has had and may continue to have on the archaeological and palaeoenvironmental resource;
- to enable a better understanding of the archaeological resource within the archaeological community and amongst the stakeholders;
- to allow better working practices to be developed, facilitating interaction and understanding between archaeologists and other professionals.

1.5 OBJECTIVES

1.5.1 The Ribble Valley ALSF Aggregate Extraction Project has highlighted those areas that are most likely to be affected by short-term proposals for aggregate and sand extraction, as defined by the *Lancashire Minerals and Waste Local Plan* (LCC 2006; Entec UK Ltd 2005; Geoplan Ltd 2006) mineral assessments, and also long-term potential for extraction, as determined by geological constraints. The following objectives, defined in the *Project Design* (OA North and University of Liverpool 2005), have served as the basis for the present project:

i) to collate, within a GIS, all available data on past, current and future aggregate extraction within the Ribble Valley, including British Geological Survey BritPits data and the Directory of Mines (BGS), Lancashire County Council (LCC) or Regional Aggregate Working Party (RAWP) sources;

ii) to produce a GIS of the aggregate resources within the Ribble Valley, drawing upon BGS maps, the LCC-commissioned aggregate survey, and published and unpublished academic geomorphological and geological mapping;

iii) to assess the character and condition of the archaeological resource;

iv) to enhance the Lancashire HER by means of documentary and secondary sources, and by linking into the Environment Agency (www.environment-agency.gov.uk/subjects/conservation/) and National Rivers Authority historic environment databases, the *Historic Landscape Characterisation for Lancashire* (Ede and Darlington 2002), and the *Countryside Agency Joint Character Area Map* for the North West region (Countryside Agency 2005);

v) to undertake a comprehensive GIS-based survey of the late Quaternary and Holocene geomorphology, using a combination of field survey and LiDAR elevation data, and, expanding on previous work, thereby identify and clarify the fluvial and glaciofluvial landform sequence within the Ribble;

vi) to undertake an exhaustive survey of published and unpublished archaeological, geoarchaeological, palaeoecological and geomorphological research to produce a greatly enhanced GIS database;

vii) to use LiDAR, aerial photography and other (Landsat) remote sensing sources to identify palaeochannels and other potential palaeoenvironmental archives;

viii) to examine the potential impact upon the archaeological and palaeoenvironmental resource of changes to the ground water levels, caused by aggregate extraction or other similar intrusions into the landscape;

ix) to undertake the modelling of surface and ground water levels and quality in response to scenarios of aggregate extraction, integrated river basin management, and climate change, with a view to quantifying the impact on the proven and potential archaeological;.

x) to identify research priorities for the future and highlight areas of urgency for research owing to threats from future aggregate extraction, changes in surface and ground water levels, and land use change;

xi) to create a Research Agenda for the Lower Ribble Valley, establishing the known resource, clear *lacunae* in the dataset, and research questions that might address these;

xii) to extend the outreach of the project to the stakeholders, and promote an understanding of the archaeological and environmental potential of the region and also the potential threats to the resource of continued aggregate extraction.

1.6 STRUCTURE OF THE REPORT

1.6.1 This report presents the results of the survey into the archaeology of the Lower Ribble study area only. The spatial coverage for the geological and geomorphological research is broader in scope to place the environmental history and the sand and gravel mineral resource in this regional context. The results of the work on the Upper Ribble will be submitted as a separate report and, subject to the commissioning of a variation to the present project, will embrace crushed rock aggregates of the Craven District as well as the sand and gravel.

1.6.2 This report examines the geology and geomorphology of the areas in relation to its archaeological resource. It opens with a background section (*Section 2*) which presents the wider geological and geomorphological context of the Ribble Valley and examines the archaeological and palaeoenvironmental context for the present study.

1.6.3 The methodology (*Section 3*) presents the traditional and new techniques that have been applied to examine the development of the terraces and to identify and characterise the archaeological resource. In particular, it highlights the value of the use of LiDAR, NextMAP and the GIS analysis. An assessment of the potential of all the archaeological and geological techniques is then made (*Section 4*), examining what has been learnt about the efficacy of such techniques in the course of the project. A series of recommendations is offered, which provide guidance on what techniques would be most appropriate if a similar study was enacted elsewhere in the North West.

1.6.4 ***Results:*** the results of the study are presented in *Sections 5-8*. *Section 5* examines the glacial and fluvial history of the valley in the light of the present work. The following section (*Section 6*) examines the distribution of the archaeological resource and examines the extent to which it is a real distribution of archaeological activity or a product of the differential archaeological investigations that have been undertaken in the valley. In the light of this, it presents a distribution of the archaeology based on an enhanced Historic Landscape Characterisation (HLC), which highlights both the actual observed resource and the archaeological potential.

1.6.5 *Section 7* highlights the sand and gravel reserves that have the greatest potential for extraction, and therefore the areas that present the greatest threat to the archaeological resource. *Section 8* presents the results of modelling changes to the valley floor as a result of present day and future fluvial erosion and deposition.

1.6.6 ***Conclusions:*** in *Section 9* the threats from fluvial erosion and aggregate extraction are considered in terms of areas of archaeological potential, examining the extent to which areas identified for potential extraction will have an impact on areas of known archaeology or areas of archaeological potential. The study examines the extent to which late fluvial deposition has buried and obscured archaeological remains, and highlights the risk that deep extraction will disturb as yet unidentified deeply buried archaeological deposits. Following on from this, *Section 10* makes recommendations for managing the risk to the archaeology, and highlights preferred options, including further research and mitigation.

2. BACKGROUND

2.1 RIBBLE TOPOGRAPHY – COUNTRYSIDE CHARACTER AREAS

2.1.1 The former Countryside Agency (now Natural England) has divided England into 159 ‘Joint Character Areas’ which represent zones of distinctively similar landscape character. Each area has a report which outlines the influences that determine the character of the landscape. The Ribble Valley catchment takes in six of these character areas (Fig 3) (Countryside Commission 1998).

2.1.2 ***The Bowland Fells***: this is a large-scale sweeping landform, cut by narrow wooded valleys and discrete cloughs that drain the moorland heights, creating a mosaic of woodland, unimproved meadows, pasture, marshes and streams. There are expanses of heather moorland and blanket bog with areas of reclaimed moorland pasture, enclosed by drystone walls at their edges. The exposed moorland tops are connected to the fertile river valleys by steeply sloping escarpments. Settlements are scattered villages and isolated farms, construction in stone dominating the building style.

2.1.3 ***Bowland Fringe and Pendle Hill*****:** this is a generally undulating landscape with local river valleys creating variations in topography, along with upland features including Longridge Fell, Beacon Fell and Pendle Hill. Limestone outcrops are common features of the Ribble and Hodder Valleys. Meandering rivers, commonly lined by trees, and dotted with oxbow lakes, are prominent in a predominantly pastoral landscape.

2.1.4 The land has undergone much in the way of improvement for dairy and livestock farming. Most grazing occurs in the lush fields of the river valley bottoms, with some grazing at higher altitudes. River bodies include the Calder, Ribble, Hodder, and the Wyre. There is semi-natural woodland, much of which is Designated Ancient Woodland, on the valley bottoms and ridges. The main settlement pattern is one of small villages, hamlets and scattered farmsteads interconnected by winding country lanes, often hedge-lined.

2.1.5 ***Lancashire and Amoundernesss Plains:*** this is a relatively flat area of gently rolling lowlands punctuated by occasional isolated hills. It is a large-scale agricultural landscape with a patchwork of pasture and arable fields with areas of woodland. It includes areas of reclaimed land, many of the fields have ponds, and drains and dykes are characteristic of the lands to the west, where there are also remnants of lowland mires and mosses. The river estuary heads are often areas of salt marsh. The pattern of lanes and tracks is more regular, taking on a rectilinear pattern, and there is a much lower occurrence of hedgeline or fencing along these transport routes in comparison with Bowland. The buildings are predominantly isolated brick farmsteads in the rural areas, with major settlements along the coasts, often comprising former Victorian seaside resorts.

2.1.6 ***Lancashire Valleys***: the broad valley of the River Calder and its tributaries runs north-east/south-west between the backdrop of Pendle Hill and the southern Pennines. The southern part of the area has an intensely urban character due to the post-industrial expansion of the towns of Blackburn, Burnley and Accrington. The industrial heritage of the area is strongly represented in the architectural styles, the main industries being cotton weaving and textiles. Many mill buildings, ponds and lodges remain as a legacy of the industrial heritage. The industry required enhanced transport routes and the area contains the Leeds-Liverpool Canal, the Preston to Colne rail link and the M65 motorway, spanning the steady and changing need from the late eighteenth century to the present day. Further north, Victorian stone buildings sit in the landscape, along with large country houses, often with associated parks. The agricultural land has been subject to a degree of fragmentation as a result of industrial development and associated urban expansion in the area. The field boundaries are markedly more regular to the west than the east and woodland is mainly limited to cloughs on the valley sides.

2.1.7 ***South Pennines*****:** this is a large-scale sweeping landform with an open character created by exposed gritstone moors at an altitude of 400-50m, deeply trenched by narrow valleys and wooded cloughs, with mixed moorland and blanket bog, and enclosed pasture at lower elevations enclosed by drystone walls. There are valuable wildlife habitats on the open moorland and moorland fringe, including semi-natural boggy mires, acid flashes and wooded cloughs, and many reservoirs throughout the area. Settlement is concentrated along the valley bottoms, with stone being favoured over brick; less dense settlement extends along the valley sides. The area has seen incongruous developments, such as windfarms, transmission masts, and overhead power lines, as well as extraction industries exploiting sandstone, gritstone and clay quarries around the fringes of the area.

2.1.8 ***Yorkshire Dales***: this is a large-scale upland landscape of high, exposed moorland dissected by deep dales. The area contrasts with the wild open moor and the sheltered dales, each with a character of its own. Agricultural usage is limited, given the high altitude and the relatively poor climate. The south and west parts are formed of limestone, with cave systems, outcrops, gills, gorges and pavements. The moors are heather or extensive blanket bogs on plateaux, with rough grazing on the upper slopes. The dale sides have more permanent pasture, and hayfields are present in the dale bottoms in the most fertile areas. Woodland is limited and mainly confined to villages and farmsteads, clumping around stream sides and steep slopes. Ancient Woodland tends to be located on steep gill and dale sides.

2.1.9 *The River Ribble Catchment Flood Management Plan* (Environment Agency 2006) was consulted, as were the *Water Framework Directive* (European Commission 2007) and the *Ribble Pilot Characterisation Report* (Environment Agency 2005). Again, a broad historic pattern of land use could be determined, as well as current information regarding the natural environment and legislation. The HLC was used to provide a spatial framework for the GIS analysis (*Section 6.4*) and to incorporate the enhanced documentary information contained within a gazetteer.

2.2 THE GEOLOGY OF THE RIBBLE BASIN

2.2.1 ***The Basin:*** the drainage basin or catchment of the River Ribble covers some 1320km^2 and comprises four major headwater tributaries: the Upper Ribble (439km^2); the Hodder (255km^2); the Calder (32 km^2); and the Darwen (130km^2)

(Fig 2). The Upper Ribble rises in the north Pennines, in the Yorkshire Dales National Park, creating a watershed between the Ribble, Aire, Wharfe, Ure and Dent, with a maximum elevation of 692m. The Hodder flows south out of the Forest of Bowland Area of Outstanding Natural Beauty (AONB), rising on the Bowland Fells and has a maximum elevation of 542m. The Calder rises in the west Pennines moors in the former industrial regions around Burnley, from a high point of 556m. The Darwen rises in the lower reaches of the west Pennines moors around Blackburn and has a maximum elevation of 402m. The Ribble flows into the Irish Sea *c*15km downstream from Preston, with a narrow flute-shaped estuary confined to the north by the rise up the Kirkham end moraine (Gresswell 1967a) and to the south by the low-level raised ground that forms the northern edge of the Late-Glacial and Holocene lacustrine basin of Martin Mere (Middleton *et al* forthcoming). The Ribble is tidal upstream as far as Preston, and in the past has sustained docks that required regular maintenance to allow the passage of ships, but since the decline of the docks and the cessation of dredging sand banks have formed at the mouth of the Ribble. The Hodder, Calder and Upper Ribble tributaries join some 35km from the coast at a marked reduction in gradient of the fluvial system, and enter a meandering reach that extends to the coast at a relatively low gradient falling 1m per km over the 35km.

2.2.2 ***Geology:*** the majority of the Ribble basin is underlain by Carboniferous strata deposited in a large basin during Carboniferous times, 290–354 million years ago (Fig 4). The oldest rocks that crop out in the Ribble basin are Silurian and Ordovician siltstone and mudstones in the Upper Ribble Valley around Settle. During the Carboniferous period a major rise in sea level produced marine conditions that covered almost all of England and Wales, encouraging the deposition of limestone during the Dinantian. During the late Carboniferous period a combination of a fall in sea level and basin infill produced a thick sequence of sandstones, the Millstone Grit Namurian strata which underlies the Bowland Fells and Pendle Hill. To the south of the study area, the Westphalian strata reflect the dense forests that grew on these Upper Carboniferous low-lying deltas forming the Coal Measures (BGS 1991). Towards the end of the Carboniferous period, the major phase of mountain building, called the Variscan Orogeny, folded and deformed these strata, producing the Pendle and Pennines monocline. In Permian times, desert conditions prevailed, with Britain lying near the Equator, and sandstones were formed from desert sand dunes. The Permo-Triassic subsidence produced a large basin that extended across lowland Cheshire and the Irish Sea, within which was a large semi-arid river system that deposited thick sequences of fluvial and aeolian sandstones. During the late Triassic period, rising water levels encouraged the deposition of extensive mudstones (*ibid*).

2.2.3 ***Geomorphology:*** in the Lower Ribble Valley, the solid geology is buried beneath thick sequences of Pleistocene deposits, mostly lain down during the last glaciation, the Devensian glaciation of Great Britain, at 75,000 to 11,500 years ago (Johnson 1985). The Ribble basin has attracted little recent attention from researchers with interests in Pleistocene history, compared to the surrounding regions of the Lake District, the Cheshire Plain and the adjacent Pennine uplands (Rose and Letzer 1977; Johnson 1985; Mitchell 1991; Glasser and Huddart 2002; Worsley 2005). The dominant land-forming processes of the last 2.5 million years have been of glacial origin. The region has probably been glaciated on several occasions during these years, with the bulk of the uninterrupted evidence for this from the isotope stratigraphy in marine sediment (Shackleton *et al* 1995). However, much of the evidence for the previous glaciation in the North West has been removed by the ice advances of the Devensian glaciation.

2.2.4 The ice that advanced to cover north-west England originated in centres in Scotland, the Lake District and the northern Pennines, and moved southwards through the Cheshire and Shropshire lowlands, reaching maximum limits near Wolverhampton. Much of the research undertaken on the glaciations of Lancashire date to late nineteenth century, when Binney (1852) and De Rance (1877a) described the coastal exposures near Blackpool. Further research accompanied the various maps and memoirs of the British Geological Survey (BGS) (Wilson and Evans 1990; Aitkenhead *et al* 1992). The most substantial geomorphic feature on the lowland plain of Lancashire is the Kirkham end moraine complex (Gresswell 1967a), which formed an arc of low former ice-marginal hills between Preston and the coast at Blackpool. Much of our understanding of the glaciation of Lancashire still relies on the work of Binney (1852) and De Rance (1877b); however, parts of the region have benefited from more recent evaluation (Crofts 2005). The area, however, is a potentially fertile region for renewed research, particularly given current views on the dynamic nature of ice stream behaviour throughout the Devensian (eg Bowen *et al* 2002) and during the retreat from the last glacial maximum (eg Thomas and Chiverrell forthcoming).

2.2.5 The rockhead or top of the solid geology in the Ribble Valley is some 20-25m below Ordnance Datum (OD), buried by a sediment fill that is in places over 50-60m in thickness. The major rivers of the Lancashire sector of north-west England, the Mersey, Ribble, Wyre and Lune, have undergone a similar sequence of late Pleistocene and Holocene development (Harvey 1985; 1997). They were heavily affected by glacial activity regularly during the Pleistocene, and their lower reaches are incised into the deposits of the last glaciation, the Devensian, and the upland upper reaches were also sculpted by ice (Johnson 1985). Borehole evidence shows that the rivers followed valley systems that existed before glaciation, but there is also evidence for glacially-induced drainage alteration and for the presence of buried palaeo-valleys shown in variations in the depth of the rockhead. Throughout the Post-Glacial period the fluvial system has responded to a multiplicity of external drivers and internal controls, with land use and climate, in particular, held to be important factors controlling the evolution of the river systems. Initially, during the Post-Glacial period, cold-stage processes led to the remobilisation of glacial deposits down-slope through solifluction slope processes and the snow-melt pulsed rivers were choked with sediment with aggrading braided or single-thread gravel-bedded channels. With vegetation and soil development, the landscape would have stabilised, reducing sediment availability encouraging incision and a single channel form. However, Lancashire experienced fairly major variations in base-level during the early Holocene, owing to sea-level change driven by a combination of eustatic and glacioisostatic factors, which would have been a fairly significant driver of the fluvial regime during late glacial and Holocene times (Johnson 1985) (Fig 5).

2.2.6 Through the Holocene, the climate has affected rivers over varying time-scales, ranging from switches in long-term hydroclimate (wet and dry) to the incidence of high-magnitude rainfall events inducing floods on much shorter timescales (Chiverrell *et al* 2006). From the Neolithic period onwards, evidence for human presence gradually increases in visibility in both archaeological and palaeoecological records, with more long-lived and/or substantial woodland clearances during Bronze Age, and particularly from the late Iron Age onwards. These changes have been linked directly with hillslope gullying in the uplands (Harvey and Renwick 1987; Chiverrell *et al* 2006), and mooted as a significant driver of increased sediment supply to lowland river systems (Harvey 1997; Chiverrell *et al* 2006). The sediment transmission behaviour of the fluvial system is also very important, moderating the response to external drivers like climatic changes and anthropogenic impacts, and their influence on and propagation through local-scale cycles of erosion, sediment supply, storage and remobilisation between the headwaters and the coast (*ibid*).

2.2.7 The relative sea level trend for central Lancashire is characterised by early isostatic rebound and subsequent eustatic sea level rise. However, most of the direct understanding of sea level is from the Holocene, with relatively little evidence preserved in the way of Late-Glacial marine features or sea-level index points. For the Holocene, extensive research by Tooley and co-workers has identified that the marine inundation of Morecambe Bay probably commenced 10,500 years ago, with relative sea level at approximately –17m OD (Tooley 1974; 1978; Huddart *et al* 1977). Eleven marine transgressive stages were identified by Tooley from the Holocene stratigraphy and dunes in the area of Lytham (Fig 5). With additional data, 28 index points were used by Zong and Tooley (1996) to produce a time-altitude plot of relative sea level for Morecambe Bay (Fig 6). The Lancashire data have also been incorporated within Post-Glacial rebound models for this region of the British Isles, with the most recent refinements by Peltier *et al* (2002) and Shennan *et al* (2006) showing rapid rise in relative sea level to *c* 1.5m above OD around 6500 years ago, and a fluctuating sea-level fall to current levels over the last 5000 years. These models, however, are still constrained by the limitations of present knowledge with regard to the dimensions of the Irish and Irish Sea ice sheets, the rates of ice retreat across the Irish Sea, and the behaviour of differing ice-streams during deglaciation from the last glacial maximum. Varying sea levels clearly provide differing base levels to which rivers grade, and so have much affected the development of the Ribble and other rivers in Lancashire, for reaches that currently grade to sea level. The headwater reaches which grade to bedrock-controlled nick-points would be less affected by these changes.

2.2.8 The objectives of this study were to improve an understanding of the geomorphology and late Pleistocene development of the Ribble Basin, partly driven by an ambition to improve understanding of the distribution of sand and gravel reserves, but also to understand the area’s geoarchaeological heritage. Previous research on the fluvial landforms and landform development in north-west England is somewhat limited, as is shown by the national-scale database compiled by Macklin and co-workers (Macklin and Lewin 1993; Lewin *et al* 2005; Macklin *et al* 2005; Johnstone *et al* 2006). The upland reaches of the Hodder and the Lune have received considerable attention, focusing upon hillslope processes and landform development during the Holocene, reviewed in

Harvey (1997) and Chiverrell *et al* (forthcoming). The River Dane, in Cheshire, part of the Mersey/Weaver basin, has also received some attention, and Chiti (2004) has examined the fluvial development of the Lower Ribble. However, an understanding of the broad-scale Post-Glacial landform development within these river systems is somewhat lacking and is not underpinned by comprehensive geochronological research; this understanding lags behind that available for adjacent regions, for example the north-east of England. This study attempts to redress this, with a clear focus on the fluvial development of the entire Ribble basin.

2.3 PREHISTORIC ARCHAEOLOGY AND PALAEOENVIRONMENT

2.3.1 ***Upper Palaeolithic Period (11,000-8000 BC):*** the 'Old Stone Age', the time of the earliest stone-tool-using cultures, spans the first settlement of Britain from the middle to the end of the Pleistocene era, between 500,000 and *c*8-10,000 years ago. During this period at least six glacial cycles occurred, until the end of the last great Ice Age, *c*10,000 years ago (Gresswell 1967b). It is evident that the occupation of the North West was dependent upon the cycles of glaciation, and the region was essentially an unoccupied icy waste during each glacial period. As the ice retreated and the climate became warmer in the Late Devensian interstadial, the vegetation on the drier land was an open birch, juniper and willow scrub with a rich herbaceous flora. This was ultimately replaced by more open grassland with less stable soil conditions as the climate became colder (Middleton *et al* 1995; Hodgson and Brennand 2006). An early undated pollen study by Pigott and Pigott (1963) from Malham Tarn shows that sedimentation started in the Late Devensian and records a temporary amelioration of the climate in Late Devensian II, when a community of juniper with a rich assemblage of herbaceous plants grew on the limestone areas.

2.3.2 The earliest evidence for human activity in the region all falls into the late Upper Palaeolithic date range (*c*16,000-8000 BC). The most famous find from Lancashire was that of an elk at Poulton-le-Fylde in 1970 (Hallam *et al* 1973), in peat, the body having flint points embedded in its leg and ribs, indicating that human hunting groups were present in the area. This has been dated to 13,417-11,769 cal BC (12,400±300BP; OxA-1500; Jacobi *et al* 1986), although it has been suggested that the sample was contaminated and that the date may be flawed (Middleton *et al* 1995). Elk have been found elsewhere, at Carnforth quarry, Lancashire, where extraction works revealed an antler of the *Megaloceros* or Giant Antlered Elk in 1973, a species which was known to be extinct by 8000 BC (Young 2002). At Victoria Cave, Settle, North Yorkshire, near the source of the Ribble, there is a repeated, albeit extensive, use of the cave from this time onwards (LUAU 1995a; Chamberlain and Williams 2001) (Figs 7, 8).

2.3.3 ***Mesolithic period (8000-4000 BC):*** the landscape during the Mesolithic period was largely wooded, the birch woods of the early Holocene (Flandrian) being replaced by dense hazel woods with pine, before a mixed deciduous forest developed. Towards the end of the period there is evidence of small-scale temporary clearances in this woodland (Hibbert *et al* 1971; Cowell and Innes 1994).

2.3.4 There is more information regarding settlement patterns and human society in Britain as a whole at this time. However, there is a lack of physical remains and the record is dominated by either individual isolated artefact finds or scatters of lithic material, of which the latter is taken as being the best indicator of settlement (Middleton *et al* 1995). The assemblages of Mesolithic material from Lancashire are found in both upland and lowland areas (Fig 8).

2.3.5 ***The Upland Evidence:*** the earliest records of flint artefacts are from those upland areas where the exploitation and erosion of peat deposits has exposed prehistoric ground surfaces. This, in conjunction with an interest in artefact collecting during the later nineteenth and into the twentieth centuries, has resulted in the recovery of thousands of flint tools of both earlier and later Mesolithic tool types and technologies (Hallam nd).

2.3.6 The central Pennine uplands of Lancashire and Yorkshire have provided one of the greatest concentrations of Mesolithic sites in the country (Fig 8) (Hodgson and Brennand 2006). Evidence of activity has been found on the western edge of the Lancashire Pennines, for example on Saddleworth Moor (Jacobi *et al* 1976). Further west, on the Anglezarke and Rivington Moors, the erosion of the peat caused by uncontrolled accidental or deliberate burning, drainage and other agents has led to the underlying mineral soils being exposed, and the recovery of extensive flint scatters (Howard-Davis 1996, 138-43; OA North in prep). One of the more significant sites was an early Mesolithic working floor at Rushy Brow, Anglezarke, tentatively dated to the eighth millennium BC. The assemblage here comprised over 400 fragments of flint and chert, with a small posthole structure, perhaps a wind break (Howard-Davis 1996). In contrast to these, the Forest of Bowland has so far revealed relatively few Mesolithic finds (OA North in prep; LUAU 1997a). The pollen evidence suggests that at this time the upland landscape was largely wooded, but with temporary clearance evidence, charcoal suggesting that the vegetation was being burnt (OA North in prep). This vegetation cover is substantiated by other studies from the region (for example Barnes 1975; Tooley 1978).

2.3.7 ***The Lowland Evidence:*** the palaeoenvironmental evidence for activity in the lowland zone of the Ribble Valley is limited (Fig 9). There is some evidence for the Mesolithic environment at Lower Brockholes (Chiti 2004), where a wooded landscape with alder growing close to the Ribble was recorded, but with some clearance phases related to a substantial peak in charcoal particles.

2.3.8 In the Upper Ribble Valley, pollen diagrams from five sites in the Lowland Craven District of Yorkshire (Bartley *et al* 1990) indicate that much of the area would have been covered by birch woods, but the subsequent invasion by hazel, pine and the broad-leaved trees *c* 9155-8455 cal BC differed from site to site. The next major change to the vegetation took place with the rapid expansion of alder, which was dated to 6595-6261 cal BC (7590±70 BP; SRR-2487) at White Moss, although at other sites pine seems to have remained important for longer, perhaps reflecting differing geology and topography (Bartley *et al*1990). Unlike the lowland mires to the west, there is no evidence of burning in the Mesolithic period from Lowland Craven (Bartley *et al* 1990), although on the higher ground at Malham Tarn (Pigott and Pigott 1963; Fig 9) and Great Close Pasture (Smith 1986) there is evidence for burning associated with clearance activity. At Great

Close Pasture, in particular, this clearance is related to the finds of abundant Mesolithic artefacts in the area.

2.3.9 Evidence of Mesolithic activity has been recovered from lowland, coastal and estuarine sites of Lancashire over the last 20 years, as a result of systematic surveys (Cowell 1991; 1992; Cowell and Innes 1994; Middleton *et al* 1995). In addition, there has been a general increase in commercial archaeological projects, which have occasionally revealed Mesolithic material.

2.3.10 Cherry (Cherry and Cherry 2000) has suggested that there may be a link between Mesolithic sites in eastern Cumbria and in Craven as a result of the presence of chalk flint at Levens Park, south Cumbria. This would suggest the use of the Lune and Wenning river valleys as both communication and trade routes, as well as for settlement sites. The Lune and Ribble Valleys would both have provided natural corridors and there is evidence indicating Mesolithic activity along them. Halton Park and the river terrace at Caton have both yielded typologically late Mesolithic material along the Lune Valley, for instance (Middleton 1993; OA North 2006).

2.3.11 Along the Ribble Valley, the site of Marles Wood (Fig 10) has produced a substantial number of later Mesolithic flints (HER PRN2894; HER PRN1868; R Cowell *pers comm*). This major find was thought to be *in situ* but, given excessive disturbance by tree roots, no stratigraphic separation of individual episodes of flint working could be determined. Despite this lack of stratigraphy, it is evident that the site represents a considerable episode of activity, although whether it was a settlement or working site / temporary camp is unknown. In addition to the flints, a ‘spearhead and canoe fragment were found in 1942, at the bend in the river at the same depth in the gravel. It is reported that they were 15 feet below the bed of the Ribble, a depth which invites comparison with the lower gravels of the Preston Dock area’ (HER PRN1872). Stray surface finds could also be indicative of larger deposits which remain sealed below the alluvial deposits, in the earlier gravel terraces.

2.3.12 It would appear that the Mesolithic evidence, though only sparse within the study area, suggests that there is a pattern of land use based on estuaries and river valleys, in addition to activity in the uplands. While there is some similarity to the pattern of late Upper Palaeolithic settlement / activity, it is also evident that there was a substantial increase in activity and that this extended onto the adjacent uplands, albeit on a transient basis.

2.3.13 ***Neolithic period* (*4000-2000 BC*):** the Neolithic period provides considerable evidence for significant changes in society in Britain, which includes the emergence of social stratification and the increase in the archaeological record of evidence for elite groups. Ceremonial monuments, henges, stone circles and mortuary structures all appear and a gradual reduction in group mobility from the end of the Mesolithic period is evident, reflecting the gradual abandonment of a hunter-gatherer lifestyle and the establishment of more permanent settlements associated with the adoption of agriculture (Edmonds 1999). The first indicator would seem to be forest clearance; however, such activity is now considered to extend back into the Mesolithic period and perhaps relates to hunter-gatherer activities (Middleton *et al* 1995, 203). A more reliable indicator for agriculture is the appearance in the pollen record of cereals, approximately at the time of the elm decline, possible early cereals having been found at

Knowsley Park, Merseyside, dating to 4340-3970 cal BC (Cowell and Innes 1994, 148). Generally, a pattern of early clearances and early indicators of cereals is seen at coastal sites (Bradley 1978, 9) and would suggest that this was the primary context for early settlement.

2.3.14 ***Neolithic Palaeoenvironment of the Ribble Valley:*** regionally, there is a rich palaeoenvironmental record, although lowland sites are more frequent than those from the uplands. An extensive body of research from Lancashire (eg Barnes 1975; Tooley 1978; Middleton *et al* 1995; Howard-Davis 1996; Fig 9) demonstrates a regional pattern, episodes of temporary woodland clearance followed by regeneration. Early cereal cultivation is consistently present in the pollen record throughout the region, but becomes less frequent in later Neolithic records. In the Lower Ribble Valley the only record to date is from a buried palaeochannel at Lower Brockholes (Chiti 2004; Fig 9). The truncated pollen profile suggests that woodland dominated the landscape in the early Neolithic period before the site reflooded, possibly as a result of clearance in the catchment area (*ibid*).

2.3.15 In the Upper Ribble Valley, the elm decline has been dated to 4044-3537 cal BC (5010±110 BP; Birm-663) and 4222-3851 cal BC (5080±100 BP; Birm-665) at Eshton Tarn (SD 918 576) and White Moss (SD 792 546). However, the data suggest that levels of anthropogenic activity were variable at the two sites after the elm decline. At Eshton Tarn, temporary clearances are recorded, with the first major clearance dating to 2275-1691 cal BC (3600±100 BP; Birm-662) in the early Bronze Age (Bartley *et al* 1990). However, at White Moss (Fig 9) there is little evidence of anthropogenic activity until the early medieval period (*ibid*). The pollen evidence from Lowland Craven illustrates a more varied history than that from the lowlands of north Lancashire, south-west Lancashire, Greater Manchester and north Merseyside. This may reflect greater archaeological activity on the limestone surrounding the Upper Ribble than to the west of the Pennines.

2.3.16 ***Archaeological Resource:*** the main evidence for Neolithic settlement in the region is lithic scatters, and the distribution of these shows a pattern of land use around river valley bottoms and coastal lowlands (Middleton *et al* 1995) very much like the Mesolithic pattern, indicating some continuity of preferred areas, for example at Friar's Hill, Over Wyre, where the same sand island was exploited in the late Mesolithic and the early Neolithic periods (Middleton *et al* 1995, 204). There is a distinct change in the nature of the artefacts during the period, in particular the appearance of single-piece leaf-shaped arrowheads and polished stone axes. The pattern of stone axe finds tends to result from a combination of casual loss and ritual deposition (Bradley and Edmonds 1993), and where thin-section analysis has been undertaken, the majority in Lancashire originate from Great Langdale in Cumbria (Clough and Cummins 1988). As Middleton states 'the axes from Lancashire have a definite riverine and mossland distribution… It is now clear, however, that many of the axes must have been deposited deliberately and the rivers had a specific significance' (Middleton 1996, 38). A group of eight polished axes were found at Pilling Moss, and a pair were found at the Delph Reservoir on Bolton Moor (Fig 8).

2.3.17 The first use of pottery provides a new durable artefact in the archaeological record. Its movement has been attested by finds throughout the North West and, in particular, 'food vessels are found in the valley of the Aire, passing westward into the Ribble and Irwell drainages of Lancashire' (Raistrick 1939). At Portfield Camp, Whalley, excavations of a later Bronze Age / Iron Age hillfort also revealed a pair of truncated pits which contained nine sherds of Neolithic Grimston-style pottery, as well as flint-work and leaf arrowheads scattered across the site (Beswick and Coombs 1986). The indications would appear to demonstrate Neolithic settlement on the site of a natural promontory, which was subsequently used as a defensive feature. These Neolithic features, despite being severely truncated, can be likened to contemporary settlements found in the south of England (Middleton 1996).

2.3.18 A site at Pilling Moss produced an assemblage of flints on the eastern edge of the moss, on an area of well-drained gravel, surrounded by the heavy boulder clay that was much less suited to agricultural practices because of its inherent poor drainage. Indeed, the most likely places for the preservation of later prehistoric material are within the areas of river gravels, where the geological history indicates that they will be buried beneath fluvial deposition episodes. This can be demonstrated at the site of St Michaels, on the floodplain of the River Wyre (Fig 8), where Neolithic flints and pottery were discovered and a peat lens was dated to 4325-3966 cal BC (5286±80 BP; GX-17293) and 4316-3810 cal BC (5230±80 BP; GX-17294) (Middleton *et al* 1995, 58). Plant remains taken as indicators of settlement were buried beneath 2m of alluvium. They included pollen and macrofossil evidence, the former suggesting small-scale clearance of the local carr vegetation. A tentative identification of possible cereal pollen towards the top of the peat suggested cereal cultivation. The macrofossil evidence contained high values of charcoal throughout the profile, suggesting *in situ* burning (*ibid*).

2.3.19 The other significant change in the archaeological record is the first appearance of formal burial monuments, specifically long barrows and cairns. The evidence in Lancashire is sparse in comparison to neighbouring areas, but equally a systematic survey of monuments is lacking in Lancashire, particularly in upland areas. However, there are two examples of chambered cairns known, both on Anglezarke Moor, east of Chorley (Howard–Davis 1996).

2.3.20 The most well known of these is Pikestones, on the south-west-facing slope of the moor, a stone-constructed cairn over a burial chamber with a short passage leading to an external facade (Middleton 1996; Bullock 1958); however, much of the stone covering has now gone, leaving the cist free-standing. During a survey of Anglezarke in 1984, a round chambered cairn was found on the west-facing slope of the moor, which bears some similarities to the megalithic tombs of North Wales (Howard-Davis 1996, 145; Bron Y Isaf; Powell *et al* 1969, 125-6).

2.3.21 ***Bronze Age* (*2000-800 BC*)*:*** the Bronze Age was essentially a period of consolidation after the massive revolutionary upheavals of the Neolithic period. There was an expansion of forest clearance, which extended onto the marginal uplands, and a substantial increase in the number of identified settlement remains (OA North in prep). Many of these are within an upland context, in part reflecting the improved survival of archaeological remains within lands that have subsequently seen little exploitation.

2.3.22 ***Palaeoenvironment:*** regionally, there is a rich palaeoenvironmental record for the Bronze Age, although lowland sites are more frequent than those from the uplands. There is, however, little to distinguish the vegetation of the Bronze Age from that of the Neolithic period, with a continuing pattern of temporary woodland clearance episodes followed by regeneration. The only difference is that these episodes were possibly more marked and cereal cultivation less frequently recorded, perhaps reflecting a pastoral economy.

2.3.23 In the later Bronze and early Iron Ages, a low but consistent level of interference with the vegetation is recorded in the pollen diagrams from Fenton Cottage and Winmarleigh Moss, Lancashire (Middleton *et al* 1995; Wells *et al* 1997; Wells and Hodgkinson 2001; Fig 9). The tree pollen recorded in these diagrams suggests that although woodland dominated the landscape it was of a secondary character, alder and hazel dominating rather than oak and elm. However, at Briarfield Nurseries, Poulton-le-Fylde (SD 337 389), where a late Bronze Age human skull, dated to 1212-843 cal BC (2845±65; AA-28733), was discovered in peat, the pollen data suggest that there was a higher level of anthropogenic activity surrounding this site than at others in Lancashire (Huckerby 2001).

2.3.24 In contrast, in the Upper Ribble Valley the first major clearance was dated to 2275-1691 cal BC (3600±100 BP; Birm-662) in the early Bronze Age at Eshton Tarn. At this site the intensity of arable cultivation increased in the Middle Bronze Age, indicated by a rise in the values of cereal pollen, dated to 1626-1216 cal BC (3160±80 BP; SRR-2481). At this time the pollen record also suggests that the limestone grassland seen today formed (Bartley *et al* 1990). However, at White Moss, there is little evidence of anthropogenic activity until cal AD 353-772 (1470±100 BP; SRR-2488). In the Bronze Age, the history of the vegetation of Lowland Craven exhibits a greater difference between the Neolithic and Bronze Age than in the lowlands of north Lancashire, south-west Lancashire, Greater Manchester, or north Merseyside. This may reflect more intensive archaeological activity on the limestone surrounding the Upper Ribble than to the west of the Pennines.

2.3.25 The evidence for Bronze Age activity within the region is well documented, one of the most distinctive features in Lancashire being the large numbers of stray finds (Middleton 1996). These are distributed across the region, with clusters in the river at Preston (HER PRN296), a group of three found at Longridge (HER PRN2660, PRN147, PRN1789), and one at Broadgate, Preston (HER PRN101). This would seem to point to the probable importance of the Lune and Ribble Valleys as natural corridors (Middleton 1996).

2.3.26 ***Preston Docks:*** during the construction of Preston Docks (Fig 11), around 1885, several prehistoric finds were made. These included a bronze spearhead, two wooden dug-out canoes, and the skulls of approximately 24 humans (Dickson 1887) Along with these were the remains of skulls and antlers of 100 red deer, the skulls and horns of 43 wild cattle and some horse remains. The finds were located between 3.9m and 4.5m below the ground surface. A flint arrowhead was also found in the Edward Albert Dock (Middleton 1996). A similar deposit was found at Marles Wood, where a bronze spearhead and a fragment of wooden canoe were found about 5m into the river gravel (HER PRN1872; HER PRN1015).

2.3.27 The large number of animal remains from the dock could suggest two broad possibilities. Firstly, occupation and/or the processing of animals was occurring in the immediate vicinity, but it would appear that a second possibility must be considered: the whole assemblage from the dock is not of one period, and they were not stratigraphically distinct. The circumstances of discovery did not accurately locate spatial deposition patterns or other such data, as a modern excavation would. The long use of the River Ribble as a means of trade and transport is illustrated by these prehistoric finds, as well as those from Marles Wood. It is possible that Preston Docks may have been the final resting place of objects which had been washed downstream, suggesting that prehistoric deposits may be concentrated in the estuary areas and scattered along the valley bottoms.

2.3.28 In addition to this, a hoard of axes was found in the Ribble in the 1800s (Burgess 1968), and a bronze spear tip at Chatburn, at the confluence of the Chatburn Brook and the Ribble (HER PRN199). A second bronze spear was found at West Bradford (HER PRN308), and a bronze rapier at Bungerly Farm, south-east of Waddington (HER PRN0794).

2.3.29 ***Settlement Remains:*** the general pattern of finds and monuments suggests that a much wider use of the landscape was occurring. In particular, the uplands seem to have been exploited through the second millennium BC, a period when the pollen records from Forest of Bowland and Anglezarke show that there was an increase in human impact on the natural environment (OA North in prep). Although the evidence of upland settlement is not as extensive and widespread as it is from Cumbria, there are nevertheless reliable indicators of Bronze Age land improvement and farming within this zone. At Nicky Nook, on the western slopes of the Forest of Bowland, a relatively sizeable cairnfield on a gently sloping plateau has 57 randomly distributed clearance cairns (OA North in prep). There were no indicators of associated settlement, however, and it is probable that any domestic structures were wooden and have not survived as surface evidence.

2.3.30 At Anglezarke (Fig 11), there were also clearance cairns and a putative cairnfield on Stronstrey Bank, which is a very distinctive natural terrace, both elevated above the adjacent low-lying plain, and relatively flat (OA North in prep). It is thus comparable to western Cumbria, where such terraces invariably were covered in cairnfields (Quartermaine and Leech forthcoming). These most often reflect Bronze Age land improvement, and it is tempting to relate those at Anglezarke to a major clearance episode dated to the late Neolithic/early Bronze Age, identified at nearby Hurst Hill (Bain 1991; OA North in prep).

2.3.31 Settlement sites on the lowlands are again invariably defined by flint scatters, in part because the structural remains may not have been very substantial. At Bonds Farm, Pilling Moss (Fig 11), a Bronze Age artefact scatter was excavated (Edwards 1991), revealing a group of postholes and stakeholes, in no particularly discernible pattern. The implication is that this was a transient settlement, and the structures were little more than tents.

2.3.32 ***Funerary Remains (Fig 12):*** burial remains are well represented in the form of substantial cairns. Such cairns seem to have been placed on areas of waste land and often on high, prominent places with a wide vista. Notable examples are two round cairns on Winter Hill (Bu'lock *et al* 1960), which are on the cusp of the flat summit and have extensive north-facing vistas, and also a prominent round cairn (*c*15m diameter) at Cat Knot Well (SD 7216 5986), which is situated on the sky-line of the broad plateau of Hasgill Fell, Forest of Bowland (LUAU 1997a). Burial monuments of this period display considerable variation of form, and include a significant number of annular monuments, which ultimately evolved from the Neolithic stone circle. A classic example is the Bleasdale timber circle on the lower slopes of the Forest of Bowland near Chipping, which is a multi-phased funerary monument, dated approximately to 2200 BC (Varley 1938). It comprises an outer enclosure with a small circle of timber posts within, and to one side of it is a burial from which two urns and a cup were recovered. It is not known if the small timber circle was contemporary with the outer enclosure, or whether this was part of a later phase of activity.

2.3.33 Although the better examples are from the uplands, lowland contexts are also represented, but again usually on waste land. Within the study area, at Winckley Lowes, on the floodplain of the Ribble near the confluence of the Rivers Ribble, Hodder and Calder, were two cairns that have been investigated, one of which is possibly considered a glacial feature. The larger of the two, Winckley Lowes I, was an irregularly shaped bowl barrow surviving up to 2.5m high with a maximum diameter of 60m south-west/north-east by 35m south-east/north-west, constructed of earth and stones. The centre of the monument was subject to limited antiquarian investigation in 1894. Members of the local Stoneyhurst College located a primary burial consisting of a cairn of large stones beneath which was a human cremation lying on top of a thin layer of charcoal. Three secondary cremations were found nearby, one was accompanied by pieces of pottery and a flint scraper. A quantity of animal bone was also found cremated burial (HER PRN23711).

2.3.34 Burials are not exclusively in high-status monuments, and there are also finds of simple cremations, of which the most notable example from the study area was from Ribchester. There, excavations within the Roman extramural settlement revealed a truncated ditch that was dated to *c*1600 cal BC, and within the ditch were five in-urned cremations (Olivier 1981).

2.3.35 ***Bronze Age / Iron Age Transition:*** the end of the Bronze Age saw a change in the pattern of land use, and it seems that some of the upland areas were abandoned, with a move towards enclosed settlement. This can be seen at Portfield Camp (Fig 11), Whalley, where a defended enclosure has been dated to the later Bronze Age (Beswick and Coombes 1986). A hoard of Bronze Age artefacts, including a gold ring and bracelet, were found in the 1960s during the laying of a pipe across the enclosure (HER PRN1176). Further south-west, on the Ribble, are two definite (HER PRN12914, Fishwick Allotments; HER PRN1293, Frenchwood Knoll, east of the current Avenham Park) and four possible sites (HER PRN15239, Mete House Wood, Fishwick; HER PRN15240, Brockholes Wood; HER PRN15241, Bolton Wood; and HER PRN15242, Red Scar Wood). If these putative promontory forts are proved to be of later Bronze Age or early Iron Age date, then it would indicate concentrated occupation of the valley bottom during this transitional period.

2.3.36 Multi-proxy indicators from peat bogs throughout north-west England suggest that there was a sharp downturn in climatic conditions in the first millennium BC, with a significant expansion of the wetlands within the range of *c* 900-400 cal BC, both in the lowlands and the uplands (Middleton *et al* 1995, 196; OA

North in prep; Bain 1991). This is also the date range for the *Grenzhorizont* of Weber (1926, cited in Middleton *et al* 1995) and Granlund's RY4 (1932). This recurrence surface has been recorded in bog stratigraphy throughout Northern Europe and Turner (1981), in a review of the evidence, concluded that it was highly likely that climatic changes caused this horizon to form. The rapidly expanding mires would have severely restricted the area of land available for cultivation, perhaps causing a decrease in the population.

2.3.37 ***Iron Age:*** the climatic deterioration continued into the Iron Age. There was an abandonment of the upland settlements and clear evidence of woodland regeneration from the early Iron Age within the pollen sequences of the region, which is coupled with proxy climatic indicators, for example recurrence surfaces in peat bogs, that clearly indicate a deterioration in climatic conditions. However, there was also a corresponding recovery, with extensive clearance represented in the later Iron Age; arable cultivation is clearly recorded in the pollen diagram from Fenton Cottage (Fig 11), (Middleton *et al* 1995; Wells *et al* 1997) and also in one from an upland site at Fairsnape Fell in the Forest of Bowland (Mackay and Tallis 1994). There is a little data that record the palaeoenvironment of the later Iron Age in the Lower Ribble Valley, from pre-rampart buried soils at Ribchester (Buxton *et al* 2000, 21-3). There, local alder carr grew beside the river before two periods of major agriculture activity, the second episode being one of intensive cultivation prior to the construction of the earliest rampart.

2.3.38 The Upper Ribble Valley demonstrates considerable differences in the pollen record. At Eshton Tarn, there were continued high levels of anthropogenic activity, both of arable and pastoral farming, throughout the Iron Age, whereas at White Moss, to the west of the Ribble in Lowland Craven, there was little evidence of either clearance or arable cultivation (Bartley *et al* 1990).

2.3.39 ***Archaeological Evidence:*** the evidence for Iron Age activity in Lancashire is quite sparse, aerial surveys (Higham 1980) locating only a few sites. There are of course also a few classic hillfort sites, presumably resulting from the increasing competition for agriculturally viable land that had diminished as a result of the climatic decline. The most notable hillfort is that on Ingleborough, near the upper reaches of the Ribble. This is a single vallate fort established across the flat-topped summit of this 723m high mountain in the Yorkshire Dales (Figs 11, 13). The rampart comprises a gritstone wall between 3m and 5m thick, and survives to a maximum height of 3m. The single rampart indicates that it could rely on the very steep-sided, natural defences of the mountain. Internally, it has 20 stone-founded roundhouses that are between 5m and 8m in diameter (Bowden *et al* 1989).

2.3.40 Closer to the Ribble is the site of Castercliff (Fig 11), near Nelson, overlooking the Calder Valley, which is a small multivallate hillfort. It covers an oval plateau measuring approximately 115m by 76m, enclosed on all sides, except the north, by three rubble ramparts, each up to 1.5m high, situated on the slope of the hill, with an external ditch up to 1.5m deep in front of each. Limited excavation of the defences indicated that the inner rampart was revetted with stone and also timber-laced. Initially thought to have been constructed in the first century BC, it is now thought that the site was actually constructed during either the sixth or seventh centuries BC (Challis and Harding 1975; Williams 1993). Similarly, Portfield Camp, Whalley, may also have continued into the Iron Age (Haslegrove 1996).

2.3.41 ***Artefactual Evidence:*** much of the evidence for the Iron Age in the region derives from isolated finds. Iron Age-type metalwork has been found: a beaded torc in Rochdale; a sword and dagger from Warton; and a dagger scabbard preserved at Pilling Moss (Haslegrove 1996). The deposition of human bodies in mosses and bogs is also known from the period, bodies having been recorded from Pilling Moss (Fig 11), Red Moss, near Bolton and from Lindow Moss (Stead *et al* 1986).

2.3.42 There is an apparent contradiction between the dearth of confirmed Iron Age sites and the palaeoenvironmental evidence that indicates increased activity and forest clearance in the later Iron Age. In part this reflects the dearth of reliably dated excavations on potential sites, and that there is a corresponding reliance on the typological dating of surface features. There is a now accepted realisation that in the North West (Quartermaine and Leech forthcoming) there was considerable continuity of settlement from the Iron Age into the Roman period, and sites that have the typical characteristics of a Romano-British settlement may in fact have Iron Age origins. For instance, a rectilinear, complex enclosed settlement at Ingleton, near to the northern reaches of the Ribble, morphologically was a classic Romano-British settlement, and the dates confirm that it was occupied during much of the Roman period; however, the earliest date (88 cal BC-cal AD 66 (2010 ± 28 BP; KIA 22910) indicates that it had an Iron Age origin.

2.3.43 Similarly, at Duttons Farm, Lathom, the remains of four roundhouses, paddocks and boundary ditches range in date from 170 cal BC to cal AD 410 (Cowell 2003), indicating that the farmstead was occupied through the Iron Age and into the Romano-British period. These sites highlight continuity of form between the Iron Age and Romano-British periods, and demonstrate that there are few grounds for reliably discriminating between Iron Age and Romano-British settlements purely on the basis of form; there is therefore a need to redefine the chronology of the period on the basis of absolute dating.

2.4 ROMANO-BRITISH ARCHAEOLOGY AND PALAEOENVIRONMENT

2.4.1 The knowledge base and understanding of the Romano-British period is greater than that of any preceding period, reflecting in part the literary accounts of the peoples and places, ranging from ‘histories’ to inscriptions. A great deal of research in the north has focused on the Roman military and in particular the northern frontier system; the principal elements of this within the study area are the forts at Kirkham and Ribchester, and a military depot at Walton-le-Dale (Fig 14).

2.4.2 The establishment of key military sites dates back to the Governornship of Petilius Cerialis, from AD 71. Three temporary camps have been identified at Kirkham, succeeded by a small installation on the summit of the hill, perhaps a fortlet (Howard-Davis and Buxton 2000). This may have acted as a beacon to connect the Fylde Coast to Ribchester, via the river itself and the roads running along it. Kirkham was linked to the other forts in the Ribble Valley by a road running along the north bank of the river (Shotter 2004).

2.4.3 ***Ribchester:*** Ribchester (*Bremetenacum*), on the northern edge of the Ribble floodplain, has been known as a major Roman establishment since the writings of Leland, the sixteenth-century antiquarian (Figs 15, 16). It is famous for the discovery of a fine Roman cavalry parade helmet, now in the British Museum, and frequent excavations have taken place during the nineteenth and twentieth centuries (Edwards 2000). The number of archaeological interventions in Ribchester (about 110 excavations, evaluations, and watching briefs from 1811 to 2003) is probably greater than for anywhere else (Philpott 2006).

2.4.4 The Roman military presence here probably began during the campaigns of Petillius Cerialis in the early AD 70s (Shotter 1999; Buxton and Howard-Davis 2000). The site is well placed at the western end of one of the few major trans-Pennine routes (taking advantage of the natural river valley corridor), and sits at the junction with the north/south road, linking it to Lancaster. It overlooks a fording point on the river and is sited at what was the most easterly navigable point of the river. The first phase of the fort was of timber and turf construction, the rampart built on a corduroy foundation and incorporating a wooden gateway. The rampart was fronted by a double ditch, which was later replaced by a single ditch (Buxton and Howard-Davis 2000).

2.4.5 The renovation of the fort, probably in the late AD 70s or early 80s, was associated with the Agricolan campaigns. The rampart was extended and the inner ditch recut, with the immediate area cleaned and new buildings erected to the north. There was a possible builders' yard, which gave way to fences associated with stable waste and manure, and may represent external horse pickets (Buxton and Howard-Davis 2000).

2.4.6 The timber fort was demolished prior to its replacement in stone in the early second century. During this operation, the site was protected by a ditch. This was subsequently and rapidly backfilled with a large amount of organic refuse, including leatherworking waste, cavalry fittings and the bodies of horses. This material seems to have been derived from buildings which had been cleared out and demolished. The turf and timber rampart was flattened and a new rampart built to the north, while elsewhere it was refaced with stone (*ibid*). This stone fort remained in occupation until the end of the Roman period.

2.4.7 A road extended north-west from the fort towards Kirkham, along which were insubstantial structures that were later replaced by a stone building displaying some evidence for high status. Other large stone buildings were erected elsewhere in Ribchester at about the same time, and the extramural settlement was defined or defended by a substantial ditch. The end of this phase of activity seems to have occurred around AD 135, after which the large building was left to decay (Olivier 1981). Coin evidence suggests a winding down of activity in this part of Ribchester during the Antonine period, when the ditch of the stone fort was allowed to silt up and become overgrown, an action perhaps associated with the blocking of the west gate. The area excavated then fell into decline and was completely abandoned except for the disposal of refuse by the end of the second century. The preservation of artefacts and ecofacts by waterlogging in the excavated area has allowed for an unusually wide range of multidisciplinary studies which greatly enhanced the evidence for daily life, hygiene, diet and other important aspects, which are not often recovered on sites where preservation is poor (Buxton and Howard-Davis 2000).

2.4.8 ***Walton-le-Dale:*** the Roman military site of Walton-le-Dale was explored between 1947 and 1960 (Pickering 1957) (Fig 17), and more extensively in 1981-3 and 1996-7. These works revealed a complex and significant site which seems to be a depot with a very strong Roman military influence, characterised by the layout, function and nature of the structures and associated features, as well as the assemblage of finds (Gibbons *et al* forthcoming).

2.4.9 The coin evidence indicates a Roman presence at the site from the mid first century AD, based upon the discovery of a group of *aes* coins which are distinctive copies of Claudian coins and thought to have circulated during the mid-50s to mid-60s (Sutherland 1937). However, the first phase of Roman building has been assigned an early second-century date, comprising a wide road running through a complex of uniformly built timber buildings. There were some variations in the internal layout of these buildings and they contained evidence of hearths /fire boxes or pits (Gibbons *et al* forthcoming).

2.4.10 The site was redeveloped essentially to the same general layout but with the individual buildings increasing in size, with a more complex and permanent water supply being established (Buxton and Shotter 1996). A third phase of remodelling occurred during the mid Antonine period. The excavations revealed furnaces / fireboxes, but little evidence of industrial refuse or slag, so the precise nature of the industrial processes has not been resolved. There exists the possibility that this was a storage and distribution depot, and some of the buildings may have served as warehouses (*ibid*). The possibility that less durable goods were being constructed, such as rope or sail cloth or even shallow-draught boats, as well as the area being used as a port or harbour, cannot be discounted.

2.4.11 ***Native Settlement:*** despite the work on these military sites, the processes and strategies of the occupation still remain only partly understood, as is the relationship between the native Briton and the Romans. Beyond the major towns and forts, there has been little research on native settlement; however, over the last few years new discoveries have allowed a new understanding of rural settlement. Metal detecting and other chance finds reported to the Portable Antiquities Scheme have greatly increased the number of Roman objects from a rural context, and aerial photographic surveys have increased knowledge of the settled landscape of the Later Iron Age and Romano-British periods. Remains of Romano-British field systems have been found within the Lune Valley, at Eller Beck, where over 60ha of field systems and associated settlements have been recorded (Higham and Jones 1985; RCHM(E) 1998; Bewley 1996; Fig 14). The excavation of several settlements has also provided a much needed absolute chronology to reinterpret rural settlement, previously reliant on typological dating.

2.4.12 Palaeoenvironmental evidence shows that woodland clearance during the late Iron Age intensified during the Romano-British period. Pollen data are however absent from the Lower Ribble Valley, but information is available for the broader area. The extensive clearance activity recorded in the Late Iron Age at Fenton Cottage, in the Fylde (Middleton *et al* 1995; Wells *et al* 1997), continued into the Roman period, with clear evidence of cultivation.

2.4.13 In the Upper Ribble Valley and on Fairsnape Fell (Mackay and Tallis 1994), there was also continuity of clearance, and at Eshton Tarn, in Lowland Craven (Bartley *et al* 1990), there was a continuing anthropogenic presence throughout the Roman period, whereas at White Moss, west of the Ribble, the pollen evidence suggests that there was very little anthropogenic activity until the early medieval period.

2.4.14 ***Roman Remains in the Ribble Valley:*** within the study area are 90 definite Roman sites recorded in the HER, as well as three possible sites. Sixty-seven of these are either in Ribchester or are sections of Roman roads that converge on the town (Fig 18). The placement of the forts at Kirkham and Ribchester is likely to have been the stimulus to encourage the growth of settled communities in the area, providing a market for grain and meat production. This would mean that the remains of Romano-British field systems and farms should be expected dotted along the fertile plains of the Ribble Valley, yet no substantial remains have been identified. This may, however, reflect the fact that they lay on good agricultural land and have been lost to subsequent agricultural improvements (Shotter and White 1995), and is supported by the finding of 'a wide distribution of find spots of Roman coins in the Fylde area, even in places removed from the Roman roads and settlement' (Graystone 1996, 84).

2.4.15 The evidence from the North West generally, and Duttons Farm (Cowell 2003), Barker House Farm (OA North 2004), and Broadwood, Ingleton (Johnson 2004) (Fig 19), specifically, indicate that rural settlement was essentially of a native, Iron Age character. The houses were round and either stone founded or of timber and often revealed little in the way of Roman material culture. The implication is that, although the native Britons may have traded with their Roman overlords, there was relatively little cultural interaction between them in the rural hinterlands of the Roman installations.

2.4.16 The roads themselves have yielded a considerable amount of Roman coins, spanning the first to fourth centuries AD, as well as milestones and sculptures (Graystone 1996). At Elston Hall, on the Ribchester to Kirkham road, a hoard of *denarii* was found, and at Fulwood and Ribbleton, coins of Nerva, and at Red Scar, Haslem Park and Clifton, third- and fourth- century coins have been found. This concentration of finds apparently contrasts with the lack of finds on the road between Ribchester and York (Graystone 1996; Shotter 1999).

2.4.17 ***Roman Decline:*** during the second century AD the pacification and increasing stability of the area appears to have led to a scaling down of military activity. Evidence from Kirkham suggests abandonment, though the production site of Walton-le-Dale continued. Ribchester itself appears to have changed in function and become more of an administrative centre (Buxton and Shotter 1996).

2.4.18 The decline of Roman rule in Britain was one which occurred not as an event but as an extended process over the latter part of the fourth century, the most obvious symptom of the administrative decline being the reduced supply of pottery and coinage. During this period army units became in effect a local militia. From AD 402 there were no more supplies to pay the army (Shotter 2004, 153-74) and the ties with Rome were effectively cut, leaving the fort commanders as at least semi-autonomous leaders.

2.5 EARLY MEDIEVAL ARCHAEOLOGY AND PALAEOENVIRONMENT

2.5.1 ***Palaeoenvironment:*** following Rome's abandonment of the province, there appear to have been two phases of partial woodland regeneration, dated to cal

AD 349-583 (1590±50 BP; GU-5144) and cal AD 558-773 (1380±60 BP;GU-5143) at Fenton Cottage, Lancashire; these phases were separated by increasing levels of grassland in the landscape (Middleton *et al* 1995, 152; Wells *et al* 1997; Fig 9). The earlier period of regeneration is contemporary on the mire surface with a change in dominance from *Sphagnum imbricatum* to *S sect Acutifolia* at cal AD 349-583 (1590±50 BP; GU-5144), suggesting a period of drier conditions at this time (Middleton *et al 1995*). There is extensive evidence for a drier period throughout the British Isles (Lamb 1977) and it seems likely therefore that the reduction in anthropogenic activity recorded was not caused by a deterioration in climatic conditions but by a genuine reduction in farming.

2.5.2 ***Historical Evidence:*** much of the evidence for the period following the end of Roman governance comes from early historical sources, but any references to the North West are usually quite general and often written with an agenda or from a specific standpoint; these include the *Anglo-Saxon Chronicle* (Garmonsway 1967) and the writings of Bede (RM Newman 1996).

2.5.3 ***Archaeological Evidence:*** in the North West there was a large concentration of Roman military installations, and associated infrastructure, and it has been suggested that many of these centres would have either stayed in use or been focal points after the Roman retreat (Higham 1994). In the Ribble Valley, Roman military sites would have been prime candidates for continued occupation as focal points, albeit not to the same scale as Carlisle (for historical sources see Webb 1998; McCarthy 2002). The military site at Ribchester, in particular, may yet yield evidence of later occupation, and any material seen as residual would benefit from re-investigation. However, the initial phase of social transition during and after the Roman withdrawal is an area that has so far yielded little information.

2.5.4 The emergence of a distinct material culture occurred from the eighth/ninth centuries onwards, although evidence for the middle centuries of the early medieval period depends heavily on both place-names of Old English and Scandinavian origin, with groupings of both found on the good agricultural land of the river valley floors (RM Newman, 1996; Higham 2004), and also in coastal areas (such as Kirkham (Kenyon 1991; Higham 2004)).

2.5.5 The Lune Valley has a concentration of stone sculpture with both Northumbrian and Scandinavian attributes, at Heysham, Halton and Lancaster (Fig 20), which indicate Christian sites in the eighth to tenth centuries (RM Newman, 1996). At Lancaster, a hoard of stycas was found at Vicarage Field (Penney 1981; Garstang 1906). A very significant burial mound was opened in 1822 at Claughton Hall (Fig 20), near Garstang, which revealed, as well as an urned cremation, an assemblage of ironwork that was of undoubted Norse origin, and included two very ornate tortoise-shaped oval brooches (Edwards 1998, 14-7). In general, a distinct pattern of settlement can be seen in the lower Lune Valley, and similar groups of material have been found in both the Irwell and Mersey valleys (RM Newman 1996).

2.5.6 The only surviving churches with early medieval fabric in the region are St Patrick’s Chapel and St Peter’s Church, both at Heysham, and a small part of the church at Lancaster. The fabric of both the church and chapel at Heysham has been dated to the late eighth century (Potter and Andrews 1994). Given the amount of sculpture at both sites, and the juxtaposition of the two churches at

Heysham, both they and the site of Halton church have been suggested as possible monastic sites (RM Newman 1996). The Ribble Valley has both Northumbrian and Scandinavian motifs on stone crosses at Whalley, and there is possibly another piece, now at Anderton, but which may have derived from Preston (RM Newman 1996). The church at Kirkham may have been in existence since *c* AD 700 (Middleton *et al* 1995).

2.5.7 ***Cuerdale Hoard (Fig 20):*** the most well-known find of the period within the study area is that of the 'Cuerdale Hoard'. This is the largest hoard of Viking hack silver and coins found outside Russia, and was discovered in the river bank near Cuerdale, outside Preston, in 1840 (Newman, RM 1996). The hoard contained over 8600 items, including silver coins and bullion, contained in a lead box (Edwards 1998).

2.5.8 In uncertain times, the safest way to store personal wealth was to bury it secretly, and it was clearly never recovered by its former owner, possibly because he was killed. The very varied nature of the hack-silver testifies to the mobility and far-ranging contacts of the Vikings. Much of it is of Norse-Irish origin, including distinctive stamped arm-rings, both whole and chopped up, and fragments of spectacular bossed penannular brooches and thistle brooches; such large and imposing items of personal jewellery were portable wealth as well as functional and decorative attachments.

2.5.9 The Cuerdale hoard contains over 7000 coins and between them they demonstrate very clearly the international scale of Viking activity, as well as providing evidence for the dating of the hoard. It is believed that the coins were buried between AD 903 and AD 910, at a time when the Ribble Valley was an important Viking route between the Irish Sea and York (Kenyon 1991). Not surprisingly, most of the coins come from England, both official Anglo-Saxon issues (about 1000) and coins of the Danelaw (about 5000). However, the hoard also contained about 1000 Carolingian coins, a handful of early Scandinavian coins, about 50 Kufic dirhams from the Islamic world, a few imitations of Kufic coins from eastern Europe, and a single Byzantine coin (Archibald 1992). The local coinage of Viking Northumbria, the largest single group in the hoard, shows some variation of wear, but all the coins were relatively new. This suggests that these issues were circulating locally, and that the hoard was buried only a few years after this coinage was first minted (Archibald 1992; Williams and Leslie 2001).

2.5.10 The hoard was so great a treasure that it almost certainly belonged to a person of importance, perhaps a Norse leader or king (Edwards 1998). The size of the hoard has also led to a belief that this may have been a war chest, belonging to Irish-Norse exiles intending to reoccupy Dublin from the Ribble Estuary, though there have naturally been many other theories regarding its ownership and purpose (Graham-Campbell 1992).

2.5.11 The location of the hoard is potentially significant being on a communication route between the Viking centre at York and Ireland, specifically the Viking kingdom of Dublin. Preston has been suggested as being the most likely harbour for an Irish-Norse fleet, again based on the assertion that the Ribble Valley provided a route to York (Graham-Campbell 1995). Given this potential importance of the Ribble estuary, weight may be added to the suggestion that the motte at Penwortham, which overlooks the Ribble to the west of Preston, may have had pre-Conquest origins (Morgan 1978). Indeed, Higham (2004) has suggested that this may have been founded as a burh by Edward the Elder in the early tenth century.

2.6 MEDIEVAL ARCHAEOLOGY

2.6.1 It was during the later medieval period that the landscape that we know today was largely formed. The pattern of villages, with their irregular radial field systems, the scattered market towns and the country road system had its origins largely in this period. The impetus for the nucleation of settlement was the intensification of lordship and manorialisation in the ninth and tenth centuries (R Newman 1996a). However, this process was impeded in the North West by the unstable political situation created by the expanding kingdoms of England and Scotland (Winchester 1987, 5) during the eleventh century. During the twelfth century, as the Norman rulers expanded their power up to the present Scottish border, a significant grouping of the characteristic Norman motte and bailey defensive earthworks developed along the line of the Lune, and the indications are that for a period in the later eleventh century this river may have served as a border (*ibid*). At the same time these defensive sites became centres of feudal administration and secular jurisdiction (Higham 1991a).

2.6.2 The Ribble Valley was the centre of an important medieval lordship, that of the de Lacys, based in Clitheroe (Fig 21; Farrer and Brownbill 1908). This lordship, and that of Lancaster, were the first Norman bulwarks created to guard against the unstable politics to the north. This is reflected in a similar line of defensive fortifications on the Ribble, to that on the Lune, with castle sites at Penwortham (HER PRN284), Tulketh at Preston (HER PRN108), Ashton on Ribble in Preston (HER PRN15201), Clitheroe, seat of the de Lacys (HER PRN1101), and possibly at Scott House, off Green Moor Lane, north of Ribchester (HER PRN5897) (Fig 20). A timber and earth castle is suggested by Wood (1996) at Preston, but this has long vanished. Some of these were subsequently rebuilt in stone, such as the distinctive keep of Clitheroe, which was built around 1186 by Robert de Lacy to protect the administrative centre of his vast estates (Farrer and Brownbill 1908). Latterly, the de Lacys also held Pontefract, thereby creating a trans-Pennine powerbase.

2.6.3 ***Towns:*** in the late twelfth and thirteenth centuries, the North West began to see the development of what were to become the major towns of the region. Prior to the Norman Conquest, towns were not a feature of the landscape (White 1996, 125), and it is probable that the earliest towns were proto-urban defended sites, such as Lancaster and Penwortham (Fig 21), where the defended settlements grew into towns (Crosby 1994). Penwortham is referenced in Domesday Book (Morgan 1978), and was possibly the earliest borough in the region; however, its position caused it to fail as a major settlement, being away from the north/south Roman road, and with no access to a port (Higham 2004). It seems that Preston rapidly supplanted it as the main town of the area. Other settlements in the area mentioned in Domesday Book are Walton-le-Dale, Whalley, St Michael’s on the Wyre, Poulton-le-Fylde, Kirkham, Ribchester and Ashton on Ribble (Morgan 1978; Faull and Stinson 1986).

2.6.4 By the mid thirteenth century, the principal boroughs of Lancashire were Lancaster, Preston, Liverpool, Manchester, Wigan and Warrington (Higham 2004). In addition to these there were other smaller towns, such as Penwortham and Clitheroe, in the Ribble Valley; the latter had developed alongside the de Lacy administrative centre of the castle, and had received its charter by the mid-thirteenth century (White 1996, 129).

2.6.5 ***Rural Settlement:*** from the twelfth century the uplands of the North West were mainly owned by the feudal lordships of Lancashire, the two largest being the honour of Lancaster and that of Clitheroe (Higham 2004). Upland settlement in the Pennines and Forest of Bowland consisted of open areas of rough grazing on moorland, which were invariably farmed by large cattle ranches known as vaccaries. Whole areas of forest land were retained and exploited by these demesne stock farms (Winchester 2006, 80), that is farms under the direct control of the lord of the manor. In the Forest of Bowland, which was a chase in the twelfth and thirteenth centuries belonging to the de Lacys, there were 15 vaccaries documented (LUAU 1997a). Most of these vaccary sites are now occupied by post-medieval farms but the original boundary lines that separated them are still in place, now defining the edges of the principal estates.

2.6.6 ***Lowland Settlement North of the Ribble:*** following the Norman take-over of Cumbria at the end of the eleventh century and early twelfth century, a period of calm encouraged nucleation of manorial settlements in the Ribble Valley. In the western, lower-lying part of the valley, the favoured sites for settlement were the well-drained drier ridges and hillocks in between the extensive marshes, and a distinct cluster of medieval settlement can be seen in the Lower Ribble, including Kirkham, Freckleton, Clifton, Penwortham (just south of the river), Longridge and Broughton (R Newman 1996a) all, for the most part, on the margins of the wetter lands.

2.6.7 ***Lowland settlement south of the Ribble:*** the area immediately south of the Ribble estuary still retains evidence of north/south orientated medieval strip field systems, which are highly visible even in the modern enclosure systems. Despite modern agricultural activity removing much of the ridge and furrow, the shape of the fields shows the earlier origins of the present landscape. These field systems can be seen at Longton, Hutton, Little Hoole and Much Hoole, of which Longton is cited as an exemplar of open-field agriculture and settlement in Lancashire (Fig 22; Higham 2004).

2.6.8 ***Monastic Influence:*** the study area is well endowed with monastic houses, with two major Cistercian monasteries in the Ribble Valley, at Whalley and Sawley, founded in 1147 and 1296 respectively (Farrer and Brownbill 1908).

2.6.9 ***Whalley Abbey*** (Fig 23): at Whalley there are six cross fragments in the parish churchyard, which indicate a pre-Conquest Christian community (Edwards 1978; 1990). However, the Cistercian abbey at Whalley was not founded until AD 1296. Roger, Baron Halton, the son of the founder of the abbey, inherited the land and dignities of his kinsman, Robert de Lacy. The de Lacys were one of the powerful families that had arrived at the Conquest and had been given large tracts of land in East Lancashire and West Yorkshire. It was through this connection that the monks of Stanlow acquired properties in Lancashire (Farrer and Brownbill 1908). Repeated flooding at Stanlow and other natural afflictions made the monks want to move, and a suitable site was found at Whalley.

Initially, they moved into the old rectory, pending the building of the great church, but as a result of various difficulties it was not until 1340 that serious work began, and the abbey church was eventually completed in 1388 (Wood 1996).

2.6.10 The last Abbot of Whalley, John Paslew, rebuilt the Abbot’s lodgings and added a lady chapel, although the latter has not been located (LUAU 1991a; 1991b). Paslew was cited as having been involved in the Pilgrimage of Grace, in 1536, which was against the ecclesiastical policy of Henry VIII, and a reaction to the dissolution of the monasteries. For this he, and some of his monks, were tried on a charge of treason, and Paslew was found guilty and executed in 1537. At the time the abbey was deconsecrated and the monks dispersed (Wood 1996; Farrer and Brownbill 1908). The abbey was then treated as though it was Paslew's personal estate and was sequestered by the Crown. It was stripped of its valuables, including the lead from the roof, and committed to John Bradyll, whom the Crown appointed bailiff in 1539 (*ibid*). Later, in 1553, he and Richard Assheton jointly purchased the abbey lands, with Assheton taking the monastic buildings, in whose family they remained until 1836.

2.6.11 ***Sawley Abbey*** (Fig 24): the Abbot Benedict, twelve Cistercian monks and ten lay brothers from Newminster Abbey in Northumberland, founded Sawley in 1147. There was a slow development of the site over the next three decades; initially, a wooden building was provided by William de Percy. Building in stone commenced in the 1150s and although few documentary records survive, there was architectural evidence of new work in the late 1300s (Heritage Trust for the North West 1997).

2.6.12 Following this initial growth, the community fell upon hard times, and struggled to survive off the land, because of a combination of poor drainage and wet climate. The leaders considered abandoning the site around 1200 (Hunt 2005) and the head of the Cistercians, the Abbot of Clairvaux, recommended that it be dissolved or moved. However, a further grant of land from the Percy family ensured survival and then in 1296 the monks of Stanlow in Cheshire moved to Whalley and were given the tithes from Whalley church. It was unusual for two abbeys to be as close as Sawley and Whalley, being only 11km apart, and this move led to friction and competition for resources.

2.6.13 In the early fourteenth century Scottish raids penetrated this far south and some of the buildings were destroyed and animals were stolen. There were supporting grants made to keep the abbey stable during this period and the community survived and continued through the fourteenth century, and re-modelled the abbey in the process (Hunt 2005), which was completed by the end of the century.

2.6.14 Sawley Abbey was suppressed in 1536, but the final days were as harshly dealt with as the buildings themselves. Following the Dissolution, monks returned to Sawley Abbey under a new abbot. However, when Henry VIII heard of this, he immediately ordered the monks to be executed for treason, as was common practice during the Pilgrimage of Grace. Therefore, in March 1537 the abbey was again dissolved. It was stripped of all its valuable materials and left to crumble, quickly falling into a state of disrepair. In the nineteenth century, the site was cleared, with a wall built to encircle the ruins, and the site became an early visitor attraction (Hadley 1997).

2.6.15 Fragments of the service buildings were found elsewhere in the village and surrounding fields, as well as the monastic precinct wall and the abbey fishponds within it (Heritage Trust for the North West 1997). The fields to the east of the ruins contain very pronounced earthworks that indicate the mixed nature of the economy; an extensive earthwork survey undertaken by English Heritage shows clearly areas of cultivation preserved as ridge and furrow, field boundary ditches and enclosures, as well as drainage systems and ponds (Hunt 2005).

2.6.16 The Friary site at Preston has now vanished (LUAU 1991), and an early Savignac site at Tulketh was transferred in 1127 to Furness Abbey (Wood 1996). The influence of a monastic house on the landscape can be considerable and, given the presence of such a number within the valley, it is likely that there was some significant effect on agricultural practices. The need to feed the monks and the lay brothers, coupled with the relative wealth of the monasteries, meant that they could and did acquire substantial tracts of land, establishing vaccaries or granges in the hill country or on lowland waste (Winchester 1987, 6). The effect was to reclaim substantial expanses of empty land. Significant holdings were granted in the Forest of Bowland by the de Lacys to Kirkstall Abbey, Leeds. These included Rishton Grange in *c*1190, which is now under Stocks Reservoir (Greenwood and Bolton 1955, 15; Shaw 1956, 219; LUAU 1997a), and a surrounding area which became known as Dalehead.

2.6.17 ***Medieval Rural Industry:*** within the medieval field systems, early rural industrial evidence can be found. Notable within the Ribble Valley are retting ponds and pits that were used to soak bundles of flax in slow-moving water, which was part of the early linen industry; this substantially increased in Lancashire in later periods. One of the best known in the Ribble Valley is a series of flax ponds, sluices and channels at Grindleton, on the Ribble, north of Clitheroe (Higham 1991b; Fig 25), which survive as earthworks in the fields. A second comparable system is found just outside the study area at Newton in Bowland (*ibid*).

2.7 POST-MEDIEVAL ARCHAEOLOGY OF THE RIBBLE VALLEY

2.7.1 ***The Rural Landscape:*** the Lower Ribble Valley study area contains 835 records assigned to the post-medieval period, of which the majority are either agricultural or domestic features, which reflect the agricultural economy of the area. post-medieval farming, to a substantial extent, reflected a continuation of medieval practices. However, there were several very significant changes, particularly the collapse of the peasant farming system. During the latter part of the medieval and the earlier post-medieval periods, the peasant farmers were acquiring the land they farmed (Taylor 1983). There was a corresponding break-up of the open fields around nucleated settlements, enclosing the aratral strip fields, their shape reflecting the oxen-ploughed ridge and furrow of the open fields, typified by the fields around Longton. There was also, during the later medieval and post-medieval periods, pressure to exploit lands that had previously been waste, and there was an increase of dispersed settlement on the outlying lands.

2.7.2 The ultimate expression of this practice was the parliamentary enclosure movement of the eighteenth- and early nineteenth-centuries, which resulted in considerable expansion onto the waste lands and a corresponding increase in the number of dispersed farms to exploit the newly won land-holdings (Whyte 2003). The effect of these changes was the expansion of the field systems, often with the characteristic straight lines of the parliamentary enclosures, the rationalisation of nucleated settlements, and the loss of the former waste, be it woodland or moorland.

2.7.3 ***Industry:*** the villages and towns owe their growth to the expansion of eighteenth- and nineteenth- century industry; indeed, it was the growth and spread of industry which characterised the broader economic growth of the North West. Yet the Ribble Valley, at first glance, would appear to be an unchanged landscape, dominated by pastoral farming and seemingly less affected by the ravages of industry than those in the south of the county (Rothwell 1990). However, the evidence does nevertheless demonstrate a large number and variety of industrial sites which formally existed throughout the valley.

2.7.4 Chatburn, West Bradford and Grindleton, for example, are villages which developed around weaving mills (Rothwell 1990; Fig 26), although it is known that earlier industries existed, such as the Grindleton and Bolton by Bowland flax growing and processing sites (Higham 1991b). It is also known that fulling mills were in operation through the area during the fifteenth to eighteenth centuries, clearly indicating the importance of the woollen industry before the nineteenth century (Rothwell 1990). Extraction industries existed also, but were mainly confined to stone quarrying and intermittent phases of lead mining in the limestone areas, which can be traced to the earlier post-medieval period, as can certain metal-working traditions (Crosby 1998). In addition to this, sandstone was quarried on Waddington and Longridge Fells, forming a primary source of building material for the Ribble area; the gritstones were also used for shaping into millstones (Mitchell 2004).

2.7.5 Lancashire’s cotton industry rose to world dominance during the late eighteenth century (Fletcher 1996), and the Ribble Valley featured strongly during the early development of this industry. The evidence suggests that the eighteenth-century expansion was financed by merchants from outside the district who saw the potential available in the natural resources of water power and the abundance of corn mills, which could be quickly converted (Rothwell 1990). Examples of these conversions can be seen at Chatburn Mill, where the fourteenth-century corn mill had been converted to a cotton spinning mill by the early nineteenth century and renamed 'Kingsmill'. This pattern can also be seen at other sites throughout the valley.

2.7.6 The earliest forms of mechanisation introduced to the cotton and linen industries were carding and jenny workshops. These required little in the way of capital investment and were capable of being powered by the smaller streams of the district, which made them capable of being started by local farmers and clothiers (Rothwell 1990). Then, during the later eighteenth century, the beginnings of large-scale mechanisation began with the introduction of the Arkwright spinning mills (*ibid*).

2.7.7 With the beginning of the nineteenth century came the shift towards steam-powered manufacture. These were not limited by the need for fast-flowing streams, and instead their locations were influenced by the introduction of new and better roads, canals and ultimately railways. This meant that a wider choice of settings became available for the new steam-powered mills, including the outskirts of many smaller towns, which came with a ready-made workforce. While some of this new industry found its way into the Ribble Valley, much of it was concentrated in the growing industrial towns to the south. The main period for mill building in the Ribble Valley was between 1850 and 1865, when 24 mills were constructed, mainly around Clitheroe and Longridge. The later nineteenth century saw a gradual decline in the spinning industry. The last mill to be built was the Jubilee Mill at Clitheroe, in 1891-2 (Rothwell 1990).

2.7.8 The burgeoning cement and limestone industries which emerged after 1850 were able to use the railway and roads to export their products and the focus of employment began to shift in the area (Rothwell 1990). The Bold Venture Limeworks near Clitheroe (Fig 26) was the largest in a local industry that had been quarrying limestone for over 400 years, both for building stone and to burn for agricultural use. Clitheroe's old lime banks are marked on the first edition OS mapping (Fig 27) and the area is riddled with workings, which include Salthill, Pimlico, Horrocksford, Coplow and Bellman Park. The site was expanded, for the cement industry, and still exists as Chatburn Limestone Quarry (Mitchell 2004).

2.7.9 The effect on the landscape of the Ribble Valley of the creation of large industrial centres to the south was a partial abandonment. The inhabitants of the rural communities could traditionally find work in locally based, water-powered mills, but later there was a need for larger pools of labour on the doorsteps of the giant factories, and so people left the countryside (Fletcher 1996).

3. METHODOLOGY

3.1 INTRODUCTION

3.1.1 This project was designed to bring together geomorphological, palaeoenvironmental and archaeological expertise to produce an integrated model of the potential for archaeology, the present and future threat from fluvial change, and the suitability of the substrata for extraction in the Ribble Valley. The techniques used have included traditional desk-based data gathering, archaeological and geological fieldwork, geostatistical and spatial analysis, and geospatial modelling.

3.1.2 Previous projects have used some, but not all, of the techniques described (notably the Lynher Valley project (Cornwall Archaeology Unit 2002)). Assessment of the success of the methodologies has been a important element of the project, since some of the techniques did not prove to be successful, or did not produce usable results (see *Sections 4.1-3*).

3.2 STRUCTURAL OVERVIEW OF THE GIS

3.2.1 Initially, separate GIS systems were constructed for the archaeological and geological aspects of the project; but both were constructed in ArcGIS 9.0 to maintain full compatibility. In the data gathering phase of the project, the datasets were constructed separately, but in the analytical phases theSE were combined into a single geodatabase, compatible with Microsoft Access 97. This format allows the spatial data normally held in a shape file, and the attribute data normally held in a database table, to be combined into a single Feature Class. By incorporating the geomorphological, environmental and archaeological datasets into the same geodatabase, they could be interrogated and analysed together, and distributed as a single combined file rather than separately.

3.2.2 The datasets included in the geodatabase are described in Table 1, and the flow diagram describing the process of constructing these feature classes is shown in Figure 28.

Feature class	**Data type**	**Features included**
Archaeological Events	Points	All archaeological interventions such as excavations, watching briefs and so on
Archaeological Events	Polygons	The actual extent of all archaeological interventions, where available
Archaeological Monuments	Points	All archaeological features within the study area
Archaeological Monuments	Polygons	The actual extent of all archaeological features, where available
Enhanced Historic Landscape Characterisation	Polygons	Quantity and density of archaeological events and monuments within each polygon
Potential for prehistoric Activity	Polygons	Areas of high, medium and low potential for activity
Potential for Roman Activity	Polygons	Areas of high, medium and low potential for activity
Potential for medieval Activity	Polygons	Areas of high, medium and low potential for activity
Palaeoenvironmental Events	Points	All palaeoenvironmental work within the study area such as boreholes, coring and so on
Palaeoenvironmental Monuments	Points	Data resulting from palaeoenvironmental events, such as radiocarbon dates and so on

Feature class	**Data type**	**Features included**
Glacial Landforms	Polygon	Moraine ridges, drumlins, deltas, kettle basins, sandur flats
Glacial Lines	Lines	Channels, ridge crests, ice-flow directions, ice divides
Glacial Point Features	Points	Mound summits, section locations
River Terraces	Polygons	River terraces, alluvial fan surfaces
Fluvial Lines	Lines	Palaeochannels
Fluvial Points	Points	Core sites, section sites
Potential for Present Fluvial Change	Polygons	
Potential for Future Fluvial Change	Polygons	
Suitability for Aggregate Extraction	Polygons	

Table 1: Datasets included in the Ribble ALSF project geodatabase

3.3 CHARACTERISING THE GEOLOGICAL AND GEOMORPHOLOGICAL RESOURCE

3.3.1 ***Previous Research and Investigations:*** prior to this project, knowledge of the Quaternary geology and geomorphology of the Ribble Valley was patchy and of variable quality. Mapping of the drift geology by the British Geological Survey (BGS) has resulted in five 1:50,000 sheets (Fig 29), only two of which are recent revisions, Garstang (BGS 1990) and Settle (BGS 1991). The other sheets, Rochdale (BGS 1974), Preston (BGS 1982) and Clitheroe (BGS 1975), are more dated, and there is considerable difference in nomenclature and detail between the sheets. The BGS are in the process of revising the Preston sheet, and the present project will contribute directly to that revision (AJ Humpage and RG Crofts (BGS) *pers comm*).

3.3.2 Further data on the Quaternary geology were available from research investigating the sand and gravel reserves within Lancashire. Three reports have been commissioned by Lancashire County Council’s (LCC) Minerals and Waste Group. The first was a Department of the Environment-commissioned report (*Sand and Gravel Resources of Lancashire* (Allot and Lomax Ltd 1990)) and the second was by Entec UK Ltd (2005) in partnership with the British Geological Survey (BGS). The general consensus (LCC and Minerals’ Operators) was that the Entec report represented a helpful start and provided a better identification of potential targets for high-grade sand and gravel deposits than the Allot and Lomax report. Few of the areas identified in the Entec report have been assessed using borehole investigations to test the quality of the resource available, and were identified solely on the basis of the available data. As it stood there was a paucity of high-quality published information relating to Lancashire’s sand and gravel geology and resources, and what did exist was largely underpinned by the BGS mapping (Fig 30). A third report, commissioned by LCC from Geoplan Ltd (2006), provided a more targeted and detailed investigation with an assessment of mineral quality. The Geoplan Ltd study drew upon a wider range of sources, including some confidential, and whilst focusing on study areas delimited during the Entec study (Fig 31) had a wider brief to look at new areas for which there was extant geological data. The Geoplan and Entec reports were the best available assessment of sand and gravel aggregate reserves within Lancashire. Further information about the late Quaternary evolution of the Lower Ribble

Valley was available from the PhD research by Bernardo Chiti at the University of Stirling (Chiti 2004).

3.3.3 The BGS mapping varies in precision between map sheets; it identified a maximum of three river terraces (Fig 32), but their location, extent and the consistency of nomenclature between map sheets were difficult to gauge. Chiti (2004) on the other hand mapped in some detail a comparatively short reach between Preston and Ribchester (Fig 33), and identified four river terraces and the modern floodplain. Chiti (2004) supported his mapping of the geomorphology with some detailed stratigraphic investigation, accurate height-range correlation between terraces, some geochronological control, and palaeoenvironmental investigation. The research by Chiti and the BGS was a starting ground for investigation of the fluvial geomorphology presented in this report. Digital copies of the BGS 1:50,000 series (LCC licence) and Entec Sand and Gravel Study digital data were obtained, whereas the maps presented in Chiti (2004) were digitised from a paper copy.

3.3.4 Boreholes clearly provided the ready means of confirming the geology depicted on published maps and they contributed significantly to the identification of potential aggregate resources. The BGS holds copies of all deposited borehole records at their national headquarters and summary data, including borehole number, location and depth, are available on their website (www.bgs.ac.uk). This facility provided a useful first search capability for identifying boreholes of use in this project and over 8000 boreholes were originally identified in the area of the Ribble catchment. This number was reduced considerably by firstly filtering out all the boreholes that were not in areas underlain by potential aggregate groups (principally glacial sand and gravel and alluvium). A second filter was then applied that excluded all boreholes of less than 5m depth (the minimum commercially useful thickness of potential aggregate resources) and those identified as confidential. Further filtering was applied based, on the selective sampling of boreholes in areas (such as motorway developments) where the very close spacing of boreholes contained redundancy. Together this was able to reduce the number of boreholes to only 600. To date, some 250 of these boreholes have been catalogued from BGS records, mainly in aggregate priority areas in the Lower Ribble Valley (Fig 34). Further boreholes were available for the drift plain to the north of the Ribble, which also has considerable potential for sand and gravel production. In this project the aim of the borehole analysis was to construct, where distribution and density permitted, two- or three-dimensional models of aggregate distribution in order to assess the potential resources.

3.4 INTERROGATION OF REMOTELY SENSED DATA

3.4.1 ***Introduction:*** the principal aim of geomorphological mapping as a tool for sand and gravel survey was to identify by rapid, accurate and cost effective means, and to delimit and characterise the potential reserves of aggregate. Conventionally, geomorphological mapping has been a field exercise, recording the location and dimensions of landforms onto base maps of varying scales (typically 1:10,000). Geomorphologists have long made use of available technologies, with aerial photography, particularly where stereoscopic coverage was available, being invaluable for desk-based recognisance of landscapes and landforms. The routine use of Geographical Information Systems (GIS) and parallel developments in remotely-sensed accurate digital elevation models (DEM) has radically altered the approach of the geomorphologist. Smith *et al* (2006) have reviewed the comparative merits of a set of various remotely sensed data in discerning the geomorphology of glacierised terrain in central Scotland. They found, through comparison against conventional field mapping, that Light Detection and Ranging (LiDAR) imagery appeared extremely reliable, although only a limited dataset was available. NextMAP Great Britain™ performed well, and the lower resolution Ordnance Survey products (OS Profile® and OS Panorama®) performed poorly. In this project, the value of LiDAR, NextMAP and OS Profile have been assessed for a broader range of geomorphic settings, both fluvial and glacial, as has the role of these data sources in identifying, characterising and quantifying potential reserves of sand and gravel.

3.4.2 ***Data Sources***: three types of remotely sensed data are utilised in this report. LiDAR data were available for all of the Ribble Valley catchment with the exception of the reach around Brockholes, from Sunderland Hall and the M6 motorway. The LiDAR data were generated using an airborne laser to measure the distance between the aircraft and the ground, and was provided by the Environment Agency. The data were collected with the principal aim of generating cost-effective terrain maps suitable for assessing flood risk, and have a spatial resolution of 2 x 2m and vertical accuracy of *c*0.15m. The data were supplied in three forms: the first as a raw unprocessed surface; the second as a surface corrected for buildings and vegetation; and a third showing the residuals between the first and second surfaces. The relatively fine spatial scale (*c*2 x 2m) means that LiDAR can penetrate vegetation canopies, more so during winter conditions (Dowman *et al* 2003; Smith *et al* 2006), which improve the accuracy of the bare ground correction.

3.4.3 NextMAP is a digital terrain model produced by Intermap Technologies and commissioned by Norwich Union Insurance to assist with flood risk mapping. NextMAP data were also generated by airborne survey using synthetic aperture radar (SAR), and employed single-pass interferometry (IfSAR) (Dowman *et al* 2003; Smith *et al* 2006). The principal differences between LiDAR and NextMAP digital elevation data were the flight height in the survey methodology: 800m for LiDAR and *c*6500m for IfSAR, with accordingly the lower precision and accuracy of the NextMAP data having a 5 x 5m spatial precision and a 0.5-1m vertical accuracy (Dowman *et al* 2003). However, the NextMAP methodology is more cost effective, and there is comprehensive coverage for the United Kingdom, whereas there is currently only *c*60,000 km^2 of LiDAR coverage. NextMAP includes two data products: the raw IfSAR product (DSM) which records all ground surface features, including buildings and vegetation; and a product corrected to produce a bare ground model (DTM). Dowman *et al* (2003) and Smith *et al* (2006) highlight two further limitations to NextMAP data; the first is that it struggles to penetrate vegetation canopies, and secondly, there is a shadow effect behind tall structures, vegetation and landforms. Both LiDAR and NextMAP data appear to perform better in flatter rural terrain that is not forested (Dowman *et al* 2003; Smith *et al* 2006).

3.4.4 The next best available national scale DEM is the Ordnance Survey (OS) Profile® dataset, which is a contour-based dataset compiled by stereo-interpretation of aerial photographs over many years since the 1980s. Problems with OS Profile stem from gaps owing to labels on maps and absence of contours around anthropogenic features, and from smoothing during cartographic presentation and digitisation (Dowman *et al* 2003). However, the OS Profile DEM has a spatial resolution of 10 x 10m and vertical accuracy of *c* ±5m. Smith *et al* (2006) suggested that the OS Profile performed badly in geomorphic research identifying and delimiting the extent of drumlins.

3.4.5 None of the poorer-resolution datasets available, for example OS Panorama data, have been used in this project; Smith *et al* (2006) have reviewed the relative merits of a wider range of remotely sensed data sources. For the geomorphological mapping, the LiDAR and NextMAP products have been used, mainly the 'bare ground' version. The specifications, limitations and availability of the data sources for the three case studies are listed in Table 2.

	Spatial Resolution	**Vertical precision**	**Acquisition date**	**Cors Geirch**	**Rhosesmor**	**Ribble Valley**
Field mapping	20m	N/A	Various	Yes	Yes	Yes
Digital elevation models						
LiDAR (Environment Agency)	2m	~ 150-250mm	2003	No	No	Yes
NextMAP GB ™	5m	~ 500mm	2002	Yes	Yes	Yes
OS Profile ®	10m	~ 5000 mm	Maintained	Yes	Yes	Yes

Table 2: Data sources for geomorphic mapping and aggregate assessment

3.4.6 ***Test Case study area 1: a small esker ridge near Clitheroe***: Figure 35 a-d, shows LiDAR, NextMAP Great Britain™ and OS Profile® data for this test locality, a small (90 x 800m) ridge north of Clitheroe, in the Ribble Valley. The DEMs shown in Figure 35 are equivalently colour-scaled for altitudes between 50m and 130m OD, using a light-dark-light colour gradation to highlight morphology within the defined height range. Comparison of the three DEMs shows that they all are capable of identifying the presence of the ridge, which has a protruding altitude of 8-16m. Discerning the presence of features in remotely sensed data in no way lessens the need for field mapping, except that the process becomes more of a truthing exercise. Discerning the nature of the ridge was also the domain of the fieldworker, where a limited exposure of fluvially rounded gravel and a sandy matrix, discerned from animal burrows and plough-marks, alongside the well-drained and lush-grassed character of the land surface, contrasted with the surrounding lower, flatter, poorly drained diamict plain; this indicated that the feature was an esker. Although the breaks in slope surrounding the ridge can easily be identified in all three digital products, accuracy and precision improve incrementally with the NextMAP (Fig 35b) and LiDAR data (Fig 35c). The identification of morphometric outline was assisted by careful manipulation of the DEM to generate an appropriately coloured and height-ranged elevation surface, closely spaced contour vector data (1000mm), and slope-angle raster surfaces, all of which help to highlight and delimit the edges of geomorphic features (Fig 35d).

3.4.7 OS Profile data allowed mapping of a broad general outline for the landform (Fig 35a), exemplified by the contouring generated for this dataset. The contours are at 2.5m intervals, which is already double the claimed precision of the product, and display a 'stepped lineation' that is a function of the raster resolution (10 x 10m). Nevertheless OS Profile provides a reasonable approximation of a landform. The NextMAP and LiDAR products, at the scale of conventional geomorphic mapping (1:2500 to 1:10,000), display fewer signs of generalisation and appear to portray the morphology of the ridge-form accurately. Furthermore, comparison of the degree of capture of drainage patterns in the surrounding lowlands highlights the value of increased vertical accuracy and spatial precision in the LiDAR data, which are capable of discerning both the detail of morphological form and the character of smaller and lower relief features.

3.4.8 ***Test Case study area 2: a restricted fluvial reach in the Lower Ribble Valley***: the first case study focused upon features with a marked differential in relief, but in Lancashire aggregate extraction has targeted river gravels deposited during both deglaciation and the Holocene, and these are within 10m of the current river level. The Lower Ribble Valley is a useful setting in which to assess the value of using the different DEM data for mapping fluvial landforms, because LiDAR (Environment Agency), NextMAP and OS Profile data are all available. Historically, aggregate extraction in the Lower Ribble Valley appears to have targeted the highest two river terraces, with extensive extraction sites near Preston, and borehole survey has confirmed that the lower three terraces were primarily composed of alluvium, with very limited gravel. The respective merits of these three DEMs for characterising the fluvial geomorphology were investigated, with an assessment of the present aggregate, and a review was made of the extent to which they distinguished features that were separated by less than 10m of relief.

3.4.9 Comparison of the three DEM products (Fig 36a-c) shows an incremental improvement from OS Profile to NextMAP, to LiDAR. The LiDAR data were clearly much superior, best exemplified by the manner in which the improved spatial resolution (2 x 2m) and vertical accuracy allows the identification of palaeochannels (Fig 36c), particularly with careful manipulation of slope-angle data derived from the LiDAR data (Fig 36d). Palaeochannels are distinguishable to a lesser extent in the NextMAP data (Fig 36b), which copes well with larger features, but less so with the series of smaller scrollbar channels on the Osbaldeston Hall meander. Representation of river terrace sequence by the OS Profile data was poor (Fig 36a), which is not unexpected given that the height-range information derived from LiDAR (Fig 36f) shows that the river terraces were only separated by 5m of relief, and the claimed accuracy of the OS Profile data is only to ±5m. Mapping and identification of terrace fragments (Fig 36e) produced identical results when undertaken independently for NextMAP and LiDAR data, although it was difficult to distinguish the boundary between Terraces 3 and 4 using the NextMAP data (Fig 36b; Fig 36e).

3.4.10 In terms of identifying sand and gravel aggregate prospects, LiDAR and, to a lesser extent, NextMAP, are useful tools for rapid desk-based mapping. However, fieldwork is still essential to truth the interpretation and check the relationship between features in critical locations. The main advantage of a LiDAR-based mapping approach is spatial accuracy and altitudinal correlation of river terrace suites, because obtaining equivalent accuracy from field survey would take a greater length of time, involve using survey equipment, and would prove less cost effective. LiDAR also shows the position of palaeochannels, where aggregate reserves are often buried by thicker accumulations of soil, laminated flood silts, and organic sediment. Combining LiDAR survey and field truthing allows the rapid delimitation of the spatial extent of aggregate prospects, which can be linked with boreholes to define accurately the prospect extent and to predict likely volumes of sand and gravel.

3.4.11 ***Mapping the Geomorphology using Digital Resources***: mapping of the geomorphology was undertaken using the LiDAR and NextMAP digital elevation datasets. The information was compiled within a spatial geodatabase using the ARCGIS software suite. The mapping made use of the capability of the GIS software for stretching elevation ranges and manipulating the display to show low amplitude landforms. Slope angle rasters were compiled to identify the edges to landforms. Contour datasets were compiled from both NextMAP and LiDAR raster datasets at sub-metre intervals (0.5-0.25m) to assist this mapping process. The geomorphology geodatabase Feature Classes are detailed in Table 1 above.

3.5 FIELDWORK: MAPPING, DRILLING, SAMPLING

3.5.1 ***Surface Landform Mapping:*** despite the advantages of high-resolution DEMs for the rapid and cost-effective production of spatially and vertically accurate maps, the morphological complexity of the river–floodplain landscape often imposes severe limitations on the interpretative capability of the remote sensing approach. Interpretative problems in DEM mapping may arise, for example, in differentiating between complex palaeochannel configurations and terrace levels, or between anthropogenically and naturally formed surface morphologies. Additional problems may arise where derived 'ground surface' DEMs involve elevation errors due to tree or building coverage. Therefore, field mapping surveys represent a necessary second stage of mapping in order to 'ground truth' and improve upon the results of the DEM desk-based study.

3.5.2 Field mapping was carried out within all detailed study reaches (including Test Case study areas 1 and 2) and at other locations for which uncertainty existed in the landform interpretation arising from the DEM mapping. Hard-copy DEM-based maps of terrace boundaries and palaeochannels were plotted on a background consisting of surface elevation, contours (0.5m intervals), slope angle and OS 1:25,000 base maps. Wherever possible, terrace edge and palaeochannel maps were modified by hand in the field. However, more complex examples of newly identified landforms were mapped using a hand-held GPS, particularly where the LiDAR coverage was lacking. All alterations compiled on the field maps formed the basis for editing the glacial landform (esker, delta, moraine ridge), glacial lines features (ridge crests, erosional channels, slope breaks), river terrace and palaeochannel layers that comprise the integrated Ribble Valley geomorphology geodatabase.

3.5.3 ***Sub–surface Sedimentology and Sampling***: sub-surface sediment sequences were investigated by coring in order to gather information on river–floodplain evolution (Fig 37) or at channel bank exposures (Fig 38). Fluvial reconstructions were based primarily on established deposit/process models, for example: (1) clast–supported rounded gravels (resultant from active channel bed deposition);

(2) graded fine gravel/sand beds (resultant from high-energy overbank flood events); (3) stratified to bedded sands (reflecting braided channel/bar systems); and (4) finely laminated silts and clays (resultant from low-energy overbank flood events). Evidence from organic remains (ie root casts, mottling, leaf, wood, shells and seed remains, soil and peat horizons) was used to provide additional information on prevailing local/regional environmental conditions (ie climate, land use, hydrology, ecology) that were operating at the time of deposition.

3.5.4 In the absence of available channel bank sections, floodplain coring was carried out using a Van Walt percussion corer (100mm and 60mm bore, open barrel) capable of penetrating up to 10m below the land surface (Fig 37). Wherever possible, cores were taken from mapped palaeochannel depressions, since these provided a focus for sediment deposition, and often contain abundant flood-transported and *in situ* organic remains suitable for radiocarbon dating (*Section 3.7.18*). It was aimed to obtain sub–surface sedimentological data from a minimum of one core/bank section from each river terrace level that had been identified within each study reach.

3.5.5 Bank section and core sediments were photographed and observations made regarding sediment structure and bedding units, colour, grain size distribution, water content and cohesiveness, organic content, fossil remains and bioturbation. The resulting depth stratigraphic data were used to construct generalised vertical sequence logs, an example of which is shown in Figure 39.

3.5.6 Bulk sediment samples were taken from each major sediment unit (approximately one sample per 0.5m depth) as a basis for later physical and geochemical analyses underpinning sediment provenance studies and for identifying aggregate-potential. A few peat sequences were sampled contiguously at high-resolution (20mm thick) intervals in order to underpin future palaeobotanical reconstruction. Organic macrofossils and bulk organic material from key stratigraphic change locations (for example, the contact between channel gravels and overlying fine-grained fill; base and top of peat; switch from low-energy flood laminae to high-energy flood beds) were sampled for subsequent radiocarbon dating (*Section 3.7.18*).

3.5.7 All core/bank sections were located with an accuracy of ± 5m using a hand-held GPS system, and coordinates were transferred into a Cores profiles layer within the Ribble geodatabase. The following attribute data were attached to the layer:

- site identification code (text);
- digital photograph(s) (link to graphic image);
- stratigraphic logs (link to graphic image);
- sampling information (text);
- radiocarbon dating (text).

3.6 OUTLINE OF APPROACH TO THE GEOMORPHIC ANALYSIS

3.6.1 The analysis of the geomorphology focused on two aspects:

- providing an enhanced assessment of the sand and gravel deposits;

- improving understanding of the fluvial and glacial history.

3.6.2 The detailed methodology of providing an enhanced aggregate assessment is detailed in *Sections 3.3-5*. The glacial history of the Ribble and lowland Lancashire has received scant attention over the last 50 years, and so the data compiled and reviewed in this project were discussed in the context of current thinking about the deglaciation of Britain at the end of the Devensian Ice Age (*Section 2.2.3*). The analysis focused on the nature and timing of deglaciation, direct evidence for ice-marginal limits, ice-flow directions and the impacts of the differing ice-streams of the British and Irish Ice-sheet.

3.6.3 The Holocene fluvial history over the last 11,500 years reflects a complex interplay of factors including: (i) human-mediated; (ii) climate-induced; (iii) storm-driven; (iv) changes in base-level (sea-level); and (v) filtering by internal system dynamics. These combine to control the sediment yield and transmission within the catchment. This project has contributed to an enhanced understanding of the history of the fluvial development of the Ribble, and particularly with the geochronological programme (*Section 3.7*); this history has been set with respect to the key forcing factors that drive or modulate the sediment transmission of the river system.

3.6.4 Impacts of climate change on fluvial development have been assessed using available proxy evidence for changing climate within the region, particularly bog-surface wetness information, derived from the stratigraphy of the region's peat bogs (Chiverrell 2001). There are no reliable and independent archives of long-term storm frequency to assess the impact of high-magnitude events, but nevertheless the implications of storm-driven changes in the fluvial system were assessed.

3.6.5 The Ribble is in the region affected by glaciation during the Devensian, and so the basin underwent a degree of glacio-isostatic depression (Tooley 1978; Shennan *et al* 2006). The impact of the changing relative sea level during the Post-Glacial period is important as this altered the base level to which the Ribble graded, and thus would impact on cycles of incision and aggradation. The fluvial record has been compared to reconstructions of sea-level history for the region (Tooley 1978; Shennan *et al* 2006).

3.7 GEOCHRONOLOGY: OPTICALLY STIMULATED LUMINESCENCE (OSL) AND RADIOCARBON DATING

3.7.1 ***Introduction***: the main objective of the radiocarbon and luminescence dating programmes was to secure the chronological framework for the glacial, fluvial and hillslope geomorphology, and to provide preliminary chronological control for potential palaeoecological sites within the Ribble catchment. The most significant advance arising from this programme would be a comprehensive understanding of the late Devensian and Holocene evolution of the Ribble. The radiocarbon dating programme was subject to approval and funding from the English Heritage Radiocarbon Dating Advisory Service and the English Heritage radiocarbon dating advisors, Derek Hamilton and Peter Marshall, approved two tranches of radiocarbon dates. The assemblage of samples selected for radiocarbon dating comprised an integrated geochronological package with ten OSL samples, and addressed the core aims of the project; the OSL dating was undertaken at the OSL facility in the Department of Geography, University of Liverpool. In the case of the OSL dating, considerable difficulties were encountered during the dating programme that have proven insurmountable, and so the full experimental procedures and testing that were undertaken are detailed to advance this approach. Recommendations for the advisability of, and a methodological protocol for, OSL dating of sediments of similarly provenanced and depositional environments are also made. The rationale for field sampling, sample selection, preparation and subsequent data analysis for the radiocarbon dating is also detailed, with the radiocarbon dating results presented in context (*see Section 5.2*).

3.7.2 ***Optically Stimulated Luminescence (OSL) of fluvial deposits from the Ribble catchment - Sampling locations***: samples were collected by hammering opaque plastic tubes into the sediments on freshly cleaned outcrop faces (Fig 40) or by drilling with a percussion corer using opaque steel tubes. The tubes were recovered and immediately sealed in opaque plastic bags. Care was taken to sample only sediment layers of sufficient thickness for a homogeneous g-dose rate, and showing no signs of post-depositional changes (bioturbation, soil formation, reduction or oxidation processes). For each luminescence sample, an additional sample was taken to determine water content and radionuclide concentrations. All samples and sampling locations are listed in Table 3.

	Field code	**Laboratory code**	**Grain size for OSL (μm)**	**Details**	**Grid ref**
1	CHEW	LV213	250-300	Chew Mill (Calder). Dug out section within well-sorted flood sands 1.5-2.0m below terrace surface	SD 720 362
2	C Bank	LV214	250-300	Calder Bank Section. Flood sand layer within upper channel fill sequence	SD 721 362
3	Morton	LV215	100-300	Morton Hall Section. Well-sorted sand. Back bar within very coarse fluvial gravel terrace	SD 739 344
4	Whalley	LV216	210-300	Whalley highest terrace: well-sorted sands overlying probable laminated lacustrine muds and diamict. Sample 3-4m below surface in degraded road-cut section. Coversands?	SD 739 360
5	Brock 1	LV217	250-300	Higher Brockholes: quarry section flood-laminated sands *c* 2.5m below surface (sampled in large metal tube)	SD 585 311
6	Brock 2	LV218	250-300	Higher Brockholes: quarry section flood-laminated sands *c* 3m below surface and 0.5m above gravel (sampled in plastic tube)	SD 584 310
7	Cross 1	LV219	250-300	Cross Gill Farm: Delta section, lower sample coarse sands	SD 695 378
8	Cross 2	LV220	250-300	Cross Gill Farm: Delta section, upper sample fine sand and silts	SD 695 378
9	OSB T1	LV221	250-300	Osbaldeston Hall, Terrace, bank section, *c* 1.5m beneath terrace surface	SD 641 345
10	OSB T2 U	LV222	250-300	Osbaldeston Hall, Terrace 2, bank section, upper sample *c* 1.15m beneath terrace surface	SD 638 347
11	OSB T2 M	LV223	250-300	Osbaldeston Hall: Terrace 2, bank section, upper sample *c* 1.8m beneath	SD 638 347

	Field code	Laboratory code	Grain size for OSL (µm)	Details	Grid ref
				terrace surface	
12	OSB T2 B	LV224	250-300	Osbaldeston Hall: Terrace 2, bank section, upper sample *c* 2.3m beneath terrace surface	SD 638 347
13	Lower House	LV225	250-300	Lower House Farm: Terrace 1, sampled with Stitz corer, from sample depth 3-4m beneath terrace surface	SD 608 326

Table 3: Samples collected for optical dating

3.7.3 ***Sample preparation***: the majority of the fluvial sediments have a coarse-grained texture, and sample preparation took into account the dominant grain-size fraction of the sediment and the requirements for luminescence dating. Conventional techniques were applied to extract quartz grains in the size of 200–300µm from the sediment (Mauz *et al* 2002). The quartz sub-sample was subsequently etched in 48% hydrofluoric (HF) acid for 40 minutes to remove the outer alpha particle penetrated rim of the grains and to clean the grain surfaces. For all samples the yield of quartz after HF etching was small, indicating highlight-fractured quartz grains.

3.7.4 For luminescence measurement, the grains were sprinkled onto stainless steel discs coated with silicon oil. Aliquots of different sizes were produced: 4-5mm aliquots (~ 400 grains) and 1-2mm aliquots (~ 100 grains).

3.7.5 ***Equivalent dose (D_e) determination of quartz samples***: all measurements were conducted with an automated Risø TL/OSL DA-15 reader, equipped with a β-source (~ 6.8 Gy min^{-1}) using blue diodes (470Δ20 nm, delivering ~ 30 mW cm^{-2}) for stimulation, and an ultraviolet-transmitting optical filter for detection. All measurement protocols were based on a single aliquot regenerated dose protocol using the standard version (Murray and Wintle 2000) or modifications (*Section 3.7.14*).

3.7.6 ***Initial tests***: considerable difficulties were encountered with the set of reconnaissance samples (low OSL intensity and sensitivity, poor signal/noise ratios, weak fast component), and an extended series of test was employed.

3.7.7 ***Luminescence components***: all samples displayed slowly decaying OSL signals. This characteristic is commonly observed in feldspars but is also known from quartz when the fast OSL component is not dominant. The etching procedure employed in sample preparation should be sufficient to remove feldspar grains completely but may not impact on feldspar inclusions in the quartz grains. OSL signals recorded after extended infra-red stimulation still show the slow decay. There are two possible explanations: even after infra-red stimulation feldspar may emit a ultraviolet luminescence under blue-light stimulation; or the quartz is dominated by medium and slow components. Linearly-modulated OSL measurements (LM OSL; Bulur *et al* 2000) were employed for clarification (Fig 41). The results support the second hypothesis, but as a result of the low signal intensities the first hypothesis cannot be fully ruled out. Using a fitting procedure based on a multiple component function (Choi *et al* 2006) to the LM OSL data, sample LV213 was further analysed. The fitting results (Table 4) indicate that the fast component is almost absent. The OSL recorded in the first seconds of stimulation time seems to derive from an ultra-fast component which is rapidly passing into a medium component. This indicates that the quartz of this particular sample cannot be used for SAR-based optical dating.

Component	**n**	**b**	**σ (cm)**
1	2719±273	2.97±0.281	$4.19^{-17}\pm4.78^{-18}$
2	6676±284	0.500±0.039	$7.05^{-18}\pm7.11^{-19}$
3	13170±757	0.043±0.003	$6.07^{-19}\pm5.74^{-20}$
4	96904±9030	0.0050±0.0003	$7.05^{-20}\pm6.18^{-21}$
5	692569±13966	0.00068±0.00005	$9.59^{-21}\pm9.34^{-22}$

*Table 4: LM OSL components. Results from fitting a 5-component function to the LM-OSL curve of LV213 (each component is defined as: I=n*b*t/p*exp(-bt^2/2p, p=2000 s) with n: the initial concentration of trapped electrons; b: the detrapping probability; σ: the photoionisation cross section*

3.7.8 ***D_e tests:*** four samples were subjected to a standard SAR protocol to assess the equivalent dose (D_e). Thermal treatments included a pre-heat of 260°C/10 s and a cut-heat of 220°C. Four major problems were encountered: low luminescence sensitivity; poor response to the SAR procedure (ie poor recycling ratios); possible feldspar contamination; and thermal transfer.

3.7.9 Five samples were then given a pre-heat of 200°C/10 s and a cut-heat of 190°C in an attempt to avoid thermal transfer and improve recycling ratios. To aid the latter the size of the test dose was also increased.

3.7.10 All samples, except one (LV217), indicated that a feldspar OSL component still contaminated the quartz luminescence. As it was not feasible to subject the samples to further acid treatment, a SAR method for removing the feldspar component was employed (double SAR protocol involving infra-red stimulation; Banerjee *et al* 2001).

3.7.11 ***Pre-heat and dose recovery tests:*** two samples (LV215 and LV216) were selected for pre-heat tests using the double SAR protocol and including a high-temperature stimulation with blue LEDs at the end of each SAR cycle to prevent thermal transfer. Low sensitivity and poor recycling continued to be major problems.

3.7.12 In a further step, a combined pre-heat/dose recovery test was performed on LV215. The test results indicated that a dose could be recovered but with only a poor precision. Employing a reduced temperature for OSL stimulation (to increase signal to noise ratio) in a similar test on LV216 resulted in a ratio of recovered to given dose of 0.96 with a relative standard deviation of 10% for a pre-heat of 200°C/10s and cut-heat of 190°C. In the next step these parameters, namely double SAR, pre-heat of 200°C/10s and cut-heat of 190°C, were combined with an OSL stimulation at 110°C/20 s (to optimise signal extraction) followed by stimulation at room temperature for 40 seconds (to remove all signals before further steps in the procedure). The results of this test are listed in Table 5.

Sample	Aliquots accepted	Dose ratio	RSD %
LV213	3	0.93	3.5
LV217	3	0.98	5.7
LV218	5	0.97	9.8
LV219	4	1.05	10.3

Table 5: Results of dose recovery tests applied to six aliquots of each sample

3.7.13 ***Estimating the D***

3.7.13 ***Estimating the D_e***: encouraged by the results of the dose-recovery tests shown in Table 5, two samples were selected for the application of the modified SAR protocol to 24 aliquots of each sample. Medium-sized aliquots (4mm) were used for LV217, and small (2mm) aliquots for LV218.

3.7.14 ***Adjustments to SAR***: the high-temperature stimulation was re-introduced to the SAR protocol to avoid thermal transfer and applied to three samples (LV221, LV224 and LV225) for a dose-recovery test on six aliquots per sample. Although thermal transfer was reduced to acceptable levels, the high-temperature stimulation affected the pattern of sensitivity changes and was the probable cause of the dose being overestimated for LV221 and LV225 (see Table 6). Additionally, an ultrafast component was observed in two aliquots of LV221. The dose was underestimated for LV224.

Sample	Aliquots rejected:			Aliquots accepted	D_e (Gy)
	Recycling	Thermal transfer	Low signals		
LV217	8	7	6	3	8 ± 2 (Mean)
LV218	1	3	18	1	18 ± 3

Table 6: SAR data for LV217 and LV218 from 24 aliquots of each sample

3.7.15 LV225 was the brightest of all the samples so six aliquots were subjected to a normal SAR procedure, whilst a further six were given a double SAR protocol in a dose-recovery experiment. All OSL signals were measured at a standard temperature of 125°C. All but one aliquot in the normal SAR group had to be rejected due to feldspar contamination, thermal transfer and poor recycling. The recovered dose was overestimated (ratio 1.15). All aliquots in the Double SAR group were rejected due to thermal transfer and poor recycling.

3.7.16 ***Dose rate***: the samples were measured in a low-level gamma spectrometer and the results are listed in Table 7. They yielded radionuclide activity data which are expected for a natural environment. The potassium activity was relatively low, indicating that potassium-rich rocks are not abundant in the Ribble catchment.

Sample	Aliquots accepted	Dose ratio	RSD %
LV221	2	1.12	0.9
LV224	3	0.84	5.7
LV225	4	1.10	3.3

Table 7: Results of dose-recovery tests incorporating a high-temperature stimulation at the end of each SAR cycle

3.7.17 ***Age determination***: fluvial sediments generally show skewed equivalent dose distributions as a result of heterogeneous bleaching. Statistical techniques are available to analyse such distributions (eg Galbraith *et al* 1999) but can only be successfully applied if single aliquots or small aliquots (containing small numbers of grains) are used (Lang and Mauz 2006). From the OSL test measurements on the Ribble samples it is clear that, given the very low luminescence sensitivity, the application of small aliquots is unfeasible. In addition, poor recycling and thermal transfer are major problems that could not be solved despite extensive testing and modification of SAR procedures. This renders any OSL ages obtained using the SAR method unreliable.

3.7.18 ***Radiocarbon dating - Field sampling and sample selection***: the radiocarbon dating strategy addresses a key project objective: to characterise the Late-Glacial and Post-Glacial fluvial evolution of the Ribble river system, identifying and constraining the phases of aggradation and incision, significant switches in the sediment supply and transfer regime within the catchment, and linkages between the major components of the system, eg hillslopes in the different headwater, headwater and lowland reaches, and flood basins. All samples were selected for radiocarbon dating based on the potential to yield geomorphologically useful age estimates. River and hillslope systems provided a number of different contexts for securing a history of geomorphic activity (Fig 42). These contexts are similar to the alluvial ensembles described by Lewin *et al* (2005), who focus on the radiocarbon dating of settings that secure the timing of geomorphic changes. A variety of contexts was identified and have been utilised in this research, and they characterise geomorphic changes in environments that range from upland hillslopes to alluvial floodplains.

3.7.19 ***Hillslope Contexts***: the first three contexts related directly to hillslope process and the coupling relationship with axial streams. Type I contexts are those where either a debris flow or a hillslope gully system had formed. The resultant debris cones/alluvial fans were relatively simple single-surface features and the sediments typically show the switch from axial fluvial to hillslope-derived sedimentation (Fig 42). Often a period of geomorphic stability preceded the hillslope destabilisation event and the soil or peat deposits associated with this stability are appropriate for radiocarbon dating. Type II contexts describe depositional settings also in single-surface alluvial fans, but where there was evidence for more than one phase of fan development. Basal organic materials underlying the initial phase of alluvial fan deposition are referred to as Type IIa contexts. Type IIb contexts occur where a period of geomorphic stability has occurred during alluvial fan and gully development, and allowed the formation of surfical soil or peat, which in turn has been buried by younger alluvial fan deposits (Fig 42). In Type I, IIa and IIb contexts, radiocarbon dating of the organic layers provide older-than ages for any underlying fan sediments and younger-than ages for the overlying phase of alluvial fan development. Type III contexts include those where the alluvial fan is a larger, more complex landform, with terracing reflecting more than one phase of fan development (Fig 42). In these settings organic materials can be associated with more than one alluvial fan terrace. Where organic materials occur beneath the oldest alluvial fan gravels (Type IIIa), perhaps overlying fluvial deposits, then radiocarbon dating will date the onset of hillslope gullying. If this type of context occurs in the deposits of a younger alluvial fan terrace, Type IIIb, then the radiocarbon dating will address the onset of this phase of renewed alluvial fan development. It is also possible to have Type IIb contexts within the deposits of any of the alluvial fan terraces, and these are referred to as Type IIIc.

3.7.20 These hillslope contexts are pertinent to this research, because the upland hillslopes can be crucial in terms of understanding sediment transfer and budget within a river system (Chiverrell *et al* 2006). Alluvial fan sedimentation at the tributary junctions of discrete gully systems with main valleys are settings where the geomorphic responses are more closely coupled to hillslope processes (Harvey 2002). There is considerable evidence for hillslope instability during the late Holocene (after 1000 cal BC) within the Solway Firth to Morecambe Bay area, extending from north-west England to south-west Scotland and encompassing the upland areas of the Bowland Fells, Howgill Fells, Lake District and Southern Uplands of Scotland. The episodes of increased gullying and alluvial fan often coincide or pre-date alluviation further downstream. Within river catchments they provide evidence for greater availability of sediment, and for the Ribble this is the case in the Forest of Bowland; however, relatively little is known about the other upland headwaters, particularly the Ribble in the Yorkshire Dales. Within this project the existing database of radiocarbon dates for the Bowland Fells has been utilised (Harvey and Renwick 1987; Chiverrell *et al* 2006). There was no need for further research of this nature in the Hodder headwaters, given the volume of available data; however, the Upper Ribble is another matter. Organic materials were sampled for a series of hillslope alluvial fans in the Ribble and Wharf headwaters, which offer a difficult rival opportunity for characterising headwater hillslope instability in Upper Ribblesdale and Wharfedale; as such this would be a barometer of hillslope erosion in the wider region, and of sediment flux to both river systems. Understanding the sequence of geomorphic change on the upland hillslopes for different parts of river catchments is crucial, because of the importance of anthropogenic activity, changes in farming intensity and woodland reduction on the hillslopes, which is a spatially variable and inherently local signature.

3.7.21 Using radiocarbon dating of organic deposits underlying alluvial fan gravels to constrain phases of gully incision requires consideration of two factors. The first is preservation potential, which arises because the fluvial geomorphic record typically comprises more gap than record (Lewin *et al* 2005). Alluvial fan sediments often consist of rapidly accumulated gravels lain down during storm events (Harvey 1986; Wells and Harvey 1987), and *Lewin et al* (2005) suggest that the radiocarbon-dated deposits may reflect only the most recent stages of fan formation in long-lived gully networks. This is not regarded as the case for the examples discussed in this report, because most of the gullies clearly are of Holocene age and typically the fan gravels overlie soils on axial stream gravels that signify relative stability within the fluvial system prior to fan development. Finally, in cases where there have been multiple phases of alluvial fan activity, there is geomorphic or stratigraphic evidence. The second concern is the radiocarbon dating itself, because the dating utilises different types of material (eg peat, soil, wood and charcoal). Radiocarbon assays from soils buried beneath or between alluvial or debris-flow deposits can provide information about the onset and duration of soil formation prior to subsequent burial (Matthews 1985). The approach used is often to radiocarbon-date the top and/or bottom horizons of the soil and to target humin and humic acid fractions within the soil organic matter (Harvey 1997). Humin is the least mobile fraction within palaeosols and provides older radiocarbon assays, whereas humic acids are mobile and provide younger age dates (Matthews 1993). Between them the radiocarbon assays for the humin fraction of the base of a buried soil and the humic acid from the top of a buried soil secures the duration of soil accumulation, and can provide 'older than' estimates for the underlying sediments and 'younger than' estimates for the overlying sediments. The suite of dates from the Bowland Fells (Harvey and Renwick 1987; Chiverrell *et al* 2006) conforms to this strategy. The new dates obtained for alluvial fans on the Ribble / Wharfe watershed were from hand-picked *in situ* plant macrofossils and so avoided the problems of migration of organic matter associated with soil radiocarbon dating.

3.7.22 ***Fluvial contexts***: the geochronological strategy for fluvial settings entails obtaining radiocarbon dates for the oldest palaeochannel (highest and most remote from the current channel) for each level of river terracing. To achieve this, reaches in the Lower Ribble, Upper Ribble, Calder and Hodder were selected and were subjected to borehole investigation of a series of palaeochannels on each terrace fragment. This final group of contexts, Type IV, comes from axial stream terraces, where the deposits reflect fluvial processes. Chronological control was possible by radiocarbon dating of: organic materials within an alluvial sequence (Type IVa); peat sequences that overlie an alluvial unit (Type IVb); and soils or peat deposits between alluvial units that signify relative stability within the accretion of the alluvial sequence (Type IVc). All of the radiocarbon dating targeted the sediment fills of surface palaeochannels, with the switch from channel gravel to back channel-style organic-rich fine-grained sediments at the base of the palaeochannel fill forming the Type IVd context. These settings provided the best prospect for constraining the abandonment of the palaeochannel and perhaps the onset of incision below this river terrace level (Fig 42). Further samples were taken from the top of the palaeochannel fill, and from the uppermost horizons within the sediment that were demonstrably still affected by flood inundation (Type IVe) to provide a later constraint on terrace abandonment.

3.7.23 In terms of securing a history of geomorphic activity, each of these contexts provided a different type of information. Type IVa contexts provide an age within the accumulation of the sequence, but do not secure either the onset or duration of fluvial aggradation. They are also susceptible to the reworking of organic materials, particularly wood or charcoal remains. Type IVb contexts can provide only an older-than age for the fluvial deposits buried beneath the peat sequence. Type IVc contexts can be dated to secure the duration of a phase of stability within the aggradation of the alluvial sequence, and to provide older-than age estimates for the underlying and younger-than ages for the overlying alluvial deposits. Radiocarbon dating of Type IVd and Type IVe contexts provide some constraint on the abandonment of individual palaeochannels and provide a minimum age for the incision producing the associated river terrace. Within this approach more than one palaeochannel was targeted for significant study reaches, with the borehole programme sampling the deposits of youngest and oldest palaeochannels on each terrace fragment.

3.7.24 ***Sample Preparation and Methodology***: in total, 68 samples from 34 horizons were prepared and processed for radiocarbon dating using the Oxford Radiocarbon Accelerator Unit (OxA) at the University of Oxford and the

Scottish Universities Research and Reactor Centre (SUERC) in East Kilbride, between January and November 2006. At Oxford, the samples were processed following the procedures detailed by Bronk Ramsey and Hedges (1997), Bronk Ramsey (2001) and Bronk Ramsey *et al* (2004). At SUERC, sample preparation and measurement followed the procedures outlined by Slota *et al* (1987) and Xu *et al* (2004). The radiocarbon age determinations were all undertaken by Accelerator Mass Spectrometry at laboratories that maintain continual programmes of quality assurance and participate in international laboratory inter-comparisons (Scott 2003), which reveal no laboratory off-sets and validate the precisions quoted in the age determinations.

3.7.25 In addition to the samples that were submitted for radiocarbon dating under the auspices of this ALSF project, additional chronological control for the fluvial geomorphology and palaeoenvironmental record for the Ribble catchment was available from radiocarbon dating (Table 8) on the Ribble river terraces by Chiti (2004) and for the Hodder, in the Forest of Bowland, by Harvey *et al* (1984) and Chiverrell *et al* (2006). For the majority of horizons selected for the new dating, the English Heritage strategy of dating two handpicked plant macrofossils for each horizon has been adhered to. The exceptions were a relatively small number of samples in the first batch submitted for dating, and, in the second batch, only handpicked plant macrofossils were admissible. The samples comprise a mixture of wood, plant remains (leaves, stems and twigs), seeds and occasional charcoal, with identification to the best possible taxonomy undertaken by Elizabeth Huckerby (OA North), Richard Chiverrell (Liverpool) and experts at Kew Gardens. In the case of wood, samples that comprised 'heartwood' were excluded from the analyses. A complete list of the radiocarbon-dated locations, horizons, and materials dated is given in Table 8.

Sample code (LV)	**U (Bq kg^{-1})**	**Th (Bq kg^{-1})**	**K (Bq kg^{-1})**
215	23.80±0.79	32.63±0.76	265±7
216	28.33±0.86	30.28±0.74	261±7
218	25.32±0.79	35.43±0.86	354±9

Table 8: Radioactivity concentrations measured in some samples

3.7.26 ***Analysis of the results and calibration***: the entire suite of radiocarbon results are presented as conventional ages in Table 9 in accordance with the international standard, the Trondheim convention (Stuiver and Kra 1986). Within later sections the dates are presented in context with the geomorphology and palaeoenvironmental interpretation, where the dates have been calibrated, which relates the radiocarbon measurements to calendar ages. All dates are calibrated using the OxCal software (v 4.0: https://c14.arch.ox.ac.uk/oxcal/OxCalPlot.html: Bronk Ramsey 1995; 1998; 2001) and the calibration curve of Reimer *et al* (2004). The probability distribution and calibration of an individual radiocarbon date is shown in Figure 43a.

Area	**Location and nature of radiocarbon-dated sites**	**Dated materials**	**^{14}CYears BP**	**Calibrated Years**
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)	cal AD 879-1206
	Lower Langden - base of organic fill in a gully	Wood remains	1780±70 (WIS-1628)	cal AD 84-403
	Main river terrace - base of overlying peat	*Betula* remains	4680±80 (WIS-1614)	3646-3125 cal BC
	Upper Langden Fan -			
	top of soil buried beneath fan gravel	Humic fraction	1450±50 (SRR-3340)	cal AD 443-668
	-	Humin fraction	1650±60 (SRR-3340)	cal AD 255-540
	base of soil buried beneath fan gravel	Humic fraction	3390±60 (SRR-3341)	1878-1528 cal BC
		Humin fraction	3970±70 (SRR-3341)	2839-2210 cal BC
	Dunsop Valley (Harvey and Renwick 1987)			
	Whittendale Fan - beneath fan gravels	Wood remains	1200±70 (WIS-1627)	cal AD 675-975
	Hodder Valley (Harvey and Renwick 1987) - base of channel fill on the low river terrace	Wood remains	4320±80 (WIS-1613)	3331-2679 cal BC
Higher Brockholes	Suite of radiocarbon dates obtained by Bernardo 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)	5208-4836 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

Area	**Location and nature of radiocarbon-dated sites**	**Dated materials**	**^{14}CYears BP**	**Calibrated Years**
	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)	5878-5673 cal BC
	Sunderland Hall Plant detritus towards base of alluvium	Organic layer in alluvium	6885±44 (AA-48976)	5878-5673 cal BC
Lower Brockholes	West of the M6, Ribble Terrace 2 (Gearey and Tetlow 2006)			
	Main palaeochannel loop northern edge (T6 Pit 4) Top peat	wood	4430±40 (BETA-213393)	3331-2922 cal BC
	Main palaeochannel loop northern edge (T6 Pit 4) Base peat	R peat (humic)	4070±60 (BETA-213394)	2867-2473 cal BC
	Main palaeochannel loop closest to river (T3 Pit 3) Top peat	R peat (humic)	2500±50 (BETA-213392)	791-416 cal BC
	Main palaeochannel loop closest to river (ETP1) Base peat	R wood (humic)	5330±70 (BETA-213391)	4331-3994 cal BC

Table 9: Previously published radiocarbon dating from the Bowland Fells (Harvey and Renwick 1987; Miller 1991; Chiverrell et al 2006) and from the Lower Ribble (after Chiti 2004; Gearey and Tetlow 2006)

3.7.27 Where two handpicked plant macrofossils for each horizon were dated, statistical comparison between the pairs of dates was undertaken to assess the significance of any differences. This has been achieved using functions within the OxCal software (v 4.0: https://c14.arch.ox.ac.uk/oxcal/OxCalPlot.html: Bronk Ramsey 1995; 1998; 2001), and in particular incorporated the ability to test whether the calibrated probability distributions for two or more dates could be combined. This process produces an agreement index, underpinned by a Chi-square comparison of the probability distributions, and assesses whether the dates can be combined dependent on threshold levels (Fig 43b). The thresholds levels are expressed as an Agreement Index. This process highlights when pairs of dates obtained for each horizon have proven statistically identical and increases the confidence chronology developed for the dated horizon. Given that all the contexts dated in this research are from fluvial settings, with a tendency towards regular reworking of materials, then discrepancies between pairs of dates are important. Figures 43b, 43c and 43e show example comparisons from the lower Calder, where the Agreement Index was acceptable and unacceptable. For the degree of agreement to be sufficient, values greater than 60% are needed, as is the case for the three dates in Figure 43b, where the overall agreement index is 128.4%; for the other example (Fig 43c) the agreement is poor, at close to 0%.

3.7.28 The details of the radiocarbon results, statistical analyses and environmental interpretation and discussion are presented in context with the geomorphology and sedimentology in *Section 5*. Throughout this report, radiocarbon dates are expressed as reported as calibrated years BC/AD (cal years BC/AD) to two standard deviations, with the end points rounded outwards to 10 years, because the error term for all the age determinations is greater than 25 years (Mook 1986).

3.8 CHARACTERISING THE NATURAL LANDSCAPE AS A HERITAGE ASSET

3.8.1 The physical environment forms an important natural archive of past climatic and environmental change, and the geodiversity and biodiversity of this environment are both under threat from a multitude of sources: climate change; resource consumption; and land surface transformation (Ellis *et al* 2007). Geoconservation of our landscape heritage is an increasingly important component of the successful stewardship of the natural environment. The physical environment is currently protected under a number of statutory and non-statutory schemes, the main statutory scheme being the SSSI (Sites of Special Scientific Interest) scheme administered across the UK by Natural England (2007), Scottish National Heritage (SNH) and Countryside Council for Wales (CCW). The non-statutory conservation and management of sites is facilitated through the Regionally Important Geological/ Geomorphological Sites (RIGS 2007) scheme devised by the former Nature Conservancy Council (NCC). The scheme is locally initiated through interest groups and supported by the Association of United Kingdom RIGS Groups (UKRIGS 2007), a national organisation formed in 1999, with the encouragement and support of the then English Nature, Countryside Council for Wales, Scottish Natural Heritage and the Royal Society for Nature Conservation (RSNC). UKRIGS represents the RIGS movement and the large number of independent RIGS groups across the UK. The Lancashire RIGS Group (2007) is a focus for activity within much of the Ribble ALSF region, with the West Yorkshire RIGS Group contributing to RIGS notification in the headwater reaches of the Ribble.

3.8.2 The process of identifying what constitutes important scientific geological or geomorphological sites has been facilitated by the *Geological Conservation Review* (GCR), coordinated by the Joint Nature Conservation Committee (JNCC). The GCR selection process is underpinned by the highest scientific standards to identify systematically important sites that would reflect the range and diversity of Great Britain's Earth heritage (Ellis *et al* 2007) and each GCR site must satisfy the legal requirements for notification as a Site of Special Scientific Interest by reason of its geology or geomorphology, which must be of international importance. International importance is conferred for a variety of reasons: to capture sites that show time interval or boundary stratotypes, are the type localities for biozones (defined by fossil content); and chronozones type localities for particular rock types, mineral or fossil species; historically important localities where rock or time units were first described, characterised, or linked to advances in geological theory; and where geological or geomorphological phenomena, concepts or theory were first recognised and described. Sites can also be listed because they have unique, rare or special features, with the intention that the highlights of British geology and geomorphology are conserved, and to ensure representative coverage of the essential features of Britain's Earth heritage.

3.8.3 Within the current SSSI and RIGS sites listed for the Ribble ALSF study area, the number that reflect the fluvial and glacial geomorphology is somewhat limited (Fig 44). This is largely a function of the relative absence of research into the lowland fluvial geomorphology of north-west England and the glacial history of Lancashire. The only fluvial geomorphology sites listed in GCR reviews that cover north-west England are in Cumbria (Langstrathdale, Wasdale, fan deltas at Buttermere and Crummock Water, Carlingill, Langdale and Bowderdale Valleys in the Howgill Fells), and the River Dane, near Swettenham, Cheshire. Langden Brook (Bowland Fells) is the only representative from the Ribble drainage basin. With the exception of upland rivers in the Bowland and Howgill Fells, there has been relatively little research of the Quaternary development of the river systems of north-west England, particularly when contrasted with the extent of research in north-east England (Macklin *et al* 2005).

3.8.4 Given that academic research appears to be one of the precursors to designation and listing of sites for geological and geomorphological reasons, it is perhaps not surprising that there are few sites currently listed within the Ribble ALSF region. Sites can be nominated for RIGS status through the site assessment process of the local RIGS groups and UKRIGS (2007). Sites can become SSSIs for geological and geomorphological criteria through the *Geological Conservation Review* series, and the GCR of 'Fluvial geomorphology' has been identified for possible revision (Ellis *et al* 2007). The research undertaken during the Ribble ALSF Project has assessed in some detailed the fluvial and glacial evolution of the Ribble, and, as a part of that work programme, the heritage value of the physical environment has been advanced. Sites that have contributed significantly to understanding the physical landscape, and the Quaternary and Holocene geomorphic history, are clearly now candidates for RIGS status and perhaps GCR nomination. Any sites that meet these criteria and are comparable in merit to existing RIGS/GCR sites will be identified in the recommendations (*Section 10*).

3.9 CHARACTERISING THE ARCHAEOLOGICAL RESOURCE

3.9.1 ***The Archaeological Database:*** the preliminary archaeological database was constructed in Microsoft Access 97 to hold the archaeological events and monuments data for the project. Events are defined as an episode of archaeological activity, such as an excavation or a survey, and the monuments are the archaeological sites that are revealed by the event. Single events, such as a survey, can result in the creation of large numbers of monuments or if they are unsuccessful, may create no monuments. Monuments by the same token may have been informed by multiple events, and in some instances, if derived from historic mapping (for example), may have no corresponding events.

3.9.2 The structure of the database was designed to obey the latest MIDAS standards (English Heritage 2000), and to incorporate standard word lists (Inscription: http://www.fish-forum.info/inscript.htm) and thesauri (http://thesaurus.english-heritage.org.uk/thesaurus.asp?thes_no=1) to ensure computability with the widest range of existing datasets. The structure incorporates the generally accepted division between archaeological events and monuments, with the additional inclusion of palaeoenvironmental event information where appropriate. Monuments were taken to include all statutory designations (ie Listed Buildings and Scheduled Monuments).

3.9.3 Initially, events and monuments were entered into the database and displayed on the GIS as point data only, then as more detailed information became available for particular events these were displayed in the GIS as boundary polygons, which were linked to the appropriate record within the database by a Lancashire HER Primary Record Number (PRN).

3.9.4 ***Previous Research and Investigations:*** during the data-gathering phase of the project, datasets were provided by Lancashire County Council and national sources. These included data on events and monuments, generally in digital form (either as data tables or as shape files), and mapping data (generally in the form of georeferenced raster images), for incorporation into the project GIS.

3.9.5 Datasets provided by Lancashire County Council comprised:

- Historic Environment Records;
- Roman roads;
- Portable Antiquities Scheme;
- Listed Buildings;
- Registered Parks and Gardens;
- North West Wetlands Survey.

National Sources comprised:

- National Monuments Records;
- Archaeological Investigations Project.

3.9.6 Records from each dataset were defined as events or monuments in the GIS, although these were not always mutually exclusive. For example, a building survey would be assigned an event record for the survey, and a monument record for the building itself. As part of the data entry process, external references were added, indicating the source dataset for each record. In some cases records were duplicated between datasets, in which case they were assigned an external reference for each source, rather than duplicating the entire record. Additionally, a grey literature search was undertaken, particularly from the archives of OA North.

3.9.7 The datasets were not entirely error-free, and data cleansing was a significant part of the data entry process. Common errors included inaccurate location information, duplication of records within individual datasets, omissions in fields, and spelling or grammatical errors. It was also necessary to change descriptive terms to ensure consistency and compliance with current standards. In general, this meant changing event types to match the ALGAO event-type list (http://www.fish-forum.info/i_alget.htm), changing periods to match the RCHME period list (http://www.fish-forum.info/i_apl.htm), and the monument type to match the broad class and type listed in the RCHME thesaurus (http://thesaurus.english-heritage.org.uk/thesaurus.asp?thes_no=1). Where alterations were made, this was noted in the project notes for return with the primary datasets. To ensure compliance with MIDAS standards (English Heritage

2000), additional fields were completed that were not generally included in the primary datasets, such as National Grid Reference Precision.

3.9.8 ***Mapping:*** the following sources of mapping were acquired for the project:

- current Ordnance Survey MasterMap (digital vector);
- current Ordnance Survey Landline (digital vector);
- current Ordnance Survey 1:10,000 (digital raster);
- current Ordnance Survey 1:25,000 (digital raster);
- current Ordnance Survey 1:50,000 (digital raster);
- Ordnance Survey First Edition 6 inch (digital raster);
- Ordnance Survey Second and Third Edition 6 inch (hardcopy);
- Ordnance Survey First Edition 25 inch (digital raster);
- NextMAP 5m contour data;
- Saxton (1577);
- Yates (1786);
- Speed (1610);
- Tithe Maps.

3.9.9 Digital vector mapping is, by nature, georeferenced and could be displayed in the GIS immediately, along with the contour data. The current Ordnance Survey digital raster mapping was supplied georeferenced and was incorporated as an image catalogue within the GIS. The Ordnance Survey first edition 1:10,560 (6” to 1 mile) mapping was obtained digitally, georeferenced and incorporated together as an image catalogue within the GIS. The Ordnance Survey Second-and Third-Edition 1:10,560 (6” to 1 mile) mapping were scanned by the Lancashire County Council Environment Directorate from hardcopy base maps. The resultant scans were then trimmed, georeferenced and also incorporated as an image catalogue.

3.9.10 The more detailed 1:2500 (25 inch to 1 mile) maps for Lancashire were made available in PDF format by the Digital Archives Association in Warrington. The number of map tiles required to give coverage of the study area would have made the trimming and georeferencing of the image files very time-consuming. As a result they were consulted as appropriate rather than being incorporated into the GIS. The other historic maps were utilised in the same way.

3.9.11 ***Air Photographs and LiDAR***: at the project outset, HER data showing the locations of available oblique aerial photography was provided by Lancashire County Council and incorporated into the project GIS. The photographic archive used included 115 oblique photographs scanned from the Lancashire Record Office, in addition to runs from the National Monuments Record and Holdings of historic RAF coverage. The entire Lancashire area was subject to vertical aerial survey in 2000 and Lancashire County Council loaned this to the project. Additionally, a small amount of extra flying was undertaken by Jamie Quartermaine of OA North, which examined the potential aggregate extraction area opposite Brockholes Quarry, and the village of Rathmell in North Yorkshire.

The aim of this exercise was to provide a comparator for an equivalent block of LiDAR data and hence this technique was not systematically applied across the study area.

3.9.12 The locations of the oblique photographs were displayed in the GIS and the images consulted, along with modern mapping, historic mapping and vertical air photographic mapping. Features seen on the air photographs were then noted and cross-referenced against all other known archaeological monuments, and only when it was confirmed that there was no duplication were they added as new sites in the database. The problem with mapping features from oblique aerial photography is resolving the oblique distortion, and in this case this was helped by direct comparison with equivalent LiDAR data.

3.9.13 ***LiDAR:*** LiDAR data was supplied under licence for the duration of the project by the Environment Agency, although full coverage of the study area was not available (Fig 45 Available LiDAR Coverage). The coverage that was available was integrated into the GIS as georeferenced raster images created from basic ASCII files. These rasters are capable of producing very precise surface models that can be examined in a variety of ways within the GIS. For the purpose of this project two methods were most commonly used: hillshades and slope models.

3.9.14 ***Hillshades***: the hillshade function calculates the illumination values for each cell in a raster representing a surface, given a hypothetical light source in a specified position. It does this by setting a position for the light source and calculating the illumination values of each cell in relation to neighbouring cells. It can greatly enhance the visualisation of a surface for analysis or graphical display by highlighting subtle changes in the topographic surface.

3.9.15 From the perspective of searching for archaeological monuments, the hillshade function simulates the effect of low-level aerial photography, in that the angle and azimuth of the sun can be selected to allow one to view the landscape as if from an aircraft. In this way landscape features stand out in the same way as they would under oblique photographic conditions.

3.9.16 Once a hillshade layer had been created in the GIS, it was overlaid onto the current vertical colour aerial photographic mapping to enhance the landscape, and this was systematically examined in transects across the study area. Any unknown features that could not be explained by the known archaeological monuments were recorded as new monuments and digitised as polygons, or points, as appropriate within the GIS.

3.9.17 ***Slope Models*****:** these were created using the height values attached to the LiDAR data. The slope model identifies the steepest downhill slope for a location on a surface. For raster surfaces, this is the maximum rate of change in elevation between a cell and each of its nearest neighbours. The lower the slope value, the flatter is the terrain; the higher the slope value, the steeper the terrain. Although full coverage of NextMAP 5m contour data was available, the LiDAR data were used where available for constructing slope models for the identification of archaeological monuments as it provided considerably improved resolution (Fig 4b Example of Slope model, Village of Waddington).

3.9.18 Both slope and hillshade were manipulated in ArcScene, which allows a three-dimensional view of the data, and allowed the landscape to be examined from virtually any angle and with different orientation of light sources. Again, the landscape was systematically examined and any new monuments recorded on the GIS (*Section 3.2*).

3.9.19 ***Secondary Sources***: a selection of secondary sources was consulted, both relating to the study area and the wider landscape:

- *Historic Landscape Characterisation* (HLC) Project (Ede and Darlington 2002);
- *Ribble Valley Catchment Archaeological Rapid Identification Survey* (LUAU 1997b);
- Documentary Survey of 1890s map (Lancashire HER 2006);
- Grey Literature from the archives of OA North/LUAU;
- Conservation Areas/SSSIs;
- Designated Ancient Woodland;
- Countryside Character Areas;
- Ribble Catchment Flood Management Plan (Environment Agency 2005).

3.9.20 The Conservation Area/SSSI/Countryside Character/Ancient Woodland datasets did not provide evidence for events and monuments, but rather for more general information about the study area, or about land designations. These were added to the GIS without any form of data cleansing and were added as external references to monuments as appropriate.

3.9.21 The main focus of this research was to enhance the information held on existing events and monuments, and to identify any that had not been addressed in the main datasets. However, this research also provided a wealth of historical background information for the project, and in addition uncovered several elements, other than archaeological remains, that were pertinent to the study area.

3.9.22 The second stage was to examine the landscape surrounding the Ribble Valley to provide a broad-based understanding of the modern character of the study area. The most useful sources for this were the Water Framework Directive (Environment Directive 2007) and the works undertaken by English Nature and the Countryside Agency (English Nature 1999a; 1999b; 1999c; Countryside Commission 1998). These provided an understanding of the modern landscape types, a brief outline of historical influences on the region, and the location of particular designated areas such as Sites of Special Scientific interest (SSSI) or Designated Ancient Woodland. The Countryside Agency has created a map of character areas (Fig 3) that divide the landscape into ‘packets’ of similar character (Countryside Commission 1998 (*Section 2.1*)). The descriptions also relate how that character has developed and how it is changing; as such they provide a context against which the archaeological development of the study area can be assessed.

3.9.23 The Record Office and relevant libraries of Lancashire and North Yorkshire were visited and local history sections searched. The scope of the material was initially wider than the study area in order to determine whether the area matched patterns observable in other parts of the north-west England, or whether it was unique. The approach taken for the secondary source information was to create a period-by-period description of the known archaeological and historical information from the North West, but focusing on the Ribble Valley.

3.9.24 Several recent publications were consulted at both a regional and site-specific level, including English Heritage's *Earthwork Survey of Sawley Abbey* (Hunt 2005), which provides a detailed survey of the earthworks and concise history of the site. The *Lancaster Imprints* publication of the excavations at Ribchester (Buxton and Howard-Davis 2000) and the English Heritage *English Landscapes* volume for the North West (Winchester 2006) were also consulted, as was the *North West England Archaeological Research Framework, Archaeological Resource Assessment* (Brennand 2006).

3.9.25 ***Field Survey and Ground-Truthing***: a rapid programme of ground-truthing was undertaken during the course of the project, utilising OA North's *Level 1 Identification Survey Methodology* (OA North 2002), which covers walkover survey by visual assessment. This level of survey represents the minimum standard of record for field investigation, and is aimed at the discovery of previously unrecorded archaeological monuments. Its objective is rapidly to record the existence, location, and extent of any monument using four elements: reconnaissance; mapping; description; and photography, and includes comments on character and condition. Monuments already identified within the study area by the NMR and HER were checked and recorded at the same level of consistency as newly discovered features.

3.9.26 This survey generated core information for entry into the project database and GIS. Each area was walked in transects at an interval between 20m and 50m, depending on local topography and ground cover. A primary part of the exercise was to ground-truth the information gathered by the remote sensing techniques, notably LiDAR, aerial photographic and cartographic data.

3.9.27 ***Creating an Enhanced Monument and Event Dataset***: the data sources listed as the *Archaeological Resource* were compiled within the GIS as either monuments or event data where appropriate. This data represented a merging of the cleansed point data for monuments, events, Listed Buildings and the Portable Antiquities Scheme findspots, with point data from the North West Wetlands Survey (Middleton *et al* 1995), the *Ribble Valley Catchment Archaeological Rapid Identification Survey* (LUAU 1997b) and the Lancashire County Council Survey of the 1890 Ordnance Survey Map (Lancashire HER 2006) This was used in conjunction with the other linear or area-based features, namely Roman roads; Historic Landscape Characterisation; and Historic Parks and Gardens (English Heritage 2007). This allowed both an initial assessment the distribution of known archaeology within the study area, and the creation of the enhanced database for the GIS analysis.

3.9.28 This data did not have a field allocated for the National Monuments Broad Class (English Heritage 2000) entry. As such, all monument data were assigned the correct Broad Class. Table 10 contains the NMR broad class list for all known archaeology prior to, and after, the addition of new sites recorded by the ALSF project.

NMR broad class List	**Count**
Agriculture and Subsistence	107
Civil	2
Commemorative	1
Commercial	35
Defence	29
Domestic	133
Education	21
Findspot	55
Gardens Parks and Urban Spaces	38
Health and Welfare	5
Industrial	161
Maritime	22
Monument	16
Recreational	9
Religious Ritual and Funerary	68
Transport	93
Unassigned	18
Water Supply and Drainage	93

Table 10: NMR broad class types found in the Lower Ribble Valley study area

3.9.29 ***Mapping**:* examination of the OS first edition mapping revealed eight new sites (Table 11) that were depicted on the maps but had not been incorporated into the HER for the study area. In addition, two earthworks were identified by comparing the LiDAR coverage with the first edition OS mapping.

Count	**NMR Class**	**Monument Type**
1	Agriculture and Subsistence	Barn
1	Industrial	Gravel bank
1	Monument <Form>	Earthwork
1	Recreational	Racecourse
1	Transport	Footpath
1	Unassigned	Reclaimed Land
2	Water Supply and Drainage	Palaeochannel

Table 11: New sites identified from OS first edition mapping

3.9.30 ***Aerial Photography***: a surprisingly small number of new sites was found using the aerial photographs alone; in total, five sites were identified in this way (Table 12). An additional eight were identified by comparison of aerial photography to LiDAR data (Table 13).

Count	**NMR broad class**	**Monument Type**
3	Monument	Earthwork
1	Unassigned	Cropmark
1	Water Supply and Drainage	Palaeochannel

Table 12: New sites identified from aerial photographs

Source	Count	NMR broad class	Monument Type
2000 VAP/LiDAR Slope	1	Agriculture and Subsistence	Ridge and Furrow
2000 VAP/LiDAR Slope	5	Monument	Earthwork
2000 VAP/LiDAR Slope	1	Water Supply and Drainage	Palaeochannel
LiDAR Slope/HER PRN3292 / / N1281 AP	1	Monument	Earthwork

Table 13: New sites identified from combinations of aerial photography and LiDAR

3.9.31 ***LiDAR**:* LiDAR was found to be an invaluable asset, which identified a total of 162 sites from examination of slope or hillshade models (Table 14).

Count	NMR broad class	Monument Type
2	Agriculture and Subsistence	Field system
27	Agriculture and Subsistence	Ridge and Furrow
1	Industrial	Mill Race
1	Industrial	Sluice
1	Monument	Bank
91	Monument	Earthwork
8	Monument	Field boundary
9	Monument	Linear Feature
1	Transport	Road
1	Unassigned	Site of (no longer extant)
3	Unassigned	Unknown
1	Water Supply and Drainage	Drain
12	Water Supply and Drainage	Palaeochannel
4	Water Supply and Drainage	Pond

Table 14: New sites identified by LiDAR

3.9.32 ***Grey Literature Search**: The Ribble Valley Catchment Archaeological Rapid Identification Survey* (LUAU 1997b) had been provided as a Shape file containing point data for each site visited during the survey. This was compared to the HER monument data for the study area and it was found that 149 of the sites recorded during the Ribble Catchment Survey were located in the Ribble Valley study area.

3.9.33 Seventy-seven sites were recorded as monuments on the county HER and these were visited as part of the survey. These needed to have a corresponding reference added to each to mark this survey event. The remaining 72 sites recorded by the survey had not been allocated a PRN number nor added to the HER records. These were allocated a number from the set of PRN numbers issued to the Ribble ALSF project by Lancashire County Council Archaeological Service. Again, each of these required a corresponding event reference to this survey.

3.9.34 The total additions made to the HER dataset for the Ribble Valley are summarised in Table 15.

NMR broad class List	Initial	Enhanced Count
Agriculture and Subsistence	107	145
Civil	2	2
Commemorative	1	1
Commercial	35	35
Defence	29	37
Domestic	133	133
Education	21	21
Findspot	55	79
Gardens Parks and Urban Spaces	38	39
Health nd Welfare	5	7
Industrial	161	167
Maritime	22	24
Monument <by Form>	16	158
Recreational	9	10
Religious Ritual and Funerary	68	76
Transport	93	99
Unassigned	18	84
Water Supply and Drainage	93	120
Total	**906**	**1237**

Table 15: Additions made to the HER dataset for the Lower Ribble Valley

3.10 CHARACTERISING THE PALAEOBOTANY OF THE LOWER RIBBLE VALLEY

3.10.1 ***Previous work in the general environs and study area*:** previous palaeoenvironmental work within the study area is restricted to the thesis by Bernardo Chiti (2004) from the Lower Ribble Valley, and a recent environmental assessment from Lower Brockholes, near Preston (Gearey and Tetlow 2006). Chiti's research concentrated on the evolution of the lower course and estuary of the River Ribble rather than the palaeoecology *per se*, although a pollen diagram through the organic fill of a palaeochannel at Brockholes provides a record of vegetational change from the middle and later Mesolithic to the early Neolithic periods.

3.10.2 A brief pollen assessment of samples from two test pits from another organic deposit at Brockholes (Gearey and Tetlow 2006), the top of which was dated to 3331-2922 cal BC (4430±40 BP; Beta-213393), suggests a generally wooded environment, with oak, hazel and alder in all three of the samples assessed from the first test pit, although the environment was more open in the middle sample. A single pollen sample from a further test pit suggests a less open environment, with alder locally dominant. The Coleoptera were assessed from a number of different transects and test pits from the site. This provides a picture of a local environment with indications of boggy backswamp and damp meadows and with some temporary or more permanent aquatic areas.

3.10.3 The only other palaeobotanical research within the study area of the Lower Ribble Valley is that from the Roman fort at Ribchester (Buxton *et al* 2000, 21-3; Huntley and Hillam 2000, 349-59) and, except for a brief pollen study of the pre-rampart soils (Innes 2000), this is closely associated with the fort itself rather than the regional picture. The pollen evidence from two consecutive buried soils records the vegetation at the site before the Roman occupation. The lower buried soil records a local alder carr beside the river before a period of major agriculture activity. The lower part of the overlying buried soil records a second episode of intensive cultivation before the construction of the earliest rampart at Ribchester.

3.10.4 Regionally, the picture is more comprehensive and there is an extensive body of palaeoecological research from the lowlands to the south-west and north-west of the most westerly section of the Lower Ribble study area. Research in the upland areas of the eastern part of the study area is more limited, with published and unpublished work from the Bowland Fells (LUAU 1997a) to the north and Anglezarke (Howard-Davis 1996) to the south.

3.10.5 Pollen diagrams from the lowland mosses of south-west Lancashire (Middleton *et al* forthcoming), north Lancashire (Middleton *et al* 1995), north Merseyside (Cowell and Innes 1994), and north Greater Manchester (Hall *et al* 1995), although in some instances related to changing sea level, do give some indications of the regional vegetation from the Late Devensian (Late-Glacial) and the Holocene (Post-Glacial). Pollen recorded in the peat from the central areas of the large raised mires is thought to record changes in the regional landscape rather than more local changes identified from the margins of raised mires (Turner 1975) or from small basins (Jacobson and Bradshaw 1981). Therefore the pollen studies from the Fylde area of Lancashire (Oldfield and Statham 1965; Barnes 1975; Tooley 1978; Middleton *et al* 1995; Wells *et al* 1997) represent regional changes to the vegetation, as do those from south-west Lancashire and Merseyside (Tooley 1978; Cowell and Innes 1994; Middleton *et al* forthcoming) and Red Moss, Greater Manchester (Hibbert *et al* 1971; Hall *et al* 1995).

3.10.6 Regionally frequent, extensive and widespread charcoal horizons are recorded in the mire stratigraphy and pollen diagrams for the Mesolithic period. This suggests both *in situ* and regional burning of the woodland. It is not possible to prove conclusively the causes of this burning, whether it was the result of natural events, such as lightening strikes, or of anthropogenic activity. However, Rackham (1986, 71-2) states that British trees, except for pine, burn like ‘wet asbestos’ and it is therefore unlikely that British wild wood would have burnt naturally.

3.10.7 In south-west Lancashire and the Fylde, the pollen record is influenced not only by climate and anthropogenic activity but also by changing sea levels, with many palaeoecological sequences interrupted by marine deposits (Tooley 1978; Middleton *et al* forthcoming). This extensive body of palaeoecological research records that towards the end of the last glaciation there was a temporary amelioration of the climate before a return to colder conditions.

3.10.8 From the early Neolithic period onwards, anthropogenic activity is recorded with more certainty in the pollen diagrams from the region, 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). These diagrams record that episodes of regeneration and short-term clearance alternated throughout the Neolithic and Bronze Age, before secondary woodland regenerated in the Iron Age. This Iron Age regeneration coincides with the identification of proxy climatic indicators in the peat stratigraphy, which suggest possible climatic deterioration.

3.10.9 The same body of published and unpublished research also records the regional vegetation from the late Iron Age to the present day. The evidence for anthropogenic activity is considerable for the remainder of the Holocene, although there are some episodes of woodland regeneration in the early part of the post-Roman period.

3.10.10 There are fewer pollen studies from the upland areas bordering the Lower Ribble Valley. In the north there is the research of Mackay and Tallis (1994) from Fairsnape Fell, as well as the tightly targeted work from the Bowland Fells undertaken as part of the *Upland Peat Project* (OA North in prep) and to the south pollen studies are confined to Anglezarke (Bain 1991; Howard-Davis 1996; OA North in prep). The chronological length of the pollen record is limited by the date of peat inception, the earliest peat forming in the Mesolithic period (OA North in prep) on the higher fells in the Forest of Bowland at 5711-5563 cal BC (6720±35 BP; SUERC-4505), gradually spreading downslope in the Neolithic and Bronze Age, with peat at Site 3 in the Forest of Bowland starting to accumulate in the Iron Age, at 732-379 cal BC (2365±40 BP; SUERC-4507; *ibid*). The pollen studies from Fairsnape Fell, to the north-east of Preston, are the nearest to the study area. Mackay and Tallis (1994) recorded changes in the vegetation from 350-2 cal BC (2105±40 BP; SRR-4507) to the present day.

3.10.11 ***Methods of prospection and analytical techniques: description of sampling work***: in the first instance the LiDAR and mapping data for the study area were examined to identify possible palaeoecological sites that could record the Holocene vegetational history. In the case of the Lower Ribble Valley no potential mire sites were noted; however, in the Yorkshire study area two possible sites were identified, one directly within the study area and one a little outside it. These were the SSSI of Long Preston Deeps (SD 81315 58296), near Goosmire Lathe (Hall Moss on the first edition OS maps), and Cocket Moss (centred SD 78557 61766). A brief visit was made to both sites and limited numbers of exploratory cores were taken with a 30mm-bore Eijkelkamp gouge auger, to record the possible depth of the peat and potential for palaeoecological analysis.

3.10.12 In the Lower Ribble Valley, the OA North environmental archaeologist visited four sites with the team from University of Liverpool (*Section 3.5.2*). The first site, an exposed section on the Calder near Whalley, was sampled and wood was retrieved for dating and identification. The other three sites were cored using a Van Walt percussion corer through the fluvial deposits, which included buried peat deposits. Samples were retrieved in the field for dating, pollen and plant macrofossil analysis.

3.10.13 A pollen assessment of samples from Flashers Moss, Cocket Moss and Long Preston Deeps was also undertaken (*Section 5.3.1*). All samples were prepared for pollen analysis using a standard chemical procedure (method B of Berglund and Ralska- Jasiewiczowa 1986), using HCl, NaOH, sieving, HF, and Erdtman's acetolysis, to remove carbonates, humic acids, particles >170 microns, silicates, and cellulose, respectively. The samples were then stained with safranin, dehydrated in tertiary butyl alcohol, and the residues mounted in 2000 cs silicone oil. Slides were examined at a magnification of 400x (1000x for critical examination) by equally spaced traverses across at least two slides to reduce the possible effects of differential dispersal on the slide (Brooks and Thomas 1967). The aim was to obtain a pollen count of at least 100 land pollen and spores for each level counted. *Lycopodium* tablets (Stockmarr 1971) were added to a known volume of sediment at the beginning of the preparation so that pollen concentrations could be calculated. Pollen identification was made using the keys of Moore *et al* (1991), Faegri and Iversen (1989), and a small modern pollen reference collection. Anderson (1979) was followed for identification of cereal-type grains. Indeterminable grains were also recorded as an indication of the state of the pollen preservation. Plant nomenclature follows Stace (1997).

3.11 ASSESSING THE MINERAL POTENTIAL AND GEOMORPHIC RISK

3.11.1 ***History of mineral extraction:*** the focus of the Ribble ALSF Project is upon land-based sand and gravel aggregates, for which previous and current extraction has targeted glacial, fluvioglacial and fluvial deposits. To assess the history of mineral extraction and future mineral planning, and to produce an inventory of current, past and future extraction of sand and gravel, information has been compiled from various sources. Since its formation in 1835, the British Geological Survey (BGS) has collected information about working mines and quarries, mainly because they provide the best sites to understand the local geology. These data have been compiled in the *Directory of Mines and Quarries* (DMQ) (Cameron 2005), which has been published at approximately two yearly intervals. The data were derived from a database called BritPits, and includes both active and inactive surface quarries and underground mines, and usefully the holdings include the name of active mines and quarries, their geographic location, address, operator, mineral planning authority, geology, mineral commodities produced and end-uses. BGS believes that BritPits is one of the most comprehensive and up-to-date sources available, and it is a useful source for identifying the history of sand and gravel extraction within a region.

3.11.2 The LCC Waste and Minerals Policy Group documentation is an important resource. Of particular importance are the *Lancashire Minerals and Waste Local Plan* (LCC 2006), and its successor, the *Joint Minerals and Waste Development Framework*, which is currently being prepared by Lancashire County Council, Blackburn with Darwen Borough Council, and Blackpool Borough Council. This, and the existing *Minerals and Waste Local Plan* (LCC 2006), set out the strategy for future minerals and waste development, and include mineral extraction, protection of mineral resources and the restoration of minerals extraction sites. To facilitate a greater understanding of the sand and gravel reserves in Lancashire, LCC has commissioned several sand and gravel studies (see *Section 3.3*). The Entec UK Ltd (2005) and the Geoplan Ltd (2006) reports provide the most detailed information on mineral quality and are particularly pertinent to the study of the aggregate resources of the Ribble catchment area. Both studies were constrained in that they focused on predetermined study areas, with only a limited brief to look at new areas, and only those for which there was extant geological data.

3.11.3 Another important knowledge base are the reports (1999-2006) of the Regional Aggregate Working Party (RAWP 1999-2006) for north-west England. The Regional Aggregate Working Parties (RAWPs) provide technical advice in relation to the supply of and demand for construction aggregates (including sand, gravel and crushed rock) to the Regional Assemblies/Regional Planning Bodies and to the Secretary of State for Communities and Local Government (DCLG), previously (before 2005/6) to the First Secretary of State for the Office of the Deputy Prime Minister.

3.11.4 All these sources were examined and analysed to compile a database of sand and gravel mineral extraction activity within the study area. These data were used to compile a spatial geodatabase of current and past extraction sites, including both solid rock and sand and gravel aggregate quarries.

3.11.5 ***Current minerals planning, survey and knowledge:*** the main resources to inform minerals planning are:

- Drift geology maps and digital databases of the BGS, particularly the five 1:50,000 sheets covering: Garstang (BGS 1990); Settle (BGS 1991); Rochdale (BGS 1974); Preston (BGS 1982); and Clitheroe (BGS 1975). The Preston sheet is currently under revision, and the present study is contributing to that process (AJ Humpage and RG Crofts (BGS) *pers comm*);
- The Department of the Environment-commissioned report, *Sand and Gravel Resources of Lancashire*, by Allot and Lomax, which reported in 1990;
- The report, *Sand and Gravel Study Stage 1*, commissioned in November 2003 by Lancashire County Council from Entec UK Ltd (2005) in partnership with the British Geological Survey (BGS), http://www.lancashire.gov.uk/environment/lmwlp/;
- The report, *Sand and Gravel Study Stage 2*, commissioned in June 2005 by Lancashire County Council from Geoplan Ltd (2006), http://www.lancashire.gov.uk/environment/lmwlp/.

3.11.6 Each of these data resources has been analysed to assess the extent to which they have identified sand and gravel prospects within the study area. The exception to this is the Geoplan Ltd report (2006), which emerged towards the end of this project, but nevertheless the findings and implications of that report have been incorporated into the later sections (*Section 7*).

3.11.7 Boreholes clearly provide the ready means of confirming the nature of areas identified as having potential for sand and gravel extraction. The BGS hold copies of all deposited borehole records at their national headquarters, with summary data, including borehole number, location and depth available from the BGS website. A list of potentially useful boreholes was collated (*Section 3.3.4*) and these were then compiled by examination and interpretation at the BGS archive at Keyworth. Additional boreholes were accessed from consultancy reports developed for past and planned mineral extractions at lower and higher Brockholes (Gearey and Tetlow 2006). This data compilation exercise was undertaken for all areas identified as having potential aggregate prospects from existing map and digital sources, and then repeated after the interrogation of the new geomorphological and Quaternary geological mapping was undertaken in the course of this study. This two phase approach has proven necessary because the process of cataloguing borehole records demonstrated that, like the comparison of new geomorphic boundary data with BGS drift boundaries, BGS maps and the minerals plans based on the BGS mapping, especially older ones, are often inaccurate in their identification of the type of glacial sediment and depiction of boundary locations between them. This arises because the traditional basis of geological mapping, the identification of lithology at the surface, is inappropriate when mapping areas of thick glacial deposits because of their inherent variability and rapid vertical and lateral transition between lithological units in glacial sediments. As a consequence of this, many boreholes identified as being located in areas of non-aggregate mineral, such as till, show significant thicknesses of potential mineral hidden by thin surface tills. More modern maps, not available for much of the Ribble area, are based on the identification of sediment-landform assemblages, which provide a more accurate depiction of likely sediment type. As a consequence of these problems, a significant number of boreholes, originally rejected as occurring in areas of non-mineral, will have to be brought back into the assessment process.

3.11.8 All borehole locations were identified and the coordinates transferred into a Boreholes layer within the integrated Ribble geodatabase. The following attribute data was attached to the layer:

- borehole identification code (text);
- borehole classification according to their usefulness;
- maximum depth;
- geomorphology associated with the borehole location;
- description of the sedimentology.

3.11.9 ***Producing an enhanced mineral assessment***: to identify and characterize the mineral aggregates for the Ribble ALSF study area, it was necessary to identify a set of search criteria that define the type of mineral aggregate that is sought. It should be emphasised that the search criteria applied within the target areas may vary depending upon local circumstances. It must also be emphasized that an assessment of the criteria requires intervention by extraction, test pit or borehole; without these types of data, confidence in any assessment is reduced. Further, gleaning this type of information from the BGS borehole archive is often difficult, owing to the variable quality of the recording.

3.11.10 ***Lithology**:* examination of the mineral plans for Lancashire suggests that there is a need to identify new sand and gravel reserves and so there is no targeted preference for particular aggregate products. However, there is an additional focus on identifying high-grade sand in both the recent LCC commissioned sand and gravel studies.

3.11.11 ***Proportion of Fines**:* in order to minimise processing, potential resources need to be relatively free of silt and clay. In their regional mineral assessment reports the BGS has traditionally used a maximum proportion of 40% fines (<0.0624mm) to differentiate between mineral and non-mineral. Consultation with the industry, however, suggests that this figure is too high and a figure of 15% is more appropriate.

3.11.12 ***Minimum thickness:*** the BGS uses an average minimum thickness of 1m to define an economically viable mineral resource. This is felt to be much too low and consultation with the industry suggests an average minimum thickness of 3m is more appropriate.

3.11.13 ***Minimum ratio of overburden:*** 'overburden' is defined as the ratio of non-mineral overlying mineral in any potential resource. This ratio is important as higher ratios increase the cost of extraction. The BGS uses a ratio of not more than 3:1 but consultation with the industry suggests that a ratio of 1:1 is more appropriate.

3.11.14 ***Waste:*** 'waste' is defined as the ratio of mineral to non-mineral within any potential resource. This is important because many types of glacial deposit, especially those deposited in ice-marginal environments, contain rapidly varying, often discontinuous, sequences of sediment, that are usually diamict or laminated or massive mud, and which serve to contaminate the potential mineral and increase the cost of extraction. Consultation with the industry suggests that a minimum ratio of waste to mineral of 1:1, or 50% of a potential resource volume is acceptable.

3.11.15 ***Minimum quantity:*** consultation with the industry suggests that the minimum quantity of extractable mineral in any potential resource likely to be used for regional scale supply should not be less than half a million tonnes. The Geoplan (2006) survey utilised a cut-off figure of one million tonnes, but recognised that it may be economic to extract quantities under that threshold.

3.11.16 ***Depth:*** in the industry the normal maximum depth of extraction, below which technical difficulties and hence costs increase, is 20m. Potential resources located below this depth have therefore been excluded.

3.11.17 ***Working conditions:*** in general, resources located above the water table are significantly cheaper to extract than those below the water table. Extraction below the water table may also cause significant environmental problems due to contamination of ground-water, alteration of the ground-water circulation system, leakage of water used in processing into river systems and disposal of water saturated with mud washed from the mineral removed. In the Lower Ribble Valley, notably the Brockholes sand and gravel site, extraction has been close to, or at, the water table and so this is not a barrier to extraction (Chiverrell pers comm).

3.11.18 ***Deleterious materials****:* deleterious materials are naturally occurring rocks, sediments or minerals such as coal, shell beds, peat and alkali-silica reactive minerals that reduce the quality of mineral aggregate or make them unsuitable for use by reducing their load-bearing or shear strength or causing chemical reaction when mixed with cement in concrete production. This information may be difficult to gauge from the available data.

3.11.19 ***Methods for identifying potential resource areas***: traditional approaches to the identification of workable sand and gravel (soft aggregate) reserves in the UK have varied from standard geological drift mapping, with borehole support, to more deductive use of sediment and landform relationships discerned through programmes of geomorphological mapping (Crimes *et al* 1992; 1994). This project has applied a sediment/landform approach and the integrated geomorphic and lithofacies models to identify and predict the distribution, quantity and quality of sand and gravel deposits (after Chiverrell *et al* forthcoming). A series of sand and gravel surveys in Wales and Lancashire has underpinned this approach; consequently, its focus spans a variety of former glacial and fluvial depositional environments. Within these areas, geomorphological mapping has demonstrated that considerable potential reserves of sand and gravel were deposited during and immediately after the retreat of the ice sheets of the last glaciation (Crimes *et al* 1992; 1994). Within these areas, economically extractable sand and gravel deposits are associated with certain sediment/landform assemblages, particularly sandur, pro-glacial alluvial and sub-aqueous fans, deltas, kames, eskers, and river terraces. Understanding the spatial sedimentological relationships and geometries within the landform types allows construction of palaeogeographical models for different depositional settings. This sediment-landform assemblage approach provides a methodology for predicting the distribution, character and quality of sand and gravel reserves.

3.11.20 Technological and methodological developments in recent years, particularly the development of high-quality digital elevation models (DEMs) (*Sections 3.4.3*-5), provide considerable scope for improving the quality and accuracy of mineral aggregate spatial databases. Integrating the information available within a highly resolved DEM, with detailed field mapping and more accurately described field truthing, can improve our understanding of the relationships between landforms and allow the production of refined spatially accurate sediment-landform models. These palaeoenvironmental models provide a framework for assessment, mapping and quantification of sand and gravel reserves.

3.11.21 Investigations of how both glacial and fluvial systems behave in terms of transport and deposition of debris have resulted in the generation of models of landform-sediment relationships, which can be used to identify potential mineral aggregate resources. The basis of these models is the recognition that particular types of landform are associated with particular types of sediment, because the landform reflects the depositional process that created it. This leads to the concept of the sediment-landform assemblage, which is defined as an area in which relatively homogeneous geomorphological, stratigraphic and lithological characteristics occur. The identification of sediment-landform assemblages therefore provides a first approximation for potential mineral resources. Four major sediment-landform assemblage zones can be recognised within the British Isles that often provide deposits utilised as reserves of sand and gravel by the aggregate industry.

3.11.22 ***Sub-glacial assemblage zone***: this includes all the landforms and sediments generated by the erosion, transportation and deposition of debris at the base of a glacier and can be divided into two sub-assemblages.

3.11.23 A sub-glacial erosional assemblage, normally associated with upland glaciation, is dominated by erosion over deposition and is characterised by the extensive occurrence of glacial erosional landforms at a wide range of scales from large cirque basins to small ice-moulded rock landforms (Johnson 1985). This assemblage covers most mountainous areas of Britain, which are, as a consequence, relatively free of glacial deposits. Where glacial deposits occur they are predominantly composed of diamict deposited in thin, irregular, often impersistent sheets. Sand and gravel occasionally occurs within diamict as a response to deposition by subglacial streams but this is often thin and discontinuous. Consequently, this assemblage has very limited aggregate potential and what occurs is frequently of low volume, is very coarse, and difficult to identify.

3.11.24 A sub-glacial depositional assemblage, in contrast, is normally associated with lowland glaciation in which eroded materials are transported through the ice and frequently redeposited further down the flow direction (Crimes *et al* 1992). This process often leads to very thick accumulations of subglacial diamict and the generation of a characteristic set of ice-moulded depositional landforms, including drumlins. Although some small areas of sand and gravel occur in isolated esker systems formed in tunnels at the base of the ice, the predominance of diamict ranks the aggregate potential of this assemblage as very low. Within the sub-glacial assemblage zone, three depositional landform types can be identified.

- *Diamict plains* are areas of relatively low amplitude, subdued topography underlain almost entirely by diamict. Where the diamict is very thick the surface is often flat and featureless and often poorly drained. These deposits are highly variable, often partly consolidated, unsorted, with high quantities of fines; consequently, their aggregate potential is negligible.
- *Drumlins* are elongated, smooth ridges on a scale of up to 1km in length, 50m high and a few hundreds of metres wide. They occur in fields, commonly with what is called a 'basket of eggs' topography. They display a common orientation running parallel with the former ice-flow direction, and are formed under fast-flowing, thick ice during episodes of major subglacial flooding, the drumlin form being a type of bedform. They are almost wholly composed of diamict except where the rapid advance of ice has moulded previously deposited well-sorted sand and gravel into drumlins, but for the most part their aggregate potential is negligible.
- *Eskers* are long, narrow, sharp-crested, often sinuous ridges up to 20m in height and are composed of sand and gravel. They represent the former position of subglacial tunnels draining the base of the ice and preserved as a 'cast' of the tunnel form, complete with its sedimentary fill. This provides good aggregate potential as the ridge form is easily exploited, but often, reflecting the high velocity of flow in subglacial tunnels, the sediment is very coarse.

3.11.25 ***Ice-marginal assemblage zone:*** this includes all the landforms and sediments deposited at the margin of a glacier. By definition, the velocity of a glacier reduces to zero at the snout and all the debris contained within and beneath it is, as a consequence, rapidly released, often in very significant volume in what is termed an ice-contact environment. Because of the rapidity of snout positional changes, wide varieties of depositional environments are generated, including ice-front alluvial fans, ice-marginal sandur and temporary lake basins. Much of the associated deposition takes place over ice which, on melt, collapses, causing complex ice-disintegration topography to be created. At the same time moraine ridges are generated, either by accumulation of debris at the margin or by bulldozing movement of the ice. Together these processes create a very distinctive suite of landforms associated with complex sequences of diamict, gravel, sand and mud. Consequently, they form potentially good sources of aggregate; they are easily identified but often difficult to extract due to their inherent coarse grain and complex inter-digitation with diamict and mud.

3.11.26 Ice-front alluvial fans accumulate at the immediate ice-margin, often on the ice itself, from meltwater stream exit tunnels. They are characteristically steep and very coarse-grained, reflecting the high velocity of flow in the feeding tunnels, and are often intercalated with sheets of diamict formed by slumping from the immediate ice-margin. Their aggregate potential is consequently low, due to the high proportion of waste and cobble and boulder content. Marginal sandur form when meltwater draining the ice-margin is obstructed by older moraine in the immediate pro-glacial area and flow is directed parallel to the ice-margin rather than directly away from it in relatively narrow, flat-floored troughs. Deposition within them is invariably coarse and often mixed with diamict formed from slumping off the adjacent ice-margin. Consequently, their mineral potential is moderate, owing to the volume of unusable coarse gravel and waste.

- *Kame terraces* are areas of mounded topography that occur in irregular bands or linear sets of isolated mounds. They form at the edges of glaciers which abut against steep rock slopes either along the flanks of valley glaciers or the edge of lowland ice-sheets. Meltwater sedimentation is channelled between the ice-margin and the rock slope and deposition takes place in a linear trough on or against the ice. In some cases the trough grades down-ice into marginal sandur. When the ice beneath the trough melts out, the sediment above collapses to form irregular ‘kame mounds’ and water-filled basins (kettleholes). When the ice-margin retreats, the inner margin of the trough of sediment accumulation collapses to form an irregular terrace edge. Mineral potential is relatively low because of the generally coarse nature of the trough fill and abundance of diamict.

- *Moraines* are linear or arcuate ridges up to 50-60m high formed at the margin of glaciers. They often occur as successive parallel ridges where each ridge represents either a temporary stillstand during retreat or a subsequent re-advance limit. The term ‘moraine’ is used in the literature to describe both a landform and a deposit; to avoid confusion the term is used here to identify a landform only. In the absence of exposure it is often difficult to classify moraines correctly on geomorphological criteria alone, as their form is often similar. A number of different moraine types can be distinguished, based primarily on their internal structure and composition, and only partly on their form.

- *Ablation moraines:* these form at the margin of the glacier by supra-glacial debris sliding off the surface of the ice-margin, or melted-out from within the ice itself and accumulating as a wedge of sediment against the snout. They are almost invariably composed of diamict and their aggregate value is minimal.

- *Push moraines:* these form by the bulldozing of debris lying in the immediate pro-glacial zone by the forward movement of the glacier during re-advance or minor snout oscillation. They are commonly highly deformed internally and their lithological composition depends upon the type of sediment incorporated from the pro-glacial zone. If this includes sand and gravel then the aggregate potential of the push moraine ridge may be high; if it includes diamict it will be low.

- *Kame moraines* are similar to kame terraces but are usually larger and more complex. They form at the snout of a stagnating glacier by the accumulation of both diamict and outwash on top of buried ice. As the ice melts a complex area of ice-disintegration topography is generated, consisting of small-scale ridges, mounds and basins, often in wide linear belts. The mineral potential is variable and depends upon the sediment of which they are composed.

3.11.27 ***Pro-glacial assemblage zone:*** this includes landforms and sediments deposited beyond the margin of a glacier. At the snout all the water derived from melt of the glacier is discharged from exit tunnels into very large melt water streams that carry exceptionally high loads of sediment. In many pro-glacial environments large lake systems develop, dammed by ice margins or moraines, or impounded in over-deepened rock basins. These act as major sediment sinks as meltwater streams immediately drop their sediment load on entry into a lacustrine system as either deltas or sub-aqueous fans. Consequently, these settings have high, good-quality aggregate potential. Within the pro-glacial assemblage zone, two depositional landform types can be identified.

- *Sandur* act as major pro-glacial sediment sinks and are formed by the lateral and vertical accretion of sediment deposited by meltwater stream systems emerging from a glacier and fanning outwards into the pro-glacial area. Reflecting the decline in stream power they decrease in surface gradient downstream and progressively deposit finer-grained sediment, and are size sorted. The upper deposits are coarse gravels, the central deposits are finer gravel and sand, and the lower deposits are fine sands and silt. As a potential mineral resource they contain clean, well-sorted gravels, sands and silts, in ordered succession, and often very thick.

- *Deltas* form when sandur stream systems enter lake basins or the sea and, due to a reduction in velocity on entering the water, the sediment is rapidly deposited. Most deltas show a three-fold internal structure. Topsets are deposited across the delta surface by progradation of the sandur system and are composed of gravel; fore-sets are deposited by avalanche down the delta slope immediately beyond the water-line and are usually composed of sand; bottom sets are deposited across the floor of the lake by suspension from the fine-grained sediment in the input water and are usually composed of silt and clay. Sub-aqueous fan systems are similar to deltas in form except they lack the topset component, and more accurately should be within the ice-marginal assemblage zone, given the need for direct ice-contact with the waterbody. There is a degree of overlap between sandur, delta and sub-aqueous fans, because if the sub-aqueous fan grows to break the water surface, delta-style sedimentation occurs, and in turn with delta progradation or ice retreat, sandur develop. Delta and sub-aqueous fan sediments are frequently dissected by fluvial action to form a series of incised terraces during and after drainage of the pro-glacial lakes, or as sea level falls in response to eustatic and isostatic factors. The topset and fore-set components of delta sediments represent significant, well-sorted aggregate resources, but the bottomset are usually too fine for use.

3.11.28 ***Non-glacial fluvial assemblage zone:*** sediment and depositional landforms lain down under non-glacial conditions have also proven valuable aggregate resources.

- *River terraces and valley alluvium*: following ice retreat, fluvial processes became dominant and stream systems attempted to adjust their courses through the cover of glacial deposits. As the sea level was low in the early Holocene, the glacial deposits were rapidly dissected by down-cutting streams and much sediment was removed, leading to the deposition of river terraces further downstream. As much of the finer sediment was washed out into the sea these terraces were formed of relatively clean, well-sorted sand and gravel, forming good potential mineral resources. However, many of these river terraces are only a few metres above modern river level and are difficult to work, as excavation extends below the watertable.
- *Alluvial fans:* following glaciation, many tributary valleys were left 'hanging' as a consequence of glacial over-deepening of the main valley. During the Late-Glacial and early Holocene, much of the debris lying on valley slopes was flushed out to form substantial alluvial fans, even for relatively small tributaries. These can provide an aggregate resource, especially in isolated areas, but can be contaminated by fines lain down by debris flows.

3.11.29 ***Identification and assessment of individual Resource Blocks:*** from the geomorphological maps generated for the Ribble, a filtering process was used to identify potential Resource Blocks. The first level of filtering was by the type of geomorphological feature. Thus, features identified as sandur, marginal sandur, ice-front alluvial fans, deltas, kames, kame terraces, eskers and river terraces were all included as, reflecting their depositional environments, they are likely to contain potential mineral. Features identified as diamict plains, drumlins, lake floors, push-moraines and ablation-moraines were excluded as they are unlikely to contain potential mineral. Within the river terraces, a further filtering was undertaken to exclude all except river terraces 1 and 2, because the lower river terrace of the Ribble, terraces 3 to 5, comprise fine-grained alluvium. The second level of filtering was done on the basis of pre-existing borehole information and section detail reported in the literature. Thus, if a pre-existing borehole provided confirmatory information of quality aggregate it was included, otherwise unpromising prospects were excluded. Each resource block identified normally equates to an individual geomorphological feature, though in some cases several adjacent features of similar type are combined together.

3.11.30 ***Calculation of mineral volumes for prospects***: one of the principal aims of geomorphology-based sand and gravel assessments is the accurate gauging of the volume of a deposit. Detailed accurate borehole information (provided by BGS) characterises and describes the composition of the prospect, and without this information there is a great deal of uncertainty associated with sand and gravel assessments. It is in the volumetric assessment of landform geometry that DEMs and GIS come into their own, because the software allows the rapid calculation of the volumetric fill for a landform or shape, compared with another surface, typically the base of the deposit. Recent practice in volumetric estimation of aggregate reserves has been two-fold (Crimes *et al* 1994); the first has been to apply an estimated averaged deposit thickness to the resource block area to calculate volume, and the second, more complicated approach, involved producing isopachytes of equal mineral thickness and relating this to the area between two isopachytes. The second approach takes account of variations in surface elevation and mineral thickness, and is analogous to the GIS approach using OS Profile data, but has less precision and accuracy. Using a DEM-based approach represents a clear methodological improvement; however, it must be stressed that volumetric estimate of aggregate within resources blocks must take account of other areas of uncertainty, including product to waste ratios and overburden thickness, which need to be taken into consideration.

3.11.31 ***Clitheroe Esker Ridge:*** on the esker ridge near Clitheroe, this test example used a uniformly flat estimate of the probable base of the deposit (68m OD). The estimated volume of deposit within the esker form highlighted in *Section 3.4.6* (Fig 35), using the same outline shape mapped from the LiDAR data, are 4,777,560m^3, 4,840,490m^3 and 4,522,620m^3 respectively for the LiDAR, NextMAP and OS Profile DEMs. Comparison of the volumetric assessments undertaken using outlines defined independently from the different DEM products provided very similar results. These values, although broadly comparable, show that the OS Profile prediction is lower than the other two, which is a function of the generalisations involved in the production of the OS Profile data.

3.11.32 ***Example of fluvial terraces:*** examples of the primary aggregate prospects of Terrace T1 near Hothersall Hall and Terrace T2 near Osbaldeston Hall (Fig 36; *Section 3.4.9*) provide an indicator of the volume calculation. The aggregate resource associated with these terraces in the Lower Ribble Valley is typically *c* 4m and 2.5m in thickness respectively for Terraces T1 and T2, which indicate that the two prospects may contain *c* 1.6 and 0.9 million tonnes of sand and gravel. As the industry works by weight of aggregate, all volumes have been converted from cubic metres, derived from area times thickness calculations, into metric tonnes using a value of 1.6 tonnes per cubic metre as the average *in-situ* bulk density. In some consolidated deposits this figure may be higher (up to 2.0 tonnes per cubic metre) but is unlikely to be much lower. Tonnages quoted are therefore minimum estimates, within the limitation of the volumetric calculation. The quantities of mineral associated with the Late-Glacial and early Holocene river terraces of the Ribble Valley are significantly lower relative to the prospect area than glacigenic landforms, including the nearby (10km) small esker ridge form near Clitheroe (*Section 3.4.6*), which has projected volumes three times greater than these river terraces (*c* 4.8 million tonnes).

3.11.33 ***Reliability of volume and quality estimates***: Resource Blocks have been classed into categories of reliability to reflect the sources of information available about each block and the method used for estimating volume and quality. These categories generally equate to the method of assessing resource-block volume and quality used, but also take into account uncertainties in landform identification, variations in the thickness of overburden, and waste.

- *High:* this is used where borehole information is available and is consistent in terms of thickness, broad grain-size and thickness of overburden. Some reliance may be placed on these estimates in the immediate vicinity of borehole locations but should not be extrapolated to adjacent areas as glacial and fluvial deposits can vary considerably over short distances.

- *Medium:* this is used where there is no borehole information, but some sample information is available from either exposed section. These estimates have a moderate margin of error but should be used with caution. A detailed drilling and sample testing programme should be undertaken before exploitation of blocks classed as of medium reliability is considered. In the case of the older river terraces of the Ribble Valley, confidence may increase because the landform suite demonstrably comprises sand and gravel throughout the Lower Ribble.
- *Low:* this is used where no borehole, sample or exposure information is available. Volume and grain-size distribution estimates are based on comparison with other blocks of similar geomorphological character and the general geological conditions in the area. Nevertheless, any estimates have a wide margin of error and should therefore be used with very considerable caution. A detailed drilling and sample testing programme should be undertaken before exploitation is considered, on blocks classed as of low reliability.

3.11.34 ***Environmental constraints***: Resource Blocks have been classified according to the degree to which they are constrained by highway access, proximity to market, environmental designations and planning zonation. It should be noted that the significance of the latter factors can vary due to changes in planning policy or commercial conditions. Similarly, environmental constraints are rarely absolute and policy towards them often changes in the light of changed economic conditions.

3.11.35 Consequently, an assessment of any particular resource block as of high commercial potential should not be taken as a recommendation. It has been assumed that, with the exception of National Parks, SACs, SPAs and RAMSAR sites, all other environmental designations or planning constraints do not, necessarily, preclude the possibility of mineral extraction. The method of assessment used applies a ranking that takes into account the potential value of the prospect and offsets it against likely restrictions.

3.11.36 ***CAESAR and the available data resources:*** CAESAR (Cellular Automaton Evolutionary Slope and River model) is a dynamic geomorphological model that simulates the movement of water and sediment and the development of landforms in river catchments and on floodplains (Coulthard *et al* 2000). The model is based on a regular grid of cells within a digital elevation model (DEM) that is a representation of the landscape. A catchment hydrological model drives the downstream movement of both water and sediment from slopes to tributary streams and to the main river channel. Each cell stores key geomorphological data: elevation; slope; water and sediment discharge; grain-size distribution; and these are updated over small time steps (ie seconds to minutes) across the entire catchment (Fig 47). This type of dynamic modelling approach will facilitate assessment of likelihood of future geomorphic change under various climate scenarios and assessment of the predicted risks for the geoarchaeological heritage. A variety of data sources was compiled to contribute to the CAESAR modelling, and these were the production of high-quality DEM, river discharge data to validate the model outputs, contemporary precipitation data to drive the model, and future climate change projections to provide scenarios for future precipitation.

3.11.37 The Ribble Valley is well represented in the *National River Flow Archive* (Centre for Flow and Hydrology 2007), with the responsibility for the 13 gauging stations within the Ribble basin lying with the Environment Agency (Fig 48). In terms of characterising flow within the main channel and major tributaries, the following stations are important: the Samlesbury station represents flow in the main Ribble system; the Blue Bridge station does the same for the Darwen; Whalley Weir station for the Calder; Hodder Place station for the Hodder; and Henthorn station for the Upper Ribble. Daily discharge data are readily available for Samlesbury from the *National River Flow Archive* (Fig 49). Precipitation data are available for several meteorological stations across the Ribble catchment, with the longest hourly record available from Preston. There appears to be a strong relationship (Fig 49) between daily discharge at Preston and rainfall at the top (Stainforth) and bottom (Preston) of the catchment. Comparisons of the annual rainfall totals shows an increase of 200-350mm between the lowland Ribble and the Pennines headwaters; consequently, rainfall data from Preston, which are the most complete and provide hourly time-step data, are appropriate for characterising both the precipitation pattern and discharge response of the Ribble.

3.11.38 ***Modelling initial conditions and testable scenarios:*** modelling of this type is extremely time intensive and consumes considerable amounts of computing power. The modelling used a digital elevation model derived from LiDAR, NextMAP and OS Profile datasets, amalgamated in that preferred order to produce a new 10 x 10m DEM for the entire catchment. To streamline the modelling process, the DEM was subdivided into four sub-catchment areas: the Hodder; Upper Ribble; Calder; and the Ribble downstream of the Ribble, Hodder and Calder confluences. The river gauging stations in the Ribble catchment are opportunely situated to validate the modelled discharges for these sub-catchment areas. The DEMs were rescaled to 50 x 50m spatial resolution, because this reduction in resolution significantly improved model run-times and minimised negative impacts on the model output. The model had to be run for the three headwater reaches: Hodder; Upper Ribble; and Calder. The hourly discharges from these rivers were recorded throughout the modelling period and the hourly discharges were then totalled for the three rivers to provide a discharge into the top of the Lower Ribble downstream of the Ribble, Hodder and Calder confluences. CAESAR was then run again, in what is termed a reach mode, using a better resolution DEM, 10 x 10m spatial resolution, for the entire period using the modelled discharges.

3.11.39 Historical and future climate modelled data were compiled from the UK Climate Impacts programme (UKCIP 2002). These data were used to identify the average climate for the catchment, and to produce average monthly rainfall and annual rainfall totals for the catchment. The aim of this analysis was to use daily Preston rainfall data to drive the dynamic geomorphic model; consequently, this Preston rainfall series has been factored to reflect catchment average rainfall totals. A future precipitation rainfall series for Preston was created based on the most likely extreme changes evident in the UKCIP scenarios for future precipitation. For example, UKCIP model predictions of increased rainfall for August in 2080, under their high emissions scenario, are shown in Figure 50. These monthly rainfall totals were used to manipulate the Preston long-term hourly rainfall data and generate a Current and a Future catchment average precipitation series, which was used to drive the CAESAR modelling. Because the model runs were carried out for three different sub-catchments, individual precipitation series were generated for each of the headwater reaches.

3.11.40 The Environment Agency has modelled the impact of climate change on the 1% fluvial event as an increase in river flow of *c* 10-20% (Environment Agency, *Draft Plan* 2006). It is now widely accepted that the UK's climate is changing over time and the reasons are thought to be the build-up of greenhouse gases (eg carbon dioxide and methane) in the Earth's atmosphere. What this means for changes in future flood risk is not well understood; however, recent research by the UK Climate Impacts Programme (UKCIP 2002), indicated that winter rainfall intensities (and therefore flood flows) might increase by as much as 20% by 2050.

3.11.41 The UKCIP (2002) scenarios show that various sub-catchments of the Ribble basin are in an area with increased winter precipitation (increase of up to 25%) and decreases in summer precipitation (decrease of up to 35%) for both low and high emissions runs (Fig 51). The UKCIP data also suggest that the number of 'intense' rainfall days may increase in winter and decrease in summer. The Environment Agency suggest that this may result in an increase in winter river flow and therefore flooding in the catchment, particularly in areas vulnerable to main river flooding. Areas susceptible to flash flooding from intense rainfall events (for example Darwen and Trawden), plus areas susceptible to flooding from culverts, may see an increase in flooding during the winter and a decrease in flooding during the summer.

3.11.42 The CAESAR modelling undertaken for this project assessed the geomorphic response of the catchment to 1) contemporary and 2) increased precipitation. Both these model runs lasted for a simulated time period of 20 years and provided indications of the potential for geomorphic change under two different sets of climatic conditions. These climate scenarios are end members of the range of UKCIP climate predictions.

3.11.43 ***Identification of potential for geomorphic change:*** the processes of erosion and deposition simulated by CAESAR result in changes to the elevation of geomorphologically active DEM grid cells. The most important output data produced by the model is a raster GRID of cumulative elevation changes modelled within a given catchment or reach over a given time period. While the amount of land-surface change, exemplified by surface lowering by erosion, surface raising by deposition, or no change in elevation, will vary spatially, for the purposes of the present project the landscape has been classified into areas with the greatest potential for change either by erosion or deposition. Variations in the degree of change have not been considered. Within ArcGIS, the following steps were undertaken to transform the CAESAR-derived elevation difference GRID into a feature class suitable for integration within the Ribble geodatabase:

1) zone the GRID into three classes that represent the nature of change, and these were ‘erosion’, ‘no change’, ‘deposition’;

2) convert the classified GRID into a three-band (RGB) TIFF image;

3) convert the TIFF image into a polygon shape file with areas for each of the colour classes.

3.12 ENHANCING AN UNDERSTANDING OF THE ARCHAEOLOGICAL RESOURCE

3.12.1 ***General Methodology***: several key techniques were used to enhance the HLC and to model the archaeological potential. They include the conversion of vector data to raster, and the use of the Kolmogorov-Smirnov (KS) test.

3.12.2 ***Raster Conversion***: this process involves creating a grid across the study area, with the value of each cell representing the value of a given variable at that point. For example, in converting an elevation model into a raster, each cell would contain the average elevation at that point.

3.12.3 When converting vector data to raster, several parameters must be taken into account. The first is the cell size of the resulting raster. A smaller cell size is more detailed but results in a larger overall file size, and when converting point data to raster, a large cell size may also result in several closely grouped points being merged into the same cell. Originally a 5m cell size was used, but this proved unworkable, as each task took a considerable amount of time to complete, and the resulting cell sizes were unmanageable. During the second phase of analysis, a 10m cell size was used, being a good trade off between file size and loss of detail.

3.12.4 The second parameter is the extent of the raster. In general, the raster is a square delineated by the extent of the shape file being converted, but it can be ‘masked’, using a second dataset to block out areas that are not required. In this case, the polygon, representing the outline of the study area, was used as the analysis mask. This has the advantage of further reducing the file size of the raster and producing a more visually attractive image.

3.12.5 ***KS test:*** the Kolmogorov-Smirnov (KS) Goodness-of-Fit test (Kvamme 1990) was used to compare statistically the location of the monuments of each period to particular background variables, such as environmental parameters or HLC classification. This is a one sample statistical test that compares a sample (in this case the location of monuments) against a background standard (the whole study area).

3.12.6 To run this test, a combination raster must be created, that contains values for every combination of the constituent rasters. Normally this is a continuous environmental parameter such as elevation or slope, and a discrete set of points such as the location of archaeological monuments. The ArcMap raster calculator ‘Combine’ function was used to create this raster, and the data table behind it was then exported into Excel, where the calculations for the KS test could be run. Table 16 shows the count of cells and their corresponding presence or absence (PA) of Roman monuments at defined elevation intervals. Table 17 shows an example of the exported data table in Excel used for KS calculations.

Elevation (m)	Roman PA	Count
0	0	7697
25	0	276919
25	1	12
50	0	222416
50	1	56
75	0	496124
75	1	15
100	0	259236
100	1	4
125	0	100367
125	1	1
150	0	35803
175	0	12488
200	0	5776
225	0	3148
250	0	813

Table 16: Attribute table for raster combining Roman presence or absence map, and elevation

3.12.7 To run the KS test, the columns were set out as in Table 17. The frequency (F) is defined as the count for a given elevation value, divided by the total count (in bold italics). The cumulative frequency (CF) is the sum of the frequencies working down the elevation values, in other words the CF for 50m is the sum of F(0), F(25), and F(50). The difference (Diff) between the CF for Roman Presence and the Total CF was then calculated, and the absolute value (Abs Diff) taken. Finally, the maximum of Abs Diff (DMAX) is found. This is then compared to a critical value (d), which is a measure of the sample size and confidence interval (σ). The confidence interval is gained from generally agreed tables, and for the social sciences a value of 95% is normally used, for which $\sigma = 1.36$, leading to the formula: $d=1.36/\sqrt{(\text{total size of sample})}$. If DMAX –d is positive, then there is a statistical correlation between the sample and the background standard, in this case the hypothesis that the location of Roman monuments within the study area is influenced by elevation.

3.12.8 ***Enhancement of the HLC - basic preparation***: at the start of the project the completed HLC for Lancashire was made available to the project (Ede and Darlington 2002). This consisted of two datasets, the first containing every individual land parcel as a single polygon, and with the detailed individual landscape types assigned, and the second with broad landscape types assigned but with all the parcels of a particular type merged into one record (Fig 52). As analysis required individual polygons for each land parcel, but with the HLC broad type, the ArcMap Append Tool was used to add this information to the required dataset.

Elevation (m)	**Count Roman Presence**	**Roman F**	**Roman CF**	**Count Roman absence**	**Total Count**	**Total F**	**Total CF**	**Diff**	**Abs Diff**
0	0	0	0	7697	7697	0.005417	0.005417	-0.00542	0.005417
25	12	0.136364	0.136364	276919	276931	0.194902	0.200319	-0.06396	0.063955
50	56	0.636364	0.772727	222416	222472	0.156574	0.356893	0.415835	0.415835
75	15	0.170455	0.943182	496124	496139	0.349178	0.706071	0.237111	0.237111
100	4	0.045455	0.988636	259236	259240	0.182451	0.888522	0.100114	0.100114
125	1	0.011364	1	100367	100368	0.070638	0.95916	0.04084	0.04084
150	0	0	1	35803	35803	0.025198	0.984358	0.015642	0.015642
175	0	0	1	12488	12488	0.008789	0.993147	0.006853	0.006853
200	0	0	1	5776	5776	0.004065	0.997212	0.002788	0.002788
225	0	0	1	3148	3148	0.002216	0.999428	0.000572	0.000572
250	0	0	1	813	813	0.000572	1	0	0
	88				***1420875***				
								DMAX	0.415835
								d	0.144976
								DMAX -d	0.270858
								CORRELATION	

Table 17: Example of KS test calculations on Roman monuments and elevation

3.12.9 The county-wide HLC dataset was ‘clipped’ in ArcGIS to the boundary of the Lower Ribble Valley study area. In some cases this broke previously single polygons into two or more pieces, which then had to be re-merged. Further analysis indicated that there were areas, known as ‘slithers’, where adjacent polygons overlapped. These are normally created during the initial process of digitising polygons on screen. It was important to remove these, as they would have a choice of two possible HLC classifications. This created a selection of 322 polygons divided into 16 broad types (Table 18).

HLC broad type	**Count**
Ancient and Post-medieval Ornamental	3
Ancient and Post-medieval Settlement	11
Ancient and Post-medieval Wood	49
Ancient Enclosure	91
Modern Communications	3
Modern Enclosure	20
Modern Industry	16
Modern Ornamental	2
Modern Recreation	11
Modern Settlement	32
Modern Woodland	7
Post-medieval Enclosure	71
Reverted Moorland	1
Saltmarsh	2
Sand and Mudflats	2
Water	1
Total	322

Table 18: Numbers of individual polygons in the Lower Ribble Valley study area by HLC broad type

3.12.10 Once the reduced dataset had been cleaned, a copy was made in which the original HLC attribute data could be removed. New fields were then added to the attribute table, into which additional data could be added. The new fields were:

- overall count of monument records within each polygon;
- count of prehistoric, Roman and medieval monument records within each polygon;
- overall density of monument records within each polygon;
- density of prehistoric, Roman and medieval monument records within each polygon;
- value statement regarding level of ground disturbance;
- numerical value regarding level of disturbance;
- count of known events;
- measurement of potential for prehistoric, Roman and medieval archaeology;
- measurement of overall archaeological potential;
- current threat (Deposition or Erosion or N/A, see *Section 3.13.15*);
- future threat (Deposition or Erosion or N/A, see *Section 3.13.15*);
- suitability for aggregate extraction.

3.12.11 Using the Intersection tool in ArcGIS it was possible to calculate many of the attributes within each HLC polygon, and this was also used to assign the HLC polygon number to each monument and event located within it.

3.12.12 Data on aggregate extraction suitability, along with calculations of threat and erosion from fluvial change, were supplied by Richard Chiverrell as a separate polygon geodatabase feature class. These data were overlain on the HLC polygons, and the intersection tool in ArcGIS used to assign the geomorphological attributes to the HLC data.

3.12.13 The queries required to aggregate the event and monument data relating to each HLC polygon could not be constructed easily within ArcGIS as only a reduced subset of SQL (structured query language) is available. Consequently, the enhanced HLC polygon shape file needed to be converted to a geodatabase feature class. This procedure allows the data tables for shape files to be manipulated and queried within a more fully-featured database environment, in this case Microsoft Access 97.

3.12.14 Once the HLC, event, monument and geomorphological data had been amalgamated into a geodatabase, it was possible to aggregate the data together to produce a gazetteer of data relating to each polygon (Fig 52). The free-text synthesis and interpretation were then filled in manually.

3.12.15 The gazetteer was output as a Microsoft Access report, which was saved as a .pdf file, with a separate page for each polygon's entry. In ArcGIS a hyperlink field was added to the HLC geodatabase feature class, which linked to the appropriate page of the .pdf for each polygon. By clicking on a polygon in

ArcGIS using the hyperlink tool, the .pdf gazetteer then opened at the correct page for that polygon (Fig 53).

3.12.16 ***Enhancement of HLC - Lynher Valley Model***: the first attempt at enhancing the HLC records followed the methodology used by the Lynher Valley Project developed by Cornwall County Council (Cornwall Archaeology Unit 2002). The Lynher model calculates the relative significance of archaeological site occurrence within HLC classes. The archaeological monuments were divided into NMR broad classes, and the HLC, by its HLC broad types. The significance was calculated by taking each HLC broad type and calculating the percentage of the total study area that it occupies. Secondly, the number of sites of each NMR Broad Type that fall within a given HLC area are calculated as a percentage of their total number within the study area. The relative significance is the NMR representative percentage divided by the HLC representative percentage. 'A figure of 1 would be expected by chance; results greater than 1 indicate a tendency to fall within the predicted HLC types; results of 2 indicate twice as likely as chance, 8 indicates eight times more likely than chance, etc' (Cornwall Archaeological Unit 2002, 100).

3.12.17 The combination of the datasets was carried out using the Raster Calculator within ArcMap. The results of all the calculations performed were combined in an Excel table that allows checks to be made against each HLC Entry Level for both the KS test and the relative frequency. These results were weighted in terms of 'High', 'Medium' and 'Low' archaeological potential.

3.12.18 Firstly, all HLC Broad types were combined with each individual monument class for all the records in the database, producing 11 calculation maps, which were then tested against the 'goodness of fit' model. All HLC Broad types were then combined with each individual monument class for all the records in the database, producing 11 calculation maps, which were then tested for relative significance and distribution.

3.12.19 All new monument records created by this project were broken down by their type and combined with each individual HLC type, producing 14 calculation maps, which were then tested for relative significance and distribution.

3.12.20 It became apparent that there was little correlation between the datasets, so it would not be possible to use this approach to create maps of archaeological potential. Consequently, this approach was abandoned in favour of exploring environmental parameters for monument location, but HLC data were also examined to establish whether there was any statistical bias between the location of monuments of different periods and different HLC types.

3.13 MODELLING ARCHAEOLOGICAL POTENTIAL

3.13.1 ***Analysis of the Lacunae***: before modelling areas of potential for hitherto undiscovered archaeology, it was necessary to analyse the distribution of the known archaeology. It was postulated that, in general, the location of known monuments would match the location of events, and conversely that areas where no archaeological monuments had been discovered represented an absence of events rather than monuments. Areas subject to development would contain below-ground disturbance, but also of archaeological assessment, and would therefore contain more known monuments but would have a low potential for the discovery of new sites. Furthermore, land uses that caused a large amount of below-ground disturbance, such as landscaping or quarrying, would also represent areas of low potential for undisturbed archaeology.

3.13.2 To provide a broad-scale assessment of disturbance across the study area, the HLC land classification was examined, and each category was assigned a score from 1 to 3 on the level of below-ground disturbance likely to have been caused by a particular historic land use. To establish whether or not there was a correlation between the location of known monuments and the level disturbance caused by a particular land use, the KS test was again used (*Section 3.12.5*).

3.13.3 To analyse whether the location of monuments was biased towards the location of events, the ArcGIS ‘Select by Location’ tool was used, which allowed the identification of the number of monuments that occurred within set distances from events (*Section 6.4.19*).

3.13.4 ***Modelling Potential***: one method of predicting the location of hitherto unknown monuments is to analyse the environmental variables (ie slope, elevation, and distance to water) responsible for the location of known sites, and look for areas with the same variables elsewhere in the study area (*Section 6.6*). To search for this correlation the KS test was used. The initial approach was to assume that monuments of a given NMR broad class would have similar locational requirements, regardless of their period. In other words prehistoric, Roman and medieval settlements would be situated in roughly similar locations. As too few monuments would give spurious results, those classes with less than 2% of the total number of monuments were not included. Similarly, the ‘unassigned’ and ‘monument <by form>’ classes were not included.

3.13.5 The second approach was to reduce the extent of the analysis to the size of the terraces, and to run the KS test in more detail on this smaller area. However, issues with the differential coverage of the datasets were encountered and it could not be continued (*see Section 6.6.9*).

3.13.6 Thirdly, the location of monuments of a given period was analysed. This procedure produced more meaningful results (*Section 6.6.12*). The environmental variables thought to have a bearing on the location of the monuments were:

- *Elevation*: this was calculated by deriving a TIN (Triangular Integrated Network) from the Landform Profile data supplied as part of the project. This dataset is not as detailed or high resolution as the LiDAR data but offers complete coverage of the study area. The study area consists of a valley and floodplain, with 88% of the area below 100m above sea level;
- *Slope*: this is defined as the maximum rate of change of elevation. It is calculated in different ways depending on if the surface is a TIN (Triangular Integrated Network) or a raster. For a TIN the slope is calculated across each triangle in the network. For a raster it is the difference between a cell and its eight neighbours. It can be calculated in degrees or percent, with higher values representing steeper slopes. Some 91% of the study area has a slope of less than 10σ from the horizontal;

- *Distance from Water*: watercourses within the study area were derived in two ways. The first was by selecting all the features from the Ordnance Survey MasterMap data that were classified as water features. This layer comprised all water features, including modern ponds and reservoirs, so these elements were removed manually. The second was to use the palaeochannel dataset that was created by the University of Liverpool during their analysis. The MasterMap water features were originally polygons, but were converted to polylines to match the geometry of the palaeochannel dataset. These two datasets were then merged, and the ArcGIS Multiple Ring Buffer Tool was used to create buffers around the features at 250m increments, up to a distance of 1000m; this maximum distance allowed coverage of the entire study area. Initially, an attempt was made to buffer the features at 100m increments, but the resulting dataset was too large to manipulate. During the initial analysis, the palaeochannel dataset was not available, and as such the original KS tests against NMR broad class were run against the MasterMap water features alone. Also, the original buffer sizes used were 100m, 200m, 500m and 1000m, but it was felt during the later stages of the analysis that equal sized buffers were required;

- *Distance from Roman Roads*: this variable was used for the Roman and medieval datasets. A shape file of the location of the Roman Roads within the study area was provided by Lancashire HER for the project. The multiple ring buffer tool was used to create buffers at 250m increments, to a maximum of 2000m, and this covered most of the study area. Thirty-four of the Roman monuments were references to the roads, so it was necessary to remove those before running the KS test.

3.13.7 For each of the four variables, the original shapefile was converted into a raster. The original rasters contained values accurate to the metre of elevation or degree of slope. It was necessary to group these values into bands in order to run the KS test. The ArcGIS ‘Reclassify’ function was used to achieve this. The elevation raster was reclassified in 25m increments, the slope raster in 10° increments, and the distance buffers in their 250m increments.

3.13.8 The monuments for each period were then selected from the database and the resulting dataset also converted to a raster. The ‘Condition’ (con) function in ArcGIS Raster Calculator was used to assign the value 0 to all cells with no monuments in, and 1 to all cells containing a monument, in other words a presence-absence (PA) map.

3.13.9 For each of the variables, in conjunction with the monument Presence or Absence map, the Raster Calculator ‘Combine’ function was used to create a new raster that contained a record for each combination of variable and monument.

3.13.10 For each period the variables where correlation occurred, and the values of the variables, were ranked according to the number of monuments that occurred at that value. It was necessary to maintain consistent ranking across each period and variable, in order to provide unbiased weightings. The elevation raster was then reclassified using the rank as the new value for the cells (Table 19).

Elevation (m)	Count Roman	Rank
0	0	1
25	12	3
50	56	3
75	15	3
100	4	2
125	1	2
150	0	1
175	0	1
200	0	1
225	0	1
250	0	1

Table 19: Ranking for elevation raster reclassified according to the number of Roman sites at each level

3.13.11 The density of known features was also thought to have a bearing on the potential for further archaeological monuments within an area, as it is an indicator of increased levels of human activity in a locality. The ArcGIS Spatial Analysis Kernel Density function was used to create a density map for the monuments of each period, calculating the density of points in the neighbourhood of any given point, using radii of 100m, 250m and 500m. The resulting map highlighted fuzzy ‘hotspots’, or clusters of sites, rather than focusing on individual locations. The particular radii were chosen as they represented a compromise between too narrow (highlighting individual sites) or too broad (highlighting only the extreme concentrations of sites such as Ribchester). The density rasters for each period were then reclassified into three bands of high, medium and low density.

3.13.12 To create the aggregated maps of potential for each period, the rasters representing variables for which the KS test indicated correlation and the Kernel Density rasters were added together. The resulting combination raster had cell values that were the sum of the values of the cells in the constituent rasters. These values could again be grouped into three bands, representing low, medium and high potential, with the highest totals representing the highest potential. Finally, the maps of potential for each period were added together to create a combination raster of overall potential for archaeology.

3.13.13 It was then possible to continue the HLC enhancement process by establishing the potential for archaeology of each period within each individual HLC polygon. Four further fields were added to the HLC dataset, representing the potential for each period and overall, and the ArcMap spatial query tools were used to select out the polygons that intersected the zones of potential. Since the potential maps had been created using other datasets alongside the HLC, the boundaries between the different zones in the potential maps did not always match those of the HLC; occasionally a polygon would contain more than one level of potential. It was decided to err on the side of caution and assign the highest level of potential in those cases.

3.13.14 ***Analysis in combination with the geomorphic mapping:*** the geomorphic data supplied by the University of Liverpool was used in three ways: firstly, to continue the HLC enhancement process by highlighting the present and future threat and potential for aggregate extraction within an individual polygon; secondly, by analysing the threat to known, existing archaeological monuments;

and thirdly, in conjunction with the maps of potential, to highlight areas at greatest threat from fluvial change and aggregate extraction. The two threat datasets contained two values: deposition and erosion (*Section 8*). The aggregates dataset contained a value for overall suitability for extraction, based on a set of criteria (*Section 7.2.6-7*), with low values equating to high suitability for extraction and vice versa. This dataset was grouped into three equal bands, representing high, medium and low suitability, for the purposes of updating the HLC.

3.13.15 The procedure for updating the HLC dataset was the same as that described in *Section 3.2.16*. A further three fields were added to the HLC attribute table to represent the two threat levels and the aggregate extraction potential. During the procedure of updating the threat fields, in the case where an HLC polygon intersected with areas of deposition and erosion, it was assigned a value 'deposition/erosion'. HLC polygons that did not intersect with the threat mapping at all were assigned a value 'N/A'. When updating the aggregate suitability field, if a polygon intersected with more than one band, it was assigned the highest level of potential suitability. Again, if a polygon did not intersect with the suitability mapping it was assigned a value of 'N/A'. To analyse the threat to existing archaeology, the known monuments of each period that fell within polygons with a threat of aggregate extraction suitability were highlighted using ArcMap's Spatial Query tools.

3.13.16 The geomorphic datasets were converted into rasters, using deposition or erosion for the threat mapping values and extraction suitability for the aggregate mapping, with a cell-size of 10m. For each geomorphic dataset and each map of archaeological potential by period, the Combine function in ArcMap's Raster Calculator tool was used to add the two rasters together. The resulting dataset had individual values for each combination of potential and threat from the constituent rasters.

4. ASSESSMENT OF METHODS

4.1 INTRODUCTION

4.1.1 The Ribble ALSF programme has been innovatory in the application of many of the data capture and analytical techniques, in particular the use of LiDAR for the determination of geomorphological form and archaeological monuments, and the use of GIS analytical techniques to establish archaeological potential. It is therefore appropriate to assess the success of these techniques, to determine whether they have potential for future ALSF or similar projects, or to what extent they may need to be adapted in the future.

4.2 ASSESSMENT OF ARCHAEOLOGICAL DATA CAPTURE

4.2.1 ***Assessment of Previous Research and Investigation:*** an assessment of the archaeological sources showed that the Ribble Valley has a substantially intact and visible historic landscape, which has largely survived the ravages of modern development. Also, it is clear that long-term land use patterns have not erased significant extant remains of earlier periods, nor removed the potential for the recovery of buried archaeological deposits. When other significant sites or discoveries (*Section 2.3-7*), such as the Viking hoard from Cuerdale (Graham-Campbell 19992), the Roman fort at Ribchester (Buxton and Howard-Davis 2002), or the prehistoric flint tool assemblage from Marles Wood (Middleton 1993), are taken into consideration, the Ribble Valley's 'known archaeology' provides an indicator of significant potential for new discoveries from many periods.

4.2.2 ***Assessment of Historical Mapping:*** the older historical maps were not found to be of sufficient detail to identify features within the landscape, but were useful to ascertain if any significant changes in the course of the Ribble had occurred since their respective publication. The most useful mapping for the project was without any doubt the OS first edition six-inch maps, which are the oldest standardised source with building and place-names, as well as boundaries and landscape features, and include natural, semi-natural and anthropogenic features; this was published between 1844 and 1852. The scale of the survey was 1:10,560, which, being similar to the modern 1:10,000 mapping, allowed for a rapid and easy comparison between them. Twenty sites were identified from the first edition mapping, which include features such as earthworks, that may be the remains of earlier structures. This prompted the use of LiDAR to investigate such potential features.

4.2.3 The location of historic extraction and industrial sites along the river valley were clearly shown on the earlier OS mapping and as such the source was of particular significance to this project. Essentially, comparisons between the OS first edition map and the modern map defined more succinctly than any other document the twin processes of industrialisation and urbanisation as these transformed the landscape of Lancashire.

4.2.4 As with the current mapping and the aerial photographic sources, the historic-mapping was used to add documentary detail to features that were identified using the LiDAR models. The OS first edition mapping often depicts archaeological monuments, some of which were in use at the time of the survey, and provides names and functions for the features. For instance, areas of palaeochannels coincided with old watercourses shown on the OS first edition mapping, and hachures were often used to depict disused spoil heaps or other substantial earthworks. Comparisons between current mapping and the OS first edition maps provide an indication of how the field systems have changed over the intervening period, and which were the oldest elements.

4.2.5 ***Aerial Photography:*** only five new sites were found using aerial photographic data alone, which is a surprisingly small number, but the aerial photographic mapping did provide full a coverage of the study area, whereas the LiDAR did not. The process of data capture from aerial photographic sources was a lengthy process, requiring the collation of all available photographic holdings in the Lancashire, North Yorkshire and Yorkshire Dales National Park collections. These required scanning (and georeferencing in the case of vertical photography), in order to be viewed easily in conjunction with the current 1:10,000 OS mapping and the GIS datasets.

4.2.6 The modern vertical colour aerial photographic mapping (supplied by Lancashire County Council) was undertaken in 2000 and provided the most recent clear representation of the study area in general. It was useful to provide a general feel for the character of the area, such as patterns of boundaries and networks of roads, and to show the scale of large extraction centres, such as Clitheroe Quarries. The oblique photography, provided by the Lancashire and North Yorkshire HERs, was in black and white, and flown in erratic sorties; as such it did not provide full blanket coverage of the area. However, the full range of vertical and oblique photography from between the end of the Second World War and 2000 highlights the changes in the landscape during this period.

4.2.7 Although only a few of sites were newly identified by this resource, it is perhaps not a reflection of its value, as oblique photography had been previously consulted and most features found had already been accessioned into the HER records.

4.2.8 ***LiDAR***: the LiDAR data proved to be invaluable for the determination of palaeochannels, which can be seen to riddle much of the area (particularly in North Yorkshire), and was effective at locating and recording all forms of potential archaeological feature. It explained the presence of landscape features encountered during the ground truthing, aided the targeting of palaeobotanical work, and avoided the need for trenching to confirm if a feature was anthropogenic in origin.

4.2.9 The landscape scale of the project demonstrated the potential use of LiDAR for both tracing and accurately measuring long linear features. This was highlighted at Ribchester, which lies at the junction of a series of Roman roads. In places the roads were known from excavation, in others they were marked as projected and were no longer seen in the landscape as a current road or hedgeline. The approach to Ribchester from the east shows such a projected line of a Roman road, and the HER has created a GIS record for this road based on the OS projections. When the entire available LiDAR raster was examined, the lines of these features were clearly defined. (Fig 54). The LiDAR hillshade function (*Section 3.9.14*) was used to show low to high height values as dark to light, and the road showed as a low bank running across the field, deviating from the OS projected line by as much as 90m to the south. The LiDAR slope models (*Section 3.9.17*) were also compared to areas of known archaeology to confirm that archaeological features were definitely being enhanced by the modelling technique. A slope model was created of the earthworks surrounding Sawley Abbey, and then further used to enhance the current vertical colour aerial photographs (Fig 55). The advantage of a slope model over a hillshade model is that no part of the landscape is left unilluminated, and that the new raster is not a product of shadow but is an actual representation of the ground and therefore can be measured. In this way the actual distance, for example between the crowns of ridge and furrow, can be measured, and allows a better determination of the form of such landscape features.

4.2.10 The most striking method of interrogating the data was to use ArcScene to examine the landscape models in close detail. ArcScene allows the user to attribute height values to the slope models in three dimensions and the ability to control the azimuth (that is the angle in degrees from north) and the Illumination altitude of the light source, in this case the hypothetical position of the sun. This creates a user-controlled oblique view that can then be panned and zoomed to identify sites. This added detail was compared to sites that had been previously accessioned into the archaeological record as cropmarks to assess LiDAR’s ability to pick up and refine subtle surface features. At Rathmell in North Yorkshire, for instance, aerial photographs have revealed areas of surviving ridge and furrow, but the LiDAR was able to enhance this area and bring out substantially more detail (Fig 56). Similarly, photographs of reclaimed marsh west of Preston Docks, around Longton, had previously identified areas interpreted as ‘Vague sub-Rectangular Cropmarks’ (HER PRN3146), but the LiDAR shows the area to comprise palaeochannels and flood defences (Fig 57).

4.2.11 LiDAR has proved to be an exceptionally useful resource, providing the main source material for the majority of the new sites identified during the project. The total number of new sites identified within the Lancashire study area was 189; of these, 162 were identified either directly from LiDAR slope or shade models or from enhancement of other sources by LiDAR.

4.2.12 The use of LiDAR for the project has clearly demonstrated the potential for this type of remote sensing to inform archaeological research, particularly at a landscape scale. The integration of data of this nature is at present comparatively rare in commercial archaeology, given the cost implications. From the results of this project, it is strongly recommended that where possible LiDAR be utilised as it provides a valuable landscape assessment resource.

4.2.13 ***Assessment of Secondary Sources:*** a literature search (*Section 3.9.19*) was used to create an overall picture of the Ribble Valley study area, the starting point being the investigation of the current landscape. As such, this borrowed from the Characterisation approach. The Countryside Character Areas (Countryside Commission 1998) and their accompanying landscape description reports, as well as GIS datasets from English Nature outlining SSSI, Conservation and Designated Ancient Woodland areas, were effective in defining the character of the landscape.

4.2.14 ***Archaeological interventions, excavations and surveys (Grey Literature):*** this information was used to enhance the known information held within the HER regarding events within the wider region as well as the study area, in order to provide a clear understanding of the circumstances under which archaeological sites have been revealed. The main contribution of this work was to provide an assessment of the known archaeological works, interventions and surveys that have been carried out in the study area, and to show how the known archaeological resource has been discovered. This work has also contributed to the assessment of areas of disturbance, for example the records regarding the construction of Preston Docks (Dickinson 1887), areas of intensive quarrying and other extractive industries, and reports from excavations in advance of urban development in recent years.

4.2.15 The largest single body of sites recorded by any event record was generated by the *Ribble Valley Survey of 1890s mapping* carried out by Lancaster County Archaeological Services (Lancashire HER 2006), which generated a large volume of sites, including 155 which fell within the study area. These mainly relate to standing buildings, and other extant features associated with post-medieval development, though the farmhouses and barns may have earlier predecessors. It clearly demonstrates the capability to produce detailed site records from high-quality map sources.

4.2.16 A second substantial survey was the *Ribble Valley Catchment Archaeological Rapid Identification Survey* (LUAU 1997b). This was carried out between January and March 1997 on behalf of the Environment Agency, and was designed to enhance the management of the archaeological resource, in the event of river management works. From the results of this survey, 149 sites were recorded, of which 77 were previously in the HER, and these were revisited in order to assess their condition. The remaining 72 sites were discovered as a result of the survey itself, but had not been added to the HER as yet. This provided a valuable source for post-medieval, mainly industrial, sites but was within a very narrow corridor centred on the line of the Ribble.

4.2.17 The *Ribble Valley Catchment Archaeological Rapid Identification Survey* showed how valuable visual assessment can be in recording the character and remains of areas of archaeological resource. Between the two surveys, some 304 sites were recorded in the study area alone. The use of such bodies of data for assessment is crucial to an understanding of the wider landscape, in contrast to the more localised micro-perspective of most excavations. Additionally, the general background history to both the wider region and the valley itself was substantially informed by the collation and synthesis of the previous research and results of excavations and surveys carried out over the last three decades across the north-west of England (*Section 3.9.4*).

4.2.18 As well as the search, a more general search of secondary sources was undertaken, which provided a wide historic and archaeological background for the project (*Section 3.9.19*). This involved visiting Local Libraries and Record Offices in Preston, Clitheroe, Northallerton, and Lancaster. Despite the extensive nature of the research, it was found that individual records in general volumes were typically those that were well documented within the HER and grey literature, as the same sources had been accessed to inform the HER.

4.2.19 ***Assessment of Ground Truthing:*** initially, two areas were chosen for this exercise, firstly an area around Osbaldeston Hall (Fig 58), immediately south of Ribchester (SD 6438 3441). The second area was a corridor running north from the village of Rathmell (SD 80423 59957) to the junction with the A65, south of Giggleswick station (SD 8067 6244; Fig 58).

4.2.20 The area round Osbaldeston Hall Farm was chosen because it was one of the locations selected by the University of Liverpool for geological drilling and could therefore link in to the geological analysis. It also had a varied topography and land use and had previously recorded monuments from the HER: Osbaldeston Hall Farm (HER PRN1815), Osbaldeston Sheepfold (HER PRN28248), Osbaldeston Clay Pit (HER PRN21619), Osbaldeston limekiln (HER PRN28249) and Dobridding Stepping Stones (HER PRN28247). The area had yielded new sites from LiDAR comprising a series of long, wide and low features (Fig 59) located on the low-lying river terrace.

4.2.21 The current land owner had no knowledge of there being any drainage or flood alleviation works being undertaken during his time there (C Bargh *pers comm*), nor was there any photographic or HER information for the immediate area. The field inspection confirmed the existence of the long linear banks, though in places these were so subtle as to be barely perceptible from ground observation, but they were ultimately interpreted as a series of palaeochannels.

4.2.22 The ground truthing demonstrated that a sheepfold (HER PRN28248), located to the west of Osbaldeston Hall Farm and close to the river bank, and a series of stepping stones (HER PRN28247), were no longer extant. New discoveries included a disused engine mounted on sandstone blocks with a brick-built foundation, located in Old Park Wood east of Oxendale Hall (SD 65406 33551), and also a field of regular, well-defined ridge and furrow west of Oxendale Hall (SD 64895 33344) in an area that did not have LiDAR coverage.

4.2.23 ***Conclusion:*** the collation of the known archaeological research and investigations was most effective for understanding the character of the archaeological resource within the study area and its wider context. It allowed an understanding of the previous settlement and land use patterns, by allowing the display of data as points, polylines or polygons within the GIS, and thus spatial patterns to be identified.

4.2.24 The data from the HLC provided a basic entry level of historic information and divided the area into parcels of HLC types which could be used in comparison with the distribution monument and event data. As the HLC was GIS based, it was possible to extract the records for the area and then add in an almost limitless number of additional fields to carry more information about each delineated area. The most useful for assessing potential and threat were the fields which had archaeological density data added to them. The HLC data were also used to capture the monument and event data within each polygon, which formed the basis of the HLC gazetteer records.

4.2.25 The only limitation of HLC data use was as a statistical test, since the nature of the primary data was too subjective and did not really represent the same kind of continuous data as a geological or topographical dataset. This was the reason for the abandonment of the Lynher Valley method, as the results were not suitable for the KS test.

4.2.26 The most useful historic mapping was undoubtedly the OS first edition six-inch mapping. This defined the area at a time of great change, developing industries and the increasing adoption of mechanised agricultural techniques, which created different patterns of land use. The associated growth of towns and the large-scale building of workers' housing encroached on the surrounding countryside. By direct comparison with the historic and current maps, it was possible quickly to see where areas have undergone higher or lower levels of change in character during the intervening period.

4.2.27 The aerial photography (both low-level oblique and vertical) has been of great help to the project, providing a visual element to the desk-based assessment, although it has been overshadowed by the LiDAR data. In conjunction with the LiDAR, however, it has allowed the detailed mapping of the landscape and the identification of many new potential archaeological sites. The ability to manipulate the LiDAR data to create different views and the ability to measure features from the images has increased the pace and detail with which new sites are discovered.

4.2.28 By taking all these sources together to investigate the landscape, a clear picture of the known resource can be identified, and from this the unknown can be predicted, and specifically predictions can be made for an archaeological resource in areas where there have been no archaeological events recorded. The use of ground truthing has been important to check that the data identified on maps, photographs and LiDAR were actual and that the interpretation was correct.

4.2.29 Visual assessment could also be used in areas in which LiDAR was ineffective, such as woodland floors, and most obviously in the gaps in the LiDAR coverage. An essential part of ground truthing is the ability to familiarise the landscape archaeologist with the study area and to get a 'feel' for the landscape, which cannot be fully achieved through mapping and photography alone.

4.2.30 One omission in the datasets is the difference between the records that exist in the Portable Antiquities Scheme (PAS) database, and those that are held by the Lancashire HER. The data received from the PAS contained 124 records in and around the study area, and the PAS contains 58 records that were recorded as being in or around Clitheroe alone. The results of this survey or any work based on the distribution of archaeological material would be altered greatly by the inclusion of the entire PAS dataset (Table 20).

Area	**Period**	**Count of PAS records (Oct 2006)**
Clitheroe	Bronze Age	1
Clitheroe	Early medieval	1
Clitheroe	Iron Age	4
Clitheroe	Medieval	31
Clitheroe	Post-medieval	10
Clitheroe	Roman	11
Preston	Bronze Age	2
Preston	Medieval	3
Preston	Post-medieval	11
Preston	Roman	16
Ribble Valley Area	Iron Age	1
Ribble Valley Area	Medieval	1
Ribble Valley Area	Post-medieval	3
Ribble Valley Area	Roman	1
Ribchester	Medieval	2

Area	Period	Count of PAS records (Oct 2006)
Ribchester	Post-medieval	3
Ribchester	Roman	3
Ribchester	Unknown	1
Whalley	Medieval	3
Whalley	Post-medieval	15
Whalley	Roman	1

Table 20: Summary table of PAS records within the Lower Ribble Valley study area

4.3 ASSESSMENT OF STATISTICAL METHODS

4.3.1 Various methodologies were applied in the enhancement of the HLC and the modelling of archaeological potential (*Section 3.13*). Unlike in the earlier stages of the project, it was not possible to assess these methodologies on the basis of new sites being created, and from the outset the statistical techniques applied were those considered most appropriate for the types of data being analysed. Furthermore, some compromises must be made when attempting to use any kind of statistical techniques on this type of data.

4.3.2 ***The Lynher Valley Approach***: this methodology produced very little in the way of usable data. The approach for calculating the relative significance of monuments within HLC polygons was slightly flawed statistically, as it compared a value that represents the percentage of an area (the HLC polygons), with a value that represents the percentage of a total (the number of monuments). By changing this approach to use the KS test, it was possible to conduct very similar analyses in a statistically valid way by comparing two sets of area percentages, giving a true indicator of correlation.

4.3.3 ***The KS Test Approach***: using the KS test on monuments represented by point data was an improvement on the Lynher Valley approach; however, it had its own limitations. Polygonal extents for all the monuments within the study area were unfortunately not available, and it was therefore decided to use point locations for consistency, which is a tried and tested approach (Ebert and Singer 2004; Wheatley 1995). There was, however, a question as to whether a single cell can truly represent the location of extent of a Roman fort or a single findspot. In this case, a 10 x10 m cell size was carefully chosen as a trade-off between file size and aggregation of closely located sites, and to provide an improved indication of the environmental parameters at a particular location.

4.3.4 This point-based approach was particularly unsuitable for linear monuments because a centroid point would be an inadequate representation of the location of the feature, and also because long linear monuments may well traverse several different elevations/slopes. It was therefore concluded that cell-based modelling was appropriate for certain types of analysis, but not in areas where many long linear monuments might be located.

4.3.5 Historically, this type of ‘predictive modelling’ has been criticised, on the grounds that the model can only be as good as the data from which it is created (Chapman 2006, 158). Also, it represents a departure from traditional methods of researching site location, abandoning ideas of settlement and subsistence in favour of land parcels (cells) and environmental parameters favouring site location (Warren 1990, 94). Ultimately, it will only be judged a success if a new site is discovered as a result of the model, yet from a cultural resource management perspective, the aim should be to avoid areas of high cost and time in terms of archaeological mitigation. Consequently, a new approach tends to be adopted, known as the 'Red Flag Model', that highlights regions of predicted high archaeological potential as areas for developers to avoid (Altschul 1990, 227).

4.3.6 From the point of view of the present project, this new model works well. It provides a method for highlighting areas (of archaeological potential) to be avoided by developers within the study area, and should be a valuable management tool in the future.

4.3.7 When applied to monuments classified by NMR Broad Types, the KS test approach failed to produce positive results. In the case of the HLC broad types, there was little correlation between HLC broad type for polygons within the study area, and the NMR Broad Type of the monuments. Similarly, there was little correlation between monuments classified by NMR Broad Type, regardless of period, and environmental parameters. The results may be valid, and may indicate that the monuments were equally spread where their Broad Type is concerned, but this may also be a symptom of the large number of NMR Broad Types and the commensurately small number of monuments of each type.

4.3.8 When applied to monuments classified by period, the results were more usable, in the sense that some clustering was evident. This classification also makes more sense from a management perspective, as it is conceivable that differing importance would be placed on monuments of different periods rather than different types.

4.4 ASSESSMENT OF GEOLOGICAL AND GEOMORPHIC TECHNIQUES

4.4.1 The principal outcomes in terms of technique development and refinement of these studies are that geomorphological mapping, with the assistance of remotely sensed DEMs, is an essential precursor to fieldwork where appropriate data are available, because of the tremendous benefits for mapping accuracy, cost-effectiveness and speed. Nevertheless, fieldwork was still clearly essential to assess the composition of identified features, for corroboration, and to assess the relationship between critical features, for example altitudinal, cut and fill, and sequence relationships. Of the available digital products, LiDAR is currently the best and it is possible to be interrogated to discern low amplitude differences between terrace features, for example the Holocene river terracing of the Lower Ribble and palaeochannel expression and morphology on the surface of river terraces. NextMAP data perform almost as well in this regard, but it was more difficult to discern features of reduced extent and amplitude in this, for example small-scale scroll-bar palaeochannels. Both datasets have limitations, particularly adjacent to standing buildings or features, and in dense woodland. OS Profile data were also capable of depicting landform geometry to a relatively high standard, but struggle as the size of the target features was reduced. The limitations of use for all these datasets reflect their specifications in terms of spatial and vertical resolution.

4.4.2 The approach adopted with this project involved computer-based mapping, using existing data sources (geological maps and georeferenced academic research), coupled with detailed interrogation of DEMs to map the landscape morphology. This initial stage was the precursor to field assessment, a process rendered more spatially precise and rapid by the computer-based assessment. The interpretations of the DEMs enable rapid identification and location of appropriate sites for the drilling programme. This stage of research is therefore a valuable and arguably essential precursor to accurate geomorphological investigation.

4.5 TOWARDS A REFINED METHODOLOGY FOR AGGREGATE RESEARCH

4.5.1 The geomorphological survey approaches advocated in *Section 4.4* are the first stage of aggregate assessment. Producing an accurate geomorphic assessment and discerning sediment-landform assemblage relationships, and then producing palaeogeographic models, allows prediction of the sedimentary composition and hence its potential as an aggregate resource. The rapidity of the computer-based geomorphological assessment means that, with geomorphological 'expert' knowledge, it is possible to assess new areas, providing links can be made with archived borehole and/or section evidence. With geomorphological expertise, aggregate surveys can cover larger areas, reducing the need for sand and gravel surveys with a restricted spatial brief (eg Entec UK Ltd 2005; and to a lesser extent Geoplan 2006). In the long-run, however, it is crucial that geomorphological and sedimentological interpretation is supported by field evidence. However, the mapping process allows refinement of the field mapping and borehole programmes to target critical locations (Crimes *et al* 1992; 1994), thereby significantly reducing the quantity of boreholes needed and reducing the cost of aggregate survey.

4.5.2 DEMs and the use of GIS software are invaluable in accurately gauging the volume of sand and gravel prospects, because cut/fill equations within raster analysis software can calculate the volumetric residual between two elevation surfaces, the first of which is the ground surface and the second an estimation of the base of the deposit. The quality of these predictions is only as good as the data on which they are based, and so access to borehole evidence, section exposure and the production of accurate sediment/landform and palaeographical models is crucial.

4.5.3 Prior to any extraction, further data will be needed to identify hydrogeological problems, clarify and quantify the nature and quality of the deposit (drilling of boreholes, excavation of test-pits, sampling of materials and grain-size analysis) (Crimes *et al* 1994). Nevertheless, the methodological improvements advocated for this first stage will improve the accuracy, cost-effectiveness and value of geomorphology-based mineral assessment for the sand and gravel aggregate industry.

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.

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 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

(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 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 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**	**δ^{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 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;

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	δ^{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**	**δ^{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.

- ***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

(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	δ^{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 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 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.

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**	**δ^{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 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.

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

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 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

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* *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, 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.

6. ARCHAEOLOGICAL RESOURCE: RESULTS

6.1 INTRODUCTION

6.1.1 The analysis of the archaeological resource involved the quantitative and qualitative evaluation of recorded sites and monuments, followed by the analysis of their location and distribution, highlighting significant patterns or groups. It should be noted that there is an inherent bias within the known archaeological resource relating to factors including geology, agricultural practice, vegetational cover, development, drainage, and previous archaeological work. The Ribble and its floodplain have been subject to canalisation, dredging and gravel extraction, which may have led to archaeological discoveries. In contrast, deposition of riverine material and intensive agricultural exploitation may mask the extent of past activity. The knowledge of archaeology within the Ribble Valley is therefore subject to the visibility of early remains and the amount and location of past interventions.

6.1.2 Differences in the distribution of the monuments (Fig 113) have been investigated, and this has entailed examining whether their absence was genuine or a matter of archaeological recording. To identify the two very different types of lacunae, the relationship between monuments and events was studied, along with the relationship between monuments and specific landscape types and environmental parameters.

6.1.3 Finally, after studying the distribution of monuments and highlighting the lacunae, maps of potential were created. These should not be considered as marking the location of hitherto undiscovered monuments, but instead highlight areas where more management of the cultural resource might be required, or where further investigation will be required in advance of any development.

6.2 THE DISTRIBUTION OF ARCHAEOLOGICAL SITES WITHIN THE LOWER RIBBLE VALLEY

6.2.1 Perhaps not surprisingly, the number of known sites increases through time, with a greater level of evidence for later prehistory, the Roman and post-Roman periods, and correspondingly the spatial distribution of activity and settlement becomes more evident. In comparison to surrounding areas, the coastal, estuarine, and river valley landscapes appear to have been favoured, presumably as they provided access to a wide range of land types and subsistence resources, and later established communication routes, such as surfaced roads.

6.2.2 ***Prehistoric Period:*** the earliest evidence of prehistoric activity within the Ribble Valley comes from flint and stone tools dating from the later Mesolithic period. While there are certainly biases within the distribution of Mesolithic material on a regional scale, river valleys and terraces do appear to have been one area favoured for habitation (Hodgson and Brennand 2006, 26), possibly due both to the variety of available resources and ease of movement and communication.

6.2.3 There is a significant assemblage of faunal and organic material from the River Ribble that remains undated, although associated artefacts provide some broad chronological indicators. prehistoric activity appears to have followed the course of the river, and subsequently there is a distinct curving line of sites running south of Preston, which reflects the more southerly, historic line of the watercourse, as shown on the first edition OS Mapping (Fig 114). Most significantly, a large assemblage of unstratified flint tools and debitage was recovered from the Marles Wood area during the 1980s, and held in the collection of John Hallam. They were subsequently examined as part of the North West Wetlands Survey and typologically dated to the later Mesolithic period (Middleton 1993, 87; HER PRN28205).

6.2.4 The assemblages from Preston Docks and from Marles Wood both contained waterlogged organic remains, and are therefore indicative of good areas for preservation of archaeological material. The Preston Dock finds included human and animal remains, stone tools, metal artefacts, and two dug-out canoes or boats, only parts of which were recovered. The flint recovered from the dock site has been classed only as 'prehistoric' by the HER (PRN2), and the assemblages of animal and human remains were found in conjunction with a Bronze Age spearhead. At Marles Wood a bronze spearhead and two canoe fragments (HER PRN1872 and PRN1015) were recovered, while two recorded finds of flint blades from the vicinity are listed by the HER as being 'prehistoric' (HER PRN2984; PRN1868). Both assemblages were also reported as being over 3.5m below the ground surface, and it is evident that there has been a significant deposition of fluvial sand and gravel, burying the archaeological remains.

6.2.5 Elsewhere, isolated finds hint at similar practices of deposition as found on other rivers in England. Boats of dug-out construction have been recovered from New Division Quay (HER PRN12882) and the railway embankment of Church Wood, Penwortham (HER PRN12883), during the mechanical removal of gravels on the river floodplain (Hallam 1989). Additional finds of metalwork include a socketed bronze axe from Penwortham New Bridge (HER PRN4952), and a Bronze socketed spearhead and axe found at Brockholes (HER PRN7 and PRN8).

6.2.6 The circumstances behind the deposition of the assemblage from Preston Docks is not known. There may have been a settlement or butchery area close by (Hallam 1986), or the material may have deposited or eroded from sites further up the river, and subsequently washed downstream until it accumulated at natural 'catch points' (Turner *et al* 2002). The area of the Ribble before the construction of the dock, as depicted on the OS first edition mapping (1850), shows a curving watercourse with a large marsh area prone to flooding on the south bank. On the same map Marles Wood is shown as a very sharp bend in the river with a large sand and gravel bank, and both of these might represent such naturally occurring 'catch points'. This may also account for the multi-period nature of the finds. It should be noted, however, that particular points within rivers and wetland locations may have been the focus for the repeated deliberate deposition of a wide range of artefactual material and human bones during prehistory (Bradley 1998, 23-4; Field and Parker Pearson 2003), and the assemblages from Preston Dock and Marles Wood do not necessarily provide evidence for settlement on the river edge or floodplain.

6.2.7 Records for prehistoric funerary activity within the Ribble Valley are confined to five sites, all dating from the Bronze Age (Fig 115). The group includes an urned cremation from Pleasington Cemetery (HER PRN7118), a ring ditch containing several urned cremations from Parsonage House, Ribchester (HER PRN4219), and two tumuli from Winckley Lowes. These were subject to antiquarian excavation, and while Winckley Lowes Barrow A (HER PRN180) contained urned cremations, Winckley Lowes Barrow B (HER PRN179) was found to contain no evidence of burial. In addition, a possible barrow site was located to the west of Winckley Lowes at Brockhall Wood (HER PRN149), the HER record describes a late nineteenth-century removal of a 'mound', in which iron spearhead was found, although the HER records this as being a Bronze Age barrow. If the earlier date is confirmed then the reuse of this monument has occurred. Workmen digging out gravel in 1887, removed another barrow at Pindar Hill, Waddington (HER PRN305), here urned cremation remains were again found.

6.2.8 Evidence of Iron Age activity is scarce in Lancashire (Hodgson and Brennand 2006, 52), and there is only one record of Iron Age pottery from the study area, recovered at Ribchester Church of England School (HER PRN4215). The only other find of this date close by is an Iron Age pin (HER PRN1629) found on Longton Marsh. A series of so-called promontory forts within the valley may also represent Iron Age occupation, and perhaps even territorial organisation, although there is little dating evidence to confirm whether these are all contemporary, or even if they date from the Iron Age at all.

6.2.9 ***Prehistoric Distribution:*** prehistoric activity, albeit sparsely distributed, appears to be concentrated along the floodplain of the former line of the Ribble. Mesolithic flintwork from the Marles Wood area would certainly indicate more than a transitory stop-over, although no structures from this date are known. The substantial assemblage from Preston Docks obviously skews this distribution to an extent, and the exact nature and depositional circumstances of this material remain far from certain (Fig 116). It should be noted that, within this context, there is a significant potential for earlier remains to have been buried by later riverborne material, and the absence of surface scatters would not be indicative of no activity, particularly given that the land in the study area is predominantly given over to pasture and there is little plough action to bring up underlying artefacts. The position of the Bronze Age funerary evidence is unlikely to be random or fortuitous, and probably reflects the importance of the area, perhaps even operating as a statement of tenure or habitation. It is possible that by the Iron Age a more organised system of territorial land division was in operation, but the dating evidence upon which to base any firm conclusions is not yet available.

6.2.10 The assemblage from Preston Docks in particular, must raise the question of deliberate deposition in the river of artefacts, human and animal remains during prehistory, as well as in later periods. The assemblage is not typical of those found on any settlement site in the North West to date, and the assemblage of human skulls, both prehistoric and later (Turner *et al* 2002), is the largest single assemblage of such material in the region. Similarly, antlers would have been a prized raw material, not normally to be discarded as carcass waste. In this context it should be noted that other points along the river, or former course of the river, may yield evidence of similar practices during below-ground disturbance.

6.2.11 ***Roman Period:*** the dominant archaeological perception of the Ribble Valley is that of a former Roman military communication route across the Pennines, policed by the forts at Ribchester (Buxton and Howard-Davis 2000) and Kirkham (Howard-Davis and Buxton 2000) in conjunction with a manufacturing and distribution centre at Walton-le-Dale. The Roman period saw the establishment of a long-distance road network of formal construction, linking military bases and crossing points of natural barriers (eg rivers). Where the roads are within an urban context, which has undergone substantial expansion in the post-medieval period, they have either been lost, deeply buried or truncated (Fig 117). Their presence would, however, certainly have encouraged activity, and concentrated settlement, not just from the Roman period, but also in subsequent periods as they continued to be used, in some cases through to the present day. Inevitably the density of archaeological finds along these arteries is a result of this activity.

6.2.12 From the available evidence, it seems likely that when the Roman army entered the North West it encountered a mixed landscape, with stock rearing and arable agriculture, widespread woodland clearance, and some areas enclosed into plots and fields (Philpott 2006, 61). The location and emphasis on the different farming practices are likely to be due both to physical and cultural factors, although the quality of soil is likely to have been a major determining element. Evidence of such settlement is scarce within the Ribble Valley, although the low level of archaeological work, a lower level of cropmark formation (Shotter 2004, 141), and post-Roman disturbance may mask the true extent of Romano-British activity in the area. River valleys, in particular, may have been favoured areas for settlement, and the distribution of known sites and findspots within the HER suggests a ribbon of activity along the valley bottom, in conjunction with the line of the Roman road.

6.2.13 The land along the Ribble Valley, forming part of the hinterland of the forts at Ribchester and Kirkham, is likely to have formed part of the supply system to the army. Similarly, the ‘depot’ at Walton-le-Dale (Gibbons *et al* forthcoming) may have required food supplies, raw materials and labour from the surrounding area. If these goods were not available at the time of the conquest, then it is likely that production and supply were to some extent instigated by the military authorities after their arrival. The distribution of find spots of coins from the Fylde area, both close to, and away from the lines of the roads (Graystone 1996), suggests a rural population that was, at least in part, involved in the official monetary economy, suggesting trade and interaction with the military authorities.

6.2.14 Whether the presence of the Roman army led directly to intensification of settlement and agricultural exploitation is not known, although the presence of the army and the occupants of the extramural settlements around the forts might suggest that this was the case. Pollen evidence from the surrounding area, beyond the valley, indicates increased tree clearance during this period. Similarly, the location of settlement may have intensified along the line of the Roman road. The valley bottom, within the environs of the Roman road, would therefore be a prime site for Romano-British activity and settlement, even if little of it is visible today.

6.2.15 ***Early medieval Period:*** the system of settlement and land division in existence during the Romano-British period is unlikely to have broken down immediately or ceased entirely following the end of Roman military administration (Fig 118). The visibility and dating of archaeological remains from this period does, however, become more problematic, with the end of Roman material culture (RM Newman 2006). Economic circumstances changed, systems of lordship, tenure and taxation are also likely to have changed, but rural settlement and agricultural production almost certainly continued. There is also some evidence that the sites of Roman administration continued to be occupied, as at Ribchester, whereas Walton-le-Dale did not (Gibbons *et al* forthcoming).

6.2.16 The presence of stone sculpture at Ribchester and Whalley suggests some form of ecclesiastical presence in the valley, and possibly organisation of estates. Two urn fragments (HER PRN155), two metal shield bosses (HER PRN154; PRN2895), and a 'Saxon' coin provide scant evidence for continued occupation at Ribchester. Political and ethnic influence may be seen in both artistic styles of stone sculpture and place-name evidence, which suggest both Northumbrian and Scandinavian influence (RM Newman 2006). The presence of the Cuerdale hoard (*Section 2.5.57*) suggests Viking activity on the river, but not necessarily settlement purely from this evidence.

6.2.17 ***Later medieval Period:*** it is during the later medieval period that the expansion of settlements into the wider landscape is demonstrable from the archaeological distribution in the study area (Fig 119). This would include the expansion into upland areas and the establishment of cattle ranches known as vaccaries (Winchester 1987, 6). The results of expansion and development of nucleated field systems dominate the landscape of the valley even today. The period also saw the development of monastic estates. Sawley (Hunt 2005) and Whalley Abbeys (Wood 1996), founded in the twelfth and thirteenth centuries respectively, represent powerful landowners within the valley up until their dissolution in 1537.

6.2.18 The study area contains 84 monuments that have been allocated a medieval date, including 12 Deserted Medieval Village sites that were all close to the Ribble or one of its tributaries. Presuming that these were small hamlets or villages predominantly carrying out subsistence farming, it can be postulated that the post-Roman and medieval period exhibited a slow movement towards nucleated settlement, although a large number of dispersed settlements also remained (R Newman 2006, 117). It is unlikely that there was any single cause for the 'failure' or desertion of some medieval settlements, or that these desertions were all in the medieval period itself (*op cit*, 120). Associated with the nucleated settlement, which was often focussed on the principal water courses, was a development of water-related rural industries, such as the flax-retting areas at Grindleton and Newton (Higham 1991b). Although these activities were probably commonplace, archaeological evidence is scarce, and low-lying areas and river terraces retain considerable potential for elucidating details of medieval water management and industrial practices.

6.2.19 The valley continued to develop economically as market towns emerged in the North West, in many instances in places determined by communications and the potential for natural defence, such as Clitheroe. Inevitably, the corridor between the centres of Preston and Clitheroe became an increasingly busy trade route. As the de Lacy family held both Clitheroe and Pontefract castles (King 1983), this may also have instigated a trans-Pennine trade route between the two.

6.2.20 The upland waste was defined by the designation of large tracts as chase, forest or parkland, the notable example being the expansive chase of the Forest of Bowland, owned by the de Lacys (Farrer and Brownbill 1908). The other notable park was that associated with Samlesbury Hall, which originated in the fourteenth century, and continued to utilise the same prime valley bottom site (LUAU 1997c). Towards the later medieval period there was, however, considerable encroachment of the chase and parkland for agriculture, and the emergence of dispersed settlement in these areas.

6.2.21 ***Post-medieval period:*** despite the rural agricultural appearance of the Ribble Valley today, the archaeological record is numerically dominated by industrial monuments. Records of sites pre-dating the post-medieval period show a broadly equal balance between ‘Agricultural’ and ‘Industrial’ activity. Records for post-medieval sites, however, suggest an increase in industrial activity, with 145 monuments being classified as relating to agriculture and subsistence, and 167 classified as Industrial.

6.2.22 This apparent change results from the nucleated centres of settlement containing large numbers of post-medieval industrial and domestic monuments, within what is otherwise a predominantly rural area. Many of the industries had their origins in the later medieval period, with fulling mills operating between the fifteenth and eighteenth centuries, and sites such as the retting ponds at Grindleton having possible eighth-century origins (Higham 1991b). Extraction industries have also scarred the landscape of the valley, the most obvious of which are the limestone quarries north of Clitheroe at Chatmoss.

6.2.23 Redevelopment has occurred since many of the mills and factories were built, which has to some extent reduced the present-day visibility of former industries in the valley landscape. The demolition or conversion of many industrial sites has effectively lowered the visual impact that industrial growth, particularly of the textile industries, had on the Ribble Valley. The localised medieval rural industries were small enough to co-exist with the farming settlements and indeed these activities often took place in the same households (Rothwell 1990). Where these structures remain, their overall condition is good, with the survival of both historic fabric and character in the individual buildings, towns and overall landscape.

6.2.24 The distribution of the post-medieval industrial monuments can clearly be seen to follow watercourses, based on the large number of mill remains (Fig 120) that were located to exploit water power. The only known medieval mill is at Samlesbury (Mill and Maltkiln, HER PRN1735), on the River Darwen. There are also two distinct groupings of extraction sites, one in the north-west outskirts of Blackburn, around Billinge Hill, and a second group, to the north of Clitheroe, which exclusively comprises limestone quarries, and reflects a geological source.

6.2.25 Unlike monuments from earlier periods, those relating to post-medieval industry are typically very visible elements within the landscape, and are often depicted on historic maps. Consequently, the distribution of post-medieval monuments defined by the present study for the most part correlates with the actual distribution and the risk of development impacting on an unknown post-medieval resource is correspondingly lower.

6.3 EXAMINATION OF THE DENSITY OF SITES

6.3.1 The density of monuments for each period was calculated using the methods described in *Section 3.13.11* in order to highlight clusters of monuments. It was hoped that this would provide further information on the distribution of monuments, by highlighting 'favoured areas' or zones of heightened activity. It might also be supposed that these areas would be of higher potential for the discovery of new monuments.

6.3.2 ***Prehistoric period***: the density of prehistoric monuments within the study area (Fig 121) is very similar to the simple distribution, as described above in *Section 6.2.* The cluster of sites around the south of Preston (*Section 6.2.2*) shows up as an area of high density, but there are also areas of high density around Ribchester, Marles Wood (*Section 6.2.3*) and Brockhall Farm/Winckley Lowes (*Section 6.2.7*).

6.3.3 In general, these highlight the clusters of monuments that are evident from the general distribution, although the area around Ribchester can perhaps be disregarded, as it is more representative of the large number of events within that area than any particular grouping of monuments. Since there are so few prehistoric monuments within the study area, each individual monument stands out as an area of higher density.

6.3.4 Disregarding the isolated individual monuments, the general picture from the density is that, throughout the study area, the zone around the Ribble and its immediate environs is an area of heightened prehistoric activity. This ties in with the postulation (*Section 6.2.1*) that river valleys were a preferred area of occupation and activity in the prehistoric period.

6.3.5 ***Roman period***: it is immediately clear from the density of Roman monuments throughout the study area that Ribchester is by far the largest cluster (Fig 112). This is not a surprise, and to some extent it obscures other pertinent detail about the pattern of Roman occupation in the area, which is the extremely close relationship between the pattern of activity and the main trans-Pennine road (*Section 6.2.11*).

6.3.6 If the monuments relating specifically to sections of the Roman road network are disregarded, then the distribution of the other monuments, and hence the density, is very even. To compare the Roman density with the prehistoric (and medieval) it is necessary to disregard the area around Ribchester, but even when this is removed there are no obvious clusters.

6.3.7 This supports the idea (*Section 6.2.14*) that there is very little known Roman activity outside the roads and forts, and that these features represent major foci within the landscape of the valley.

6.3.8 ***Medieval period***: the larger number of monuments can be partly attributed to their greater visibility, but also, to the increase in population and land use in this period (*Section 6.2.17*). This has several effects on the density map in comparison with earlier periods, as it now shows considerably more areas of high density, but also more areas of clustering, around villages and towns (Fig 123).

6.3.9 Settlements such as Ribchester remain areas of high density. This may represent continuity of occupation from the Roman period, but may also be the result of more archaeological investigation within the area (see S*ection 3.13.1*). However, in the medieval period, the area of high density around Ribchester is concentrated less on the settlement itself, but continues to the north-east, taking in the villages of Stydd and Lower Dutton. In general, though, the density map does not provide any new information on the distribution of monuments.

6.4 MONUMENTS, EVENTS, AND THE HLC

6.4.1 ***Introduction***: HLC-type classification groups together those areas where the same historic processes have shaped the landscape. As a result, every polygon of a particular HLC type should display broadly similar historic characteristics. By studying the quantities and densities of monuments within particular landscape types it was hoped to identify correlations or trends between the two. Furthermore, by examining the relationship between landscape types, monuments, and archaeological events, an understanding of the shortcomings or lacunae in the dataset could be sought.

6.4.2 Rather than the kernel density calculations (*Section 3.13.11*), the density of monuments per unit area was used in this case (see *Section 3.12.10*). This allowed the distinction between polygons of differing areas having commensurately few or many monuments, and follows on from the Lynher Valley model (Cornwall Archaeological Unit 2002). The count and density of monuments of each period, and overall, were then included in the enhanced HLC (see *Section 3.12.10*).

6.4.3 ***Monument Density:*** density maps were created for all monuments, and for monuments of each period: prehistoric; Roman; and medieval. The polygon representing the ancient and post-medieval settlement of Ribchester was found, not unsurprisingly, to contain the highest number, and the highest density of monuments overall within the study area (Fig 124); unsurprisingly, this polygon also contains the largest number of events. Before jumping to the conclusion that *lacunae* in monument distribution occur where no events have taken place, it was necessary to examine further the distribution of monuments within other settlement polygons (*Section 6.3.1*).

6.4.4 The density per HLC polygon calculations threw up what initially appeared to be interesting results, but which in the event turned out to be more a function of the number of polygons of particular types than a trend in the distribution of monuments. For example, there are 31 polygons containing prehistoric monuments, and the HLC class containing the highest density of prehistoric monuments is 'Ancient and Post-medieval Settlement'; however, this is again skewed as there is only one record, the historic core of Ribchester. This has a very small extent, and consequently a high density, whereas the finds at Preston Dock are considerably larger in scale and number but are represented by only two monument records, and as such have a relatively low density. The lowest density of prehistoric material is within the HLC class 'Water', which essentially is the single HLC polygon for the River Ribble, and as such is a large area (Fig 52).

6.4.5 This line of analysis also tends to support the conclusions already drawn elsewhere, for example, that the historic core of Ribchester is also the area of highest density of known prehistoric, Roman and medieval monuments as well as overall. The area of lowest density of monuments of all periods is in HLC class 'Water', which is represented by the entirety of the Ribble.

6.4.6 ***Link Between Monuments and Landscape Type***: more monuments have been found in areas of 'Ancient Enclosure' than any other landscape type (Table 29). However, the average number of monuments per polygon is lower than landscape types such as 'Modern Ornamental'. When considering the factors that led to the identification of monuments, their existence is only one factor; others are visibility, and development activity. The large number of monuments within 'Ancient Enclosure' landscapes may be due to the high visibility of extant features, and similarly the relatively small numbers of monuments in landscape types such as 'Ancient Woodland' and 'Modern Woodland' may reflect relatively low site visibility within such contexts.

HLC broad type	Number of Polygons	Total Number of Monuments	Average Number of Monuments
Water	1	29	29
Ancient and Post-medieval Settlement	11	125	11.36
Modern Ornamental	2	19	9.5
Ancient Enclosure	91	478	5.25
Modern Settlement	32	163	5.09
Post-medieval Enclosure	71	240	3.38
Modern Recreation	11	34	3.09
Modern Industry	16	44	2.75
Ancient and Post-medieval Ornamental	3	6	2
Modern Enclosure	20	32	1.6
Ancient and Post-medieval Wood	49	65	1.33
Modern Communications	3	2	0.67
Modern Woodland	7	3	0.43
Reverted Moorland	1	0	0
Saltmarsh	2	0	0
Sand and Mudflats	2	0	0

Table 29: HLC landscape types, showing the total and average number of monuments per polygon

6.4.7 In order to examine the relationship between monuments and landscape types statistically, the KS test (*Section 3.12.5*) was used. This demonstrated some correlation between landscape type and the location of prehistoric and Roman monuments, but not of medieval, which essentially means that it would appear to be possible to predict the types of landscape that prehistoric and Roman monuments are more likely to be found in. The results of this test were used in the construction of the maps of potential (see *Section 3.13.4-13*).

6.4.8 For prehistoric monuments, the correlation showed that statistically less monuments than would be expected have been found in areas of 'Ancient Enclosure' and Post-medieval Enclosure', given that 'Ancient Enclosure' is the type of landscape where most prehistoric monuments have been found, and covers over half the study area. Nevertheless, more monuments of this period might be expected in areas of this landscape type.

6.4.9 For Roman monuments, there were statistically less monuments found in both 'Ancient and Post-medieval Woodland', and 'Modern Woodland', which may reflect the fact that monuments are less visible in these landscape types, or that they are likely to be disturbed (*Section 6.5.2*). There was also correlation, albeit less, between monuments of all periods and HLC broad type, with statistically less monuments occurring in areas of 'Ancient and Post-medieval Woodland'.

6.4.10 Table 30 shows the comparison between HLC polygons of each landscape type containing no monuments, and the total number of polygons of each type. No particular landscape type can be highlighted as having a greater proportion of polygons containing no monuments, and as such this cannot be used to highlight lacunae in the monument distribution.

HLC Polygons containing no Monuments	Count of Polygons with no monuments	Total Count of Polygons
Ancient and Post-medieval Ornamental	2	3
Ancient and Post-medieval Settlement	2	11
Ancient and Post-medieval Wood	25	49
Ancient Enclosure	25	91
Modern Communications	2	3
Modern Enclosure	8	20
Modern Industry	6	16
Modern Ornamental	1	2
Modern Recreation	2	11
Modern Settlement	10	32
Modern Woodland	5	7
Post-medieval Enclosure	21	71
Reverted Moorland	1	1
Saltmarsh	2	2
Sand and Mudflats	2	2
Water	0	1
Totals:	**114**	**322**

Table 30: Breakdown of HLC polygons by landscape type, showing number of polygons containing no monuments

6.4.11 ***Density of Events***: the purpose of analysing the distribution of events was to highlight areas where development had taken place, and as such where there would be a better understanding of the nature of any archaeological monuments, buried or otherwise. Conversely, in areas where no events had taken place there would be a reasonable understanding of the visible monuments, generally of later periods, but no real evidence for buried, which are more likely to be earlier monuments.

6.4.12 This is problematic, for several reasons. Firstly, there are events such as the *River Ribble Catchment Survey* (event LA0005, LUAU 1997b) that had a specific aim: to conduct a rapid survey of the region, concentrating on the eighteenth- and nineteenth-century industrial monuments. Monuments of other periods were not recorded, therefore this survey cannot be considered objective in terms needed for the current study. As such, it has been discounted from the general event distribution for this analysis.

6.4.13 Secondly, a centroid (point) location for an event is not a good indicator of its extent or of the amount of development that precipitated it. Consequently, it was decided that the quantity and density of events within HLC polygons should be considered. As each polygon represents a parcel of land of the same landscape type, an event, or its accompanying development, can be thought of as acting over the entire land parcel.

6.4.14 After excluding events relating to the *River Ribble Catchment Survey*, 294 out of a total of 322 HLC polygons contained no events, which encompass approximately 75% of the actual land area. All HLC landscape types are represented in this number, but over half (113) comprise 'Post-medieval Enclosure' and 'Ancient and Post-medieval Wood'. When the total numbers of parcels of these landscape types are considered (Table 31), it can be seen that only a very small number of events have taken place in these landscapes (Fig 126). These are, however, landscapes that will have conversely seen little recent development. Table 31 shows that these landscape types also contain large numbers of parcels with no monuments. This could be a reflection of the lack of development / archaeological activity, but for the landscape type 'Ancient and Post-medieval Wood' it is probably also a reflection of the reduced visibility of any monuments in those areas.

6.4.15 The largest number of events in an individual polygon was found in the area of 'Ancient and Post-medieval Settlement' representing the historic core of Ribchester, as expected. This landscape type also has a high average number of monuments per polygon (Table 31), reflecting the large levels of development-led archaeological events that have taken place in these areas. The extremely high average for the 'Water' landscape type can be disregarded because there is only one polygon, representing the entirety of the Ribble.

HLC broad type	Number of Polygons	Total Number of events	Average Number of Events
Water	1	7	7
Ancient and Post-medieval Settlement	11	30	2.7
Modern Industry	16	8	0.5
Modern Settlement	32	8	0.25
Ancient Enclosure	91	20	0.22
Modern Recreation	11	1	0.09
Ancient and Post-medieval Ornamental	3	0	0
Modern Enclosure	20	2	0.1
Post-medieval Enclosure	71	8	0.11
Ancient and Post-medieval Wood	49	2	0.04
Modern Communications	3	0	0
Modern Ornamental	2	0	0
Modern Woodland	7	0	0
Reverted Moorland	1	0	0
Saltmarsh	2	0	0
Sand and Mudflats	2	0	0

Table 31: HLC broad types, showing the total and average number of events (excluding LA0005) per polygon

6.4.16 ***Link between Landscape Type and Events***: the historic core of Ribchester contains the highest density of monuments overall, and of all periods, and is an area classified as 'Ancient and Post-medieval Settlement'. The other areas of this HLC type are Grindleton, West Bradford, Sawley, Waddington, Riley Green, Samlesbury, Chatburn, Barrow and some of the outer areas of Preston (Fig 127). Unlike Ribchester, which contains monuments of all periods, these other settlements contain either only archaeology of medieval and post-medieval date, or later, or, in the case of the settlements of Chatburn and Barrow, contain no monuments at all within the study area.

6.4.17 If the event data for these polygons are examined, it is clear that Ribchester has been subject to considerably more events (28, as opposed to its nearest rival - Sawley, with four). However, the relationship between monuments and events is not straightforward. As Table 32 shows, several of these areas contain monuments but no events. This would suggest that any relationship, if it exists, is between the location of earlier, buried monuments and events. On the whole, medieval and particularly post-medieval monuments are more likely to be extant surface features, and as such can be identified without the need for intrusive events such as excavations.

Area	Total Monument Count	Prehistoric Monument Count	Roman Monument Count	Medieval Monument Count	Event Count
Barrow	0	0	0	0	0
Chatburn	0	0	0	0	0
Grindleton	1	0	0	0	0
Preston	2	0	0	0	0
Preston	4	0	0	0	0
Ribchester	85	2	42	3	28
Riley Green	3	0	0	0	0
Samlesbury	7	0	0	2	1
Sawley	10	0	0	2	4
Waddington	8	0	0	1	0
West Bradford	5	0	0	0	1

Table 32: Areas of 'Ancient and Post-medieval Settlement', and the breakdown of events and monuments within them

6.4.18 If the distribution of monuments was truly related to the distribution of events, then the monuments should be should be in the proximity of the events. The results of running the 'Select by Location' tool on the monuments are shown in Table 33.

Distance from Event (m)	Number of Monuments	Percentage of total	Cumulative Total
25	111	8.99	8.99
50	62	5.02	14.01
75	44	3.56	17.57
100	35	2.83	20.4
150	77	6.23	26.64
200	62	5.02	31.66
250	51	4.13	35.79
500	245	19.84	55.63
750	167	13.52	69.15
1000	160	12.96	82.11

1500	145	11.74	93.85
2000	40	3.24	97.09
>2000	36	2.91	100
Total	**1235**	**100**	

Table 33: Number of monuments at given distances from events

6.4.19 Table 33 shows that less than 50% of monuments are located within 250m of an event, and as such there is no clear geographic relationship between the locations of monuments and events. This is borne out by a study of the sources of the monuments; 423 monuments were identified in three single events: the 1890 documentary survey (Lancashire County Council), the *River Ribble Catchment Survey*, and this project; a further 225 are extant listed buildings. Of the remainder, a large majority (approximately 200) were located from historic mapping and, consequently, intrusive archaeological interventions account for only a very small number of monuments within the study area. They could thus not be used as an indicator for the potential discovery of new sites.

6.4.20 In conclusion, analysing the distribution of events and monuments within HLC polygons has highlighted landscape types that may be under-represented in the monument distribution, but has also highlighted a relationship between the location of events and monuments, albeit not a strong one. This may be due to relatively low levels of development-led archaeological investigation, or simply to low visibility of surviving remains. The issue of the amount of development, or below-ground disturbance, is considered as a key factor in the survival of buried, archaeological monuments (*Section 6.5.2*).

6.5 ANALYSIS OF THE *LACUNAE*

6.5.1 Having established that the distribution of monuments earlier than the post-medieval period throughout the study area does have some limited relationship to the amount of development-led archaeological investigation, the next step was to look further at factors that would affect the survivability or visibility of earlier buried monuments. Many factors, such as chemical or biological effects, were beyond the scope of this project, but the influence of below-ground disturbance was considered.

6.5.2 ***Survivability***: it was postulated that, in areas of below-ground disturbance, either archaeological intervention would have taken place and uncovered buried monuments, or no archaeological intervention had taken place but the level of disturbance would have destroyed any monuments.

6.5.3 The HLC landscape types were used to classify polygons in terms of the amount of below-ground disturbance this would cause (Fig 128). Modern land uses that require considerable landscaping or excavation were classified as bad. Ancient land use types were considered more stable, and were classified as either medium or good (Table34).

HLC Broad Class	Disturbance Level	Number of polygons
Ancient and Post-medieval Ornamental	Medium	3
Ancient and Post-medieval Settlement	Good	11
Ancient and Post-medieval Wood	Good	49

HLC Broad Class	Disturbance Level	Number of polygons
Ancient Enclosure	Good	91
Modern Communications	Bad	3
Modern Enclosure	Medium	20
Modern Industry	Bad	16
Modern Ornamental	Bad	2
Modern Recreation	Medium	11
Modern Settlement	Bad	32
Modern Woodland	Bad	7
Post-medieval Enclosure	Good	71
Reverted Moorland	Good	1
Saltmarsh	Medium	2
Sand and Mudflats	Medium	2
Water	Medium	1

Table 34: HLC broad types showing disturbance classification

6.5.4 The KS test, comparing the location of monuments and the disturbance of HLC land use types, showed that there was a correlation. The calculations show that statistically more monuments are known in areas of higher disturbance. The implication is that land uses causing below-ground disturbance are subject to higher levels of archaeological investigation or exposure, so more monuments are found. However, given the levels of development and disturbance, it is unlikely that these areas will yield any new monuments.

6.5.5 ***Visibility***: factors such as fluvial deposition in the vicinity of rivers would have an effect on the visibility of monuments within those areas. Terrace T4 and the floodplain have formed and continued to develop since the prehistoric period (S*ections 5.2.23 and 5.2.34*). These are areas that are likely to have seen considerably more activity in the prehistoric period (*Section 2.3*), and as such there is a likelihood of archaeology buried under the fluvial deposits. However, the depths of these deposits, up to 7m in the Lower Ribble Valley (*Section 5.2.23*) and 3.5m in the Lower Calder Valley (*Section 5.2.34*), mean that it is unlikely that anything other than deep excavation will expose any buried archaeological remains (*see also Section 9*).

6.5.6 Unlike *lacunae* resulting from disturbance, *lacunae* because of bad visibility cannot be used as a factor in a discussion of potential. Bad visibility does not affect the potential of an area to contain archaeology; it merely affects our ability to discover it. Although any archaeology in these areas will potentially be buried at a considerable depth, they would be exposed by aggregate extraction and would require careful management and monitoring, given their nature.

6.5.7 ***Conclusion:*** there are two elements to consider when excavating *lacunae*: firstly survivability, or *lacunae* resulting from disturbance; and secondly, visibility. Knowledge of below-ground disturbance can be used to classify areas as having lower potential for surviving archaeology. Low visibility does not affect the potential for archaeological remains, but these areas would require more careful management and monitoring.

6.6 STATISTICAL ANALYSIS

6.6.1 ***NMR broad class:*** the KS test was originally run on the monuments separated by NMR broad class, rather than period (*Section 3.12.5*).

NMR broad class	Total Number of Monuments	Distance from Water	Slope	Aspect	Elevation	Number of correlations
Agriculture and subsistence	145	No	No	No	No	0
Civil	2	N/A	N/A	N/A	N/A	N/A
Commemorative	1	N/A	N/A	N/A	N/A	N/A
Commercial	35	No	No	No	No	0
Defence	37	Yes	No	Yes	Yes	3
Domestic	133	Yes	No	No	Yes	2
Education	21	N/A	N/A	N/A	N/A	N/A
Findspot	79	No	No	No	Yes	1
Gardens, parks and urban spaces	39	No	No	No	No	0
Health and welfare	7	N/A	N/A	N/A	N/A	N/A
Industrial	167	Yes	Yes	No	Yes	3
Maritime	24	Yes	No	No	Yes	2
Monument <by form>	158	N/A	N/A	N/A	N/A	N/A
Recreational	10	N/A	N/A	N/A	N/A	N/A
Religious, ritual and funerary	76	No	No	No	No	0
Transport	99	Yes	No	No	Yes	2
Unassigned	84	N/A	N/A	N/A	N/A	N/A
Water supply and drainage	120	Yes	Yes	No	Yes	3
Number of correlations		**6**	**2**	**1**	**7**	**16**

Table 35: Results of KS test using NMR broad class

6.6.2 It is clear from Table 35 that the distance from water and elevation are the parameters that have the highest number of correlations with Broad Class, and would imply that they had the biggest effect on monument location, whereas slope and aspect appear to have less of an effect. This can perhaps be explained by the topography of the study area, where the narrow valley reduces aspect to one of two choices (in other words which side of the valley is chosen), and slope is reduced to a choice of valley bottom/floodplain or valley sides. Further analysis to test this assumption might involve the reclassification of the aspect into two very broad groups, roughly south-east-facing and roughly north-west-facing. The slope could be grouped as roughly flat or roughly sloping. However, given the eventual decision to concentrate on analysing the monuments by period, it was felt that this was beyond the scope of the project.

6.6.3 When exploring the results by Broad Class (Table 35), no single Class correlated against every environmental parameter. However, the classes ‘defence’, ‘industrial’ and ‘water supply and drainage’ correlated against three factors. This implies that environmental conditions do have an effect on the location of these classes of monument.

6.6.4 ***Defence***: this class correlated most highly with elevation, but an analysis of the monuments themselves shows that 26 of the sites relate to the Roman fort at Ribchester. Putting this cluster aside, it is still clear that environmental factors make a contribution to the location of this type of monument (Fig 129). All but three of the defence-class monuments lie within 50m above sea level, typically reflecting an association with the river. From the putative promontory forts along the north of the Ribble, to the motte and bailey castle at Penwortham, there would have been a need to either control a river crossing, or use the river as part of the defences; in both instances it would have been important to have a good view over the line of the river.

6.6.5 When a map of the potential for the 'defence' class was constructed, it highlighted the area of the Ribble floodplain as being of greatest potential, with zones of medium potential extending up the valleys of the tributary rivers and streams. The zones of lowest potential were the north- and north-west-facing slopes on the southern side of the Ribble Valley. A rough visibility analysis using viewsheds showed that the northern valley side does allow good visibility of the approaches up the river from the estuary at Preston, but more detailed viewshed analysis would be necessary to develop this inference.

6.6.6 ***Industry***: this class correlated most highly with distance to water, with most monuments clustered at 100-200m from water, which reflects the importance of water power on the siting of industrial sites. The second highest correlation was with slope, most being located on slopes of 5-10° above the horizontal. Thirdly, most sites were between 0m and 100m above sea level. The most numerous of the 167 known monuments of this type are pits (typically for coal); (21 sites) and quarries (31 sites), mainly medieval, post-medieval or modern period, spread relatively evenly across the study area with no obvious clustering.

6.6.7 When a map of the potential for monuments of this class was constructed, most of the study area was shown to be of medium to high potential, as expected, given the even spread of known sites (Fig 130). There are some areas of medium to high potential that do not contain any known monuments, the most obvious of which is the area to the west of Ribchester.

6.6.8 ***Water Supply and Drainage Sites***: unsurprisingly, this class correlated most highly with distance from water, with most sites being within 100m of a water source. The majority are on slopes of between 10° and 20° from the horizontal, and less than 50m above sea level. The majority of monuments of this class are wells (70 sites) and weirs (13 sites). The wells were mainly medieval in date and were spread fairly evenly across the study area, whereas the weirs are clustered on the tributaries of the Ribble, such as the Darwen (ten sites). A map of potential for this class of monument clearly highlighted the majority of the area as being of low potential, with only the zones close to the river and its tributaries being of medium or high potential (Fig 131).

6.6.9 ***Analysis for the Terraces***: it was decided that repeating analysis for the much smaller area covered by the river terraces might provide more useful and detailed information, and allow questions to be asked about the differing uses of the terraces from the prehistoric period to the present day. However, when producing slope, aspect and elevation models for the terraces, it became clear that more detailed base data would be required to differentiate between the small variations in the topography between one terrace and the next. Unfortunately, the LiDAR dataset, which would have provided the additional detail, did not provide full coverage of the area of the multiple terraces. Attempts to merge this with other contour data failed, as the resolution of the final dataset could only be as good as the poorest of the datasets used, which was no better than the initial data.

6.6.10 ***Conclusion***: it seems that this kind of analysis was interesting but not particularly useful. To highlight an area as having high potential for industrial monuments would not provide any indication of the activity in other periods, and yet it is arguable that the method of dealing with likely prehistoric monuments would be different from that for the post-medieval period and later.

6.6.11 If the monuments of a broad class were also split into period, this would lead to 70 different combinations of period and class, and many of these would then have too small a number of monuments to be significant statistically, and it would be a very time-consuming exercise. As a consequence, it was decided to repeat the analysis solely by period, as this would be produce more manageable and meaningful results, and perhaps be more useful as a planning tool.

6.6.12 ***Predictive Modelling: Analysis by Period:*** the second phase of statistical analysis was to look at the distribution of monuments by period. Whilst originally this seemed counter-intuitive, as different types of monument require different environmental parameters, a society of any period would, by necessity, create a landscape of monuments in the area of their choosing. Running the KS tests on these datasets (Table 36) produced results, where 'Yes' indicates correlation.

Period	Number of Monuments	Elevation	Slope	Distance to Water	Distance from Roman Road
Prehistoric	38	Yes	No	No	N/A
Roman	97	Yes	No	Yes	Yes
Medieval	100	No	No	Yes	No

Table 36: Results of running KS test on monuments by period compared to environmental parameters

6.6.13 ***Prehistoric Activity*****:** the prehistoric monuments correlated with only one parameter, elevation. The effect of this is that most of the study area appears suitable for prehistoric monuments, because the other environmental factors do not rule zones out (Fig 132).

6.6.14 All but four of the monuments were situated between 1m and 75m above sea-level, with an even spread throughout the 25m, 50m and 75m increments. Of the four above this elevation, only the urn from Pleasington Cemetery is significantly above, being at 100m above sea level. It is possible that this site was significant, and viewshed analysis may prove or disprove this, but it was beyond the scope of this project. The position of the main body of monuments, slightly above the level of the river, might be to avoid flooding, but it would be necessary to reconstruct the prehistoric river course to investigate this more thoroughly.

6.6.15 To create the map of potential for prehistoric monument location, the elevation raster was ranked according to the number of monuments within each band (one for less than three monuments, two for between three and ten, and three for more than ten monuments). This was added to the density map (Fig 121), the HLC Landscape Type map (Fig 52) and the HLC Disturbance Map (Fig 128). This produced a raster with potential values ranging from four to 12 (since each raster was ranked between one and three within the study area). In fact, the maximum score was 11, indicating that there were no areas within the study area that scored three in each category. To simplify the map, these scores were grouped into three bands to create zones of low, medium and high potential (Fig 132).

6.6.16 This map shows that the zone of high potential is dictated mainly by the elevation, as expected, covering the valley floor and lower reaches of the tributary rivers, although the rivers themselves are of medium potential. The zones of lowest potential are the built-up areas, where the highest level of disturbance might be expected, such as Blackburn and Clitheroe. Only one of the known sites falls within a zone of low potential, the urn from Pleasington Cemetery (*Section 6.2.7*). This site is officially classified as a findspot, although the description (pottery sherds and burnt bone fragments) implies an *in situ* cremation. Other monuments classified as religious, ritual or funerary within the study area fall safely within the zones of high potential, and comprise barrows and similar remains. The Pleasington Cemetery site should be seen as anomalous within the study area and perhaps subject to further investigation, if only to ensure that it has not been mis-classified.

6.6.17 ***Roman Activity***: the Roman monuments correlated with three of the parameters: elevation; distance to water; and distance from the Roman road (Table 37). The greater number of parameters with a correlation has the effect of ruling out larger areas as being of lower potential (Fig 133). This in turn makes the study area appear to have less potential for Roman monuments than for the prehistoric period, but the comparison is misleading and should be avoided.

6.6.18 The largest correlation was with distance from the Roman roads, followed by elevation, and then distance from water. The KS test indicated that 45 out of the 60 monuments other than the roads, were located within 250m of a Roman road. This was then broken down into smaller increments using the Spatial Location Query Tool.

Distance from Road (m)	Number of Monuments	Percentage of Total (%)
0-50	20	44.5
50-100	14	31.1
100-150	9	20
150-200	1	2.2
200-250	1	2.2
Total	**45**	**100**

Table 37: Distribution of monuments with distance from a Roman road

6.6.19 Almost half of the Roman monuments are located within 50m of the Roman road system (Table 37), but while this looks very significant, further analysis shows that all the Roman monuments within 250m of the road system are clustered around Ribchester. As such, this distribution does not indicate that the road system is a particularly high potential zone, despite the strong correlation found using the KS test. Of the remaining 15 monuments, 12 are findspots, including three coin hoards and five single coins, indicating that there was some limited Roman activity within the study area but away from the established lines of the roads and the main focus at Ribchester. Nevertheless the overall results do appear to support the hypothesis (S*ection 6.2.13*) that the main foci of Roman activity was indeed the fort and road system, with relatively little activity known outside of those areas. To an extent this may be biased by the fact that the Roman fort and road system has been known for a considerable period, and that archaeological and antiquarian investigations have commonly targeted sites of known Roman character (see, for instance, Edwards 2000).

6.6.20 The KS test for elevation shows that the majority of sites (83 of the total, including roads) are situated between 1m and 75m above sea-level, with the majority in the 50-75m band. Again, the cluster of monuments around Ribchester accounts for this, with most of the remainder representing the route of the road. Further analysis of the exact line of the road would probably show that it holds to a specific elevation through most of its route through the valley. Only those monuments away from the road (*Section 6.6.18*) are outside this elevation band.

6.6.21 The KS test for distance from water shows that all of the Roman monuments are within 750m of water, and that 73 of the total are within 250m of it. As for the KS tests for Elevation and Distance from the Roman roads, these results are somewhat skewed by the cluster of sites around Ribchester. Since the Roman roads run in almost straight lines through the study area, whereas the rivers meander, it is the monuments representing parts of the road that are outside the 250m band.

6.6.22 The Roman KS test results taken together show that the distribution is heavily skewed towards the fort and settlement at Ribchester, as expected (Fig 133). Further analysis might include removing those sites, allowing analysis to concentrate on the outliers, but it is fair to say that the zone around Ribchester has by far the highest potential for future sites.

6.6.23 To create the map of potential for Roman monument location, the three correlating rasters were ranked from one to three according to the number of monuments per band. They were then added together, along with the Roman density map (Fig 122), the HLC Landscape type map (Fig 52) and the HLC disturbance map (Fig 128). This produced a raster with potential values from 6 to 18, and the actual values fell between 7 and 18. This means that there are no zones of minimum potential (a score of one in each category), but there are zones of maximum potential (a score of three in each category) within the study area. The area of highest potential overall is, not surprisingly, a radius of approximately 1km around the fort at Ribchester.

6.6.24 When the map of potential was grouped into bands of low, medium and high, the majority of the study area was shown to be of medium potential, with zones of high potential along the line of the roads around Ribchester, and along the river tributaries such as the Darwen (Fig 133). The lower reaches of the Ribble itself, west of Preston, have a low potential, and the remainder is medium. Other zones of lower potential occur in those HLC polygons classified as having high disturbance.

6.6.25 When the known Roman monuments were superimposed onto this map of potential, it was clear that, disregarding those clustered around Ribchester, most were in the zones of high potential along the roads, as expected. However, the zone around the River Darwen was a large area of high potential that contained no known monuments. There are almost certainly other factors at stake in the location of Roman monuments, but this area would appear to be worth further investigation. There are other zones of high potential containing no known monuments around the villages of Waddington, West Bradford, and Sawley, and a long strip from Myerscough, through Samlesbury to Walton and Lower Penwortham. These areas are smaller in size, but would also be worth investigating.

6.6.26 ***Medieval Activity***: the KS tests for medieval monuments showed correlation with only one factor: distance to water. The factor of the distance from a Roman road had been included to examine the possibility that there was continuity of settlement and activity in the areas of Roman settlement through to later periods, but the KS test did not demonstrate this (Fig 134). Again, the results of the KS test for distance to water showed that the majority of sites (76 of 99) were within 250m of water (Table 38).

Distance from water (m)	Number of Monuments	Percentage of Total (%)
0-50	28	36.8
50-100	20	26.3
100-150	12	15.8
150-200	7	9.3
200-250	9	11.8
Total	**76**	**100**

Table 38: Monuments within 250m of water

6.6.27 The distribution of monuments is more even than that of the Roman monuments (see Tables 37 and 38), showing only a slight tailing off with increasing distance. When the NMR broad classes were examined, all of the monuments in the following classes were within this area: Defence; Findspot; Health and Welfare; Industrial, Transport; Unassigned; and Water Supply and Drainage. Discounting the Findspots, which can be taken as evidence for unspecified activity within the area, it is likely that the other classes of monument required a supply of water nearby.

6.6.28 To create the map of potential for medieval monument location (Fig 134), the ‘distance from water’ raster was ranked from one to three, according to the number of monuments per band. This was then added to the reclassified medieval density map (Fig 123) and the reclassified HLC disturbance map (Fig 128) to create a combination raster with a potential score of between three and nine. The actual score was from three to nine, indicating that there were zones of minimum and maximum potential within the study area.

6.6.29 There are two zones with a score of nine. The first is the area around Ribchester, and the second around Great Mitton. These represent areas with a high density of known medieval finds; Ribchester contains a number of monuments relating to St Wilfrid’s Church and several early medieval metal finds. Great Mitton also has a medieval church and hall.

6.6.30 When the map of potential was grouped into three bands (Fig 134), it showed that more of the area than might be expected was of low potential. This includes the river itself, but also the parts of the area furthest from water, and those areas with high levels of disturbance. The areas of medium potential are those of medium density of known monuments, and close to water. The few small areas of higher potential are those with the highest density of known monuments, the overall result being more predictable than those for prehistoric or Roman potential activity, where the disturbance and density effects were counterbalanced by the greater number of environmental parameters. Having said that, 36 of the possible 100 known monuments were within the relatively small zones classed as higher potential, compared to only 16 within the zones of lower potential.

6.6.31 The zones of high potential are relatively small and discrete. There are zones smaller than 1km in diameter around Sawley, Great Mitton, Hurst Green, Samlesbury, Samlesbury Bottoms, Cuerdale, and a larger zone around Ribchester. That the largest zone is focussed on Ribchester is not surprising, as it has remained a focal point of settlement and activity from the Roman period to the present day.

6.6.32 ***Conclusions:*** when the three reclassified rasters of potential were added together, this created a new combination raster representing the potential of the study area for monuments of any period (Fig 135). The range of values in the combination raster was from three to nine, indicating that there are parts of the area that have both the minimum and maximum overall potential.

6.6.33 The areas with the lowest potential overall (a score of three) are mainly located on the edges of the major urban areas within the study area, in particular on the margins of Blackburn and Clitheroe. The lowest reaches of the Ribble within the study area are also zones of lowest potential.

6.6.34 The areas of highest potential overall can be found around Ribchester, Sawley, Samlesbury, Samlesbury Bottoms and Cuerdale Hall. None of these locations are particularly surprising, given the high density of existing monuments in those areas.

6.6.35 When the layer was reclassified into zones of low, medium and high overall potential, most of the study area was classified as of high potential, with zones of medium and low potential restricted to the peripheries and small, discrete areas.

6.7 HLC ENHANCEMENT

6.7.1 ***Geomorphic Enhancement - Aggregate Weighting:*** the aggregate terrace data supplied by the University of Liverpool (*Section 3.11.29*), classified in terms of suitability for aggregate extraction, were superimposed on the HLC polygons. This made it possible to add information to each HLC polygon on the suitability of aggregate extraction.

6.7.2 A study of the types of landscapes potentially affected by aggregate extraction shows that, of the 322 HLC polygons within the study area, 222 do not contain river terraces and are therefore not liable to threat from extraction. Of the 100 remaining, Table 39 shows the breakdown of HLC Types by extraction suitability.

Aggregate Suitability	**HLC broad type**	**Polygon Count**	**Percentage of Total Area of HLC broad type**
High	Ancient and Post-medieval Settlement	1	5.3
High	Ancient and Post-medieval Wood	2	9.8
High	Ancient Enclosure	7	3.8
High	Modern Enclosure	4	38.5
High	Modern Industry	6	45.2
High	Modern Recreation	3	17.1
High	Modern Settlement	3	36.1
High	Modern Woodland	1	1.5
High	Post-medieval Enclosure	8	13.2
High	Saltmarsh	1	72.2
High	Sand and Mudflats	1	49.7
High	Water	1	100
Medium	Ancient and Post-medieval Ornamental	1	80.0
Medium	Ancient and Post-medieval Wood	12	19.4
Medium	Ancient Enclosure	23	53.5
Medium	Modern Communications	1	58.1
Medium	Modern Enclosure	2	6.2
Medium	Modern Settlement	1	3.1
Medium	Post-medieval Enclosure	9	28.4
Low	Ancient and Post-medieval Settlement	1	24.2
Low	Ancient Enclosure	9	9.2
Low	Modern Settlement	2	2.4
Low	Post-medieval Enclosure	1	1.1
	Total	100	

Table 39: Breakdown of HLC broad types by suitability for aggregate extraction

6.7.3 Given the fact that the suitability for aggregate extraction decreases with distance from main roads and the M6 junction in particular (*Section 7.2.6*), because of the cost of transport and the need to improve any roads that will carry large amounts of aggregate, the HLC polygons likely to be highly suitable for extraction are within the western part of the study area, grouped around Preston. They are split into two discrete groups, linked only by the polygon representing the Ribble itself (Fig 136). As a whole, this grouping includes almost half of the total area of 'Modern Industry', and over a third of 'Modern Settlement' and 'Modern Enclosure' landscape types. The western area is predominantly classified as 'Modern Industry', along with the estuarine 'Saltmarsh' and 'Sand and Mudflats'. The eastern sub-group is centred on Higher Brockholes and is considerably less industrial in nature.

6.7.4 The HLC polygons rated medium cover a much larger area but are less diverse, with less Broad Types represented. This area, moving eastwards from Preston and largely covering the area to the north of the Ribble, is mainly designated 'Ancient Enclosure', with areas of 'Ancient and Post-medieval Wood' and 'Post-medieval Enclosure'.

6.7.5 Only a few HLC polygons were considered to have a low level of suitability for aggregate extraction. These are small, discrete areas, with the two largest centred on Ribchester and Osbaldeston Green, and two further areas around Waddington and Great Mitton.

6.7.6 Over two-thirds of the study area are not considered at risk from aggregate extraction at all, which include most of the study area south of the Ribble, but the most northern extent, and parts of Preston, to the north of the Ribble, are also not at risk.

6.7.7 ***Geomorphic Enhancement - Present Threat***: as with the aggregate weightings (*Section 6.7.1*), the present fluvial threat dataset collated by the University of Liverpool (*Section 3.11.43*) was superimposed onto the HLC polygons.

6.7.8 Only 85 of a total of 322 polygons are considered to be at threat from fluvial change (Fig 137). There is an even breakdown by threat type, with 31 polygons at risk from deposition, 25 from erosion and 29 from a risk of both deposition and erosion (Table 39).

Present Threat Type	**HLC broad type**	**Number of Polygons**	**Percentage of Total Area of Type**
Deposition	Ancient and Post-medieval Settlement	2	26.1
Deposition	Ancient and Post-medieval Wood	2	4.3
Deposition	Ancient Enclosure	14	17.5
Deposition	Modern Communications	1	58.1
Deposition	Modern Enclosure	1	5.0
Deposition	Modern Settlement	1	19.4
Deposition	Post-medieval Enclosure	10	19.1
Deposition/Erosion	Ancient and Post-medieval Ornamental	1	71.0
Deposition/Erosion	Ancient and Post-medieval Wood	8	23.0
Deposition/Erosion	Ancient Enclosure	11	26.7
Deposition/Erosion	Modern Industry	1	28.1
Deposition/Erosion	Post-medieval Enclosure	7	24.6
Deposition/Erosion	Water	1	100
Erosion	Ancient and Post-medieval Settlement	1	16.7
Erosion	Ancient and Post-medieval Wood	4	4.4
Erosion	Ancient Enclosure	10	8.1
Erosion	Modern Enclosure	3	8.2
Erosion	Modern Settlement	4	5.6
Erosion	Post-medieval Enclosure	3	4.5
	Total	**85**	

Table 40: Breakdown of present threat by HLC broad type

6.7.9 Most of the western and southern parts of the study area are under no current threat from geomorphological change, with the exception of small discrete areas around Walton and Penwortham that are subject to deposition (*Section 8.1*; Fig 138). Moving east, the river meanders through some wide curves, and the land immediately outside these curves are also subject to deposition. The majority of this area is enclosed land and classified as ‘Ancient’, ‘Post-medieval’, or ‘Modern Enclosure’. North of the river, and in the far north-east of the study area, there is a threat from both deposition and erosion, albeit in different places, and at the meeting of the Hodder, the Calder and the Ribble the threat is also from erosion.

6.7.10 ***Geomorphic Enhancement - Future Threat***: more polygons are likely to be subject to geomorphological change in the future (*Section 8.2*), 115 polygons out of a total of 322 being subject to future change, as opposed to 85 for present-day fluvial change (Fig 139). Of these, 17 are likely to be subject to deposition, 21 at risk from erosion and 77 from both deposition and erosion, albeit in different parts of the polygon. In comparison with the present, slightly fewer polygons will be at risk from either deposition or erosion, but more will have a combined risk (Table 41).

Future Threat	HLC broad type	Number of Polygons	Percentage of Total Area of Type
Deposition	Ancient and Post-medieval Settlement	3	43.6
Deposition	Ancient and Post-medieval Wood	1	1.1
Deposition	Ancient Enclosure	8	6.7
Deposition	Modern Enclosure	1	6.4
Deposition	Modern Settlement	1	2.1
Deposition	Post-medieval Enclosure	3	3.1
Deposition/Erosion	Ancient and Post-medieval Ornamental	1	70.1
Deposition/Erosion	Ancient and Post-medieval Settlement	2	30.7
Deposition/Erosion	Ancient and Post-medieval Wood	13	40.5
Deposition/Erosion	Ancient Enclosure	33	67.3
Deposition/Erosion	Modern Enclosure	4	23.9
Deposition/Erosion	Modern Industry	1	28.1
Deposition/Erosion	Modern Settlement	4	33.9
Deposition/Erosion	Post-medieval Enclosure	18	44.2
Deposition/Erosion	Water	1	100
Erosion	Ancient and Post-medieval Wood	7	10.2
Erosion	Ancient Enclosure	6	2.7
Erosion	Modern Enclosure	2	4.2
Erosion	Modern Settlement	2	1.8
Erosion	Post-medieval Enclosure	4	3.4

Table 41: Breakdown of future threat by HLC broad type

6.7.11 The most striking differences can be seen when the future and present threats are compared (Table 42). It can be seen that the threat of combined deposition and erosion on ‘Ancient Enclosure’ and ‘Post-medieval Enclosure’ will increase in the future. This is balanced in part, but not entirely, by a diminished risk of deposition in these Broad Types. The areas likely to be affected in this way are mainly in the central part of the study area, with a second zone around the confluence of the Ribble, Hodder and Calder and other smaller zones to the north.

Future Threat	Present Threat	HLC broad type	Difference
Deposition	Deposition	Ancient and Post-medieval Settlement	1
Deposition	Deposition	Ancient and Post-medieval Wood	-1
Deposition	Deposition	Ancient Enclosure	-6
Deposition	Deposition	Modern Enclosure	0
Deposition	Deposition	Modern Settlement	0
Deposition	Deposition	Post-medieval Enclosure	-7
Deposition/Erosion	Deposition/Erosion	Ancient and Post-medieval Ornamental	0

Future Threat	Present Threat	HLC broad type	Difference
Deposition/Erosion	Deposition/Erosion	Ancient and Post-medieval Wood	5
Deposition/Erosion	Deposition/Erosion	Ancient Enclosure	22
Deposition/Erosion	Deposition/Erosion	Modern Industry	0
Deposition/Erosion	Deposition/Erosion	Post-medieval Enclosure	11
Deposition/Erosion	Deposition/Erosion	Water	0
Erosion	Erosion	Ancient and Post-medieval Wood	3
Erosion	Erosion	Ancient Enclosure	-4
Erosion	Erosion	Modern Enclosure	-1
Erosion	Erosion	Modern Settlement	-2
Erosion	Erosion	Post-medieval Enclosure	1

Table 42: Comparison between future threat and present threat, by HLC broad type

6.7.12 ***Potential Enhancement:*** the maps of potential (*Section 3.13*) were also superimposed onto the HLC dataset to establish the potential of each polygon for archaeological monuments of each period, and overall. As the maps of potential are quite different for each period, the potentials for each period within a particular HLC polygon are also quite different.

6.7.13 ***Prehistoric Potential***: when the prehistoric potential mapping (*Section 6.6.13*) was used to enhance the HLC dataset, the overwhelming majority of the polygons (256 out of 322) contained at least some areas of high potential (Fig 140). Sixty-five polygons contained areas of medium potential at best, and only one contained areas of only low potential. This adds further support to the idea that, according to this type of analysis, most of the study area can be considered to have a high potential for prehistoric monuments.

6.7.14 The area of low potential is a very small polygon that is a remnant of a much larger area representing Samlesbury Aerodrome. It was created when the HLC dataset was clipped to the study area (*Section 3.12.9*), but is really too small to be of use. The areas of medium potential are mainly situated around the peripheries of the study area, with zones to the west of Preston and in the far north and north-east. The biggest zone is in the south of the study area, comprising the 'Modern' development and 'Ancient Enclosure' on the outskirts of Blackburn. A further aggregated group of polygons having medium potential for prehistoric activity can be found around Hurst Green, and in particular Stoneyhurst College (Table 43).

HLC broad type	High Potential for prehistoric Monuments	Medium Potential for prehistoric Monuments	Low Potential for prehistoric Monuments
Ancient Enclosure	81	10	0
Post-medieval Enclosure	54	17	0
Ancient and Post-medieval Wood	43	6	0
Modern Settlement	23	9	0
Modern Enclosure	15	5	0
Modern Industry	11	4	1
Ancient and Post-medieval Settlement	8	3	0
Modern Recreation	8	3	0
Modern Woodland	4	3	0

HLC broad type	High Potential for prehistoric Monuments	Medium Potential for prehistoric Monuments	Low Potential for prehistoric Monuments
Modern Communications	3	0	0
Ancient and Post-medieval Ornamental	2	1	0
Modern Ornamental	1	1	0
Reverted Moorland	1	0	0
Saltmarsh	1	1	0
Water	1	0	0
Sand and Mudflats	0	2	0
Totals	**256**	**65**	**1**

Table 43: Breakdown of HLC broad types by potential for prehistoric monuments

6.7.15 ***Potential Enhancement: Roman Activity***: the Roman HLC enhancement is more evenly divided than for the prehistoric period; of the 322 polygons, 149 contain areas of high potential, 173 contain areas of medium at best, and none contain only a low potential (Fig 141). While more polygons were rated medium, the physical area of high potential is greater. The medium potential polygons are less peripheral than those rated medium potential for the prehistoric period, although they are still confined mainly to the outer limits of the study area. The exceptions to this are zones around a series of meanders in the in the centre of the study area.

6.7.16 There is no real distinction between the Broad Types of HLC and their potential for Roman sites, although there are marginally more polygons of Broad Types 'Ancient and Post-medieval Settlement', 'Wood' and 'Enclosure', and 'Modern Communications' assigned high potential rather than medium (Table 44).

HLC broad type	High Potential for Roman Monuments	Medium Potential for Roman Monuments
Ancient Enclosure	51	40
Ancient and Post-medieval Wood	28	21
Post-medieval Enclosure	27	44
Modern Settlement	12	20
Ancient and Post-medieval Settlement	7	4
Modern Enclosure	6	14
Modern Industry	5	11
Modern Recreation	5	6
Modern Communications	2	1
Modern Woodland	2	5
Ancient and Post-medieval Ornamental	1	2
Modern Ornamental	1	1
Water	1	0
Reverted Moorland	0	1
Saltmarsh	1	1
Sand and Mudflats	0	2
Totals	**149**	**173**

Table 44: Breakdown of HLC broad types by potential for Roman monuments

6.7.17 ***Potential Enhancement: Medieval Activity***: the medieval potential HLC enhancement breaks down as follows: 62 High; 254 Medium; and 7 Low. This has the highest number of low potential polygons, and the lowest number of high potential of any of the periods (Fig 142; Table 45).

6.7.18 The low potential polygons form discrete groups. The first is a stretch of the Ribble in the far west of the study area. Moving east, the area of Preston Docks is of low potential, mainly because it has already been highly disturbed. The brewery at Samlesbury and the quarry at Billinge Hall in Blackburn are the other larger areas of low potential.

HLC broad type	**High potential for medieval monuments**	**Medium potential for medieval monuments**	**Low potential for medieval monuments**
Ancient Enclosure	21	68	2
Post-medieval Enclosure	15	56	0
Ancient and Post-medieval Wood	10	38	1
Modern Settlement	5	26	1
Ancient and Post-medieval Settlement	3	7	1
Modern Enclosure	2	18	0
Modern Industry	1	13	2
Modern Recreation	1	10	0
Modern Woodland	1	6	0
Water	1	0	0
Ancient and Post-medieval Ornamental	0	3	0
Modern Communications	0	3	0
Modern Ornamental	0	2	0
Reverted Moorland	0	1	0
Saltmarsh	1	1	0
Sand and Mudflats	1	2	0
Total	**62**	**254**	**7**

Table 45: Breakdown of HLC broad types by potential for medieval monuments

6.7.19 ***Potential Enhancement: Overall***: when the overall potential was examined for each HLC polygon, the breakdown was as follows: 258 High; 63 Medium; and 1 Low, which closely mirrors the distribution of the potential prehistoric activity. The one polygon of low overall potential is the same as for the prehistoric potential, namely the aerodrome at Samlesbury. The only difference is that two further polygons are of medium potential, in areas of ‘Modern Settlement’ and ‘Modern Industry’ at Grimsargh and the brewery at Samlesbury respectively (Fig 143).

6.7.20 ***Conclusions***: the various types of analysis have tended to support the initial hypotheses about the development of human occupation within the Ribble Valley. Examination of the relationship between the different historic landscape types of the HLC, and the distribution of monuments and events, has shown that lacunae in our knowledge may be related to the level of below-ground disturbance. Furthermore, the small number of intrusive events within the study area appear to have skewed the distribution of known monuments to those that are later and more visible, compared to those that are earlier and are less visible, perhaps buried by fluvial deposition. The dating of the terraces indicates that Terrace T2 at Lower House Farm, for example (*Section 5.2.15*) formed in the Iron Age: the basal flood horizon for Terrace T2 produced a date of 387-205 cal BC (2232±28 BP; OxA-15687 and also cal AD 467-650 (1480±35 BP; SUERC-10648). At the same location, Terrace T4 produced dates of cal AD 239-383 (1739±27 BP; OxA-15689) and cal AD 135-378 (1770±35 BP; SUERC-10666), securely in the Roman period. This accords with the fact that the only major prehistoric sites from the valley floor, at Marles Wood and Preston Dock, were identified at depths of between 3.5m and 5m below the surface. This would suggest that any prehistoric sites at the western end of the Lower Ribble Valley are likely to be buried by relatively recent fluvial deposits. As such, the lacunae of pre-Iron age sites in some parts of Terrace T2 and pre-Roman sites on Terrace T4, reflects that only very deep interventions / explorations would have been able to identify them.

6.7.21 Nevertheless, examination of the potential of the study area for monuments of different periods has highlighted that some areas are worthy of further investigation or monitoring, particularly in the light of the data on aggregate resource and geomorphological change created by the University of Liverpool (*Section 3.11*).

7. SAND AND GRAVEL RESERVES OF THE RIBBLE REGION

7.1 EXISTING KNOWLEDGE BASE

7.1.1 Three reports are available to Lancashire County Council (LCC) Minerals and Waste Group about the sand and gravel reserves in the county (*Section 3.3.2;* Allot and Lomax 1990; Entec UK Ltd 2005; Geoplan Ltd 2006). The latest of these reports had a relatively wide brief to look in greater detail at areas defined in previous reports and to target new areas for which there was extant geological data. Whilst the Geoplan Ltd and Entec UK Ltd reports are the best available assessment of sand and gravel aggregate reserves, there remains a paucity of high-quality published information relating to Lancashire's sand and gravel geology and resources.

7.1.2 *The Lancashire Minerals and Waste Local Plan* (2006) set out a policy to release additional land to provide 3.2 million tons of high-grade sand (defined as sand washed to British Standard (BSI) before sale) before 2006. This will be achieved by:

- extraction from existing sites and small-scale extensions to existing sites;
- new small-scale sites operated (briefly) in conjunction with existing plant;
- sites to be worked prior to development for other purposes (avoiding sterilisation of deposit);
- new sites in three main areas of search: north and west of Preston; Leyland-Chorley area; and the Lower Ribble Valley;
- new sites in areas outside these areas of search, but outside and not in the periphery of the Forest of Bowland AONB.

7.1.3 The Geoplan Ltd report, *The Lancashire Minerals and Waste Local Plan,* and the draft *Regional Aggregate Working Party* report (RAWP 2006) show that in Lancashire high-quality sand and gravel with planning permission are currently available from Lydiate Lane (2.01 million tonnes (mt)) and Sharples Quarry (1.45mt) (Fig 144). Achieving the BSI grade for high-quality sands can be facilitated by switching plant processing from dry to washed screening of the sand and gravel, as has been the case at Lydiate Lane. Low-quality sands are extracted at Bradley's Sand Pit and from St Anne's Foreshore (Fig 144). Inactive and dormant permissions exist for German Lane and Lundsfield, with further dormant workings with very little materials remaining at Sale Wheel and Ashton and Lea Marshes (Fig 144). The Higher Brockholes Quarry has now ceased operations (2005) and is being restored. Future provision may be enhanced subject to planning applications at Lower Brockholes (0.95mt), Runshaw (4.3mt) and Sandons Farms (0.6mt).

7.1.4 The mineral assessment by Geoplan Ltd (2006) calculates the probable available reserves, their likely quality and degree to which extraction would be constrained. In calculating the mineral quantities, they have used a 20m buffer around rivers, roads, canals and property, and used an estimated average mineral thickness to calculate volumes. The volumes are moderated by a wastage factor of 15% and converted from cubic metres to tonnes using the following factors: 1.6 for sand; 1.7 for sand with some gravel; and 1.8 for sand and gravel. Geoplan Ltd then examined the degree to which Resource Blocks were constrained by higher tier planning constraints, which include AONBs, national and internationally designated ecological and geological sites (for example ~ SSSIs, NNRs, RAMSARs). From this the sites were divided into four categories using a matrix of criteria underpinned by sand quality and potential mineral volume compared against the degree of planning constraint. This assessment was based on greater detail being available about the mineral resources and so represents an improvement on previous sand and gravel surveys. Throughout the report the caveat is made that prior to any extraction a comprehensive survey should be undertaken to prove the nature of the deposits, and the findings and the predicted aggregate quantities must therefore be regarded as indicative estimates. The responsibility for acquiring new geological knowledge of this type via borehole and test pit survey must rest with the industry rather than local authority planning departments.

7.1.5 The main limitation to the Geoplan Ltd and all previous sand and gravel surveys in Lancashire is that the primary source of information on distribution of sand and gravel is the BGS mapping and knowledge acquired from the aggregate industries. This limitation makes the statement in the report that new areas '…are unlikely to be identified by any county wide sand and gravel study' (Geoplan Ltd 2006, 15) seem extremely naive. County-wide surveys underpinned by extensive borehole survey are not realistic and unlikely to be funded by local government, but the preliminary examination of the Kirkham moraine complex (*Section 5.1.9*), using remotely sensed elevation models with some field survey and use of available borehole records, allows geomorphologists to understand sediment~landform relationships. This can identify and refine our understanding of the likely distribution of usable sand and gravel within complicated former glacial environments. Furthermore, a programme of geomorphic mapping for the Holocene river terraces of the Ribble shows the BGS mapping of the distribution of these features was at best a first approximation, and given that particular terraces form the aggregate Resource Blocks in this region, an improved understanding of the geomorphology can improve the assessment and quantification of fluvially derived aggregates. The value of using a geomorphological approach to sand and gravel assessment is demonstrated when focusing on the Ribble Valley and its environs. The work programme entailed in obtaining these data was neither expensive nor time-consuming, but must be underpinned by expert geomorphological knowledge (Crimes *et al* 1992).

7.2 REVISED SAND AND GRAVEL MAPPING FOR THE RIBBLE

7.2.1 From consideration of the distribution, origin and character of glacial and fluvial deposits in the Ribble basin, and the wider environs of Lancashire and the Craven District of North Yorkshire, the following general conclusions regarding potential areas of search for sand and gravel aggregates may be drawn. The upland areas, including the majority of the Yorkshire Dales National Park and the Forest of Bowland AONB, are predominantly erosional, and glacial deposits are limited in extent and thickness, highly localised, mostly thin and discontinuous, and predominantly composed of diamict or coarse-grained gravel, largely unsuitable for mineral extraction. This essentially precludes any realistic potential sand and gravel aggregate extraction from the Craven District of North Yorkshire. The National Park and AONB are also so heavily constrained on environmental and aesthetic grounds that an expansion of existing crushed rock aggregate quarries within these regions is discouraged in the *Minerals Plans* of the respective counties. The consideration of crushed rock sources is outside the scope of the current project; this is, however, the subject of a variation to the funded contract that focused on the Craven District (OA North and University of Liverpool 2007), but this has not as yet been commissioned.

7.2.2 Whilst reviewing the results of the present project, a focus is maintained on the defined study area (*Section 1.3.2*), consideration of the resources is extended to the other Resource Blocks in lowland Lancashire, particularly in the Kirkham End Moraine complex, which contains the thickest sequence of Pleistocene deposits in the county (*Section 5.1.9*). To facilitate a discussion of the sand and gravel aggregate reserves, the region has been divided into three provinces on the basis of mode of deposition and distribution.

- The Ribble fluvial terraces (1), which have sustained the only recent sand and gravel workings within the study area (Higher Brockholes) and includes a zone subject to a current planning application (Lower Brockholes). The history of extraction demonstrates substantial quantities of gravel and particularly sand, but the Resource Blocks become increasingly constrained by poor access and environmental controls progressing upstream from the M6 crossing of the Ribble.
- The glacigenic landforms that flank the Lower Ribble (2) between just upstream of Clitheroe and Preston, formed in or around the Ribble ice-dammed lake (*Section 5.1.14*). These extensive benches on both sides of the valley comprise a range of glacial landforms, which, over historical timescales, have been utilised for sand and gravel aggregates (Hurst Green). These Resource Blocks are on the margins of the Forest of Bowland AONB and its fringe, environmental constraints which, when combined with their ice proximal fairly coarse-grained nature, renders the deposits unlikely targets for future extraction.
- The extensive end moraine complex of the Kirkham ridge (3) is composed of significant quantities of sand and gravel, but conventionally this has been regarded as difficult to extract owing to surface diamict. Sand and gravel has, and is, extracted within the moraine complex, with the workings at Bradley’s Sand Pit. In addition, the borehole records reveal the presence of large sand reserves. Part of the problem with assessing the sand and gravel potential of the Kirkham moraine has been the lack of detailed geomorphological investigation to provide a process-based reconstruction of the palaeogeography that draws upon both geomorphology and the available data on exposures and from boreholes. This has been rectified to some extent in this project.

- The remainder of lowland Lancashire is largely composed of sub-glacial deposits, with either drumlins composed of thick diamict or by ice-moulded diamict plain and bedrock, and so are largely devoid of potential mineral. Small areas of sub-glacial fluviatile sedimentation, in the form of sub-glacial esker systems, could potentially yield usable aggregates. The other river systems of the Wyre and Lune are zones likely to yield sand and gravel mineral, with a long history of extraction along the Wyre exploiting flanking sandur deposits and higher river terraces. These fall outside the scope of this project and are only mentioned for completeness here.
- Coastal sands, including dune and beach sand, form another potentially good mineral resource and are exploited at St Anne's foreshore. These zones are also subject to considerable environmental controls and so future utilisation of these reserves must be regarded as uncertain. Marine-won aggregates, almost entirely sands, also form an increasing proportion of the mineral supplied to Lancashire, with materials landed in Liverpool and at Heysham. Both marine and coastal sands are beyond the scope of this project and are only mentioned for completeness here.

7.2.3 ***Ribble fluvial terraces:*** the 35km reach from the Ribble, Calder and Hodder confluences downstream to the estuary has been comprehensively mapped by a combination of field survey and the use of Nextmap and LiDAR elevation datasets (Figs 145, 146). Upstream of this point, available borehole data and river bank exposures show that the thicknesses of sand and gravel thin to uneconomic proportions. The mapping, the borehole data and the history of aggregate extraction show that it is Terraces T1 and T2 that provide good-quality sands and gravels, with finer grained alluvium typifying the lower terraces. Combining this understanding with a substantially more accurate assessment of the distribution and dimensions of these features completely alters the extent and distribution of Resource Blocks identified and used in the Entec UK Ltd (2005) and Geoplan Ltd (2006) surveys. It also shows the problems implicit in using outdated BGS data to underpin aggregate assessments; the modern series of maps produced by the BGS (1974; 1975; 1982; 1990; 1991) are less susceptible to this problem because the expansion of geomorphological and Quaternary expertise involved with the mapping programmes.

7.2.4 The meander loops for the upper half of the reach between the estuary and the Ribble, Calder and Hodder confluences (Fig 145) are annotated with the Sub-Resource Areas codes used in the description of Resource Block 1H by Geoplan Ltd (2006). For the lower reaches down the estuary, Geoplan did not assign codes and there is only a partial overlap with Resource Blocks 2B and 2A (Fig 144). There are three sequences of boreholes (Figs 147, 149) that traverse the Ribble floodplain at the inner estuary west of Preston, along the M6 and slightly further upstream across Elston Old Hall Farm. Boreholes taken for the M6, the M6 widening and for Tilcon to assess the aggregate at Higher Brockholes reveal the sand and gravel deposit thicknesses associated with Terrace T2 at Brockholes as varying between 10m and 5m, and show that the thicker accumulations of overburden are in the more substantial palaeochannels. This aggregate thickness is confirmed by the proposed extraction at Lower Brockholes (Geoplan Ltd 2006). The deposit thicknesses are also similar at the estuary transect; however, it must be stressed that this sequence does not extend to the extensive Terrace T1 sub resource area (LIV 7: Fig 146) to the north of the river, where deposit thickness may be much greater. At the Old Elston Hall Farm, the borehole sequence drilled during pipeline preparation in the area also shows aggregate thicknesses for Terraces T1 and T2 to be 5-7 m, and this is supported by data obtained by Redlands Ltd in 1971 for a planning application to develop this site for aggregates (Geoplan Ltd 2006). Geoplan Ltd indicate that the Old Elston Hall Farm deposit may extend down some 13m, although it is possible this may incorporate some misidentified weathered-top to the underlying Permian sandstone bedrock. In their assessment of the aggregate quantities, Geoplan Ltd used wastage ratios of 15%, an average mineral thickness of 5m and a 1.8 volume to tonnage conversion factor for high gravel content.

7.2.5 For assessment and comparison in the present project, a wastage ratio of 15% and 1.8 volume to tonnage conversion factor was used. The calculations that follow use the redefined resource block mapped outlines. However, the thicker extractable mineral is associated with Terrace T1 which is some 2-3m higher than Terrace T2; the altitude relative to the river level for both terraces is c. 8.5-9.5 m above river for Terrace T1 and *c* 6.5-7m above the river for terrace T2. The borehole evidence and drilling suggest the deposit thickness is greater for Terrace T1, and so a deposit average thickness of ~6m for Terrace T1 was used, and the deposit thickness of areas of Terrace T2 was used to ~3.5m. Any areas of Terraces T3 and T4 have been relieved from the analysis because they comprise fine-grained flood-laminated alluvium.

7.2.6 ***Mineral Assessment for the Ribble between the M6 and Calder tributary:*** of the 15 Resource Blocks (Fig 150), 11 are identified as having mineral present in workable quantities (Table 46). These 11 blocks contain an estimated 24 million tonnes of mineral. According to our reliability index, with the exception of sub-resource areas A1, B, C and G (Fig 145), where borehole data are available and so have a high reliability, the reliability of the remainder of the assessment is medium (*Section 3.11.30*). In terms of constraints (Table 47), the majority of Resource Blocks are unaffected by ‘Urban’, ‘HER sites, ‘Listed Buildings’, ‘Scheduled Monuments’, AONB and the AONB fringe environmental controls. Resource Block A1 is on the margins of ancient woodland, but this has not precluded the mineral extraction at Higher Brockholes. Resource Blocks G, H and I contain either scheduled monuments or listed buildings, with H reflecting the concentration of archaeology around Ribchester. There is a high degree of urban area in Resource Block H (Ribchester), and Resource Block P is within the zone defined as the (Forest of Bowland) AONB fringe, where mineral extraction is discouraged in the county *Minerals and Waste Plan* (2006). However, one of the main constraints to mineral extraction in the Lower Ribble Valley is poor access. Table 47 highlights the problem by recording the distance to the nearest A-road, and whilst Resource Blocks A1, A and C are reasonably close to either the M6 junction or the A59, all other resource areas would have to connect either south to the A59 or north to the B6244 or B6243. Throughout this area, the B and minor road network is covered under ‘quiet road’ planning. The totals have been summed to provide an overall total for adjacent areas within each sub-Resource Area.

7.2.7 The distances to roads listed for Resource Blocks B, D, F and P are misleading because access would have to be from the north, and for H and I access would either be north to Longridge or across the bridge, connecting to the A59. It is feasible that bridge construction could connect Resource Blocks A and B with previous extraction at Higher Brockholes, providing easier access to major road networks, but this would be subject to a cost-benefit analysis. In summary, combining the information on the quantity of mineral available with limitations to use by constraint produces a relative viability index (Fig 150), which shows that the best prospects within the Lower Ribble Valley are A1, A, B, C, D and J/K, with the other subject to substantial constraint.

Resource area	**Source**	**Terrace**	**Depth (m)**	**Volume (m^3)**	**Weight (tons)**	**Usable (tons)**	**Reliability**	**Workable**
A	Liverpool Group 2006	1	6	1,085,048	1,953,086	1,660,123	M	Y
A	Liverpool Group 2006	2	3.5	922,977	1,661,359	1,412,155	M	Y
A (total)	Liverpool Group 2006			2,008,025	3,614,445	3,072,278	M	Y
A1*	Liverpool Group 2006	2	3.5	852,443	1,534,397	1,304,238	H	Y
A1**	Liverpool Group 2006	2	3.5	2,886,584	5,195,852	4,416,474	H	E
B	Liverpool Group 2006	1	6	852,525	1,534,546	1,304,364	H	Y
B	Liverpool Group 2006	2	3.5	902,888	1,625,198	1,381,418	H	Y
B (total)	Liverpool Group 2006			1,755,413	3,159,744	2,685,782	H	Y
C	Liverpool Group 2006	1	6	895,201	1,611,362	1,369,658	H	Y
C	Liverpool Group 2006	2	3.5	435,861	784,549	666,867	H	Y
C (total)	Liverpool Group 2006			1,331,062	2,395,911	2,036,524	H	Y
D	Liverpool Group 2006	1	6	239,699	431,458	366,740	M	Y
D	Liverpool Group 2006	1	6	302,112	543,802	462,232	M	Y
D	Liverpool Group 2006	2	3.5	394,998	710,997	604,347	M	Y
D (total)	Liverpool Group 2006			936,810	1,686,257	1,433,319	M	Y
F	Liverpool Group 2006	1	6	1,483,525	2,670,345	2,269,793	M	Y
F	Liverpool Group 2006	2	3.5	318,621	573,517	487,490	M	Y
F (total)	Liverpool Group 2006			1,802,146	3,243,863	2,757,283	M	Y
G	Liverpool Group 2006	2	3.5	795,054	1,431,097	1,216,432	H	Y
H	Liverpool Group 2006	1	6	38,572	69,430	59,015	M	Y
H	Liverpool Group 2006	1	6	129,144	232,460	197,591	M	Y
H	Liverpool Group	1	6	1,609,909	2,897,836	2,463,161	M	Y

Resource area	**Source**	**Terrace**	**Depth (m)**	**Volume (m^3)**	**Weight (tons)**	**Usable (tons)**	**Reliability**	**Workable**
	2006							
H	Liverpool Group 2006	2	3.5	133,333	240,000	204,000	M	Y
H	Liverpool Group 2006	2	3.5	417,995	752,391	639,532	M	Y
H (total)	Liverpool Group 2007			2,328,953	4,192,116	3,563,299	M	Y
I	Liverpool Group 2006	1	6	322,698	580,857	493,728	M	Y
I	Liverpool Group 2006	2	3.5	488,316	878,969	747,123	M	Y
I	Liverpool Group 2006	2	3.5	650,490	1,170,882	995,250	M	Y
J/K	Liverpool Group 2006	2	3.5	1,912,622	3,442,719	2,926,311	M	Y
P	Liverpool Group 2006	2	3.5	475,360	855,648	727,301	M	Y

*Table 46: Mineral volumes expressed as total estimated sand and gravel for the workable Resource Blocks identified on Figure 145. Workable Resource Blocks have to exceed 500,000 tons usable mineral. A1** denotes the exhausted reserves at Higher Brockholes. A1* denote Resource Blocks subject to planning application*

Resource	**Road (m)**	**Name**	**Urban**	**Designated sites**	**AONB**	**Fringe**	**HER**	**Listed Buildings**
A	671	A59	0	0	0	0	0	0
A	915	A59	0	0	0	0	0	0
A (total)								
A1**	293	A59	0	1	0	0	0	0
A1*	293	A59	0	1	0	0	0	0
B	1,684	A59	0	0	0	0	0	0
B	1,241	A59	0	0	0	0	0	0
B (total)								
C	1,466	A59	0	0	0	0	0	0
C	1,574	A59	0	0	0	0	0	0
C (total)								
D	1,853	A59	0	0	0	0	0	0
D	1,789	A59	0	0	0	0	0	0
D	1,514	A59	0	0	0	0	0	0
D (total)								
F	2,302	A59	0	0	0	0	0	0
F	2,078	A59	0	0	0	0	0	0
F (total)								
G	2,201	A59	0	0	0	0	0	1
H	2,394	A59	0	0	0	0	0	0
H	2,358	A59	0	0	0	0	0	0
H	2,281	A59	51	0	0	0	3	12
H	2,289	A59	0	0	0	0	0	0
H	2,021	A59	0	0	0	0	0	0
H (total)								
I	2,178	A59	0	0	0	0	0	0
I	2,386	A59	0	0	0	0	0	0
I	2,087	A59	0	0	0	0	0	1
J/K	1,571	A59	0	0	0	0	0	0
P	2,551	A59	0	3	0	83	0	0

*Table 47: Environmental constraints for the workable Resource Blocks identified on Figure 145. Workable Resource Block have to exceed 500,000 tons usable mineral. A1** denotes the exhausted reserves at Higher Brockholes. A1* denote Resource Block subject to planning application for Lower Brockholes. Urban refers to the % of urban area in the Resource Block, with equivalent % area calculations for designated sites (SSSI, NNR, LNR, Ramsar). Listed buildings and scheduled monuments from the HER are counts within the Resource Block. Connectivity to the road network is based on distance in metres to the nearest A-road.*

7.2.8 ***Mineral Assessment for the Ribble between Preston and the Estuary:*** between Preston and the estuary, nine resource areas are identified has having mineral present in workable quantities (Fig146; Table 48). These nine blocks contain an estimated 91 million tonnes of mineral, although admittedly, some of this volume is locked beneath major roads and settlements. According to our reliability index, with the exception of sub-resource areas LIV7 and LIV6, where borehole data are available and so have a high reliability, for the remainder the reliability of the assessment is medium. In terms of constraints (Table 49), the majority of resource bocks are unaffected by HER sites, Listed Buildings, Scheduled Monuments and AONB environmental controls. The exception is LIV6, which is within zones designated as SSSI. There is a high degree of urbanisation in Resource Blocks DAR 1 and DAR 3, LIV2-4, and a minor amount of urban area in LIV7. Compared to the Resource Blocks further up the Ribble, this area is less constrained by poor access. Table 48 shows the distance to the nearest A-road, with all the sites within 500m metres of a major road. In summary, combining the information on the quantity of mineral available with limitations to use by constraint produces a relative viability index (Fig 151), which shows that the best prospects within the Lower Ribble Valley are LIV6 and LIV7, with the other Resource Blocks too heavily constrained by proximity to urban areas for viable mineral extraction. The location of Resource Block LIV7 in relation to the glacial geomorphology is intriguing, because the terrace has formed on the south side of the Kirkham moraine complex at a point where a major former ice-marginal channel system cuts through the moraine. Although there is little borehole data for this location, this feature potentially is a former ice-marginal sandur or a partly eroded ice-marginal sandur, and so the potential for high-grade mineral is high. The Geoplan Ltd (2006) report includes part of this Resource Block in their zone 2B (Fig 144), where, they report, limited borehole data show a deposit of variable thickness, but reaching a thickness of 16.4m. For the present assessment (Tables 48 and 49), a deposit thickness of ~6m has been used consistent with other examples of Ribble Terrace T1. The quantity of mineral associated with this individual prospect is very large, ~35mt, but that will reduce because it includes land-area covered by roads. Nevertheless, it is a large mineral prospect that is serviced by the A583.

Resource area	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Useable (tons)	Reliability	Workable
DAR1	Liverpool Group 2006	1	6	573,577	1,032,438	877,573	M	Y
DAR3	Liverpool Group 2006	1	6	953,823	1,716,882	1,459,350	M	Y
LIV 1	Liverpool Group 2006	1	6	1,437,138	2,586,848	2,198,820	M	Y

Resource area	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Useable (tons)	Reliability	Workable
LIV 2	Liverpool Group 2006	1	6	1,649,825	2,969,686	2,524,233	M	Y
LIV 2	Liverpool Group 2006	2	3.5	1,071,845	1,929,321	1,639,922	M	Y
LIV 3	Liverpool Group 2006	2	3.5	6,953,596	12,516,472	10,639,001	M	Y
LIV 4	Liverpool Group 2006	2	3.5	2,444,641	4,400,354	3,740,301	M	Y
LIV 5	Liverpool Group 2006	1	6	6,264,539	11,276,170	9,584,744	M	Y
LIV 6	Liverpool Group 2006	2	3.5	15,366,981	27,660,567	23,511,482	H	Y
LIV 7	Liverpool Group 2006	1	6	23,092,130	41,565,834	35,330,959	H	Y

Table 48: Mineral volumes expressed as total estimated sand and gravel for the workable Resource Blocks identified on Figure 146. Workable Resource Blocks have to exceed 500,000 tons of usable mineral

Resource	Road (m)	Name	Urban	Environ	AONB	Fringe	HER	Listed Buildings
DAR1	0	A675	72	0	0	0	0	0
DAR3	238	A675	11	0	0	0	0	0
LIV 1	0	A6	0	1	0	0	0	1
LIV 2	121	A582	54	0	0	0	0	1
LIV 2	220	A582	68	0	0	0	0	0
LIV 3	0	A59	87	0	0	0	0	2
LIV 4	596	A583	0	0	0	0	0	0
LIV 5	490	A59	0	0	0	0	0	0
LIV 6	0	A583	0	15	0	0	0	0
LIV 7	0	A584	5	0	0	0	0	0

Table 49: Environmental constraints for the workable Resource Blocks identified on Figure 146. Workable Resource Block have to exceed 500,000 tons usable mineral. Urban refers to the % of urban area in the resource block, with equivalent % area calculations for designated sites (SSSI, NNR, LNR, Ramsar). Listed buildings and Scheduled Monuments from the HER are total counts within the Resource Block. Connectivity to the road network is based on distance in metres to the nearest A-road.

7.2.9 ***Ribble Valley Glacigenic Deposits:*** during deglaciation, the Lower Ribble Valley and the Bowland Fells became free of ice relatively early and returned to local ice-stream control, through the south Lake District Icestream and a Ribble Glacier. It appears that the Lower Ribble glaciolacustrine environments extended from just east of Preston, upstream in the Lower Ribble and Calder, in the Vale of Chipping, and throughout much of the Hodder, but the lake probably varied considerably both in size and water depth throughout its existence. Critical to the existence of the lake is the damming mechanism across the Lower Ribble Valley near Preston. A glaciolacustrine depositional environment for the Lower Ribble provides a different context in which to interpret the extensive glacial mounds and flats that diversify the marked topographic bench between 50m and 75m OD in the Lower Ribble Valley. Some of the mounds between the Hodder confluence and Longridge (Fig 65), have been interpreted as esker/kame mounds (Aitkenhead *et al* 1992). The ice-marginal delta sequence in a former gravel pit at Hurst Green and other exposures of sands suggest a different depositional setting and highlight this area as a potential source of well-sorted sand and gravel (GLA1-10: Fig 152). The gravel exposures show a deposit thickness in excess of 15m locally at the Hurst Green pit, and thick deposits of sand-rich gravels are shown in gully sections at GLA1, Hothersall Hall. Further upstream (Fig 152), the landform types likely to yield quality mineral are esker ridges (ESK1-12) which are extend between 80m and 150m OD along the bench between the Ribble and the Hodder north of Clitheroe. The ridges have a relief of 25-19m above the diamict bench and so comprise reasonable volumes of aggregate. It is possible that these ridges were a mixture of pro-glacial, sub-aqueous fan and sub-glacial esker forms which were produced as the margin of the Ribble glacier retreated eastwards, in which case the potential for good-quality mineral increases.

7.2.10 Twenty-six resource areas are identified as having mineral present in workable quantities (Fig 152; Table 50). The volume calculations are underpinned by estimated average deposit thickness of 8m for the deltaic features and 5m for the eskers. Eskers are linear ridges and so the deposit thickness is very much an estimate. The potential errors inherent in volumetric estimation for irregular landforms from an average deposit thickness have been highlighted (*Section 3.11.31*) and are exemplified here for ESK5, for which two volumetric estimations are shown (Table 50); one was derived using an average thickness method and the second, much higher and probably realistic, by cut-and-fill calculations using the ground surface DEM and a deposit-base surface. If borehole data were more widespread within this esker field, this DEM-based approach would improve the assessment of aggregate volumes, although admittedly some of the volumes shown (Table 50) are locked beneath roads and settlements. According to our reliability index, with the exception of sub-Resource Blocks GLA1, GLA6-8 and ESK5, where exposures are available and so have a high reliability, the remainder are inferred resources and the reliability of the assessment is medium to low. Prior to any extraction, a comprehensive survey must be undertaken to prove the nature of the deposits, and the predicted aggregate quantities shown here must be regarded as indicative estimates.

Resource Block	**Source**	**Terrace**	**Depth (m)**	**Volume (m^3)**	**Weight (tons)**	**Usable (tons)**	**Reliability**	**Workable**
ESK11	Liverpool mapping	Esker	5	854,827	1,538,689	1,307,886	M	Y
ESK10	Liverpool mapping	Esker	5	1,258,838	2,265,909	1,926,023	M	Y
ESK9	Liverpool mapping	Esker	5	724,154	1,303,477	1,107,956	M	Y
ESK8	Liverpool mapping	Esker	5	705,437	1,269,786	1,079,318	M	Y
ESK7	Liverpool mapping	Esker	5	618,093	1,112,567	945,682	M	Y
ESK6	Liverpool mapping	Esker	5	830,696	1,495,253	1,270,965	M	Y
ESK5	Liverpool mapping	Esker	5	2,426,520	4,367,736	3,712,576	M	Y
ESK5**	Liverpool mapping	Esker	DEM	4,777,560	8,599,608	7,309,667	M	Y

Resource Block	**Source**	**Terrace**	**Depth (m)**	**Volume (m^3)**	**Weight (tons)**	**Usable (tons)**	**Reliability**	**Workable**
ESK4	Liverpool mapping	Esker	5	821,528	1,478,750	1,256,938	M	Y
GLA14	Liverpool mapping	LG Delta	5	829,237	1,492,626	1,268,732	L	Y
GLA13	Liverpool mapping	LG Delta	5	850,547	1,530,985	1,301,337	L	Y
GLA12	Liverpool mapping	LG Delta	5	7,564,124	13,615,423	11,573,110	L	Y
GLA11	Liverpool mapping	LG Delta	5	3,168,081	5,702,546	4,847,164	L	Y
GLA10	Liverpool mapping	LG Delta	5	2,429,310	4,372,757	3,716,844	L	Y
GLA9	Liverpool mapping	LG Delta	8	9,830,533	17,694,959	15,040,715	M	Y
GLA8	Liverpool mapping	LG Delta	8	3,664,161	6,595,489	5,606,166	M	Y
GLA7	Liverpool mapping	LG Delta	8	1,020,666	1,837,198	1,561,619	M	Y
GLA6	Liverpool mapping	LG Delta	8	5,190,229	9,342,413	7,941,051	M	Y
GLA5	Liverpool mapping	LG Delta	8	9,023,226	16,241,807	13,805,536	M	Y
GLA4	Liverpool mapping	LG Delta	5	1,806,485	3,251,673	2,763,922	M	Y
GLA3	Liverpool mapping	LG Delta	5	2,467,625	4,441,724	3,775,466	M	Y
GLA2	Liverpool mapping	LG Delta	5	4,094,263	7,369,674	6,264,223	M	Y
GLA1	Liverpool mapping	LG Delta	5	5,442,886	9,797,196	8,327,616	M	Y

Table 50: Mineral volumes expressed as total estimated sand and gravel for the workable Resource Blocks identified on Figure 152. Workable Resource Blocks have to exceed 1,000,000mt usable mineral

7.2.11 In terms of constraints (Table 50), because these resource areas border the Forest of Bowland AONB all the esker Resource Blocks are affected by being within the AONB or the AONB fringe zone. The deltaic deposits in Resource Blocks GLA1 -GLA14 are also affected by AONB, urban area, Scheduled Monument and Listed Building constraints. Like the upstream parts of the Ribble between the M6 and Calder tributary, this area is also constrained by poor access. The ESK1-12 and GLA11-13 traffic would have to pass via Clitheroe, although Resource Blocks GLA1-10 could be accessed via the B6244 or B6243 to Longridge (Table 51). In summary, combining the information on the quantity of mineral available with limitations to use by constraint produces a relative viability index (Fig 153) which shows that most of the Resource Blocks are of low viability for future use. The Geoplan Ltd (2006) report does not touch upon these areas and they are included here for completeness. The quantity of mineral associated with these prospects is, however, large, potentially of the order of ~100mt. A growth area in terms of development within National Parks and AONBs is the use of local stone and mortar in building projects for aesthetic reasons, for instance colour matching of mortar and stone. In other regions, such as North Wales, this has seen an interest in the possibility of creating local permissions for mineral extraction to service this specialised market. The prospects fringing the Forest of Bowland may be valuable in that regard.

Resource	Road (m)	Name	Urban	Environ	AONB	Fringe	HER	Listed Buildings
ESK11	1,509	A671	0	0	0	100	0	0
ESK10	1,598	A671	0	0	0	100	0	0
ESK9	1,947	A671	0	0	0	100	0	1
ESK8	2,237	A671	0	0	0	100	0	1
ESK7	2,868	A671	0	0	0	100	0	0
ESK6	2,378	A671	9	0	77	23	0	0
ESK5	2,562	A671	33	0	59	41	0	3
ESK4	3,117	A671	0	0	34	66	0	0
GLA14	0	A671	39	18	0	0	0	0
GLA13	3,036	A671	15	0	100	0	0	5
GLA12	3,319	A671	1	0	100	0	0	2
GLA11	2,700	A671	0	1	77	23	0	0
GLA10	2,510	A59	0	5	0	100	0	1
GLA9	2,961	A59	0	5	61	39	0	2
GLA8	2,551	A59	18	3	0	83	0	0
GLA7	2,283	A59	0	12	0	0	0	0
GLA6	2,615	A59	3	2	0	35	1	4
GLA5	2,065	A59	0	5	0	0	0	4
GLA4	2,816	A59	0	5	0	0	0	0
GLA3	3,252	A59	4	1	0	0	0	0
GLA2	3,132	A59	0	2	0	0	0	0
GLA1	2,924	A59	0	5	0	0	0	0

Table 51: Environmental constraints for the workable Resource Blocks identified on Figure 152. Workable Resource Block have to exceed 500,000 mt usable mineral. Urban refers to the % of urban area in the resource block, with equivalent % area calculations for designated sites (SSSI, NNR, LNR, Ramsar). Listed buildings and Scheduled Monuments from the HER are total counts within the Resource Block. Connectivity to the road network is based on distance in metres to the nearest A-road

7.2.12 ***The Kirkham End Moraine Complex:*** although not part of the current study area, arguably one of the best prospects for finding significant quantities of sand and gravel in Lancashire lies in the low ridges that extend from east of Preston to the coast north of Blackpool, collectively termed the Kirkham End Moraine (*Section 5.1.19).* It is an area of considerable archaeological potential, reflecting that is raised dry land, edged by the wetlands of the Fylde to the north, and consequently has attracted settlement since the early prehistoric period (Middleton *et al* 1995). The Romans built a military installation on the Kirkham End Moraine, and nearby a medieval town developed around a parochial centre (Howard-Davis and Buxton 2000; White 1996).

7.2.13 Stratigraphic information on the mineral potential of this region is limited to descriptions of the coastal sections at Blackpool (Fig 64), the M55 borehole sequence (Wilson and Evans 1990; Aitkenhead *et al* 1992); (Fig 66), and the north/south M6 boreholes (Fig 67). The detailed mapping of the geomorphology (Fig 69) and the borehole and section evidence (Figs 64 and 66-7) show that the glaciofluvial sands and gravels thicken in the inter-moraine areas (Figs 64 and 66-7). These deposits provide the best prospect for mineral extraction within the stratigraphic sequence. The moraine ridges show that ice retreat was punctuated by oscillations of the ice margin and between these ridges the depositional model predicts that ice-marginal outwash plains (sandur) would form. These sandur would be wider and comprise thicker deposits near the major through-moraine outwash channels: the Skippool and the Kirkham Channels (Figs 69 and 66). Towards the eastern end of the M55 and southern end of the M6, borehole sequences, the surface diamicts and the thick sequence of glaciolacustrine laminated clays preclude aggregate extraction (Fig 67), but to the west there are clearly thick sequences of glaciofluvial sands and gravels. The surface diamict laid down during the ice-marginal oscillations responsible for the ridges often buries these glaciofluvial sands and gravels, but the diamict drape thins in the inter-moraine areas and can be shallow (1-3m) on the moraine ridges.

7.2.14 Further data on the mineral reserves within the Kirkham moraine are available from past, current and planned mineral extraction sites: Chain Lane; Bradley's Sand Pit; Higher House Farm; Myerscough; and Sharples Quarry (Geoplan Ltd 2006); (Fig 154). Higher House Farm was refused planning permission for mineral extraction in 1983 and the limited information within the Geoplan Ltd report (2006) suggests that a fairly limited deposit of glaciofluvial sand and gravel was the target mineral, with a predominance of sand ~72%. The setting is one of an inter-moraine sandur flat, and so is a zone with high potential for glaciofluvial sands and gravel. Further confirmation of ice-marginal sandur-style deposits associated with this flat that are commercially extractable is gained from mineral reports from nearby exhausted workings at Myerscough (Fig 154) (Geoplan Ltd 2006). Bradley's Sand Pit to the south-east is also within an inter-moraine area, and the mineral reported is some 25m in thickness, buried by 4-4.5m of diamict/clay. The geomorphological setting is intriguing, because the nature of the deposits and inter-moraine setting suggests a sandur depositional environment, but the sandur would have been very restricted in extent between the flanking ridges. However, the total thickness of deposit may relate to the phase of ice retreat formed as pro-glacial outwash, with ridge-forms created by later ice-marginal advance. Further to the west, at Chain Lane, a restored gravel pit was worked glaciofluvial deposits during the 1950s, and again the geomorphic setting is in an inter-moraine flat. In summary, all previous mineral extraction in the Kirkham moraine complex has targeted the inter-moraine areas.

7.2.15 The database of Resource Block reports by Geoplan Ltd (2006) also warrants further scrutiny in comparison with the geomorphological control. Resource Blocks 1F and 1G form an area of raised ground at 35-40m OD, which apparently comprise sands and gravels of *c*5m thickness. These areas of flat ground are raised above the surrounding lowlands and abut against the incline up to the Bowland Fells; they are topographically higher than the sandur system between Myerscough and Higher House (Fig 154). The most logical palaeogeographical interpretation is that an ice-marginal sandur/kame terrace existed between the ice margin and the rising bedrock relief of the Bowland Fells and ice-marginal drainage deposited sand and gravel in a conduit that fed into more extensive sandur to the south. The selection of Resource Block 3H for further analysis (*ibid*) is intriguing, given that the geomorphology shows that it is a moraine ridge and so likely to comprise thicker surface diamicts, as is confirmed by the reported 5-7m of silty-clay sand and gravel (Geoplan Ltd 2006). The zone immediately to the south would have made a more logical block for assessment. Resource Blocks 4C and 4D further highlight the potential resource within the Kirkham moraine, with 8m-thick sand and gravel deposits (Geoplan Ltd 2006), but again differences in borehole records between moraine crests and inter-moraine areas are not made. Examination of the M55 borehole series around the M55-A585 interchange (Fig 66) shows the thickest sand deposits, potentially 15-20m in thickness, that lie in this inter-moraine sandur associated with the Kirkham Channel (Fig 69). The reports for Resource Block 4E (Geoplan Ltd 2006) around Bradley's Sand Pit confirm this interpretation, that mineral is present but is laterally variable. There probably is sufficient density of boreholes to assess whether the thickest deposit is confined to the inter-moraine area (Fig 155).

7.2.16 In summary, our mapping of the geomorphology and preliminary assessment of published borehole records (Wilson and Evans 1990; Aitkenhead *et al* 1992) shows that there are considerable potential mineral resources in the Kirkham moraine complex. Further detailed examination of the borehole evidence will improve the interpretation, but although local variability from this rule is possible, at present the thickest sand and gravel deposits concentrate in the inter-moraine areas. Conveniently, the surface diamict overburden is also much thinner in the inter-moraine areas, which is more convenient for the extractive industries. Further mineral assessment in this region should be undertaken, but it must be underpinned by a sound understanding of the geomorphology and landform-sediment relationships. This integrated approach should also be extended to other parts of lowland Lancashire, where the geomorphological story is poorly constrained and has a great deal of information to impart.

8. DYNAMIC GEOMORPHOLOGICAL MODELLING STUDIES

8.1 LANDSCAPE CHANGE UNDER PRESENT-DAY HYDROLOGICAL CONDITIONS

8.1.1 A computerised modelling process (CAESAR) was used to determine the erosional and depositional impacts of the Ribble, Hodder and Calder Rivers upon the floodplain under present-day hydrological conditions and under predicted future conditions; this highlights those areas that are at greatest risk from fluvial change. The CAESAR programme was used simulate geomorphological change under the present-day hydrological regime and examined the tributary catchments of these rivers as well as the Lower Ribble reach.

8.1.2 The catchment scale runs (simulated time scale five years) predict a relatively high degree of geomorphological change (ie erosion and deposition coverage) within the Upper Ribble, and a relatively low amount of landscape change for the Calder. In general, this reflects the lower relief and slope angles over which water and sediment are moved from the West Pennine moor headwaters through the Calder system, and the higher slope angles involved in routing water and sediment from the central Pennines (ie Upper Ribble headwaters).

8.1.3 For the Upper Ribble (Fig 156a), CAESAR predicts a limited degree of hillslope erosion in steeper low-order tributary streams, with extensive sedimentation along the main river valley. This pattern appears to represent a coupled geomorphological effect, whereby storm-eroded hillslope stream/gully material is conveyed to the main valley in high-power discharge events, and subsequently redeposited across the valley floor within overbank flood waters. The most extensive form of erosion appears to have occurred in the form of undercutting at slope base locations along the margins of the river valley.

8.1.4 Results for the Hodder catchment (Fig 157a) show an intermittent pattern of hillslope erosion and valley floor deposition. Tributary stream/gully erosion is restricted to the steeper hillslope systems in the west of the catchment. In the upper part of the catchment, the pattern of valley floor sedimentation generally reflects the distribution of hillslope erosion. Widespread fluvial sedimentation has occurred only in the lower Hodder, where stream gradients are at a minimum. There, overbank floods have triggered undercutting and erosion of hillslope base sites along the flanks of the valley. Apparent extensive erosion shown within the main river valley close to the confluence with the Ribble is thought to be a result of problems with the DEM elevation data.

8.1.5 The Calder catchment (Fig 158) appears to have been very resilient to the geomorphological impacts of present-day hydrological forcings. Very little erosion and deposition has occurred within the hillslope tributary systems. The main focus for geomorphological change is the main river valley, but this was limited to two reaches in the upper and lower part of the valley. In these reaches, an alternating pattern of erosion and deposition has been modelled, probably representing a subtle geomorphological adjustment of local stream gradients to form pool–riffle-type channel bed morphology.

8.1.6 Geomorphological changes in the Ribble Valley (Fig 159) are dominated by sedimentation, almost all of which has occurred within the river channel, along relatively low gradient stretches in the upper and middle part of the reach. A limited degree of outer meander bend and valley marginal undercutting erosion has been simulated, suggesting low rates of landscape change as a result of lateral channel migration and overbank flood erosion respectively. The impact of the predicted fluvial change upon the identified archaeological resource is outlined in *Section 9.2*.

8.2 LANDSCAPE CHANGE UNDER FUTURE HYDROLOGICAL CONDITIONS

8.2.1 CAESAR was used to simulate geomorphological change under the UKCIP-forecasted hydrological regime for AD 2050 (higher winter rainfall scenario). For each study area, higher winter rainfall intensities, and hence flood magnitudes, have triggered a greater degree of geomorphological change than was simulated under the present-day hydrological scenario (*Section 8.1*).

8.2.2 For the Upper Ribble, the future hydrological scenario has resulted in the widespread extension of hillslope gully incision across many of the upland tributary valleys (Fig 156b). Fluvial sedimentation has extended across a larger area of the ‘flood basin’, and along the whole of the confined river to the south of it. Increased flood magnitudes appear to have triggered a greater degree of valley margin slope-base erosional activity, and alluvial fan-type deposits have been simulated at the base of some of the gully-eroded upland tributary sub–catchments (Fig 156b).

8.2.3 Differences between present-day and future modelled geomorphological responses appear to be most dramatic for the Hodder catchment (Fig 157), in which hillslope stream/gully erosion has extended into the majority of upland sub–catchments, and valley alluviation has spread across most of the main river and its piedmont tributaries. Slope undercutting as a result of overbank flooding now affects most of the confined valley floor reach. Increased hillslope gully/stream erosion, together with incomplete slope/channel coupling, has resulted in the development of several small alluvial fan or debris cone slope base deposits.

8.2.4 Unlike the northern catchments, the Calder catchment seems to have remained geomorphologically insensitive to simulated future hydro–climatic changes. Hillslope stream/gully erosion is virtually absent. Valley floor geomorphological changes modelled under future conditions are much more extensive within the main river and its major feeder tributaries, but as with the present-day scenario, occur only in the form of locally alternating erosion/deposition patterns indicative of minor channel bed (pool/riffle-type) gradient adjustment. The Calder is also a heavily urbanised catchment, with substantial flood protection measures in place that further reduce the potential for geomorphic change.

8.2.5 Once again, geomorphological changes in the Lower Ribble Valley (Fig 159b) are dominated by within–channel sedimentation. This sedimentation is clearly greater than under present–day conditions, having spread to all but the lowermost meander bend of the reach. Increased sediment supply because of hillslope erosion in the feeder catchments would appear to be responsible for this change. Despite increased flood magnitudes, burial of the floodplain by sediments contained within overbank flood water remains negligible. Floodplain erosional activity, mostly in the form of outer meander bend migration, has increased noticeably, particularly in the upstream section of the study reach. The impact of the predicted fluvial change upon the identified archaeological resource is outlined in *Section 9.2*.

8.3 FLOOD RISK DYNAMICS

8.3.1 The CAESAR flood inundation simulations for the Lower Ribble (Fig 160), flood events of estimated magnitude 200m³, 400m³, 600m³ and 800m³ s^{-1}were passed through the river–floodplain DEM produced by the reach scale geomorphological modelling runs under present-day and future hydrological conditions. Flood simulations were carried out along a 4km stretch of the river between Ribchester and Hothersall Hall.

8.3.2 For both modelled landscapes, each flood magnitude produced overbank water inundation, with the extent of inundation increasing in accordance with the size of the event. The maps clearly demonstrate that pre–existing fluvial morphology (terrace sequence and boundaries, palaeochannels) exert an important control on within-reach variations in flood extent. For example, the Ribchester meander bend, dominated by the highest fluvial terraces, T1 and T2, is unaffected by flooding. In contrast, the Osbaldeston meander, which includes a large extent of lower Terraces T3 and T4, is clearly at higher risk of flooding. Within the flooded areas, the position and arrangement of palaeochannel hollows clearly acts as a focus for overbank water flow. Inundation of a large palaeo–meander bend at Osbaldeston has resulted in the expansion of the inundated area onto the higher terrace zone for floods of 400m³ $s^{-1}$and higher.

8.3.3 For any given flood magnitude, the extent of inundation is significantly greater across the landscape produced under the future climatic scenario, and this reflects the reduced capacity of the channel to convey flood waters due to increased river bed sedimentation. For example, under the present-day scenario, a flood event of ~200 m^3s^{-1} appears capable only of inundating fragments of low Terraces T4 and T5, whereas inundation by the same event across the future landscape extends to the higher terrain of T3 and impinges into the large palaeochannel inset into T2. Thus, flood risk attributable to the future modelled 200 m^3s^{-1} flood is very similar to that produced by a larger, 400m^3s^{-1} flood under the present-day geomorphological configuration. The maps suggest that the change in flood risk (the difference in water extent) due to climatically induced geomorphological activity is greatest for the 200 m^3s^{-1} event, but declines with increasing flood magnitude. In this respect, the model runs indicate that the impacts of future climate change may be to increase the extent of flooding for relatively frequent (annual to interannual) events.

8.4 SUMMARY

8.4.1 The CAESAR model has proved to be a useful tool for assessing likely future geomorphological and hydrological changes in the Ribble catchment and its river–floodplain environments. The implications of these modelling scenarios are that future UKCIP-forecasted environmental changes (ie higher winter rainfall intensity) may be expected to increase dynamic erosional and depositional responses throughout the Ribble tributary catchments and within the Lower Ribble Valley.

8.4.2 The Upper Ribble, Hodder and Calder tributary catchments appear to have a different sensitivity to the geomorphological impacts of anticipated future environmental change. The geomorphological effects of heightened winter rainfall during the twenty-first century may, however, be expected to increase the frequency, extent, and hence high risk of flooding along the Lower Ribble. The model runs span a relatively short time period (ie five years). It seems likely that the impact of future climate change on geomorphological and flood risk dynamics would have been more dramatic given the availability of longer simulation periods.

8.4.3 ***Archaeological Impact:*** the detailed impact of continued geomorphological change upon archaeological monuments within the wider Ribble Valley is outlined in *Section 9.2*. Inevitably, the greatest change is in the immediate proximity to the present course of the rivers, and for the most part this impact relates to monuments that are specifically located so as to exploit the rivers. In general, because of the risk of flooding, the floodplain has been an area that has been avoided for settlement in the past; but industrial remains that exploit water power, or water retting, are inevitably adjacent to the rivers and therefore are at risk from changes to the course of the rivers. Similarly, communications across the rivers, such as bridges and similar features, can be affected by this geomorphic change.

9. ANALYSIS AND DISCUSSION

9.1 THE SUPERIMPOSITION OF THE ARCHAEOLOGICAL RESOURCE ON THE AGGREGATE TERRACES

9.1.1 Radiocarbon dating of the river terraces was undertaken at various locations along the Ribble (*Section 5.2*), and as a result relatively secure dating sequences were established for the Lower Ribble Valley and the Calder Valley, with less information available for the Hodder and the Upper Ribble. The sequence established indicates that, from Terrace T2 onwards, there is the potential for archaeological monuments to exist buried under the gravels and sediments.

9.1.2 The terrace formation procedures are complex, however. *In-situ* monuments and artefacts may be obscured by sediment overburden in earlier terraces, but episodes of erosion and deposition may also move artefacts from their original location and redeposit them on later terraces. Using the dating sequence provided by this project, hypothetically Terrace T2 could potentially contain obscured prehistoric monuments *in-situ*, whereas the later terraces are more likely to contain redeposited artefacts. However, if monuments are indeed buried in Terrace T2, the significant depth of overburden means that they will be obscured beyond any means of archaeological investigation yet may be at risk from aggregate extraction.

9.1.3 Superimposing the location of known prehistoric monuments, and in particular artefacts, on the map of river terraces allows us to highlight areas that may require further investigation or monitoring (Fig 161). Although there are also post-medieval monuments identified on these terraces, the distribution of the prehistoric monuments provides the best indicator of a significant archaeological resource that is potentially buried within the areas of terracing.

9.1.4 Monuments and artefacts found in Terrace T2 may be *in-situ*, implying deposition whilst the terrace was being formed. Aggregations of artefacts found in Terrace T3 may represent material redeposited from elsewhere, eroded from Terrace T2 further up the river.

9.1.5 Five prehistoric monuments have been found in areas now known to be part of Terrace T2 (Table 52).

HER Monument Number	Monument Name	Monument Type
HER PRN2	The Albert Edward Dock	Stone: Flint arrowhead
HER PRN6	Preston Docks	Metal: Bronze spearhead
HER PRN100	Near Higher Brockholes Farm	Stone: Flint arrowhead
HER PRN1410	River Ribble, Opposite Castle Hill, Penwortham	Organic: Wooden dugout canoes
HER PRN4952	Preston	Metal: Bronze

Table 52: Prehistoric monuments found in Terrace T2

9.1.6 Three of the artefacts (HER PRN18079, HER PRN6 and HER PRN1410) were found in very close proximity, in the area now occupied by Preston Docks. HER PRN6 and PRN1410 were found in the late nineteenth century during the construction of the docks, and HER PRN2 in 1934, in the same area (*Section 2.3.26*). HER PRN2 was associated with human and animal remains and HER PRN1410 with bronze implements. These were deeply buried in the gravels, with one of the dugout canoes (HER PRN1410) being recorded at 14 feet (4.26m) below the surface. These aggregations of finds may represent catchpoints, where material has collected at bends in the river (see *Section 6.2.6*). The other artefacts in that area, and HER PRN100 at Higher Brockholes Farm, may be redeposited isolated finds, and HER PRN100 in particular was found considerably closer to the surface (1ft (0.30m)). The aggregation of these finds seems to imply that the T2 terrace around Preston might contain further buried prehistoric artefacts and monuments. These are likely to be found only in the event of further deep excavations, such as aggregate extraction. *Section 7.2.8* suggests that this area (LIV3) is not particularly suitable for extraction as it is urbanised, but should intrusive work of any kind take place it should be closely monitored.

9.1.7 A further four prehistoric finds were found in areas mapped as Terrace T3 (Table 53). They are all extant earthworks in the area of Brockhall wood, close to the confluence of the Ribble and the Calder (Fig 162).

Monument Number	**Monument Name**	**Monument Type**
HER PRN149	Barrow, Brockhall Wood	Barrow
HER PRN179	Winkley Lowes	Barrow
HER PRN180	Winkley Lowes	Barrow
HER PRN28088	Winkley Lowes	Earthwork

Table 53: Prehistoric monuments and artefacts found within Terrace T3

9.1.8 This collection of barrows and earthworks has not been closely dated, although HER PRN179 and PRN180 were excavated by antiquarians in 1894 (*Section 2.3.34*). Radiocarbon dates for the palaeochannels on the surface of this section of terrace suggest infilling took place between *c* 970 cal BC-cal AD 490 and cal AD 650-890 (*Section 5.2.34*), but this does not narrow down the possible date-range for these monuments, indicating only that they were constructed after 1065-860 cal BC.

9.1.9 There are other aggregations of finds on bends in the river that do not fall exactly within the river terraces (according to the location recorded in the HER) but may also represent catchpoints in the river worthy of further investigation. The collection of artefacts discovered at Marles Wood may represent such a site. HER PRN1015 and PRN1872 (Fig 163) are a wooden dugout canoe and a canoe fragment respectively (*Section 2.3.11*); a spearhead was also found with HER PRN1872. These artefacts do not appear to be *in-situ*, but do highlight the fact that the river was an important channel for activity in the prehistoric period. Charting where these artefacts were originally deposited is, however, beyond the scope of this project.

9.1.10 Also at Marles Wood is a small collection of flint scatters (HER PRN1868, PRN2894 and PRN28205). These are thought to be *in-situ* and not part of the aggregation of finds at the catchpoint, but support the idea that this was an area of prehistoric activity.

9.1.11 In conclusion, these groupings of prehistoric monuments and artefacts on and close to Terraces T2 and T3 imply that these terraces may have a high archaeological value. Further work could develop the idea that certain points in the river act as catchpoints for finds deposited upstream. Highlighting areas of known activity close to Terraces T2 and T3 might point to the location of buried monuments and artefacts within the gravels that will only be discovered during deep, intrusive excavations such as extraction. A monitoring strategy could be established that concentrates on these areas if extraction takes place.

9.2 THE IMPACT OF GEOMORPHOLOGICAL CHANGE ON THE ARCHAEOLOGICAL RESOURCE

9.2.1 ***Present Geomorphological Change:*** the location of the known archaeological monuments, and the maps of archaeological potential, were superimposed onto the models created by CAESAR (*Section 3.11.36*) to assess the impact of present geomorphological change on the archaeology. For the purposes of this project, change is defined as erosion or deposition. These clearly have differing impacts on the archaeology, and require different management approaches.

9.2.2 *Section 8.1.3* indicates that the CAESAR model has predicted a relatively high degree of change within the Upper Ribble Valley. However, much of this does not fall within the study area for this project, and as such there is no quantification of the archaeology there. Further south, the model predicts a relatively low level of change around the Calder, and an intermittent pattern of hillslope erosion and valley floor deposition for the Hodder catchment. In the Ribble Valley the changes are dominated by sedimentation with limited areas of erosion around the outer bends of meanders.

9.2.3 When superimposed on the map of known archaeological monuments (Fig 164), 15 such sites were in the areas identified in the model as possibly affected by geomorphological change, either erosion or deposition (Table 54).

Threat Type	Primary Reference Number	Monument Name	Monument Type	NMR Broad Type	Period
Deposition	LM0054	Trawers Ferry	Ferry	Maritime	Post-medieval
Deposition	LM0055	Dinkley Aqueduct	Aqueduct	Water Supply and Drainage	Post-medieval
Deposition	LM0056	Dinkley Gravel Pit	Gravel Pit	Industrial	Post-medieval
Deposition	HER PRN1022	Bullasey Ford	Battlefield	Unassigned	Early-medieval
Deposition	HER PRN1581	Near Hacking Hall	Aerial Photograph	Unassigned	Unknown
Erosion	LM0060	Winckley Mill	Mill	Industrial	Post-medieval
Erosion	LM0061	Hodder Limekiln	Limekiln	Industrial	Post-medieval
Erosion	HER PRN290	The Old Lower Hodder Bridge, Aka Cromwell's Bridge	Bridge	Transport	Post-medieval
Erosion	HER PRN6102	Winckley Hall	House: Domestic	Domestic	Post-medieval
Erosion	HER PRN6102	New Bridge, Lower Hodder	Bridge	Transport	Post-medieval
Erosion	HER PRN3112	South-east Of Cross Gills, Hurst Green	Earthwork	Monument <by Form>	Unknown

Threat Type	Primary Reference Number	Monument Name	Monument Type	NMR Broad Type	Period
Erosion	HER PRN3114	Lower Hodder Bridge	Aerial Photograph	Unassigned	Unknown
Erosion	HER PRN3115	East Of Great Mitton	Earthwork	Monument <by Form>	Unknown
Erosion	HER PRN3117	North Of Cat Scar Wood	Earthwork	Monument <by Form>	Unknown
Erosion	HER PRN18851	River Hodder	Metal: Gold coin	Findspot	Medieval

Table 54: Currently known monuments at risk from geomorphological change

9.2.4 Eight of the monuments are situated within the large zone of erosion close to Great Mitton at the confluence of the Ribble and the Lower Hodder. However, this may be illusory rather than real, resulting from a problem with the digital elevation data (*Section 8.1.4*). As such, it is probably less important to monitor this area than others highlighted. However, the monuments within this zone are worthy of further investigation, should the area be subject to any kind of geomorphological change.

9.2.5 Within this zone there are four further earthworks of unknown period (HER PRN1581, PRN3114-9, PRN3117), described as circular or sub-circular features, which could perhaps be prehistoric roundhouses, although they could also be modern cattle feeding areas (Fig 165). This area has no LiDAR coverage, and no further investigation was undertaken for this project. HER PRN290, the Old Lower Hodder Bridge, or Cromwell's Bridge, is the only Scheduled Monument (SM13691) that is considered at risk from present geomorphological change.

9.2.6 To the north, outside the study area, the HER records considerable prehistoric activity, around the meanders of the Hodder (Fig 165). At Horse Hey Farm and Crooked Field, close to Bashall Eaves, are prehistoric settlements (HER PRN 2303 and PRN 1875 respectively). Further south, within the study area, at High Hodder Bridge and in the woods close to Kemple End, polished stone axes have been found (HER PRN 1878 and PRN 190 respectively). Further south again, at the confluence of the Ribble and the Calder, are two Bronze Age barrows (HER PRN179 and PRN180). It is conceivable, therefore, that these earthworks could provide evidence of further prehistoric settlement in an area of obvious prehistoric activity, and this zone should be flagged up as extremely important for monitoring and resource management.

9.2.7 The remainder of the monuments at risk from present geomorphological change are either of early medieval date, or unknown period. Five monuments subject to impact by deposition are all situated extremely close to the present course of either the Ribble or the Calder (Fig 166). Three are post-medieval, a fourth possibly of early medieval date, and the fifth is of unknown date. The monument of unknown date (HER PRN1581) is an area of earthworks seen on an aerial photograph, in an area outside the LiDAR coverage, so no further identification could be made. There is, however, a considerable potential that these unclassified earthworks related to prehistoric activity. Of the other monuments affected by fluvial deposition, the impact is perceived to be of little significance. Trawers Ferry (HER PRN28254) is identified on the 1848 OS first edition map and nothing was seen on a site visit. Dinkley Aqueduct (HER PRN28255) and the gravel pit (HER PRN28256) are still extant, but unlikely to be badly affected by fluvial deposition. The Bullasey Ford site (HER PRN1022) is actually a documentary reference, and has been suggested as the site of a battle of AD 798 between Eardwulf, King of Northumbria, and the rebel King Wada (Farrer and Brownbill 1908). Evidence for this is sketchy, but if correct, the site would be of considerable importance, given its period. The likelihood of stray finds relating to the battle would be quite high, although none have been recorded to date.

9.2.8 ***Potential***: the areas at greatest threat from geomorphological change in the Lower Ribble Valley are confined almost entirely to the immediate confines of the Ribble and represent sedimentation rather than erosion. This area is classified as of medium potential for archaeological monuments overall (Fig 167), medium for prehistoric (Fig 168) and Roman (Fig 169), and with low potential for medieval monuments (Fig 170). As these areas are mainly at threat from deposition rather than erosion, there is perhaps less of an issue for future management as any monuments are likely to be protected by being buried under accumulated sediment. It is unlikely that development will be a problem so close to the river, unless this relates to water management.

9.2.9 In the area around Dinkley (Fig 167), considerable numbers of small brooks and streams drain into the Ribble, and these may be at risk of erosion. This area has a considerable potential for archaeology, being scored high for prehistoric, medium for Roman and medium for medieval activity. The areas affected by erosion are very small and discrete and would have only a localised effect on archaeological remains in their vicinity, but this should be monitored, given the considerable levels of prehistoric activity to the north, around the Hodder. The Ribble itself continues to be subject to deposition around Dinkley, and is an area of medium potential overall.

9.2.10 The large zone of potential erosion around the Lower Hodder coincides with areas of low, medium and high overall potential for archaeology. For the prehistoric period there is a zone of medium potential formed by a meander of the Hodder, surrounded by areas of high potential, whereas for the Roman and medieval periods there are discrete pockets of high, medium and low potential. The area of greatest concern, if the model is accurate in this area (*see Section 8.1.4*), would be to the west of the Hodder around the Lower Hodder Bridge.

9.2.11 To the north-east of the study area, beyond Clitheroe (Fig 167), there are discrete areas at risk from erosion around the Ribble itself, with discrete areas of deposition also around a wide meander in the Ribble between Edisford Hall and Waddow Hall, north of Clitheroe. The zones of erosion all fall within areas of high overall potential for archaeology, but again are so localised as to be of less concern. The areas of deposition fall within a zone of medium potential overall, and medium potential for each of the broad archaeological periods. Again, the localised nature of these zones means that they present little threat. Further north-east, towards Chatburn, the threat from both erosion and deposition increases. From Horrocksford to the confluence with Swanside Beck, south of Sawley, is a zone of deposition along wide meanders on the north bank of the Ribble. On either side of this and the river are areas at threat from erosion, including some larger zones around Chatburn. The zone of deposition is in an area of high potential for archaeology overall, high potential for prehistoric, and medium for Roman and medieval monuments. The largest area of erosion falls mainly within Chatburn Quarry, which by its very nature is an area of low potential overall. The smaller zones of erosion to the north fall within an area of medium potential overall, and medium potential for each of the periods.

9.2.12 In the far north of the study area are a few small discrete zones of erosion and deposition. One of these, an area of erosion, is in the environs of Sawley Abbey, and two patches of deposition are also very close. This is an area of high potential for archaeology overall, with each of the broad periods having a high potential also. While these areas of threat are very small and discrete, their proximity to one of the most important archaeological zones within the study area means that they should be considered as a significant threat, despite their limited size.

9.2.13 ***Future Geomorphological Change:*** CAESAR was also used to simulate the effect of future geomorphological change until AD 2050 (*Section 3.11.36*). Under this scenario, higher winter rainfall intensities would trigger a greater degree of geomorphological change than under present conditions. This would lead to an extension of the areas of erosion and deposition in all areas apart from the Calder catchment, which appears more stable.

9.2.14 Given the wider geomorphological area that would be affected, considerably more known monuments would potentially be affected by this threat than at present, 115 in total (Table 55, Fig 171). This accounts for almost 10% of the total monuments known within the study area and, of these, 82 are projected to be subject to deposition and 33 to erosion. The overwhelming majority of these monuments are post-medieval or modern in date (Table 55), which is representative of the fact that there are considerably more monuments of those periods within the study area.

Period	Erosion	Deposition	Total
Prehistoric	0	2	2
Roman	0	4	4
Medieval	3	7	10
Post-Med/Modern	21	59	80
Unknown	9	10	19
Total	33	82	115

Table 55: Breakdown of monuments at risk from future geomorphological change, by period

9.2.15 Two monuments are of prehistoric date: HER PRN28205, the Mesolithic flint scatter at Marles Wood (Fig 172), is likely to be subject to deposition in the future. Although badly disturbed by tree root activity, this was thought to be *in-situ* at the time of discovery, implying that there may be further evidence of Mesolithic activity in the area. Burial by further river sediment is unlikely to cause further significant disturbance to any surviving archaeological remains, but this area should be highlighted for monitoring. The second prehistoric monument is the findspot of a Bronze Age spearhead (HER PRN199). The account recorded only an approximate location, and thus it can be taken as nothing more than an indication of Bronze Age activity in the area. As such, there would be little or no management requirement in this case.

9.2.16 Four monuments are Roman in date. Two are classified as findspots (HER PRN151 and PRN1846), HER PRN151 being a hoard of approximately 30 objects found close to Ribchester, and HER PRN151 was some pottery found in 1971 during a sub-aqua survey of the Ribble river bed near Samlesbury. Taking findspots as indicators of activity, and perhaps of no longer extant monuments, then these will be unaffected by fluvial deposition. The two other monuments (HER PRN1568 and PRN15510) are sections of the Roman road near Ribchester. As extant sections of road, these will be more affected by fluvial deposition, and as such should be highlighted as areas for monitoring and management.

9.2.17 Ten monuments are classified to date as medieval, of which three are at risk from future erosion and seven from future deposition. Of the monuments at risk from future deposition, one, Bullasey Ford (HER PRN1022), is also at risk from current deposition (*Section 9.2.8*). HER PRN2570 is a findspot of a ceramic jug, found during drainage work.

9.2.18 The four remaining known monuments (HER PRN28014, PRN28109, PRN28111 and PRN28129) at risk from future deposition are situated in the Waddington/Grindleton/Chatburn area. They all appear to be related to the small-scale linen production that is well known in the locality. HER PRN28109, PRN28111 and PRN28129 are grouped together to the south-east of Grindleton and form a complex of retting ponds, leats and sluices. HER PRN28014 is an earthwork close to Waddington that was identified from LiDAR as part of this project, possibly related to the former retting system at Waddington (HER PRN12898). It should be noted that HER PRN12898 was classified in the HER as of post-medieval date, but within the context of cultural resource management this collection of sites possibly represents an important fragment of medieval landscape within the study area. Future fluvial deposition is unlikely to cause damage to these monuments, but they should be monitored.

9.2.19 Of the three monuments subject to risk from future erosion, one is a findspot (HER PRN18851), the approximate location of a fifteenth-century gold coin. As a findspot it is indicative of activity in the area but is probably not an indication of a site directly at risk from erosion. HER PRN1013 is Dinkley Hall, a rebuilt farmhouse on a medieval site. This should perhaps be monitored as part of a future management plan, but there is little evidence about the quantity and quality of any extant medieval remains. HER PRN22363 is a documentary reference to a medieval chapel and hermitage; these no longer survive as surface features, but could potentially be buried monuments.

9.2.20 Eighty post-medieval or modern monuments are at risk from future fluvial change (Fig 173). This includes Old Lower Hodder Bridge (HER PRN290), the only Scheduled Monument to be affected (*Section 9.2.5*). There are also several listed buildings in this group, but monuments covered by statutory constraints such as scheduling or listing will be subject to higher levels of protection and monitoring in the future, so any damage from fluvial change is likely to be mitigated on a case-by-case basis.

9.2.21 However, this period of monument forms the core of the Historic Landscape Character (Fig 52) within the study area and as such coherent groupings of unscheduled and unlisted monuments under threat should be considered significant. Fluvial deposition or erosion would also, at the least, obscure ridge and furrow or other ephemeral earthworks that contribute greatly to an interpretation of the landscape.

9.2.22 The majority of these monuments are in the north of the study area, where there are two significant groupings, and a large number of outlying individual sites. South-east of Grindleton is a series of ridge and furrow earthworks (HER PRN28033, HER PRN28116, HER PRN28117, HER PRN28120-6, HER PRN28128), which are in a large meander of the river that would be affected by future deposition. Adjacent to these is Fields House (HER PRN12897), which is the best-preserved flax pond system on the Ribble floodplain. The only monuments possibly at risk from erosion are HER PRN2091 and PRN17938, which are extant farmhouses (listed Grade 2* and 2 respectively).

9.2.23 A further aggregation of monuments at risk from future deposition is around Sawley, and most of these are substantial extant remains, but there are again traces of ridge and furrow (HER PRN28023, PRN28100). Within this area, three Grade 2 listed houses (HER PRN17939, PRN17940, PRN18080) are possibly at risk from erosion, along with the Sawley Arch (HER PRN23905).

9.2.24 Towards the south and west of the study area are fewer groupings of monuments, and more single sites. The monuments in this area are situated close to the river and are mainly industrial, maritime, or are water-related. Many of them are also known from documentary references only, shown on historic OS maps, and are not necessarily extant now, nor are they shown on modern mapping. Around Winckley, the monuments are likely to be at risk primarily from erosion, whereas in the remainder of the study area the main risk is from deposition.

9.2.25 ***Potential***: the areas likely to be affected by future geomorphological change in the far north of the study area comprise large zones of potential deposition surrounded by smaller zones of potential erosion. From Sawley to Waddington these are in zones of high overall potential for archaeology (Fig 174), high for prehistoric activity (Fig 175), and medium for Roman (Fig 176) and medieval sites (Fig 177). The area that is of high potential overall and for all the periods is around Arnot House, south-west of Sawley, which is an area of predicted future deposition. The largest zone of potential for future erosion is along Swanside Beck, south of Sawley. This is a zone of medium potential overall, and medium for the individual periods.

9.2.26 To the south-west, towards Clitheroe, the areas of potential future deposition are bordered on either side by zones of potential erosion, and continue to coincide with areas of high overall potential for archaeology, high for prehistoric, medium for Roman and medium for medieval activity. The main exception to this is the quarry at Chatburn, which by its very nature is an area of low potential for archaeology, and is an area of potential erosion.

9.2.27 Around Great Mitton and Lower Hodder Bridge are areas of potential future erosion but no deposition. The first of these continues to respect the zones of high overall potential for archaeology, high for prehistoric, medium for Roman and medium for medieval activity. Great Mitton itself is an exception, as it has a high potential for medieval monuments. The zone around the Lower Hodder is mainly of medium overall potential, although zones are of low potential for medieval and Roman activity, including the River Hodder itself in this area.

9.2.28 To the west, the zones of potential future fluvial change are restricted mainly to the immediate confines of the Ribble. The river itself is an area of potential future deposition, and the banks to either side contain zones of potential erosion as far down as Ribchester. Below Ribchester there are virtually no areas of erosion. The river itself in this area is of medium overall potential for archaeology, high for prehistoric, medium for Roman and low for medieval activity. The banks on either side are of high potential overall, high for prehistoric, and medium for Roman and medieval sites.

9.2.29 South-west of Samlesbury, the zones of potential future deposition still follow the line of the river, with isolated patches on either side, before petering out as the river passes into Preston. These are zones of medium overall potential, medium for prehistoric and Roman, and low for medieval activity. The exceptions are patches around Cuerdale, which is a zone of high overall potential, high for prehistoric, and medium for Roman and medieval sites.

9.3 THE IMPACT OF AGGREGATE EXTRACTION ON THE ARCHAEOLOGICAL RESOURCE

9.3.1 Some 387 monuments fall within the areas of river terracing throughout the study area. This accounts for approximately 30% of the total number (Table 56). The majority (61%) are post-medieval or modern date, and consequently present less of a management concern, as they are more likely to be extant, robust and visible.

Period	Number of Monuments
Prehistoric	17
Roman	52
Medieval	31
Post-medieval/Modern	239
Unknown	48
Total	387

Table 56: Monuments within river terraces, broken down by period

9.3.2 Following the protocol set out in *Section 7*, the remainder of this analysis concentrates on the two main areas of aggregate extraction suitability along the Ribble: namely the M6 to the Calder; and from Preston to the estuary. Within those two areas are discrete sections with a good prospect for extraction, containing large quantities of minerals, which are also subject to few constraints (*Sections 7.2.6 and 7.2.8*).

9.3.3 ***The Ribble between the M6 and the Calder Tributary:*** The best prospects within the Lower Ribble Valley for mineral extraction are Resource Blocks A1, A, B, C, D and J/K (*Section 7.2.6*). Within these blocks are 14 known monuments (Fig 178, Table 57).

Monument Number	Name	Type	Period
HER PRN100	Near Higher Brockholes Farm	Stone: Flint arrowhead	Prehistoric
HER PRN15394	Connerie Bridge	Stone: worked stone	Roman
HER PRN1569	Near Ribchester Bridge	Road	Roman
HER PRN1570	Ribchester Bridge	Aerial Photography Site	Unknown
HER PRN1613	Red Scar Wood, Near Preston	Metal: Coin	Roman
HER PRN16519	North Of Salesbury Hall	Moated Site	Medieval
HER PRN1716	Higher Brockholes	Farmhouse	Post-medieval
HER PRN1720	Lower Brockholes, Brockholes Brow, Preston	Farmhouse	Medieval
HER PRN18785	Alston	Deserted Medieval Valley	Medieval
HER PRN1975	Elston Bottoms	Metal: bronze flat axe	Prehistoric
HER PRN28052	Field Boundary	Field boundary	Post-medieval
HER PRN28053	Ridge and Furrow	Ridge and Furrow	Post-medieval
HER PRN28106	Linear	Linear feature	Post-medieval
HER PRN28173	Earthwork	Earthwork	Unknown

Table 57: Monuments within Resource Blocks of considerable suitability for aggregate extraction between the M6 and the Calder tributary

9.3.4 There are two prehistoric sites, three Roman, three medieval, four post-medieval and two of unknown period (Table 57). The prehistoric sites (HER PRN100 and PRN1975, in Resource Blocks A1 and B respectively) are findspots. Resource Blocks A1 and B comprise Terraces T1 and T2, so were created prior to 6750 Cal BC (*Section 5.2.23*). Consequently, it is very unlikely that these findspots are pointers highlighting the location of other monuments buried under the terraces. Considered in context, they are relatively close (within 2km) to two possible promontory forts (HER PRN15241 and PRN15242) on the north bank of the Ribble, but otherwise are some distance from the main concentrations of prehistoric monuments in the area and may be indicators of prehistoric activity.

9.3.5 The Roman monuments within these Resource Blocks comprise a possible section of the Roman road going east from Ribchester, and associated earthworks (HER PRN1569, in Resource Block J/K), a findspot of three Roman coins near Red Scar Wood (HER PRN1613, in Block A1) and some worked stone incorporated in Connerie Bridge (HER PRN15394, also in J/K). Of these, the monument most at risk from extraction must be the Roman road and earthworks. No work has been undertaken in this area to determine the nature of the earthworks, and as such this should be recommended before potential aggregate extraction takes place. Resource Block A1 comprises Terrace T2, of abandonment date 7150-6750 Cal BC (*Section 5.2.23*), and as such the findspot is unlikely to represent unknown, buried monuments. Similarly, Resource Block J/K is also on Terrace T2.

9.3.6 The medieval monuments likely to be affected by any extraction are extant features, and are therefore less at risk from inadvertent destruction. HER PRN1720, in Block A1, is a sixteenth-century farmhouse that has now been modernised. HER PRN1720, in Block J/K, was described in the HER as a possible moated platform close to Salesbury Hall. It is a very subtle feature, and no further information could be gathered by studying the LiDAR. HER PRN18785 in Block D is recorded in the HER as a possible deserted medieval village. It falls within an area with no LiDAR coverage and is not visible on the vertical aerial photography or on the first edition OS mapping, so no further information is available.

9.3.7 The maps of archaeological potential were overlain on the Resource Blocks deemed most suitable for aggregate extraction. Almost all the blocks were in areas of high potential for each period, with smaller areas of lower potential (Fig 179). This highlights the fact that using the location of known archaeology alone as a measure of the impact of extraction may not always be enough, and some level of archaeological survey should be undertaken in those areas prior to extraction.

9.3.8 ***The Ribble between Preston and the estuary***: the best prospects for aggregate extraction between Preston and the Ribble estuary are LIV6 and LIV7, to the north of the river (Fig 180). Only six known monuments are situated in these zones, comprising one post-medieval bridge (HER PRN11887), a modern floodgate (HER PRN28265) and four earthworks of unknown date (HER PRN3146, PRN4502, PRN28192 and PRN28194). Two of the earthworks (HER PRN4502 and PRN28192) have been identified using aerial photography and LiDAR and have the appearance of cropmarks of post-medieval features. HER PRN3146 is an ill-defined sub-rectangular feature, and HER PRN28194 is a sub-circular feature also identified using LiDAR.

9.3.9 It should be noted, however, that much of Blocks LIV6 and LIV7 is outside the study area for this project, and as such the small number of monuments located may not be accurate. If extraction were to take place within those Resource Blocks, an equivalent data-gathering exercise would need to be undertaken to ensure that no other monuments were affected.

9.3.10 Although not highlighted as particularly suitable for aggregate extraction, LIV3 has potentially *in-situ* prehistoric remains (*Section 6.2.4*) that were found during the construction of Preston Docks. Any further work in this area should be closely monitored.

9.3.11 The small sections of the Blocks that lie within the study area have mixed archaeological potential (Fig 181). Although it would be inadvisable to infer very much about the potential in the remaining area from the small section inside the study area boundary, it would appear that the potential increases slightly from east to west for all periods. This implies that a thorough survey of the affected Blocks would be necessary before any extraction could take place.

10. RECOMMENDATIONS

10.1 INTRODUCTION

10.1.1 The prime resource blocks for future sand and gravel mineral aggregate extraction in the study area are the terraces of the Lower Ribble, and Terraces T1 and T2 in particular. The age control for these terraces shows that T1 is a late Pleistocene terrace that aggraded until a poorly constrained incision during the late glacial and early Holocene, caused by gradual landscape stabilisation and lower base levels, and T2 aggraded during the early Holocene, 8000-4000 cal BC, with the subsequent incision constrained to *c* 4000-1500 cal BC. The relative ages of the fluvial deposits have implications for the potential for archaeology, in the case of Terrace T1, namely that any earlier archaeology must overlie the fluvial deposits. The sand and gravel deposits of Terrace T2 comprise a mixture of Terrace T1 sand and gravel that was not eroded during the preceding incision activity and newly aggraded T2 sand and gravel. Consequently, there is potential for Mesolithic and Neolithic archaeology to be incorporated within the Terrace T2 sand and gravel, as well as being a feature of the overlying soil and colluvium. In the case of any, admittedly unlikely, extraction of glacial deposits in the Lower Ribble Valley, any potential archaeology must overlie the target mineral. The guidance as to the potential archaeology should therefore inform the strategies employed by the extractive industries at the planning and development stage. This information also provides a framework for the mitigation and monitoring programme necessary to characterise and record the archaeological and geological heritage during mineral extraction.

10.2 FURTHER WORK

10.2.1 In terms of the sand and gravel mineral aggregates, little future research is needed for the Lower Ribble river terraces and the glacial landforms within the Ribble Valley. The aggregate inventory provided in this report improves understanding of the distribution of sand and gravel reserves, and should be of benefit to the extractive industries. In addition, the now improved understanding of the deglacial history of the area gathered in this project should be used to inform future sand and gravel investigation within the county. In particular, the identification of ice-marginal settings, where glaciofluvial or lake-edge glaciolacustrine environments exist around the Lower Ribble glacial lake should highlight excellent candidate locations for good-quality aggregate. However, prior to any proposed extraction, a comprehensive survey should be undertaken to confirm the aggregate resource in that particular locale.

10.2.2 Preliminary assessment of the Kirkham moraine shows that the potential for usable mineral is high, but at present the mineral resource is poorly understood. Geomorphological interpretation linked with the available borehole and section evidence would improve our understanding of the distribution of mineral within the moraine complex. Clearly, the Kirkham moraine (Fig 182) is an area of search that would benefit from a detailed investigation of the geomorphology and Quaternary geology. The area south of the Ribble, particularly the broad swathe including and between Resource Blocks 3G, 3A and the coastal lagoons of Martin Mere, is another such area of search. The Geoplan Ltd (2006) report shows that mineral is present, but the geomorphology of the region is poorly understood and, given the ice-marginal context, proximity to the edges of major ice streams and association with the Ribble ice-dammed lake, considerably more could be achieved through a programme of geomorphological research.

10.2.3 There is a general need for a comprehensive re-evaluation of the glacial geomorphology of lowland Lancashire, which must underpin future sand and gravel surveys, otherwise nothing new is gained and assessments simply re-invent the wheel, providing only limited amounts of additional detail. The principal problem is that investigations focus on desk-based definitions of target areas and use a database that has flaws, notably the BGS 1:50,000 sheets. This style of geomorphic survey need not be prohibitively expensive because modern DEM data allow a desk-based assessment of the geomorphology, which, if combined with access to the BGS, roads authority and local authority borehole records, plus a limited amount of field mapping to ground-truth interpretations, would make significant improvements to the understanding of mineral reserves. There is no need for a new programme of boreholes to accompany this stage of research, as there is an existing, albeit erratic, spread of boreholes across the county, and because the onus for that type of investigation would be upon the aggregate industries when assessing the potential of specific sites.

10.2.4 This ALSF project focused on soft aggregate, sand and gravel, and the present study area boundaries were defined on this basis. Consultation with the North Yorkshire County Council Minerals Officer (Chris Jarvis) revealed that the *Minerals Plan* for North Yorkshire County Council (NYCC 1997) included an area of search for aggregates that was only partly encompassed by the study area of the present project. The reason for the discrepancy is that, in Craven District and the Yorkshire Dales National Park, the main source of aggregate is limestone rather than the soft geology. At present, the worked sources of aggregate are all limestone quarries within the Yorkshire Dales National Park, but it is North Yorkshire County Council’s and the Yorkshire Dales National Park Authority’s policy to discourage further extraction within these, and any applications for new quarries or extensions to existing quarries within the National Park will be rejected. In Lancashire, there is also extensive use of crushed rock for aggregate, including extraction within the Bowland Fells. This ALSF study has concentrated on the sand and gravel mineral, but within the Ribble basin crushed rock is a favoured local source for mineral aggregate. There is a need for extended research to include all areas of potential aggregate extraction, including hard rock geology resources. This was the subject of a variation proposal during this project, but in the event, the funding for a variation was not available in 2006/7, although there is some possibility that the funding will become available in 2007/8.

10.3 FUTURE ENVIRONMENTAL AND GEOMORPHOLOGICAL RESEARCH

10.3.1 ***Glacial heritage of lowland Lancashire***: the landscape of Lancashire reflects the cumulative impacts of overriding ice, with the 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, Loud and Hodder valleys, with an extensive ice-dammed lake blocked in by ice to the east of Preston and fed by waters draining the retreating Ribble glacier. The work undertaken in this project has only begun to scratch the surface of this complicated deglacial history of lowland Lancashire and, compared to surrounding regions, Cheshire, Cumbria and the Pennines, glacial research has lagged behind, with little undertaken since the early pioneering work of De Rance (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 an understanding of the glacial history in this region. This would be of some significance given the current academic focus on ice-stream behaviour during deglaciation from the last glacial episode because of the association between the Kirkham moraine complex and quantities of high-grade sand and gravel mineral.

10.3.2 ***Fluvial geomorphology and heritage*****:** this project has demonstrated the value of comprehensive investigation of the geomorphic record in fluvial valleys and how it contributes to an understanding of 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. This study has highlighted the comparative lack of this type of investigation in the North West, and the geomorphologies of the rivers Lune, Wyre and Eden at present are a 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 geomorphological history and its links with the cultural heritage for these areas remains an important objective. This has, to some extent, been addressed in the case of the Lower Ribble Valley, but there remains considerable potential to fill gaps that remain even in the Ribble Valley, for instance the Long Preston Deeps alluvial flood-basin.

10.3.3 The geochronological framework for the Ribble geomorphic system covers hillslope geomorphic systems in the headwater reaches, three main tributary reaches (the Hodder, Ribble and Calder) and the main Lower Ribble trunk stream. The staircases of river terrace were investigated by coring and dating of several palaeochannels, using a strategy that targeted basal and uppermost flood layers in the palaeochannel fills. For almost all contexts, plant-specific macrofossils were used to date the stratigraphy and for a large number of contexts radiocarbon dates were duplicated using different plant macrofossils. Statistical analysis and Bayesian modelling of the sets of radiocarbon dates have combined to improve confidence in the geochronological model.

10.3.4 From an academic point of view, but not related specifically to aggregate extraction, these approaches allow a number of key themes to be addressed in further work and publications. In particular, the varying importance of the relative impacts of different forcing/conditioning factors, such as base-level changes driven by eustatic sea-level change appear to have been more critical during the early Holocene, with climate and human impacts on the landscape more important in driving change in the fluvial system during the mid- to late-Holocene. Of critical importance and routinely overlooked, the sediment transmission and storage behaviour of river systems play a critical role in moderating the response to external forcing, and the research into the Ribble allows an understanding of the switching between terrace levels which may be time-transgressive between sediment sinks/stores, or even between nearby meanders. These conceptual advances arise directly from the Ribble ALSF project and future research should focus upon communication of these findings within the academic and wider community, and in providing further corroboration.

10.3.5 Another aspect that warrants further investigation is the sediment transmission behaviour of the Ribble and the linkages between different parts of the fluvial system. An extensive database has been compiled that allows the connectivity between hillslope, mid-reach and lower reaches of the Ribble to be examined. However, the Ribble flows into the Irish Sea and has an estuarine zone that receives seaward flow from the Ribble and Douglas rivers. The coastal zone in this area is of considerable complexity, owing to the cycling of sediment received from the Alt, Mersey and Dee further south. There has been considerable research examining the sedimentology of the coastal plain south of the Ribble down towards Liverpool (Tooley 1978) and to the north up towards Blackpool. Much of this research has focused upon reconstructing sea-level change during the last 10,000 years. Borehole records from across the inner estuary, obtained for the aborted west Preston by-pass, reveal the broad sedimentology (www.bgs.ac.uk). Devensian diamicts underlie the sequence, with the Ribble Valley, forming a broad incision into the glacial terrain. The Ribble Valley sediment fill downstream of Preston towards the head of the estuary comprises basal fluvial gravels and terrestrial silts and clays, which are buried by 3-4m of sands rich with marine fossils, and these in turn are buried by 3-4m of estuarine/fluvetile sands and latterly clays. The dominance of sand-size materials is reflected in the character of Ribble fluvial sediments and also the proximal sea-floor.

10.3.6 In addition to the summary borehole data compiled during the Ribble ALSF project, there have been a number of palaeoenvironmental studies for other parts of the estuary. At Lytham, various sites (Tooley 1978) show that nearly 16m of sediment have accumulated since *c* 6500 cal BC, with other sites showing 3-4m in the last 3000 years. South of the Ribble, there have been extensive programmes of coring to address the sea-level history, at Martin Mere (100 cores), various mosslands extending southwards from Martin Mere to the river Alt, Scarisbrick, Redacre, Halsall, Plex, Downholland and Altcar mosses (Middleton *et al* forthcoming). These basins largely comprise lacustrine silts and clays and terrestrial raised mire peat deposits, interspersed with marine influenced horizons. Nearer the coast, the marine influence is greater, and several metres of marine silts and latterly wind-blown sand have accumulated. Clearly, the coastal estuarine zone flanking the Ribble has attracted considerable attention, but none of this work has specifically focused on sediment accumulation, provenance and budgets. In terms of the areas requiring a greater focus, the inner estuary and a seaward transect from the inner to outer estuary would be crucial. Rivers act as conveyor belts to transport sediments from the land to the sea. The sediment is then redistributed along the coast to form beaches, marshes and other coastal features that shape a coast. Tide levels as well as the run up of storm waves are determined by the coastal geometry; understanding river dynamics is thus essential in order to understand coasts. The linkage between coastal sediment accumulation and river behaviour is often rather complex and determined by many factors, and during the recent past, major changes in river behaviour have been forced by climate change and human impact. Unravelling these changes is not always straightforward, as rivers filter and modulate the effects of human impact and climate change. This also means that predicting future change in the estuarine and fluvial zones is impossible without understanding how connectivity and internal modulation works, and how these factors evolve through time.

10.4 ARCHAEOLOGICAL INVESTIGATION

10.4.1 The present project has highlighted the degree to which known archaeological monuments coincided with the most economically exploitable reserves of aggregate, and has also demonstrated that there are areas where there is a considerable potential for significant buried archaeological remains. The project has also shown that these are likely to be prehistoric remains, buried by later deposition of sands and gravels as a result of river action. As such, the project has provided valuable information to target future aggregate exploitation away from significant archaeological resources and has also considered the methodologies needed to assess the archaeological impact accurately in any particular area.

10.4.2 The project has also highlighted areas beyond the limited extent of the Ribble Valley (such as the Kirkham moraine and the Craven Gap), where there are economically viable sources of aggregate, and there is thus a need both to explore the potential of these reserves and to investigate the archaeological resource that may suffer adverse impact should the reserves be exploited.

10.4.3 ***Further Investigation within the context of the Regional Research Agenda:*** the North West Archaeological Research Framework has identified a series of lacunae in archaeological knowledge within the North West. In particular, archaeological knowledge in Lancashire is perceived to be weak, for particular periods and for particular themes and subjects (Chitty and Brennand in press). Any future work within the county will have significant potential to address many current research issues, providing adequate mitigation strategies and methodologies are formulated. The River Ribble represents both a natural boundary and a routeway, and the deposits within its valley have the potential to contain evidence for multi-period episodes of occupation and landscape change, with significant potential for organic and palaeoenvironmental preservation.

10.4.4 The deposits within the Ribble Valley, and indeed, across north Lancashire, contain a significant palaeoenvironmental resource, especially for later prehistory and the historic period, where it has been widely acknowledged that ‘considerable further work needs to be undertaken on environmental analyses, especially on lowland and later deposits that have not been truncated’ (Chitty and Brennand in press, 1.4). Analyses could potentially address changes in river level and river navigability (Philpott and Brennand in press (*Section 3.15*)), long- and short-term palaeoenvironmental change (Brennand *et al* in press), and levels of pollution associated with later industrial development (Newman and McNeil in press).

10.4.5 Period-specific studies have the potential to address the apparent gap in evidence between Cumbria and Cheshire, for both prehistoric and historic periods. In particular, knowledge of Neolithic and Bronze Age religious practice is predominantly reflected in monumental construction, which is not as evident in Lancashire as those areas to the north and south (Hodgson and Brennand in press). The riverine deposits do, however, have potential to contain significant votive or religious deposits, so far unknown north of the Trent. The considerable potential for organic preservation also offers the opportunity for the recovery of material not normally recovered from dry land sites. The nature and depth of the river has implications for the Roman occupation of north Lancashire, alongside potential waterborne access to riverside settlements. An improved understanding of the system of communications between sites at Walton-le-Dale, Ribchester, and Lancaster on the Lune, would have far reaching implications for military traffic, trade, taxation and policing. During the early medieval period the river would have provided access to the Irish Sea, representing a busy and vibrant communication corridor to the western seaboard of Britain, Ireland and beyond. Added to this, the Ribble may have operated as the southern boundary to the kingdom of Northumbria, with both differing styles of stone sculpture and language or dialect on either side of the river (Newman and Brennand in press).

10.4.6 ***Other Areas of Potential Extraction in the County:*** the Kirkham moraine has been highlighted by this study as an area that has substantial reserves of sands and gravels (*Section 10.2.2*). The moraine lies to the south of the extensive Fylde wetlands, and settlement activity seems to have been concentrated on these better drained areas. It therefore has a relatively high density of archaeological remains from all periods. In particular, the area has been described as ‘one of the most dense areas of Neolithic and Bronze Age activity in the North West’ (Middleton 1996, 96), although this in no small way reflects the extensive fieldwalking by the North West Wetlands Survey (Middleton *et al* 1995). Concentrations of prehistoric sites were found particularly west of Kirkham, where a concentration of arable cultivation in the area allowed the recovery of artefacts from ploughsoils (Middleton 1993); other areas of permanent pasture are, of course, less receptive to non-invasive fieldwalking.

10.4.7 The prehistoric dataset from the area includes stone and flint tools and waste flakes, metalwork and organic evidence, such as the famous Palaeolithic elk found at Poulton-le-Fylde. The elk was found in peat (Hallam *et al* 1973), the body having flint points embedded in its leg and ribs, indicating that human hunting groups were present in the area. It has been dated to 13,417-11,769 cal BC (12,400±300 BP; OxA-1500; Jacobi *et al* 1986), and such represents the earliest firm evidence for human activity in the area. Additionally, survey work in the Lytham and Skippool Valley in 1992 has revealed a pattern of Bronze Age activity on the higher boulder clays of the lowland valleys, as well as on well-drained gravelly soils (Middleton 1993). It would appear from their distributions that the early agricultural communities actively sought out gravel ridges in a landscape mainly covered in boulder clay (Middleton 1996, 40).

10.4.8 A series of Roman camps, culminating in a stone-built fort of the second century, attest to a Roman military presence to the west of Preston (Howard-

Davis and Buxton 2000); this was linked to Ribchester and Walton-le-Dale by a network of roads. The possibility of the road continuing to the mouth of the Wyre, as has sometimes been claimed (see discussion in Middleton *et al* 1995), would be crucial to understanding if the *'Portus Setantiorum'*, actually existed there (Middleton 1993). If such a road existed it is likely to have attracted some settlement and the potential for recovering Roman material is high (Middleton 1993). The proven success of LiDAR to pinpoint the line of the Roman road north of Ribchester (and its suitability to show linear features in general) would suggest that this would be an essential tool to address this question.

10.4.9 The extent to which the extensive wetlands acted as a block to settlement in the medieval period is difficult to assess. Certainly the one principal town in the area developed on the moraine at Kirkham, although settlement also developed on the estuarine coast at Freckleton and Warton. The land use, evident from the arrangement of the field systems, reveals considerable antiquity and suggests that there has been a marked continuity of occupation across the area.

10.4.10 The area around Craven in North Yorkshire has also been highlighted as an area suitable for the extraction of hard rock aggregate (*Section 10.2.4*). This area is rich in palaeoenvironmental and archaeological remains (Bartley *et al* 1990) and is a candidate for combined geomorphological and archaeological investigation similar to the Kirkham moraine. It is therefore recommended that a programme of investigation should take place, should permission be sought for extraction.

10.4.11 ***Mitigation Strategy*****:** if the areas discussed above should be subject to aggregate extraction, it is clear (*Sections 10.4.1-6)* that the potential for disturbance of archaeological remains would be substantial, and that a programme of archaeological investigation would be required to establish the character of the resource and the extent to which it would be impacted on by extraction. A programme of archaeological investigation would need to characterise and map, using a GIS, the County's historic environment resource in relation to areas of past, present and potentially future extraction of sand and gravel. Through this mechanism the County's capacity to manage the impact of aggregate extraction on the historic environment would be improved. Such work should:

- validate and enhance the Historic Environment Record (HER) in relation to areas of sand and gravel extraction;
- enhance an understanding of the palaeoenvironment in areas that are likely to be affected by aggregate working;
- define the threat to geoarchaeology and historic landscapes and model risk from aggregate extraction, river change and flooding;
- and, using the baseline data map the historic environment's sensitivity to change from aggregate extraction.

10.4.12 The methodology employed to achieve such outcomes should largely follow that developed in the present project, as this has proven to be a cost-effective way of collating and analysing data. GIS techniques are clearly integral to any such strategy, allowing the integration and analysis of a wide spectrum of data sources (documents, maps, HER, aerial photographs, LiDAR and limited ground truthing). HLC enhancement should also result, providing a management tool for future planning.

10.4.13 A certain level of statistical work should also be undertaken to establish whether or not any common environmental parameters are identifiable. If this is the case, then areas could be highlighted as requiring higher levels of monitoring based on the likelihood of further, unknown sites in the vicinity. If this approach did not prove appropriate, or provide useful results, then a more qualitative approach could be undertaken.

10.4.14 This work should concentrate on the more sensitive, fragile and less-visible monuments rather than extant, robust known sites. In actuality, this would mean concentrating less on post-medieval sites, that are much more likely to be known and visible, and more on the sites of earlier periods.

10.5 MANAGEMENT RECOMMENDATIONS

10.5.1 No further work is needed in advance of extraction that has already gained consent in the Lower Ribble Valley, beyond the conditions already in place as part of the planning process. However, if proposals for further work are submitted in the future, it is recommended that archaeological, palaeoenvironmental and geomorphological input is sought. A programme of test-pits and field assessment should be undertaken that could operate in parallel with pre-extraction testing undertaken by the aggregate company. While, this would determine the character and depth of any deposits, it would not provide a comprehensive assessment of any archaeological remains at this stage. A programme of radiocarbon dating should also be undertaken to establish the formation dates of the deposits, which would establish whether or not the deposits pre-dated any possible human activity within the area and thus would inform the need for further archaeological input during the course of the extraction programme.

10.5.2 Depending on the results of this process, archaeological evaluation trenching, to a depth of up to 4m, may be required to provide a more informed judgement of the archaeological remains within the area, and to investigate the possibility of deeply buried remains, that are likely to be of prehistoric date. Due to the possible depth of any remains, and intermixing with overlying ‘natural’ fluvial deposits, it is clear that standard evaluation techniques would not be appropriate, as it is standard practice to limit the depth of evaluation trenches to the depth of the natural subsoil. Thus it is possible that conventional archaeological evaluations in the Lower Ribble Valley may have provided misleading information on the whereabouts of prehistoric remains.

10.5.3 Where such pre-extraction evaluation identified important archaeological, palaeoecological and geomorphic sites, a pre-defined programme of investigation may be necessary as part of the mitigation strategy, including palaeoecology, radiocarbon dating, and preservation of archaeological remains. During the extraction process, a programme of field monitoring should be undertaken during site preparation and removal of overburden, as this is the most likely zone for archaeological remains to be discovered. Continued episodic monitoring should be undertaken during each phase of quarry extraction.

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