EVALUATING AND ENHANCING THE GEOARCHAEOLOGICAL RESOURCE OF THE LOWER SEVERN VALLEY

Robin Jackson, Andrew Mann and Tony Roberts

With contributions by Tony Brown, Christopher Bronk Ramsey, Gordon Cook, Andy Howard, Mark Kincey, John Meadows, Elizabeth Pearson and Phil Toms

Illustrations by Carolyn Hunt

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Historic Environment and Archaeology Service,
Worcestershire County Council,
Woodbury Building,
University of Worcester,
Henwick Grove,
Worcester WR2 6AJ

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Part 1 Project summary

'Evaluating and enhancing the geoarchaeological resource of the Lower Severn Valley' (The Severn Geoarchaeology Project) is an English Heritage Aggregates Levy Sustainability Fund supported project which has been undertaken with the primary aim of improving the methodological approaches and baseline information for this river valley. Effective approaches and good information are seen as essential in this environment as they underpin strategic planning and individual application decisions relating to widespread mineral extraction in this area, as well as evaluation and mitigation strategies designed in response to these. In particular the project has identified the high potential of LiDAR derived digital terrain modelling to cost effectively map landform units (terraces, alluvial deposits, palaeochannels, etc) and cultural features within a GIS environment, whilst also demonstrating the potential of both Optical (OSL) and radiocarbon dating programmes in advancing understanding of chronological development of the valley floor.

Information derived from the approaches used and developed by the project has identified new features and enhanced understanding of known features of potential archaeological interest within project study areas. Together with existing information, the newly mapped resources highlight the potential of using a wide range of information sources within a GIS environment to develop predictive models for assessing the likely archaeological resource of any given area. The regular application of these techniques is therefore recommended for use in the management, selection and exploration of areas and individual sites proposed for mineral extraction in this river valley.

The defined project area encompassed both active, and anticipated, areas of large-scale extraction of aggregates along a 50km stretch of the Lower Severn Valley, from Stourport to below Gloucester (Fig. 1). Within this area, a pilot programme of mapping and modelling was undertaken which sought to begin to redress the historic lack of geoarchaeological and palaeoenvironmental research in the Lower Severn. Such understanding is essential to fully elucidate, explore and effectively manage the associated cultural landscape, the prehistoric and Roman aspects of which are 'masked' by alluvium across wide areas of the valley floor.

A number of ALSF projects completed elsewhere have sought to understand the geoarchaeological and chronological development of large river valleys (for example the Trent Valley, Till-Tweed and Ribble Valley projects; Carey *et al* 2006; Howard *et al* 2008; Challis *et al* 2008; Chiverrell *et al.* 2008 and Passmore and Waddington 2009). These systems are characteristic of highly mobile, gravel-bed rivers, however, in contrast, the Severn is different because it has remained relatively stable within its floodplain and been dominated by the vertical accretion of fine grained sediments, with movement possibly restricted to channel avulsion. Therefore, the Severn offered the potential to develop a new model for the evolution of such systems and the testing of techniques that have been successfully developed for other river catchments, which are not necessarily effective or applicable to rivers like the Severn.

Two pilot areas were selected at Frampton-on-Severn, Gloucestershire and Clifton, near Severn Stoke, Worcestershire. These provided contrasting elements of the Severn floodplain and associated terraces; Clifton being representative of the relatively narrow buried/alluviated floodplain of the upper reaches and Frampton-on-Severn of the wider gravel island and well developed terrace environment of the lower reaches. The project especially focussed on testing those techniques which have proved most effective elsewhere and were therefore felt most liable to be applied within the development control process in the Severn Valley.

The principal technique tested was the use of LiDAR derived, digital terrain modelling to map landform units and cultural features within a GIS environment the potential value of which for archaeological prospection is now widely recognised (English Heritage 2010). A total of 94 landform units, 60 previously unrecorded cultural features and enhanced understanding of a further 12 sites resulted, thus demonstrating the considerable benefits of undertaking such mapping within the Severn Valley. It was, however, noticeable that the benefits were considerably greater in the Worcestershire pilot than in the Gloucestershire one and this almost certainly reflects the greater thicknesses and extents of alluvium present in the latter. Additionally the Gloucestershire pilot study area was located near the confluence of the Frome and Severn and thus less clarity might be expected here. Lastly this area was also characterised by the presence of very extensive areas of medieval ridge and furrow earthworks which in themselves will have a masking effect on earlier features.

Landforms identified primarily comprised terrace units, terrace edges, alluvial accumulations, and palaeochannels whilst cultural features mainly comprised surviving earthworks relating to cultivation (ridge and furrow), watermeadows and other water management features but also included a number of enclosures, building platforms and settlement features. The landforms were subsequently correlated with data derived from existing sources such as Historic Environment Records (as well as the newly identified cultural features) to provide better understanding of the likely archaeological resource present within these areas. Such data has the potential to improve predictive modelling for use in strategic decision making and in identifying which prospection techniques might be most appropriately employed when evaluating or mitigating future mineral (and other) development applications.

Other approaches to mapping and enhancing understanding of landform units were also successfully tested such as the use of historic map analysis in identifying and tracing palaeochannels with high palaeoenvironmental potential. A rapid, cost effective and largely desk-based methodology for assessing this potential was also trialled and identified 25 areas within the two study areas that have high potential for the preservation of organic remains which may be suitable for palaoenvironmental analysis. An approach to the integration of environmental data into HERs developed by WHEAS was extended to into a pilot area in Gloucestershire, demonstrating the potential of making this information available though the HER as both a planning and research resource.

The mapping programme undertaken was accompanied by a two strand programme involving the testing of the use of both Optical (Optically Stimulated Luminescence; OSL) and radiocarbon dating in developing chronologies for the landform units. Optical dating was demonstrated to be effective in dating both gravel terrace and alluvial units, providing a series of age estimates which, although accompanied by analytical caveats, were on the whole consistent with their relative stratigraphic positions. Whilst anticipated ages were achieved for most of the units investigated, a series of four dates from terrace deposits at Ball Mill, Grimley, nr. Worcester provided a major disagreement with the existing understanding of the terrace chronology. These deposits, mapped by BGS as Terrace 4 (Kidderminster) and forming part of the Holt Heath Member as recognised by Maddy *et al.* (1995), dated into MIS5a-d (early Devensian) as opposed to the anticipated MIS2 (late Devensian); thus demonstrating the importance of undertaking such dating programmes to underpin terrace chronologies. Further importance lies in the fact that at the previously estimated date these deposits were assessed to have very low archaeological and Quaternary research potential (Buteux, Keen and Lang 2005, 37) but at this revised date they could theoretically contain Middle or Upper Palaeolithic stone tools. Consequently, the use of single grain Optical dating approaches to the dating of sand and gravel units anticipated to be associated with Severn Terraces 1 and 2 is recommended as a result of this work, whilst use of two or ideally three samples from each unit to be dated is recommended to improve assessment of the reliability of dating.

The results of a programme of radiocarbon dating of organic deposits from a palaeochannel appear to validate the OSL age estimates previously obtained from the alluvial sequence within which the palaeochannel was located. These also indicated that greater reliance should be placed on the dating of identified terrestrial plant macrofossils rather than bulk organic sediment samples in order to obtain the most reliable chronology for organic-rich palaeoenvironmental sequences. The results suggest two phases of accumulation at this location, in the late third millennium BC and the first millennium AD.

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The current ALSF cycle (2008/9 to 2010/11) provided a potentially unique opportunity for the completion of this project which was developed as a result of discussions between a project team drawn from the two local authority archaeology services covering this area (Gloucestershire and Worcestershire) along two university departments with specialist expertise in this field of knowledge (at Southampton and Birmingham) supported by the OSL dating team at the University of Gloucestershire.

The project was managed by Robin Jackson from Worcestershire County Council's Historic Environment and Archaeology Service (WHEAS) supported by Toby Catchpole from Gloucestershire County Council Archaeology Service (GCCAS).

The success of the project owes much to the work of the two project leaders involved, Andrew Mann (WHEAS) and Tony Roberts (GCCAS) and input of the specialist support team comprising:

- Dr Andy Howard and Mark Kincey (University of Birmingham) – Geoarchaeology, environmental change and LiDAR analysis
- Professor Tony Brown (University of Southampton) – Geomorphology and geochronology
- Dr Phil Toms (University of Gloucestershire) – OSL dating
- Elizabeth Pearson and Alan Clapham (WHEAS) – Palaeoenvironmental research
- John Meadows (Scientific Dating Team, English Heritage) – Radiocarbon dating and Bayesian modelling
- Carolyn Hunt (WHEAS) - Illustration
- Further important advice and help came from:
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- Victoria Bryant and Emma Hancox (WHEAS) and Tim Grubb (GCC) – HER integration and data structure
- Emily Beales and Richard Axe (WHEAS) – environmental processing

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Part 2 Detailed report

1. Project background

1.1 Introduction

Since the inception of the Aggregates Levy Sustainability Fund in 2002, a number of projects have demonstrated the great value of understanding the evolution of terrestrial English river valleys. Understanding of these valleys is essential to elucidate, explore and effectively manage their associated cultural landscapes which have been, and continue to be, heavily affected by mineral extraction. Such understanding has been considerably developed through the trialling and testing of a range of airborne and ground based remote sensing (LiDAR, IFSAR, Casi, ATM, GPR, ERGI), invasive sampling and geochronological (OSL, AAR, radiocarbon) methodologies which are especially suited to the investigation of river valley landscapes.

This corpus of applied research has all been undertaken in large river valleys such as the Trent and Till-Tweed which are dominated by highly mobile, gravel bed river systems. In contrast, the River Severn, one of the last major valley floors to still hold significant aggregate resources, is somewhat different having remained relatively stable within its floodplain and developed largely through vertical accretion of fine grained sediments.

The Severn Geoarchaeology Project was consequently developed in recognition of the fact that investigative techniques, geoarchaeological mapping and models of development established for other river catchments might not necessarily be effective or applicable within the active gravel extraction landscapes of the Lower Severn Valley (Fig. 1). Investigative techniques and models of development were therefore identified for testing within this particular river valley. This was with the specific intention that successful techniques and models identified might then be reliably and consistently used in the future to underpin archaeological input to regional mineral development frameworks (LDFs), as well as within development briefs and resultant curatorial and commercial archaeological responses to individual aggregate applications.

The importance of such methodological development, and resultant improved baseline information, for the Severn Valley had been demonstrated over several years prior to the project's inception by several instances where PPG16 Assistance had been required to support mitigation work relating to commercial mineral extraction programmes. The provision of consistent, proportionate, readily applicable and evidence-based approaches to archaeological investigation and mitigation is seen as a primary requirement within the *Mineral Extraction and Archaeology: A Practice Guide* (MHEF May 2008), the importance of which is in turn reflected in guidance accompanying Planning Policy Statement 5 (DCLG 2010; DCLG, DCMS and EH 2010, 31).

The Severn Geoarchaeology Project was therefore developed and targeted to help delivery of these approaches within the Lower Severn. Further, this work has generic application to other river systems of similar character found elsewhere in the Midlands and southern England and thus will have use beyond the Severn catchment.

1.2 Frameworks

The Lower Severn Valley is a significant regional aggregate production area with a high aggregate apportionment and tax yield (Brown 2004a; 2004b; 2009) and a recognised high archaeological potential (English Heritage 2004; Mullin 2008; Jackson and Dalwood 2007).

The project represents one of the major outcomes arising from a series of initiatives undertaken within the Severn Valley by a range of stakeholders with particular interests in the archaeological landscapes of this river valley. These initiatives have primarily been supported through the ALSF in recognition of the ongoing, and predicted increasing, impact of aggregate extraction in this area.

These have formed part of a sustained and strategically developed response to gravel extraction within this river valley. This response has been both informed by, and undertaken within, an overall framework identified for ALSF-funded projects in the Severn Valley and Severn Estuary (English Heritage 2004). This has had the aim of informing the continuing development of initiatives within the Severn Valley which are not constrained by political boundaries and which work towards delivery of consistent and well-informed archaeological responses to minerals planning at both a strategic planning level and in respect of individual applications.

Two key ALSF projects, the aggregate resource assessments undertaken for Gloucestershire and Worcestershire (Mullin 2008; Jackson and Dalwood 2007), provide a detailed framework for research within the Lower Severn aggregate producing areas. Both of these, along with the respective regional research frameworks for the West Midlands and South-West regions, highlighted the need for further geoarchaeological and palaeoenvironmental research in the Lower Severn Valley. Additionally, some of the key absences noted in the cultural record within the Severn Valley, and especially those for the prehistoric period (papers in Garwood 2007), were felt to almost certainly result from the limitations of traditional prospection techniques for identifying cultural features within this deeply alluviated valley floor environment. Such observations emphasise the important role that understanding the evolution of the valley floor plays in understanding and investigating the cultural record; an issue highlighted by the recent history of English Heritage PPG16 Assistance grants associated with programmes of fieldwork at Ryall and Clifton Quarries (Barber and Watts 2008; Mann and Jackson 2011; Mann forthcoming). Further, the testing and refinement of methods developed in previous ALSF rounds for modelling fluvial systems, especially within active quarrying areas, had been identified as a potential area for strategic development for the ALSF round within which this project fell (Flatman *et al* 2008).

The Severn Geoarchaeology Project adopted a staged approach to the testing of investigative approaches, which were comparable to those developed in the Trent Valley and its tributaries and managed within a GIS framework (Carey *et al* 2006; Howard *et al* 2008; Challis *et al* 2008), as well as in other river valley environments such as the South-West Valleys Project (Hosfield *et al*. 2006; Brown *et al*. 2010), the Ribble Valley (Chiverrell *et al.* 2008), the Suffolk Rivers Project (Howard *et al* 2009) and the Till-Tweed (Passmore and Waddington 2009). These have been successfully employed by two of the project partners elsewhere in the region, at Wellington Quarry, Herefordshire (Sworn and Jackson 2008; Carey and Howard 2008). The importance of this commercially funded evaluation project and the high potential of the techniques applied has been highlighted within a recent review of archaeological mitigation strategies for the Lower Lugg floodplain (Bapty 2008: PNUM 3336).

Despite this extensive body of research, the resultant models are not readily transferable models for the Severn for the following reasons:

1. The Lower and Middle Severn (below Coalport) terrace sequence only formed in the Middle and Late Devensian (MIS3-2) following the formation of the Ironbridge Gorge. This means that the terraces formed far more rapidly and in a shorter time period than any other terrace sequence in the UK. This must have an influence on their archaeological potential and this project will help define this potential.
2. Partly due to this Late Pleistocene history the terraces and floodplain of the Severn are far more laterally confined than other river valleys, until below Gloucester and this must also have archaeological implications. In particular it may be responsible for high rates of overbank deposition in the Holocene which has caused deep burial of prehistoric land surfaces.
3. The Severn has formed both a routeway and a barrier in a frontier region, a unique geographical aspect unlike any other English river.

For these three reasons, it was considered uncertain whether the models and investigative techniques developed for these other rivers in the UK would be applicable to the Middle and Lower Severn and comparable river systems, especially in the West Midlands. The primary objective of the Severn Geoarchaeology Project therefore lay in determining whether those approaches which have proved most effective elsewhere could be equally successfully employed in the Severn Valley.

1.3 Aims and Objectives

1.3.1 General

The project was a largely desk-based exercise, providing the first phase of a staged approach necessary for the effective use of this suite of techniques. Further, since the dating framework for the Severn Valley is so poorly developed, the opportunity was taken to test and refine potentially applicable dating approaches.

Methods utilised are described in detail below (Section) but in summary comprised:

1. Mapping of geoarchaeological units (terraces, terrace edges, palaeochannels, alluvial units) and cultural features, primarily through use of LiDAR survey data kindly supplied for use by the project by the Environment Agency;
2. Mapping of areas of palaeoenvironmental potential;
3. Testing of the application of OSL dating of terrace units within the Severn Valley; and
4. Exploration of the potential complexity and longevity of palaeochannel fill sequences (resulting from patterns of re-incision and infill within channels) through a programme of radiocarbon dating of associated organic deposits.

Project data and mapping was managed within a GIS framework (ARCGIS 9. ARCMAP Version 9.3), allowing integration and comparison of all newly collected geoarchaeological and cultural data and mapping with that already available within the county HERs (including aerial photographic mapping) and other (specifically from the completed aggregate resource assessments) sources. Landscape Character Assessment (LCA) and Historic Landscape Characterisation (HLC) mapping and data for both study areas were also incorporated and preliminary geochronological models were established for parts of the valley floor. Investigation of the relationship of geomorphological features (landform units) with the known cultural resource and landscape character mapping was also undertaken to improve understanding and support predictive modelling. Lastly, the techniques trialled were evaluated to determine their potential effectiveness.

The broad aims of the project were:

- To fill a significant methodological and knowledge gap in the active aggregate extraction landscapes of the Lower Severn Valley, one of the last major UK valley floors to still hold significant aggregate resources
- To provide considerable benefit to minerals operators in the region by enhancing the quality, consistency and reliability of the baseline data available through the county HERs; data which is used by archaeological planning officers in developing regional mineral development frameworks (LDFs) and determining individual aggregate extraction applications.
- To highlight the archaeological potential and complexity of this poorly understood landscape and support provision of effective, consistent, appropriate and cost efficient evaluation and other mitigation strategies in relation to future aggregate applications. The importance of developing improved and more effective prospection techniques and predictive models has been emphasised in recent years at both Ryall and Clifton Quarries where PPG16 Assistance has been required to support mitigation work relating to commercial mineral extraction programmes.

Stage 1 of the project comprised the production of a Project Design.

Stage 2 of the project comprised the work described in this report. This has focussed on the undertaking of pilot mapping, deposit modelling and dating studies within two contrasting archaeological landscapes at Frampton-on-Severn, Gloucestershire and Clifton, Worcestershire. These were selected with the aim of providing examples of the geomorphological variation in the Lower Severn from the relatively narrow buried/alluviated floodplain of the upper reaches (Clifton) to the wider gravel island and well developed terrace environment of the lower reaches (Frampton).

Both pilot study areas are associated with known significant archaeological deposits and both are subject to ongoing quarrying. They consequently provided the project with highly relevant case studies within which the relationships between geoarchaeological features, archaeological deposits of demonstrable importance and commercially exploitable aggregate resources could be explored. This was with the objective of enhancing the Worcestershire and Gloucestershire HERs and providing feedback and guidance to minerals operators, strategic planning bodies and archaeologists working in this region on appropriate prospection and investigative techniques as well as emphasising the high archaeological potential of these landscapes.

Through presentation of a case study from Wellington Quarry in the Lugg Valley in conjunction with the results of the Stage 2 work, the project also had the aim of highlighting the potential of those elements of the prospection 'toolkit' which have been tested in the Severn Valley as well as presenting an example of the overall 'toolkit' being successfully employed in the region within a development-led environment.

Potential further stages for the project (for which a funding source has yet to be identified), have been outlined within this report and are envisaged to encompass extension of the mapping and deposit modelling beyond the pilot study areas and further development of the prospection ‘tool kit’ through the testing of applicable field techniques. This would be undertaken with the aim of providing mapping and deposits modelling for the whole of this aggregate producing area and ‘ground truthing’ and enhancing models developed though the mapping work and further ‘sharpening’ prospection techniques.

1.3.2 Aims

The project had two overarching aims:

- To increase the geoarchaeological understanding of the aggregate producing landscapes of the Severn Valley; and
- Through the testing of a range of prospection techniques which have proved especially effective in other river catchments to provide a 'toolkit' which will increase the effectiveness of archaeological mitigation strategies within the particular environment of the Severn Valley.

Further aims were identified and linked to EH Corporate Objectives as follows:

- A1. Improving baseline information (EH Objective 1A Research programme A1)
- A2. Developing new approaches (EH Objective 1D, research programme D1 and research within the Severn Valley as well as further afield.
- A3. Communicating information and providing guidance and training (EH Objectives 4A-C)
- A4. Providing accessible information and supporting sustainable management (EH Objective 1C and 1D)
- A5. Supporting research frameworks (EH Objective 1A; research programme G2).

1.3.3 Objectives

To ensure that these aims could be fulfilled, a number of specific objectives were identified:

- O1. To establish historical, geological, landscape character and archaeological base mapping for the whole of the Lower Severn aggregate extraction area (as defined by the completed aggregate resource assessments for the two counties) within a project GIS;
- O2. To update and enhance this dataset with important new information from ongoing and recently completed archaeological projects within two defined pilot study areas (at Frampton and Clifton);
- O3. To undertake site visits to the pilot study areas to familiarise the Project Team with these areas and establish potential sampling locations for the OSL dating;

- O4. To develop and extend the addition of environmental data drawn from grey literature and other sources into the Gloucestershire pilot study area as a specifically searchable and accessible dataset. This also ensured that consistent and accessible baseline environmental data was available to the project and that the value of mapping such data within HERs was highlighted;
- O5. To develop, and undertake appropriate training in, a methodology for the mapping and interpretation of geoarchaeological features (landform units) from LiDAR derived data and comparable to that already developed for the mapping of cultural features by the two county units (itself based on approaches used by the NMP);
- O6. To derive topographic models (DSMs) of the two pilot study areas using LiDAR data (secured on licensed from the Environment Agency), and through subsequent analysis of the DSMs to undertake mapping and preliminary interpretation of terraces, palaeochannels, and other geomorphological (landform) units along with any visible cultural features;
- O7. To map and undertake desk-based assessment of features/landform units with high palaeoenvironmental potential within the two study areas using historic OS mapping and other sources;
- O8. To undertake ‘ground truthing’ and enhancement of the desk-based mapping through field visits to the two pilot study areas;
- O9. To collect and undertake a preliminary dating programme on samples from the current working pits and their environs within the two study areas. This included testing of the application of OSL to the dating of terrace units and due to a shortfall in available sample locations required sampling of deposits at a third site.
- O10. To collate, compare, assess and briefly describe all resources within the project GIS for the two pilot study areas and explore the potential relationships between the geoarchaeological, palaeoenvironmental, cultural and landscape character data available as well as identifying potential knowledge ‘gaps’ or ‘conflicts’ in understanding;
- O11. To assess and evaluate the potential uses and research value of the derived mapping, deposit modelling and other investigative techniques trialled within the two pilot study areas and enable specific recommendations to be made regarding an effective and readily applicable prospection 'toolkit' within the Severn Valley and other comparable systems in both research and commercially driven projects;
- O12. To compile a report for submission to English Heritage describing project methods, results and outputs and including presentations of recommendations arising from evaluation of the applications tested;
- O13. Through articles in stakeholder magazines and other presentation formats, to provide information, feedback and guidance to HERs, minerals operators and other stakeholders on the outcomes of the pilot mapping and modelling work in order to highlight the application and potential effectiveness of the prospection techniques tested in investigating the landscape of this river valley; and to raise awareness of the distinct character and archaeological potential of the mineral producing areas of the valley;
- O14. To edit the report following English Heritage feedback and deposit the archive with the HERs and the ADS: comprising project report, GIS mapping (landform units and cultural features), geoarchaeological and palaeoenvironmental modelling and accompanying explanatory and interpretative text derived from the pilot study areas.

Objectives for future research are outlined in Section 7.

1.4 Scope and project parameters

1.4.1 The current project

The project was completed during the period September 2009 to January 2011 and focussed on the mapping, modelling and investigation of geoarchaeological and palaeoenvironmental deposits using a range of sources and techniques. This work was undertaken within a broadly defined study area covering the Lower Severn Valley from Stourport in Worcestershire to below Gloucester (Fig. 1). Within this stretch of the river valley and its tributary terraces (e.g. Frome, Worcestershire Avon and Teme), investigations were restricted to aggregate extraction areas as defined within the relevant aggregate resource assessments for the two counties (Mullin 2008; Jackson and Dalwood 2007).

Application and trialling of the project methodology was largely undertaken within two pilot study areas selected within this wider area, at Frampton-on-Severn, Gloucestershire and Clifton, near Severn Stoke, Worcestershire. A third quarry site at Ball Mill, Grimley, north of Worcester, was also included during the course of the project as part of the OSL dating programme due to a shortfall in suitable exposures within the two study areas.

Data derived from airborne remote sensing provided a key component of the project and the chosen method was through use of LiDAR. Other methods such as Casi and IFSAR were considered but, although their potential use is acknowledged, these were not employed during this project as LiDAR was felt to be the most cost effective, accurate and productive technique available at the present time. Certainly with respect to Casi hyperspectral data, off the shelve products were not available and would have required additional data acquisition.

The project identified a range of components (landform units) of the geoarchaeological and palaeoenvironmental resource and only selected deposits (units) and areas were identified for further investigation to test techniques and ‘ground truth’ mapped components of the resource and meet project aims and objectives. Components of the geoarchaeological and palaeoenvironmental resource which extended beyond these defined project study areas were noted for future reference but were not formally mapped or modelled. Cultural features identified were also recorded, mapped and described, and this information was accessioned to the county HERs but no further investigation of these was undertaken.

It is recognised below (Section 1.4.2) that 'ground truthing' and further investigation of landform units using a range of subsurface investigative techniques (GPR, ERGI, etc) can form important essential and associated elements of any prospection 'toolkit' for such features.

Project outputs take into account the 'case study' noted above at Wellington Quarry in the nearby Lugg Valley, which provides a valuable example of the application of the prospection 'toolkit' within the commercial sphere; both emphasising the practical application of the 'toolkit' within the development control process as well as highlighting the use of certain other techniques, which were not trialled at this stage of the current project.

Lastly, whilst investigation undertaken as part of the project has encompassed active quarrying areas, the project has not in any way replaced or underwritten the existing obligations of the quarry operators as required through the planning process; although indirect benefits may result to the investigation and understanding of the archaeological resource as revealed within these areas as part of agreed mitigation strategies and/or to future extraction proposals.

1.4.2 Future options

Further project stages, whilst not likely to be realised in the near future (due to funding constraints), are envisaged to incorporate extension of the geoarchaeological mapping programme to cover the entire Lower Severn. Additionally, a greater range of applications should be tested to 'ground truth' the mapped data and thereby better evaluate and enhance this information and provide a more robust and complete 'toolkit'.

This could include, for example:

- ERGI and GPR terrestrial remote sensing survey and gouge coring to test and enhance geomorphological mapping;
- Confirming the presence/absence of mapped palaeochannels through coring;
- Assessing the survival of palaeoenvironmental deposits in palaeochannels and where present sampling of any organic material which could be used for radiocarbon dating and/or palaeoenvironmental reconstruction (using palynology and other microfossil and macrofossil analyses); and/or
- An extended programme of OSL and radiocarbon dating of terrace and palaeochannel sequences.

1.5 Outputs

Apart from this report, three short articles are intended for publication in order to reach a wider audience and 'signpost' the presence of project outputs on the Archaeology Data Service (ADS) website as well as the availability of the project mapping through the Worcestershire and Gloucestershire HERs.

2. Description and definition of the study areas

2.1 Main project study area

The main project study area covered the Lower Severn Valley from Stourport to below Gloucester. This encompasses the lowest currently non-tidal reach and the upper part of the tidal reach and is 52 km in length (Fig. 1). The area was extended outwards (2-5 km) from the main channel and floodplain to cover all the main valley terrace gravels and other gravel outliers (e.g. patches of glaciofluvial gravel); it therefore includes the aggregate extraction areas of the Lower Severn as defined within the completed aggregate resource assessments for the counties of Gloucestershire and Worcestershire (Mullin 2008; Jackson and Dalwood 2007).

The study of tributary terraces (*e.g.* the Frome, Avon and Teme) was included and particular attention was paid to confluence areas as these have both a high potential for sediment preservation and high attraction for humans in the past. There is considerable aggregate extraction in the area (*c.* 9 active quarries) and much of the area is zoned for possible future extraction (Worcestershire MLP; Gloucestershire MLP; Brown 2009).

2.2 Pilot study areas

Two study areas were selected within the main study area from the outset to pilot mapping and application of a suite of investigative techniques; at Frampton-on-Severn in Gloucestershire and at Clifton in Worcestershire. Both are subject to active aggregate (sand and gravel) extraction and were chosen to be contrasting and representative of the geomorphological variation in the Lower Severn, from the narrow buried/alluviated floodplain of the upper reaches to the wider gravel island and well developed terrace environment of the lower reaches.

The association of both pilot study areas with well-researched cultural deposits meant that they also provided good case studies for examination of the relationships of the mapped geoarchaeological (landform) units and palaeoenvironmental resources with cultural remains.

During the course of the project a shortfall in appropriate sand and gravel exposures within the active quarries in these pilot study areas meant that, to enable the OSL dating pilot to be fulfilled, a third site at Ball Mill Quarry, Grimley in Worcestershire was also used, though only for this aspect of the project.

2.2.1 Frampton-on-Severn

The study area at Frampton-on-Severn is located to the south of Gloucester on a spread of gravel immediately below the confluence of the River Frome with the Severn (Fig. 2). The study area covers 16km², measuring 5km wide (maximum east to west) and 4kms long (north to south) encompassing a representative extent of alluvium, terraces and river at this point.

The area has been heavily exploited for aggregate extraction since the 17th century (Elrington and Herbert 1972, 139) and a considerable body of significant archaeological information is available from the area. Recently completed work undertaken by GCCAS has examined the archive material from Atkinson's 1940s excavations at Netherhills Quarry alongside several museum collections including material from other local quarries at Perryway and Eastington (ALSF projects 4625/5171; Mullin in press). In parallel with this examination of the archive material from the Frampton-on-Severn area, aerial photographs were transcribed for the area to NMP standards.

Together with the results of fieldwork undertaken in January 2007 to the south of the area excavated by Atkinson (within the Netherhills Quarry), this has revealed important evidence for prehistoric activity, spanning the Neolithic and the Bronze Age, as well as later features to build a picture of the prehistoric, Roman and Anglo Saxon exploitation of the Frampton-on-Severn area (Fig. 3) including:

- Palaeolithic and Mesolithic flints which provide the first evidence of activity of this date from the Severn Vale in Gloucestershire (Fig. 3:1);
- A later Neolithic pit and evidence for Beaker period activity recorded during the GCCAS 2007 fieldwork at Netherhills along with other Neolithic and Beaker activity represented in the Atkinson archive. These probably indicate the presence of a series of Neolithic and Early Bronze Age pits and cremation burials in the area (Fig. 3:2);
- A series of ring-ditches constructed in the Bronze Age, including one which might have been constructed over an earlier pit. Together these form the only known round barrow cemetery in this part of the Severn Valley; the only other comparable site in the valley in England being the five ring-ditches excavated in advance of gravel extraction at Holt, Worcestershire (Hunt *et al.* 1986), within the intensely quarried area now focussed at Ball Mill (Fig. 3:3);
- A Bronze Age 'hengiform' enclosure as well as one Iron Age and several Romano-British burials and other activity evidenced at the Netherhills Quarry, the location of which may have been influenced by the barrow cemetery (Fig. 3:4);
- Roman rural cemeteries at Eastington and Perryway, both probably associated with nearby settlements (Fig. 3:5);
- Material of Anglo Saxon date, including a loom weight and bone objects from Eastington Gravel Pit were identified in the archives at Stroud Museum, along with a single human skeleton. No dating evidence is available for the latter, and, although other skeletons were recovered from this quarry during extraction in the 1930s (Gardiner 1932) none of these survive in the archives (Fig. 3:6);
- Extensive areas of ridge and furrow (Fig. 4).

2.2.2 Clifton

The study area at Clifton, Severn Stoke, Worcestershire, lies in a westwards meander of the River Severn some 9km south of Worcester. The study area measures 3km wide maximum (east to west) and 6kms long (north to south) encompassing the full extent of alluvium, terraces and river at this point and taking in both a broad meander as well as a more constrained cross-section to its north and south (Fig. 5).

A single, active major quarry, Tarmac's Clifton Quarry, lies within the study area which for the most part comprises low lying agricultural land used for both pasture and arable. The entire area is subject to flooding at times throughout the year with recent major floods recorded in both winter and summer months. Apart from the Severn, a number of smaller streams and low lying areas provide broad north to south drainage alignments, linking into the Severn towards the base of the meander. These depressions and the areas flanking the main river channel are occupied by alluvium which is of variable thickness. In two cases, palaeochannels and peat deposits (one of which is the focus of a SSSI) have been recorded in these areas which are separated by elongated ridges of sand and gravel of the Severn second terrace.

A considerable body of significant archaeological and palaeoenvironmental information is available from the study area and derives in the main from programmes of excavation, salvage recording and watching brief mitigation work undertaken in advance of, and alongside, gravel extraction (Fig. 6; PNUM 5379 and PNUM 5714; Mann and Jackson 2009; Mann forthcoming). Investigated deposits comprise a range of nationally, regionally and locally significant remains including:

- Late Neolithic pits (below alluvium), including nationally significant charred plant remains assemblage (barley and crab apples) (Figure 6:1);
- Middle Bronze Age burnt mound and associated features (below alluvium) (Fig. 6:2);
- A major Early Iron Age settlement on the Worcester Terrace (Fig. 6:3);
- An extensive complex of Late Iron Age and Romano-British settlement enclosures on an area partially mapped as alluvium – although the results of a geophysical survey and large quantities of finds of Roman date appear to indicate that this site probably occupies higher ground on the western limits of Terrace 5) (Fig. 6:4);
- Early medieval flax retting pits (below alluvium) (Fig. 6:5);

Palaeochannel deposits associated with one or more former channels of the Severn dating from the Late Mesolithic through to Early Bronze Age.

Of these the Early Iron Age, Late Iron Age and Romano-British settlement areas and a palaeochannel were identified during evaluation. However, the presence of the Neolithic pits, burnt mound and early medieval flax retting pits buried below alluvium was not established while the full extent and significance of the Early Iron Age settlement was not defined. As a result two of the stages of the required mitigation programme undertaken to date have required contingency salvage recording during watching brief works and due to the significance and unexpected quality of deposits recorded have since received PPG16 Assistance funding in support of their post excavation programmes (PNUM 5379 and PNUM 5714; Mann and Jackson 2009; Mann forthcoming).

Further, during recent (2008) flooding, complex palaeochannel fill deposits relating to at least two separate episodes of channel incision were exposed in a collapsed and eroded quarry margin. These indicate that the channel sequence sampling approaches used in many comparable studies and based on dating of top and bottom samples derived from organic channel fills (and particularly from borehole sampling) are liable to be overly simplistic. Whilst this has been recognised in many project outputs, it is felt that for the current project (since these deposits were recorded and sampled - monolith and bulk samples) an opportunity is available from the outset to explore the potential complexity and timeframe over which these channel incisions and infill deposits were developed and highlight the need for carefully designed and well-resourced dating strategies.

These discoveries emphasise both the very high archaeological potential and complexity of the valley floor deposits and the considerable difficulties in designing and undertaking effective evaluation and mitigation strategies within this landscape despite the availability of information derived from aerial photography and other HER data, from previous palaeoenvironmental studies in the immediate vicinity (Brown 1982; 1983) and from completed phases of evaluation and mitigation at the quarry (Miller, Darch and Griffin 2001; Vaughan 2005; Head 2005; Head 2007).

2.2.3 Ball Mill Quarry, Grimley

The additional study site selected at Ball Mill Quarry, Grimley, Worcestershire, lies on the west bank of the River Severn some 6km north of Worcester (Fig. 7).

This an active quarry (Ball Mill Quarry: Church Farm West) located on the Third (Main) Terrace of the Severn within an area which has been subject to extensive quarrying since at least the 1960s (Jackson and Dalwood 2007).

Investigated deposits within this quarrying area comprise a range of nationally, regionally and locally significant remains including:

- Late Neolithic to Beaker period deposits;
- Early Bronze Age ring-ditches and associated funerary activity;
- Extensive complexes of Iron Age and Romano-British settlement enclosures and field systems (Dalwood and Jackson 2007).

3. Methods and development of techniques

3.1 Project GIS and establishment of baseline data

A project GIS (using ARCGIS 9, ARCMAP Version 9.3) was established incorporating digital data and base mapping for the main study area. Data was derived directly from the Gloucestershire and Worcestershire HERs and based upon the aggregate extraction areas within the Severn Valley as defined for the completed aggregate resource assessments for these two counties. This provided baseline archaeological, geological, drift and historic mapping and associated data for the entire project.

The following base mapping was obtained for the main study area:

- Modern OS (@ 1:50,000 and 1:10,000);
- Historic OS (1st edn);
- Geology;
- Drift;
- Soils.

For the pilot study areas at Frampton-on-Severn and Clifton the following base mapping was added:

- HER data (including AP mapping);
- Selected tithe and enclosure plans;
- Historic Landscape Characterisation (HLC) and Landscape Character Assessment (LCA) data.

Aerial photographic mapping for the 2 pilot study areas used:

- for the Frampton-on-Severn study area, NMP completed mapping; and
- for the Clifton study area, scanned and geo-referenced AP transcriptions (as used by the Worcestershire Aggregates Resource Assessment) as well as independently transcribed mapping kindly made available to the project by Mike Glyde.

All base mapping was combined within a single GIS a copy of which was maintained by each county for the duration of the project.

A considerable amount of important archaeological data was available for both pilot study areas which was not available at the time of undertaking the Aggregate Resource Assessments for the two counties and this was extracted from the HERs and/or added to them. This ensured data used was fully up-to-date at the time of project.

New mapping created for the two counties was restricted to the two study areas. This was separately layered and maintained by the respective County based teams within a copy of the GIS in order to enable the work on both pilots to run in parallel. This has also facilitated deposition of the project archive within the respective HERs.

3.2 LiDAR Mapping

3.2.1 LiDAR Mapping methods: Introduction

Methodologies have been developed elsewhere for the mapping of both cultural features and geomorphological/landform units from LiDAR data derived Digital Surface Models (DSMs; see for instance Challis 2004 and English Heritage 2010).

LiDAR data is collected by an aircraft mounted laser, most often a pulse laser working at rates in excess of 30 MHz, projects a coherent beam of light at the ground surface, the reflection of which is recorded by a sensitive receiver. Travel times for the pulse/reflection are used to calculate the distance from the laser to the reflecting object. To enable coverage of broad areas, a swath beneath the moving aircraft is scanned by using rotating mirrors to direct the laser. The spatial resolution and scan swath width are determined by the frequency of the laser pulse and altitude of the aircraft at the time of survey. Typically, the receiver is able to record multiple returns for a single pulse, allowing recording, for example, of a partial return from the top of a semi-opaque object such as a woodland canopy (usually referred to as a first-pulse (FP) return) and from the opaque ground beneath the canopy (a last-pulse (LP) return). Other information, such as the intensity (amplitude) of the reflection may also be recorded.

LiDAR derived topographic models have been shown to be clearly superior in resolution to models based on other data sources (such as NextMAP and OS Profile data) through a number of surveys (*e.g.* Smith *et al.* 2006). This reflects the relatively fine spatial resolution (at least 2.00 x 2.00m) and vertical accuracy (*c.* 0.15m) of the LiDAR data in comparison with other sources.

3.2.2 LiDAR Mapping methods: Project application

3.2.2.1 *Data sources, processing and mapping approaches*

Full coverage was available from the Environment Agency (EA) of both pilot study areas at 2.00 x 2.00m resolution with higher resolution data (1.00 x 1.00m) for some parts of the survey areas (15% of the Clifton study area; 50% of the Frampton study area). This was kindly made available by the EA free of charge on licence to the project.

Training was provided at the VISTA centre at the University of Birmingham in the processing and use of LiDAR data to produce DEMs and in the method of enhancing and manipulating the resultant DEMs (and sub-sets of data) within the GIS to highlight topographical variations revealed (*i.e.* geomorphological/landform units and cultural features). Training was led by Mark Kincey and based upon methods developed within the Trent Valley by members of the current team (PNUM 3307; Challis 2004; Baker 2006, 2007).

Assessment, analysis and mapping for the two pilot areas was subsequently undertaken by the Project Officers drawn from the county units who as far as possible worked in parallel, thus ensuring that decisions on minor methodological adjustments required or additions identified could be jointly made in consultation with the Senior Project Manager and Expert Team.

The LiDAR data supplied was processed to generate first pulse and last pulse DSMs and DTMs. The former (Digital Surface Models) provide a digital elevation model of the land surface, recording the highest points including trees and buildings, whilst the latter (Digital Terrain Models) provide a digital elevation model of the bare earth with trees and building removed.

The DSMs and DTMs were subsequently processed to create hill-shade models that were lit from 8 different directions at the same elevation. Mapping was completed by 1km² tile. Landforms and cultural features identified on the LiDAR were digitised on layers within the GIS thus allowing transfer at the end of the project to the respective HERs as shape files. A single unique number was used to identify each digitised point, polygon or line regardless of the actual number of LiDAR features this represented. The location of each feature was also recorded within the corresponding GIS layers attributes including the relevant OS 1km grid square and its centroid coordinates. The centroid elevation of each unique identified feature was also recorded.

The transcriber was responsible for ensuring that the numerical series for each study area was maintained and where features were found in more than one square; *e.g.* where linear features or large areas were mapped as polygons the transcriber assigned the grid square in which the centre point of the feature was located.

3.2.2.2 *Mapping geomorphological features (Landform Units) from LiDAR*

Specific approaches, standards and mapping conventions for geomorphological features for the Severn project were developed by the Birmingham University Team in consultation with other project partners (and were based on criteria already agreed with English Heritage monitors for various Trent Valley projects). These were developed within a similar methodological framework to that used for mapping of cultural features (see below) and also within the overall framework utilised for mapping landscape features (as employed within HLC projects). The overall aim was to produce a simple and relatively rapid approach to this task which did not require a high level of geoarchaeological knowledge; thereby making the approach both cost effective and as accessible as possible. In the longer term it is hoped that the approaches used for this project for mapping geoarchaeological features from LiDAR could be developed as a standard ‘toolkit’ for use in a comparable manner to the NMP standards and conventions used to map cultural features.

Analysis of the LiDAR Digital Surface Model (DSM) data was undertaken for both pilot study areas to extract (to map and assess) significant landscape features such as terrace edges and 'morphological' palaeochannels from the DSM. Approaches, standards and mapping conventions used for transcribing and recording geomorphological features are described in detail in Appendix 1.

Information about each geoarchaeological landform unit was collated within the GIS (through Attribute tables) and each newly mapped feature was cross-checked and compared with other sources of information within the GIS such as air-photographs, other remotely sensed data, HER data and landscape character mapping to improve the reliability and quality of the mapped data.

3.2.2.3 *Mapping cultural features from LiDAR*

The effectiveness (in terms of time, cost and accuracy) of LiDAR for recording cultural features surviving as earthworks has also been widely recognised and demonstrated in other river valley surveys (Challis 2004, 51, 56; Brown et al 2005, 192; Challis 2006; OA North and University of Liverpool 2007; MHEF 2008).

For cultural mapping the project utilised methods and standards developed by GCC within their Forest of Dean Survey Project (PNUM 4798) for use in mapping cultural features from LiDAR derived DSMs. This methodology has been further developed by WCC within a Forestry Commission sponsored project covering the Wyre Forest. No further methodological development was necessary and the approach taken is summarised below.

Analysis of the LiDAR Digital Surface Model (DSM) data was undertaken to identify cultural features such as watermeadow systems, flood defences, other water management features, ridge and furrow, field systems and former settlement areas. Approaches, standards and mapping conventions used for transcribing and recording cultural features are described in detail in Appendix 2.

Information about each cultural feature identified was collated within the GIS (through Attribute tables) and each newly mapped feature was cross-checked and compared with other sources of information within the GIS such as air-photographs, other remotely sensed data, HER data and landscape character mapping to improve the reliability and quality of the mapped data.

3.3 Chronological modelling

3.3.1 Introduction

Both an OSL pilot and a radiocarbon dating programme were undertaken to help define appropriate dating ‘toolkits’ for use in mitigation strategies within the Severn Valley. Results of the dating programme have been integrated with a programme of dating of Holocene alluvial deposits (which interleave with the channel sequences and overlie terrace sand and gravel deposits at Clifton Quarry) undertaken as part of the 'Severn Valley Alluvial Geochronology and Alluviation Project'; a separate project being undertaken by the Universities of Southampton and Gloucestershire.

The OSL dating pilot focussed on testing of this technique as a method for dating the underlying, and therefore older, sand and gravel terrace deposits (as opposed to overlying alluvial accumulations and channel incisions). OSL is the only practical dating method for the Severn gravels as they are generally highly quartz dominated with no shell available for AAR or U series. OSL is therefore the principal scientific dating method that can be used. Although it was hoped that the dates secured would support some advance in understanding of the terrace geochronology ('range finding'), it was not intended to develop any detailed geochronology.

Similarly, the radiocarbon dating programme focussed on developing models to apply when sampling organic deposits from Holocene channel sequences and ensure that secure dates and understanding of potential chronological complexity are being achieved. As highlighted by recent projects in the lower Ribble Valley and Suffolk Rivers Projects, the fragmentary and non-sequential nature of sediment and landform survival can cause considerable difficulties in producing secure chronologies for such geomorphological sequences (Chiverrell *et al.* 2008; Howard *et al* 2009). Within the Ribble Project, robust methodologies were developed for radiocarbon dating of sequences using large numbers of dates and replicate measurements from single horizons. This facilitated assessment of the potential levels of reworking of organic materials and enabled use of Bayesian approaches to test chronological models developed. Such studies clearly have implications for design of dating programmes and sampling strategies devised for the Severn Valley and other river systems characterised by palaeochannel re-occupation and avulsion rather than by simple migratory patterns. In such instances models based on sampling of top and basal deposits are liable to be overly simplistic and misleading.

3.3.2 Sample collection

Active quarrying areas at the two pilot study areas, at Clifton and Frampton-on-Severn were visited for the collection of OSL dating samples from exposed terrace deposits in the quarry faces. Four samples were proposed from each pilot area, however, in the event a lack of appropriate exposures resulted in sampling being undertaken at a third site at Ball Mill Quarry (Retreat Farm West), Grimley, Worcestershire. Detailed methods statements and results for the OSL dating are presented in Appendix 3.

In total nine new samples were taken all of which were conventional sediment samples, located within matrix-supported units composed predominantly of sand and silt collected in daylight from sections by means of opaque plastic tubing (150x45 mm) forced into each face. Three further samples which had been collected in 2008 have also been considered.

The sample used for this assessment thus comprised twelve samples; nine of which were taken from primary terrace material (2 from Frampton, 4 from Clifton and 3 from Ball Mill), two of which derived from alluvial sediments at Clifton and one of which was collected from aeolian sediments at Ball Mill. These alluvial and aeolian deposits capped the terrace deposits at these sites and were sampled in order to attain an intrinsic metric of reliability. Where possible, two samples were obtained from stratigraphically equivalent units targeting positions likely divergent in dosimetry on the basis of textural and colour differences. Each sample was wrapped in cellophane and parcel tape in order to preserve moisture content and integrity until ready for laboratory preparation. For each sample, an additional *c.* 100g of sediment was collected for laboratory-based assessment of radioactive disequilibrium.

Written and photographic records were made of the exposed terrace deposit sections from which these were collected and the stratigraphic sequences and positions of each optical dating sample were recorded.

Suitable samples for the proposed radiocarbon dating programme had previously been collected from Clifton during recording and sampling completed by WCC following flood damage to a quarry face in 2008. This exposed a complex palaeochannel fill and incision sequence and this has provided material for this element of the dating work.

3.3.3 OSL dating methods

The OSL dating pilot followed the standard methodology and protocols used by the Geochronology Laboratory at the University of Gloucestershire as followed by PRoSWEB (Toms *et al*. 2008), described in the recent guidelines published by English Heritage (Duller 2008). The results and associated stratigraphic sequence are described in Section 4.2 which also discusses the potential implications of the OSL dating programme. The OSL dating methods and results are described in detail in Appendix 3.

3.3.4 Radiocarbon (AMS) dating

Sampling of a palaeochannel sequence exposed at Clifton Quarry was undertaken in 2008 by WHEAS (with WCC and Tarmac support) and included a monolith and associated bulk sampling by spit. At the same time, interleaving alluvial deposits were sampled for OSL dating by Tony Brown as part of a separate research project focussing on the Holocene geochronology of the Severn (Severn Valley Alluvial Geochronology and Alluviation Project). The resultant OSL dates (CLIF01, 03, and 04) have been made available for consideration within the Severn Geoarchaeology Project.

The palaeochannel fill sequence appeared to incorporate two phases of organic infills separated by a coarse fraction, high energy sediment and a band of alluvium. This suggested that the lower organic fill may represent silting up of an abandoned early channel incision with the later alluvium, coarse fraction and organic fill sequence indicative of a period of alluviation resulting from overbank flooding followed in turn by channel re-occupation and subsequent re-abandonment. A final accumulation of alluvium had largely infilled the abandoned channel; however, it survives as a faint landscape feature in the form of a shallow depression and this had provided the route by which the recent floodwaters had entered the quarry.

Sub-samples from this channel sequence were therefore identified and processed (by washover) to extract and identify suitable plant macrofossil material for consideration for incorporation into a dating programme. Following discussion with the EH dating advisory team (John Meadows and Peter Marshall), a radiocarbon dating programme was then completed to test a radiocarbon dating model approach for Severn Valley channel palaeochannels.

Samples were submitted to the English Heritage dating team for analysis which aimed to highlight the potential problems that overly simplistic dating models and limited dating programmes can present especially where complex patterns of incision, abandonment and re-occupation and reworking of deposits are present.

Detailed methods and results for the radiocarbon dating programme are presented in Section 4.3 which also considers their relationship with the associated OSL dates.

3.4 Mapping features with palaeoenvironmental potential from OS, other historic mapping and aerial photographs

The potential for mapping of geomorphological features with palaeoenvironmental potential from OS, other historic maps and aerial photographs has been recognised elsewhere (Baker 2006). This was undertaken for the two pilot study areas.

Methodology was based upon map-based approaches developed within the Trent Valley (Baker 2006; Baker 2007) and also by the WHEAS environmental team on three study areas within Worcestershire (Appendix 4).

The focus of this work lay in identifying features visible on 1st edition OS maps which may contain organic deposits and have potential for palaeoenvironmental reconstruction. Aerial photographs and aerial photographic transcriptions were also considered to provide additional information.

The following were digitally mapped as a separate layer within the GIS:

- Peat bog, reed swamp;
- Osier beds;
- Natural ponds;
- Areas where a watercourse follows along a parish or County boundary, then diverts (usually a meander separates away from the boundary line). Peat deposits may have formed inside the meander, and as most boundaries have their origins in the early medieval period, any peaty areas located in such areas may be of some antiquity. Marked as ‘meander movement’. Pronounced meander loops were also included;
- Visible former channel alignments (on aerial photographs);
- Fishponds and moats; and
- Mill ponds, leats and races

The resultant mapping was compared with the palaeochannel mapping derived from the LiDAR analysis to provide a cross-checking mechanism and thus more comprehensive and reliable information on palaeochannels.

Subsequently an assessment was made of the potential of these deposits for organic survival based upon estimated size on the 1st Edition OS map/AP transcription and any apparent change in the waterlogged state of the feature on modern OS maps, such as drying out or silting up. Secondly, accessibility was scored based upon the extent to which the feature is presently covered by development such as buildings, tarmac or trees. Features were 'flagged' where there was archaeological or historical information available through the HER which is of direct relevance. This did not, however, affect the scoring as high values are biased towards features of known archaeological or historical relevance but many natural features of unknown date could also be of high potential.

Note: Although no ‘ground truthing’ of these deposits through augering was undertaken, the importance of undertaking such work is recognised and is included as a suggested future task for any extension project which may be developed.

3.5 Ground truthing

'Ground truthing' of landforms and cultural features mapped from the LiDAR derived DSMs involved a two stage process.

Initially, as described above, mapping was cross-checked against other sources, notably AP mapping but also including other data sources included in the project GIS.

Secondly, site visits were undertaken to ‘ground truth’ and verify the desk-based mapping and interpretation of landforms and cultural features identified as well as to check relationships between features. Hard copies of the desk-based mapping of geoarchaeological (landform units) and cultural features derived from the LiDAR DSMs for the two pilot study areas were plotted and taken into the field. This enabled a sample of features to be cross-checked against the mapping to verify the broad accuracy of the mapping, while in critical locations where relationships could not be firmly established (from the mapping) surface evidence was examined with members of the Expert Team to clarify these. Mapping was annotated and modified in the field.

The project methodology also allowed for additional data to be collected and mapped using a hand-held GPS (Trimble GeoExplorer 2005 Series, GeoXT) for incorporation with the GIS mapping where visible features deviated substantially from, or presented greater complexity than the mapped data; however in the event this was not required.

3.6 Indexing and mapping of existing palaeoenvironmental data to the HER

The value of incorporation of palaeoenvironmental data within the HER in a structured, consistent and accessible format has been recognised within Worcestershire since 2004. As a result an index of environmental data drawn from published sources and grey literature has been extracted and mapped within the HER for the county as a result as part of a separate initiative funded through the County Council. Archaeological planning briefs now require the completion of a table which enables this data index to be consistently recorded and maintained and HER search outputs for the county now routinely incorporate the resultant data and mapping information, thus benefiting all HER users. (An online conference paper and associated documentation further explains the rationale for the Worcestershire initiative and the approaches used - Bryant and Pearson 2004).

Environmental data of this type was extracted for the Clifton pilot study area and incorporated in the project GIS.

The value of incorporation of similar palaeoenvironmental data within the GCC HER has been recognised as part of a proposed development framework for the HER in that county. Although funds are not currently available to complete such development and new fields cannot be incorporated within the existing system, the completion of a pilot was seen as desirable to demonstrate the potential for establishing such a resource. Further, any project output could be incorporated at the future, while in the interim use of free text in the memo field of the current system would at least render data more accessible than is currently the case. An index and mapping of environmental data was therefore completed for the Frampton-on-Severn study area in Gloucestershire.

This was undertaken using a comparable methodology and data structure to that developed for Worcestershire. A database was created based on that used for indexing and mapping palaeoenvironmental data for the Worcestershire HER. All "old" data published in grey literature was indexed and mapped, as well as that in journals and monographs. Data from older, smaller sites which are "hidden" in monument records (for example, notes on animal bone or charred grain being found on monuments, or during relatively old development work, often reported in newspapers or by members of the general public) was also taken into account to ensure that a complete and accessible source of palaeoenvironmental data was available to the project.

3.7 Correlation of datasets

The resultant mapping and information were used in developing textual descriptions of the project results. GIS and descriptive text outputs were formatted both to meet the specific needs of this project and to provide information in a form, which is readily usable by the Worcestershire and Gloucestershire HERs and stakeholders using those resources.

In particular, use was made of a Report Form specifically designed for this purpose, one of which was completed for each geoarchaeological landform unit according to a standard methodology (as described in Appendix 5).

The Report Forms collate and summarise data and include:

- the location and extents of each landform unit;
- information on associated landform units;
- a description of the landform unit;
- cross-referencing to associated Historic Landscape Character type and cultural features; and
- an assessment of the archaeological potential of the mapped landform.

These forms have been drawn upon in Section 4.1 and are included in the report appendices (Appendix 6 and 7).

3.8 The project archive

The principal project output takes the form of GIS data. All of the GIS data generated has been archived and is accompanied by descriptive metadata following the format proposed in the Archaeological Data Service guidelines (Gillings and Wise 1998).

For each archive directory an ASCII text file has been created as an index for the directory contents using the following format: Directoryname_Contents.txt comprising a list of the files in the directory by name with brief description including the following information:

1. Filename
2. Computer software used
3. Date of data capture/purchase
4. Who created the file
5. Data source
6. Scale and resolution of data capture
7. Scale and resolution of data storage
8. Purpose of data set creation
9. Method of original data capture

All GIS data generated as part of the project has, as far as licensing restrictions allowed, been collated and supplied in appropriate archive formats to the respective County HERs and the Archaeological Data Service (ADS).

The archive is accompanied by appropriate metadata following the Dublin Core standard recommended by ADS.

Copies of accompanying reports and articles have been deposited and the OASIS entry updated.

4. Results

4.1 LiDAR

4.1.1 Clifton pilot study area (Andrew Mann)

4.1.1.1 *Geomorphology (Figs. 8, 10 and 11)*

The processed LiDAR images proved an effective tool for mapping the general geomorphological detail, topography and structure within this study area (Fig. 8). Most of the terrace units and major palaeochannels mapped from the LiDAR were also visible either on aerial photographs or the British Geological Survey (BGS) mapping, although these features were often obscured by vegetation on the aerial photographs.

The main result of the geomorphological mapping was that it provided a record of the spatial distribution of terrace units and palaeochannels within the study area, although fine geomorphological details such as ridge and swale were not readily identified.

The terrace stratigraphy identified by this project largely agrees with the mapping produced by the British Geological Survey (BGS; compare Figs. 9 and 10); however, on the western side of the river, additional intermediate deposits which are not mapped by the BGS have been identified and are tentatively assigned Terrace 3 in current morphostratigraphic frameworks. Although the majority of the terrace units had previously been mapped by the BGS, the LiDAR provided finer detail, specifically around the edges of the terrace units and in some cases increased their spatial extent.

It was also possible to map numerous palaeochannels (30 in total) incised into the terraces (Fig. 11); the more accessible of which were confirmed during the field mapping stage of the project. The largest palaeochannels were identified on Terrace 5, although one was also identified on the contemporary floodplain. The majority of the other palaeochannels were much smaller and were often associated with existing watercourses, suggesting they are likely to be of late Holocene age.

The larger palaeochannels identifiable on the LiDAR were also visible on the aerial photographs as the edges of these channels were often reflected in the field boundaries. In some areas; however, this was only apparent once they had been initially plotted using the LiDAR demonstrating the value of this approach. The latter also provided finer resolution where there had been ground cover or where more recent alterations had been made to the field boundaries moving them away from the channel's edge.

4.1.1.2 *Cultural remains (Figs. 12-14)*

LiDAR was most effective when mapping ridge and furrow and water meadow features during which two new water meadows and ten new blocks of ridge and furrow were identified (Fig. 12). The detail provided by the LiDAR also significantly enhanced the extents of 3 water meadows (*e.g.* Fig. 13) and 1 block of ridge and furrow previously recorded on the Historic Environment Record (HER).

In general evidence for ridge and furrow was identified on the western side of the river on indeterminate terrace units, the remaining being identified on Terraces 3 and 5. The majority were found on the higher ground away from the main floodplain suggesting if they had extended onto the lower ground they have subsequently become covered with alluvium. Where identified on the LiDAR the boundaries of individual ridge and furrow blocks appear to reflect and mirror the geomorphological units (terrace edges specifically) and do not readily cross over unit boundaries. This was also apparent while mapping the watermeadow ditches, which were mostly found within and respected the boundaries of the larger palaeochannels. This probably reflects the lack of modern cultivation on unsuitable/waterlogged ground.

Other than ridge and furrow and water meadow features the LiDAR also facilitated in the identification of a further 31 new archaeological sites, including earthworks, enclosures and building platforms.

Two new enclosures, discovered beneath woodland cover, in Frieze Wood (Fig. 14) and Dripshill Wood, on the western side of the river appear to have extant earthworks surrounding them, suggesting that they are well-preserved. On morphological grounds they are suggested to be of either Iron Age prehistoric or Roman date and were found at the highest points within their surroundings; new discoveries of such hilltop enclosures are rarely made and since these are liable to be well-preserved they have a high archaeological potential.

Using the LiDAR also helped to enhanced the HER records of a further 3 earthworks/enclosures, providing clarity and refinement to large HER polygons encompassing the monuments and everything within the land parcel in which they sat.

The known archaeological resource on the HER generally clusters on Terrace 5 on the eastern side of the river. When the LiDAR derived cultural features are plotted there is, however, an obvious bias towards the west of the river; although the majority of those features are quarry pits associated with the local brick works. This implies there is a bias on the HER towards the recording of sites in areas where there has been greater archaeological intervention, which may create a false hotspot when compared to the surrounding landscape.

Only one site was identified from the LiDAR on the floodplain and only six (out of 62) known sites on the HER were within the modern floodplain. Of these all six were of medieval or post-medieval date, implying pre-medieval deposits or cultural remains are buried below alluvial layers. Other than 3 sites, the previously known prehistoric archaeology is mostly confined on to Terrace 5 or along the margins of palaeochannels incised into this terrace. This includes a significant Grooved Ware pit as well as a well-preserved Bronze Age burnt mound and associated features, all of which were located below alluvium on the margins of a palaeochannel (Mann and Jackson 2009). One interesting group, a small barrow cemetery recorded on the HER, appears to be placed on the higher ground at the confluence of two palaeochannels on Terrace 5, a location which may have influenced their positioning. Such preference for confluence locations and gravel ridges within low lying landscapes has been widely noted before for Neolithic and Bronze Age funerary and other monuments both regionally, as at Wellington in Herefordshire (Jackson and Miller in press), as well as more widely as in the Thames Valley (Thomas 1999) and appears to be indicated here within the Severn Valley.

4.1.2 Results: Frampton-on-Severn pilot study area (Tony Roberts)

4.1.2.1 *Geomorphology (Figs. 15, 17 and 18)*

The LiDAR data provided clear indications of the geomorphological features that were extant in the lower reaches of the Severn covered by the relatively limited study area (Fig. 15). Most of the terrace units and other features that were mapped from the LiDAR were also visible on aerial photographs or previously highlighted on British Geological Survey mapping (compare Figs. 16 and 17). In common with the Clifton study area, vegetation obscured some detail on aerial photographs and mapping was therefore easier with the LiDAR.

The study area covered the confluence of the rivers Severn and Frome which, as a consequence, made the attribution of terrace features to a particular river system more problematic; although it is noted that this also benefited the project by providing a more challenging area to map thus raising some issues which had not been identified for the Clifton pilot study area.

The lower, more extensive, terrace that dominated the survey area (Fig. 17: Terrace 2) is a terrace of the River Frome rather than the River Severn. The geographical limits of the study area did not extend to the full width of the Severn valley, which is considerable in its lower reaches, and was restricted to the east bank of the Severn in the Frampton area. Consequently, the full range of the potential terrace sequence attributable to the Severn was not visible, making identification of geomorphological features less certain. This may also be a reason for the lack of significant palaeochannels within the study area, only two small palaeochannels of the River Frome being visible on Terrace 2 (Fig. 18). A large palaeochannel of the Severn may be present running east to west in the north of the survey area (feature 2017); however, only a fraction of it is visible allowing only a tentative identification. A further reason for the lack of visible palaeochannels could be the depth of alluvium in this portion of the river system which could be deep enough to bury detectable traces by LiDAR. The presence of large swathes of well-preserved ridge and furrow may also have affected visibility and provide a clear indication of the fertile and deep soil that has attracted cultivation for many years.

Nonetheless, the geomorphological features that were present were clearly identifiable on the LiDAR. The major units such as the edges of Terrace 2 and the floodplain of the River Frome could be traced in the field boundaries in the landscape. Interestingly, more modern cultural features such as the Gloucester and Sharpness canal follow the higher ground to the north edge of Terrace 2.

4.1.2.2 *Cultural Remains (Figs. 19 and 20)*

A range of cultural features were mapped across the Frampton-on-Severn study area (Fig. 19); however, a relatively large portion of the study area had been subjected to active quarrying or was occupied by the villages of Frampton-on-Severn, Saul and Whitminster reducing the land area available for examination.

The most significant feature within the study area was the extensive ridge and furrow that was widespread over the whole area. A number of furlong boundaries and headlands were more clearly visible as earthworks on the LiDAR used for this project than on the aerial photographs utilised for the NMP mapping (Fig. 19: boundary features). Given the good state of preservation, much of the ridge and furrow had been identified by the NMP (Fig. 4), although it is not recorded on an individual field basis in the HER. The ridge and furrow is clearly not present in the floodplain of the River Frome where the remnants of water meadows are visible on the LiDAR (Fig. 19). In general, the ridge and furrow reflects the geomorphological landforms, particularly the terrace edges.

Other than ridge and furrow, the LiDAR enabled the identification of a further 29 new sites including earthworks and enclosures. In addition, a number of enhancements to general references to features within the HER were made. In particular, the earthworks of two deserted settlements from the medieval period (*e.g.* at Wheatenhurst, Fig. 20), and a series of post-medieval building enclosures were more clearly defined enabling more accurate mapping within the HER.

The known archaeological resource within the HER and new sites derived from the LiDAR were evenly dispersed across the study area. The cultural remains (prehistoric to post-medieval) confirm a continuity of settlement on the deep alluvium to be found in the area with no obvious geographical bias. However, the knowledge of the significant prehistoric and Roman sites in the area has only arisen through the actions of previous quarrying on Terrace 2 (*e.g.* at Netherhills Quarry, Mullin in press) which again, as in the Clifton area, demonstrates and highlights the bias of the HER towards the recording of sites in areas where there has been greater archaeological intervention.

4.2 Optically Stimulated Luminescence Dating of Lower Severn Valley stratigraphy (by Tony Brown with a dating report by Phil Toms)

4.2.1 Introduction

Samples were taken from sand and gravel deposits at Frampton-on-Severn (BGS: Terrace 1; Power House Member), Clifton (BGS: Terrace 2; Worcester Member?) and Ball Mill (BGS: Terrace 4; Holt Heath Member), with sampling at Clifton also including alluvial deposits (Elmore Member) and at Ball Mill an aeolian deposit.

Detailed results of the dating are presented in Appendix 3 (Toms 2010) and in Table 1. The recorded site stratigraphies are described below along with consideration of the methodological, stratigraphic and archaeological implications of the OSL dates. Finally recommendations for future use of OSL dating are presented.

4.2.2 Site stratigraphies

4.2.2.1 *Frampton on Severn*

Only a small exposure of the gravels has remained available at Frampton. One section was used for the OSL sampling (Fig. 21; Section 1; Samples FRAM01/GL10017 and FRAM02/GL10018) and this is summarised in Table 2. The section was chosen to allow the dipping of the beds to be revealed and although close in height the OSL samples could be sampled in stratigraphic order.

A combination of the characteristics of the sequence suggests that it may have been formed by the River Frome rather than the Severn (a suggestion supported by the analysis of the LiDAR DSM, see above).

The alternation of relatively high angle dip to the cross-bedded beds and the presence of sandy lenses of short lateral extent, lack of large clasts (max. 11cm axis), relative angularity of clasts and predominantly local Cotswold lithologies (Cornbrash, Ironstone, Oolitic limestone) all support an origin from the Frome tributary possibly deposited under a meandering or wandering gravel–bed channel pattern. At the time of reporting, dating is underway of a charcoal sample as a check on the OSL dates from the section (funded by Southampton University and currently with Beta Analytic).

Inspection of the contact between the upper gravels and the loam overburden adjacent to the section revealed several examples of tree-throw activity (Fig. 22) which clearly indicates that this low terrace was wooded and that the upper 1m of the gravels could locally be bioturbated.

4.2.2.2 *Clifton*

Two areas of the quarry were used to provide the OSL samples dated in Appendix 3.

Sections 1 and 2 were located in the 2008 quarrying area and had been recorded and sampled following exposure of a palaeochannel in a breach in the quarry margin caused by heavy flooding in the summer of that year (Fig. 23). The records and samples taken provided suitable material for the current project for the OSL dating programme, as well as for radiocarbon dating of palaeochannel deposits revealed in the breach (from Section 5 - see below).

Section 1 was an east facing exposure within the 2008 working area of the quarry and adjacent to the flood breach. The section revealed 3.55m of bedded sand and gravel (Fig. 24; Table 3). The section is made up of many thin beds, all either sand, or sandy gravel and is generally matrix supported, with shallow current structures. This suggests relatively shallow flows carrying abundant sand load both in suspension and through saltation of individual grains. The sedimentology suggests a shallow braid plane with the thalweg (line of maximum velocity and depth) of the multiple channels switching across it but some distance from this section at the time of deposition. Samples CLIF01 (GL08057) and CLIF02 (not processed) were taken from this section.

Section 2, a north facing exposure, was located immediately to the south of Section 1 within an east-west section created by a flood breach (Fig. 25). As shown in Table 4 it displayed a lower sand and gravel unit above which was a sand-silt unit containing an organic palaeosol. The top of the sequence was part of the Holocene floodplain which gently declined in elevation to the west. As can be seen from Table 4 the sequence contained a basal bedded sand and gravel grading up to a silty sand, above which was a laterally continuous black organic palaeosol and an upper sandy silt unit. Samples CLIF03 and CLIF04 (GL08059 and GL08060) were taken from this sequence, the first within medium to coarse bedded grey-red sand near the base of the sequence, the second from a red, blocky to prismatic silty clay alluvial deposit. The contact between the lowest sediments in Section 2 and the Section 1 deposits was not observable since it was obscured by talus, flood debris and flood deposits; however, as can be seen from photographs (Fig. 25) the Section 2 sequence has to be cut into the edge of the terrace sequence as revealed in Section 1. This therefore represents the boundary of a cut and fill sequence orientated approximately north-south at the edge of a tract of Holocene floodplain that bisects the Worcester Terrace (BGS Terrace 2).

Fieldwork undertaken as part of the project took samples (CLIF05-CLIF07) from two new faces at the site from the 2010 quarrying area which lay to the east of the area sampled and recorded in 2008 (Section 3, Samples CLIF05/GL10021 and CLIF06/GL10022; Section 4, Sample CLIF07, GL10023; Figs. 26 and 27). These provided better exposures of the tripartite sequence (clayey gravel over sands over clean gravel) that is common throughout the quarry (as summarised in Table 5). The contact at the top of the mid-sequence sands is characterised by numerous gravel-filled ice-wedge casts with additional areas and halos of clay migration into the sands from above. The sequence clearly represents a transition from high energy braided conditions which created the bedrock scour holes and the clast supported gravels, to medium energy sand braid plane conditions prior to the freezing of the floodplain and the deposition of gravels with a high silt and clay content typical of debris flow deposits. Although the conditions of deposition for this type of sediment deposit are not fully understood, they may relate to the erosion and solifluction of adjacent gravel terraces (such as Terrace 3) onto the lower floodplain surface.

4.2.2.3 *Ball Mill (Top Barn) Quarry*

A long and complex exposure orientated approximately north-south at the western edge of the upper active quarry area was described and sampled for OSL dating. Two sections were described (Sections 1 and 2; Fig. 28; Tables 6 and 7) and two samples taken from each; Samples BMIL01 (GL10024) and BMIL02 (GL10025) deriving from Section 1 and Samples BMIL04 (GL10027) and BMIL03 (GL10028) from a deeper section to the south.

As can be seen from Table 6, Section 1 reveals a bedded grading upwards sequence of sands and even silts capped by fine gravel (Fig. 29). The low angle cross-bedding and the wavy nature of the thinly bedded units suggests they represent the upper part of a braided river sedimentary sequence, but with a strong re-activation surface marked by the horizontally extensive superficial gravel bed. The bed from which BMIL01 (GL10024) was taken is, at first appearance, a typical loess or re-worked loess. In places this becomes increasingly silty with a trace of clay and pink mottled colouration suggesting a weakly developed palaeosol. Samples were taken of this bed in order to confirm this by either trace mineral analysis and/or fabric analysis. If this is the case there is possible archaeological significance as this could be a relatively short lived land-surface upon which loess was deposited.

Section 2 was situated to the south of Section 1 and extended down into a scour feature in the Triassic mudstone bedrock (Table 7). The scour-feature is at least 1.5m deep and appears linear extending from north-north-east to south-south-west with a sharp edge that can be clearly seen in Figure 30. It is filled with horizontally planar bedded, well-sorted sands, although these sands were only visible in the small area excavated into the base of the scour feature required for the OSL sampling (BMIL03/GL10026). The lower planar and cross-bedded sands represent medium energy braided conditions which were probably reduced from the high-energy conditions that created the scour channel into which they were later deposited.

To the north of the two recorded and sampled sections, the north-south exposure also revealed a number of very pronounced vertical fissures in the sandy silts underlying the loess-like bed and the upper gravels. In some cases they extended from the loess/palaeosol level through the sands and into the lower cross-bedded units, a depth of over 1m. These examples exhibited an upper 'plug' of sediment derived largely from the cover soil, a central tunnel and a basal plug of sediment very similar to experimental results for ice-wedge pseudomorphs (Harris and Murton 2005). The wedge-pipe shaped pseudomorphs are vertical slightly inclined fissures which disrupted the bedding and contained finer silt within the sand infill (Fig. 31). They are very similar to frost wedges as seen in modern arctic environments and they suggest a period of freezing of the floodplain surface and possibly permafrost (Harry and Gozdik 1988) although recent studies in the sub-Arctic have shown similar features forming in environments with an annual temperature of –4ºC due to below-normal winter air temperatures (Burn 2007).

Due to the height of this part of the Ball Mill Quarry (Top Barn) it is most likely to equate to Terrace 4 (Holt Heath Member) rather than the Terrace 3 gravels (as at first thought) which surround it. This is an important sequence and the most extensive and valuable sequence yet recorded into the Holt Heath Member and further work will be undertaken by the author on the stratigraphy, including the drawing-up of a long section and analysis of the deposits' sedimentary properties.

4.2.3 Methodological Implications of the OSL Dates

The methodological implications of the 12 OSL dated samples are detailed in the OSL report attached to this report (Toms: Appendix 3). However, it is worth re-emphasising the conclusions here:

1. Severn Valley alluvial sediments are well-suited to OSL dating as there appears to be no geologically inherited cause of systematic error and they have sufficient datable mass. Errors are therefore likely to be associated with partial bleaching and bioturbation, and vary from sample to sample.
2. The occurrence of partially bleached samples at Frampton (FRAM01/GL10017) and at Clifton (GL08057/CLIF01, GL08059/CLIF02 and GL10021/ CLIF05) suggests that future work should employ single-grain approach to the dating of Terraces 1 and 2.
3. The divergent dosimetry approach has been shown to be valuable and this could be capitalised upon by either profile dosimetry or the sampling of multiple samples and dating of only those with significantly different mean dose rates.

4.2.4 Stratigraphic and archaeological implications

Remarkably little geological dating has been undertaken in the Middle Severn Valley in comparison to its left-bank tributary the Worcestershire Avon (Maddy *et al.* 1991) and the other systems such as the Thames (Bridgland 1994; Maddy *et al.* 2001) and the Trent (White *et al.* 2007). Such work elsewhere has included not only radiocarbon dating programmes but also OSL, amino acid racemisation (AAR) and biostratigraphy. This is partly because the sediments of the main (Severn) valley are poor in organic remains and because, ever since the classic work by Wills (1938), it has been assumed that the entire valley stratigraphy post-dates the creation of the Ironbridge Gorge and thus post-dated the Late Glacial Maximum.

The only exception to this has been work on the Holocene valley sediments by Brown and members of the International Geological Correlation Project 158A in the 1980s (Gregory *et al.* 1991). Although the Severn Valley Formation (which includes all the gravel terraces) was extended back to MIS11/10 in Bowen (1999), the main trunk terrace staircase of Power House Member, Worcester Member and Holt Heath Member were still ascribed to MIS2 and only higher terraces (Bushley Green and Spring Hill) ascribed to MIS8-MIS11. The OSL dates from this pilot study are the first OSL dates on the lower part of this sequence and therefore act as a test of the Wills (1938)-Maddy *et al* (1991) model.

As can be seen from Table 8 there is one area of major disagreement between the existing chronology and the new dates. This is with the dates from Grimley (Ball Mill Quarry) which firmly position the upper Ball Mill gravels mapped by BGS as Terrace 4 (Kidderminster) and part of the Holt Heath Member as recognised by Maddy *et al*. (1995) into MIS5a-d (early Devensian) and not into MIS2 (late Devensian). The correlation of the gravels with the Holt Heath Member of Maddy *et al.* (1995) is not in doubt as the gravels exposed in the upper quarry at Ball Mill Quarry can be traced, both on the ground and from aerial photographs, to the location of the former Holt Heath quarry that lies directly to the north. The southerly extension of the terrace caps the interfluve to the south and the gravels at Hallow. Assuming this is correct and the caveats on the dates include over-dispersion of regenerative dose data (BMIL01 & BMIL04) and moderate U disequilibria (BMIL02 & BMIL04), neither of which should lead to a consistent asymmetric error, then the sedimentation of this widespread terrace gravel must significantly pre-date the Last Glacial Maximum and probably the coldest, possibly glacial, phase of MIS4-3.

Although this is not the place to discuss it in detail, this necessitates a re-evaluation of the detailed sedimentological and environmental studies of Dawson and Bryant (1987) which suggested deposition by large floods as these cannot have been melt-water driven and therefore probably relate to snowmelt and the hydroclimatic environment.

A second implication is archaeological. If these gravels are MIS5d to MIS5a to very early MIS4, and were not deposited under extreme periglacial conditions, then they could theoretically contain Middle or Upper Palaeolithic artefacts. Assuming the British Isles were not populated during MIS5a, recent work from Dartford suggests occupation by at least MIS5d-c (Wenban-Smith, 2010) and along with other studies this suggests re-occupation of Britain in (MIS5d-MIS3) by *Homo neanderthalensis*. These sites include both caves and open floodplain/waterhole sites the most spectacular example of which is Lynford (Boismier 2002) at 67-64 Ka. Given the acidic and decalcifying nature of the Severn Formation the survival of bone and antler is unlikely but stone tools could remain. It is suggested that the finds records for these sites and areas be re-investigated to identify any such artefacts. If these deposits do not contain such artefacts and the dating is confirmed then this begs an interesting question: Was this at or beyond the limit of human occupation of the British Isles during this period?

The dates obtained on the intercalated sands in the Clifton Quarry (CLIF05-CLIF07) are very much as expected dating to the period of deglaciation following the LGM when melt-waters would have been cascading through the Ironbridge Gorge from the Shropshire-Cheshire deglacial basin. When combined with the stratigraphy it suggests that the sequence preserved at Clifton shows the period of transition between the late glacial Older Dryas and Windermere Interstadial and the initiation of the Younger Dryas cold stage deposition (post 12 Ka). Rapid deposition during cold-climate conditions would not be conducive to occupation by *H. sapiens* and evidence of Late Upper Palaeolithic occupation post-dates 16 Ka where it has been identified on sites lying to the south, such as the caves of the Wye Valley (Barton 1995; Brown *et al*. 2005). The preliminary data presented here reinforces the notion that the Worcester Formation (BGS Terrace 2) is archaeologically sterile except of course for its surface and any eroded surficial pockets or channels.

The two dates from Frampton-on-Severn are both problematic but it is likely that the gravels date to *c*. 9-10 Ka at the Younger Dryas-Holocene boundary. This is perhaps a little later than expected and it is important as it provides a maximum date for the downcutting of the Severn and its tributaries (including the Frome which cuts through the Severn gravels). If these gravels post-date the Younger Dryas then it is possible that they could contain early late Upper Palaeolithic/early Mesolithic material and so it is recommended that dating at a less problematic site with more extensive exposures be undertaken to confirm this potential.

The Holocene dates from the edge of the terrace gravels at Clifton are particularly interesting. Firstly as shown by CLIF04 the sand component is well suited to OSL dating and this will enable OSL to provide detailed chronologies for fine alluvial sediments in this part of the Severn Valley. Such deposits have a high potential to answer many important archaeological questions concerning the agricultural contribution to alluviation and valley flood change. The date below the palaeosol (CLIF03) suggests that the period of organic floodplain development (with low overbank sedimentation) is post Middle Iron Age. Taken together they suggest that the accelerated alluviation indicated by the upper sand unit is probably medieval in age. This agrees with many other studies in the English Midlands but not with earlier dates in other parts of the Lower Severn Valley (Brown 1987; 1991). This could be just the result of local sedimentation patterns or tributary inputs or indeed to the lack of precision and bias involved in the earlier studies, which had to use radiocarbon dating alone. The lower date (CLIF01) is interesting as few dates on this age have been recorded from alluvial sequences and again this probably reflects the bias of radiocarbon dating for systems that may have been undergoing significant clastic deposition. The stratigraphic position of this sand suggests that it was a widespread sand and fine gravel unit into which a channel incised prior to the deposition of the overbank unit containing the organic palaeosol and tree remains. Again there is the high possibility that these are reworked local sediments derived from erosion of the adjacent terrace.

This pilot has consequently shown that the sandy alluvial sediments of the Lower Severn are highly suitable to OSL dating and this should be exploited to re-evaluate the alluvial history of the West Midlands and test the relative efficacy of later prehistoric, Roman and medieval alluviation in this region which has good archaeological records for these periods.

4.2.5 Recommendations

From this discussion of the implications of this pilot study it is recommended that;

1. An attempt is made to OSL date the 3rd or Main Terrace which crops out under much of Worcester, the lower area of the Ball Mill Quarry and extensively on the western side of the valley. Field mapping of the Holt Heath-Grimley-Hallow area should be undertaken to establish the relationship between the remnants of Terrace 4 and the surrounding Terrace 3 (Holt Heath Member and the Main Terrace *sensu* BGS).
2. In order to test the diachrony of cold (but not glacial) stage floodplain formation samples from the Holt Heath Member should be obtained from the eastern side of the valley since during this period the valley floor would appear to have been 3-4 km in average width.
3. An effort should be made to check the supposed post LGM date for the Worcester Member (BGS Terrace 3).
4. The suitability of the Holocene sandy alluvium of the region should be used to test the existing radiocarbon dated chronology for valley alluviation in relation to field-archaeological evidence.

4.3 Radiocarbon dating of palaeochannel fills (John Meadows, Christopher Bronk Ramsey, Gordon Cook, Robin Jackson and Phil Toms)

4.3.1 Background

Radiocarbon (AMS) dating of organic remains recovered through borehole sampling of palaeochannel fills has featured as an element of a number of comparable river valley surveys funded through the ALSF (*e.g.* Chiverrell *et al.* 2008; Howard *et al* 2009). Where OSL dating has been possible, the OSL dating of the intervening valley floor units has typically been used to complement the radiocarbon dating of organic sequences from palaeochannels, thus respectively providing channel incision and abandonment dates. In other cases where conditions have not been suited for effective use of OSL dating, radiocarbon dating of palaeochannel sequences has provided the principal chronological control.

Typically upper and basal deposit radiocarbon dates have been secured to establish the potential lifespan of the organic deposits within the sampled channels. These have been used in conjunction with other data (*e.g.* derived from archaeological sites investigated on associated terraces and, as noted above, from OSL dating of terrace units) to create chronological models for valley floor development and identify potential cultural associations of particular valley floor landform units. However, as highlighted by a recent project in the lower Ribble Valley, the fragmentary and non-sequential nature of sediment and landform survival can cause considerable difficulties in producing secure chronologies for such geomorphological sequences (Chiverrell *et al.* 2008). Although this had been recognised as a potential problem within the output from earlier work in the Trent Valley (Brown *et al*. 2007, 118-9), within the Ribble Project, robust methodologies were developed for radiocarbon dating of sequences using large numbers of dates and replicate measurements from single horizons. This facilitated assessment of the potential levels of reworking of organic materials and enabled use of Bayesian approaches to test chronological models developed.

Recent work undertaken by several of the project partners at Wellington Quarry in the Lugg Valley has highlighted the potential complexity and longevity of palaeochannel accumulations in this region; one channel revealing a sequence indicative of four channel re-occupations following its initial incision during the early Holocene (Carey and Howard 2008; Sworn and Jackson 2008).

Such studies clearly have implications for design of dating programmes and sampling strategies devised for the Severn Valley and other river systems characterised by palaeochannel re-occupation and avulsion rather than by simple migratory patterns. In such instances models based on sampling of top and basal deposits are liable to be overly simplistic and misleading and have a high potential to include reworked material.

The exposure of a sequence of organic-rich palaeochannel infill deposits within alluvial terraces at Clifton Quarry (Figs. 23 and 32; Section 5) therefore provided an opportunity to compare the Optically Stimulated Luminescence (OSL) chronology for terrace deposition with a radiocarbon chronology for channel infilling, and to compare the radiocarbon ages of different components of the organic sediments.

The palaeochannel fill sequence recorded incorporated at least two main phases of organic infills (contexts 1002-5 and contexts 1007-9; Table 9) separated by a band of dark grey/blue alluvial clay alluvium (context 1006). This suggested that the lower organic fills (1007-9) may represent silting up of an abandoned early channel incision with the later alluvium (1006) and upper organic fill sequence (contexts 1002-5) indicative of a period of alluviation resulting from overbank flooding followed in turn by channel re-occupation and subsequent re-abandonment. A final accumulation of alluvium (context 1001) had largely infilled the abandoned channel; however the latter survives as a faint landscape feature in the form of a shallow depression (as mapped through LiDAR) and this, along with the softer organic fills, had created a weak area in the quarry wall through which the floodwaters had broken.

Bulk (1L) samples and a monolith were taken from successive layers of the organic-rich fills (Fig. 33) when the sequence was recorded, and these were sorted for macrofossils by Alan Clapham. Short-lived, single-entity plant macrofossil samples of emerged species (whose carbon content is derived entirely from photosynthesis of atmospheric carbon dioxide), of taxa which would have grown beside such a stream, were selected from four layers, two (1002 and 1005) from the upper part of the organic sequence, and two (1008 and 1009) from the earlier part of the sequence, beneath clay-rich layers 1006 and 1007. Bulk organic sediment samples from the same layers were also submitted for radiocarbon dating; as such samples are often dated when suitable plant macrofossils are not available. This aimed to check whether their results were consistent with those from macrofossils. A single macrofossil of a submerged species, whose carbon content is derived from photosynthesis of carbon dissolved in the water, was dated to test whether there was a significant reservoir, or hard-water, effect in this catchment, which may also have affected the radiocarbon ages of the bulk organic sediment samples.

4.3.2 Measurement and Results

The samples were dated by Accelerator Mass Spectrometry (AMS) radiocarbon dating at the Oxford Radiocarbon Accelerator Unit at Oxford University (following the laboratory methods described by Brock *et al.* (2010) and Bronk Ramsey *et al.* (2004)) or at the Scottish Universities Environmental Research Centre in East Kilbride (technical procedures are given by Vandenputte *et al.* (1996), Slota *et al* (1987), and Xu *et al.* (2004)). Internal quality assurance procedures at both laboratories and international inter-comparisons (Scott 2003) indicate no laboratory offsets, and validate the measurement precision quoted.

The results (Table 10) are conventional radiocarbon ages (Stuiver and Polach 1977), quoted according to the format defined by the Trondheim convention (Stuiver and Kra 1986). The calibrated date ranges have been calculated by the maximum intercept method (Stuiver and Reimer 1986), using the program OxCal v4.1.7 (Bronk Ramsey 1995; 1998; 2001; 2009) and the IntCal09 data set (Reimer *et al.* 2009), and are quoted in the form recommended by Mook (1986) Figure 1 shows the calibration of the radiocarbon results by the probability method (Stuiver and Reimer 1993), again using OxCal 4.1.7 and the IntCal09 calibration data.

4.3.3 Discussion

In order to develop the most accurate age-depth model, it is necessary to assess which, if any, of these results provide reliable dates for sedimentation at the level from which the sample was taken. Ideally, for this purpose, each radiocarbon sample would consist of a short-lived terrestrial plant macrofossil which ceased photosynthesis only when it was deposited at the level in the sediment column where it was found. There is always a risk, however, that plant remains in fluvial environments are reworked from older organic-rich sediments, and thus produce spuriously old dates for sedimentation at their present level. Samples of submerged species, such as *Potomageton* sp., may give misleadingly old radiocarbon ages due to hard-water, or reservoir effects, because they photosynthesise underwater, using dissolved carbon dioxide, which may not be in isotopic equilibrium with contemporary atmospheric carbon dioxide.

Samples of bulk organic sediment can produce misleadingly old radiocarbon ages for both of these reasons (the humified organic material dated could have been derived, in part, from reworked plant remains and from remains of submerged species), and may also have significant intrinsic ages (both because the sediment in the bulk sample may have taken a number of years to accumulate, and because its organic content may in part be derived from decomposed wood from long-lived species). Bulk organic sediment can also give dates which are too recent for sedimentation, if part of the organic material is derived from the roots of plants growing at a higher level. Visible rootlets are manually removed in the radiocarbon laboratory, but decomposed root matter cannot be separated, physically or chemically, from other sources of organic carbon.

The laboratory can date the carbon content from two chemical fractions of the same bulk organic sediment sample, the humin and humic acid. If the humic acid was derived from the humification (decomposition) of the plant remains which also produced the humin, then the two fractions should give consistent radiocarbon ages, which *may*, nevertheless, be misleading for the reasons discussed above. If the two fractions produce inconsistent results, however, at least one result *must* be misleading, and a subjective assessment must be made of which fraction provides a more reliable date for sedimentation at that level. Although humic acids can be mobile, they are more homogenous in radiocarbon content than the humin fraction, which, given the small quantity of sediment required for AMS dating, can easily produce anomalous radiocarbon results, due to the presence of a single organism different in date to the rest of the organic matter. In general, it is more difficult to interpret the radiocarbon ages of bulk organic sediment samples when there is a discrepancy in date between humin and humic acid fractions.

At Clifton Quarry, bulk humin, humic acids and macrofossils each appear to increase in age with increasing depth (Fig. 34). The three results from context 1002 are statistically consistent with a single radiocarbon age (T'=2.3, T'(5%)=6.0, ν=2; Ward and Wilson 1978), so it is theoretically possible that all these samples date the same event, which is what we would expect to find if all three samples reliably dated sedimentation at this level. Further down the column, however, apparent age discrepancies emerge within context 1005. Here, the two macrofossil results are statistically consistent (T'=0.3, T'(5%)=3.8, ν=1; Ward and Wilson 1978). This suggests that the hard-water or reservoir effect at this moment was negligible (otherwise, an older radiocarbon result should have been obtained for 1005a, the *Potomageton* sample, than for the emerged plant *Sagittaria sagittarifolia)*, and that neither macrofossil was reworked. The bulk sediment results are not quite consistent with each other

(T'=4.0, T'(5%)=3.8, ν=1; Ward and Wilson 1978), however, and the humin fraction appears to be slightly older than the humic acid. Both the bulk humin and humic acid fractions are apparently older than the two plant macrofossils (if all four results are compared, T'=105.9, T'(5%)=7.8, ν=3; if the bulk humin is omitted from the comparison, T'=47.6, T'(5%)=6.0, ν=2; Ward and Wilson 1978). This may mean that some of the organic content of the bulk sediment was reworked (*e.g.* from old peat), as a hard-water effect does not appear to be responsible for the discrepancy between the bulk humin and macrofossil results. The humic acid result appears to lie between the bulk humin and macrofossil results, and could represent *in situ* decomposition of both reworked and contemporary organic material.

Within context 1008, the bulk sediment results are again slightly inconsistent (T'=4.4, T'(5%)=3.8, ν=1; Ward and Wilson 1978), and again both are apparently older than the macrofossil (if all three results are compared, T'=11.7, T'(5%)=6.0, ν=2; Ward and Wilson 1978), with the humic acid fraction result apparently lying between the macrofossil and humin results (the humic acid and macrofossil results are not statistically significantly different, however: T'=1.9, T'(5%)=3.8, ν=1; Ward and Wilson 1978). Not having dated an aquatic macrofossil from this level, we cannot exclude the possibility of hard-water effects, but equally this pattern could be caused by the presence in bulk sediment of reworked organic or inorganic carbon, as in context 1005. Within context 1009, the bulk sediment results are clearly inconsistent (T'=12.5, T'(5%)=3.8, ν=1; Ward and Wilson 1978), with the humin significantly older than the humic acid fraction. Even the humic acid fraction is definitely older than the macrofossil (T'=10.6, T'(5%)=3.8, ν=1; Ward and Wilson 1978).

Thus the discrepancies in radiocarbon results between samples from the same level may appear to increase with the depth, or age, of the level to be dated. The number of levels dated is perhaps too small to show that this is a real trend, but where there are discrepancies, the order of radiocarbon results is always the same: the humin fraction is older than the humic acid, which in turn is older than the macrofossil(s). If this pattern reflects the presence of reworked organic material in the bulk humin, then the radiocarbon age offset between macrofossils and bulk humin depends both on how much reworked material was present, and on how old it was at the time it was redeposited. A larger offset could mean that a greater proportion of the humin was reworked, or that the reworked component was older.

If the dated macrofossils are not reworked, then the bulk humin fractions probably include some organic material contemporary with sedimentation, as well as some reworked material. If the humic acid fraction is not mobile, and its radiocarbon age reflects the contributions of the contemporary and reworked components *in the same proportions* as the bulk humin result, then there should be no discrepancy between the humin and humic results (although both would be too old for the date of sedimentation). The general pattern of humic acid fractions producing more recent radiocarbon results than bulk humin (Bayliss *et al.* 2008, fig. 9) might be explained, however, if some of the 'reworked organic material' in bulk humin was either geological in origin (coal, shale), or if it had at least partly decomposed elsewhere; compared to its contribution to the bulk humin, such material might contribute proportionately less carbon than freshly deposited plant remains to the *in situ* formation of humic acid.

Two independent age estimates are available for terrace deposits associated with the palaeochannel. These were obtained by Optically Stimulated Luminescence (OSL) dating of sand samples taken from Section 2 which was located several metres west from the monolith (in Section 5) when these deposits were initially exposed in 2008 (Figs. 23 and 32). These samples were dated by Dr Phillip Toms, as part of a separate project with Professor Tony Brown. Sample CLIF04 (GL08060, 0.78±0.06ka) is stratigraphically later than the organic sequence, whereas sample CLIF03 (GL08059, 2.5±0.3ka) probably corresponds to the alluvial clay layer (context 1006; and possibly organic clay 1007) within the palaeochannel sequence. GL08059 may have been subject to incomplete bleaching, which means that it could be regarded as a maximum age for sedimentation at this level. Another OSL date, from a stratigraphically earlier part of the terrace sequence at Clifton Quarry (Section 1: sample CLIF01, GL08057, 6.6±1.0ka), is also regarded as a maximum age for sedimentation, given the risk of incomplete bleaching.

To compare the radiocarbon and luminescence chronologies, a simple Bayesian model of the results has been created using the Sequence function in the program OxCal v4.1.7 (Bronk

Ramsey 2009). In this model (Fig. 35), each result is regarded as a realistic estimate of the date of sedimentation at the corresponding level, despite the discrepancies between radiocarbon results discussed above, and the possibility of incomplete bleaching in two of the three OSL samples. A more constrained age-depth model, which takes into account the vertical separation of dated levels (P_Sequence; Bronk Ramsey 2008) could not be constructed on this occasion, as the precise vertical positions of the radiocarbon samples are not known, and it would not be possible to convert the OSL sample depths into heights in the column sampled for radiocarbon. The levels dated by OSL would also have been subject to a completely different sedimentary process to the organic-rich layers dated by radiocarbon.

The Sequence model tests whether the radiocarbon and luminescence dates are consistent with the relative dates of sedimentation known from the stratigraphic sequence. The good overall agreement (A_{model}>60; Bronk Ramsey 2009) indicates no contradiction between the stratigraphic sequence and the dating results, which means, in effect, that the discrepancies between radiocarbon results from contexts 1005 and 1008 are too small to be detected by the sequence model (for example, the humin result from 1008 is not so early that it could not be later in date than the macrofossil sample from 1009). A better fit between dating results and stratigraphic sequence would have been obtained by omitting the bulk sediment radiocarbon results from the model.

The radiocarbon results clearly fit within the period bracketed by the luminescence results, which supports the argument that OSL dating provides accurate depositional dates in this environment. Samples CLIF01 and CLIF03 may have been affected by incomplete bleaching, but their results are not much older than stratigraphically later radiocarbon samples. A more rigorous test of the accuracy of the OSL age estimates where incomplete bleaching is suspected would be a comparison with the dates from stratigraphically earlier radiocarbon samples, which is possible only for samples CLIF03 and CLIF04. Neither age estimate appears to be too early; although (as with the radiocarbon results from bulk sediment samples) small offsets would not be detected by the Sequence model shown in Figure 35.

Given the discrepancies seen between the dates of macrofossil and bulk organic sediment samples from the same levels, we must be sceptical about the value of dating bulk sediment from levels in which macrofossils are not available. A chronology based solely on bulk sediment dates would fit the stratigraphic sequence and therefore appear to be reliable, although it would (in this case) be systematically biased towards older ages. In 1002, the one level in which the bulk sediment results do not appear to be too old, the humin and humic fractions gave statistically consistent results, whereas when the two fractions produced inconsistent results, both fractions appear to be too old. These discrepancies seem to be due to the presence of reworked organic (or inorganic) carbon in the bulk sediment, not, in this case, to the presence of aquatic plant matter.

The question arises as to whether, in a situation in which some levels can be dated by macrofossils, the radiocarbon ages of bulk sediment samples from intermediate levels can provide useful chronological evidence, particularly when humin and humic acid fractions give inconsistent radiocarbon results. The Bayesian model shows that while the bulk sediment results are generally too old, neither the humin nor the humic acid results are so much older than macrofossils from the same levels that they would be rejected on the basis of macrofossil dates from stratigraphically earlier levels. Although it is difficult to generalise on the basis of a small number of samples, any reworked organic material in the bulk sediment appears to have contributed to the humic acid radiocarbon age as well as to the humin radiocarbon result, so that the true date of sedimentation lies not between the dates of the two fractions, but after both of them.

The Bayesian sequence model, including OSL age estimates, provides some support for the belief that the dated macrofossils provide a realistic chronology for the palaeochannel fills. A more robust chronology for the organic sequence might have been obtained through greater replication, as it can be argued that radiocarbon results from two or more short-lived terrestrial macrofossils should be statistically consistent if they provide reliable dates for the same event, namely their deposition at a particular level in the organic sequence. This approach was not tested here.

The project also did not compare the dates of single-entity plant macrofossils with those of bulked identified macrofossils, which are often dated in preference to bulk organic sediment, when the available macrofossils are all too small to date individually. Like bulk sediment, bulked macrofossils could include fragments of different dates, and their radiocarbon results may therefore be misleading. Statistical consistency between radiocarbon results from two or more samples of bulked macrofossils from the same level does not mean that the macrofossils dated are all of the same date. By identifying bulked macrofossils, however, it is possible to exclude intrusive rootlets and aquatic taxa, which cannot be removed from humified bulk sediment. The species composition of bulked macrofossils may also be argued to indicate that the probability that any macrofossil was reworked is relatively low, if the natural habitat of the taxa selected for dating is equivalent to the setting of the palaeoenvironmental investigation.

4.3.4 Conclusion

Radiocarbon dating results appear to validate the OSL age estimates previously obtained from this alluvial sequence. These support the approach of dating identified terrestrial plant macrofossils rather than bulk organic sediment samples in order to obtain the most reliable chronology for organic-rich palaeoenvironmental sequences, although where these are not available the radiocarbon ages of bulk sediment samples from intermediate levels can provide useful chronological evidence.

The results suggest two phases of organic channel fill accumulation at this location, one during the late third millennium cal BC and the other in the first millennium cal AD. These phases of deposition are separated by a phase of alluvial deposition which OSL dating places during the middle of the first millennium BC, while the later organic accumulation is sealed by a further phase of alluvial deposition which OSL dating indicates was also laid down during the later part of the first millennium AD.

4.4 Environmental deposit mapping using historic and current OS

4.4.1 Worcestershire

This work identified 127 sites in the Worcestershire pilot study where palaeoenvironmental deposits may survive, although only 17 of these scored as having a high potential, while 19 were of medium potential (Fig. 36).

The 17 high scoring sites included ponds, marsh areas, osier beds and meander loops. Of particular interest, however, was a possible large palaeochannel, running in an approximate north-south direction, mirroring the larger palaeochannels identified from the LiDAR on Terrace 5. This channel sits on Terrace 4 on the east of the current river and for the most part is located outside the study area. The northern and southern ends of this possible channel were, however, inside the study area but were not visible on the LiDAR. This possible channel was located by plotting mapped marsh areas and unusually elongated field boundaries running between them that appeared on the 1st edition OS map. It is thought that this channel was less visible on the LiDAR as it was older, being on Terrace 4, and therefore had longer to become infilled and masked by alluvial deposition and the effects of cultivation.

A second area of medium potential, not plotted using the LiDAR was located on the west of the current river. This possible east-west aligned channel was plotted as on the first edition OS map it is marked as being a marsh; however, a modern road obscures this feature on the LiDAR and therefore it was not identified on this.

Both examples illustrate the importance of plotting the areas of peat potential from the OS maps and for generally using OS mapping new and old in conjunction with the LiDAR to develop the most detailed and comprehensive coverage possible.

4.4.2 Gloucestershire

This work identified 59 sites where palaeoenvironmental deposits may survive, although only 8 of these were scored highly, while 31 were of medium potential (Fig. 37). The high scoring sites included ponds, marsh areas and meander loops. However, the majority of the sites tended to be isolated small ponds that had been present in the landscape for a significant period. Only two areas of greater significance were noted. One was a marshy area at the northern extremity of Terrace 2 fringing a possible large palaeochannel of the Severn (feature 2017) through which the Gloucester and Sharpness canal had been built. The second, a ribbon-like area, runs for approximately 750m within the floodplain of the River Frome.

5. Discussion and evaluation

5.1 Introduction

The use of the combination of investigative approaches described above has proved particularly effective in delivering project objectives (as opposed to any technique used in isolation); however, three techniques have proved to be particularly effective, namely:

- use of the LiDAR derived digital terrain model for mapping geomorphological and cultural features,
- use of desk-based analysis for identifying and assessing the potential of palaeochannels; and
- use of Optically Stimulated Luminescence dating in conjunction with radiocarbon dating to support the development and refinement of geochronologies.

The pilot studies undertaken to model, map, date and analyse geoarchaeological and palaeoenvironmental deposits using these approaches have provided a range of new and enhanced baseline information within the project study areas. Subsequent examination of this information in combination with other archaeological and landscape characterisation data held by the HERs has enhanced overall understanding of the relationships between these combined resources and their potential use in developing predictive models. Although largely restricted to the two study areas, the resultant information has made a contribution towards redressing the considerable research gap which exists in the understanding of the character of this major river system.

The following discussion and evaluation therefore examines these results in the light of current research frameworks for the Lower Severn Valley and is primarily focussed around the two principal aims and objectives of the project as described in Section 1; namely:

- to develop investigative approaches (EH Objective 1D, Research programme D1) for this poorly understood, major river catchment; and
- to improve baseline information (EH Objective 1A, Research programme A1).

Lastly, a brief consideration is made of the other project outcomes.

5.2 Developing investigative approaches

5.2.1 The use of LiDAR derived digital terrain models for mapping geomorphological and cultural features

The effectiveness (in terms of time, cost and accuracy) of LiDAR for examining floodplain geomorphology has been amply demonstrated elsewhere, for instance in Trent Valley GeoArchaeology 2002 (component 2b; Challis 2004; Challis, 2006; MHEF 2008). Such landform assemblages have been shown to be characterised by identifiable archaeological potential (Passmore *et al.* 2002; OA North and the University of Liverpool 2007; Howard *et al.* 2008; Waddington 2008; Passmore and Waddington 2009).

In the Lower Severn Valley, the use of LiDAR mapping has also proved highly effective, clearly demonstrating the value of adopting this technique for identifying and mapping landform units as well as cultural features. Mapping encompassed the entire area of both pilot study areas (16 x 1km² for the Frampton-on-Severn study area and 17 x 1km² for that at Clifton). In the Clifton study area, Worcestershire the completion of this work resulted in the identification of 73 landform units (39 terrace blocks and 34 palaeo-deposits) and 31 new cultural features, allied to enhanced understanding of 6 previously known sites. At Frampton, Gloucestershire rather fewer features were identified but 21 landform units were mapped along with 29 new cultural features and enhancement of understanding of 6 previously known sites. Such cultural features can be used in retrogressive-type analysis to provide a terminum-post-quem for alluvial and colluvial deposition.

Within the project, eighty-two and a half person days were used for processing of the LiDAR data, and analysis and transcription within a GIS of geoarchaeological features (landform units) and cultural features from the resultant digital terrain models. This represents a rate of 2.5 person days per 1km² including baseline data entry on attribute tables, thereby providing a cost effective approach in relation to information gained. It is further noted that this was a pilot and that a more rapid rate should be achievable within longer-term or larger-scale surveys and/or where the transcriber has prior experience of the process.

The value of cross-checking with other sources (a process embedded within the transcription work) and making site visits to 'ground truth' mapped data was also established as has been demonstrated elsewhere (Brown *et al.* 2007, 253; OA North and University of Liverpool 2007, section 3.5); although it is noted that no new features or alterations to the desk-based mapping resulted from the site visits and that the cross-checking with other sources such as aerial photographs proved to be a considerably more effective approach to 'ground truthing' results. Further, it is recognised that the 'ground truthing' completed as part of the current project has limitations and that further field-based work is ideally required to enable full confidence to be placed in some aspects of the mapping produced. For example, the coring of palaeochannels mapped from LiDAR during the Suffolk Rivers Project demonstrated that some were not palaeochannels (Howard *et al* 2009).

The resultant mapping has extended and refined mapping of the river terrace and alluvial units (as previously mapped by the BGS). Many previously unmapped palaeochannels and numerous previously unknown cultural features have also been mapped in both pilot study areas. Cultural features identified mainly comprised surviving earthworks relating to cultivation (ridge and furrow), watermeadows and other water management features but also included a number of enclosures, building platforms and settlement features.

The greater information gain in the Worcestershire pilot than in the Gloucestershire one can be attributed to several factors, the most significant of which is that greater thicknesses and extents of alluvial deposition (both riverine and estuarine) are present in the Frampton-on-Severn study area. These deposits will have 'masked' both geomorphological and cultural features, especially those of earlier date, to a greater degree than in the Worcestershire study area, where alluvial deposition is not as extensive or as deep (although 'masking' is also recognised as a factor within the Clifton pilot study). Additionally the Frampton pilot study area was located near the confluence of the Frome and Severn and thus less clarity might be expected since the study area did not encompass the whole floodplain width of both rivers. This is believed to have especially hindered the development of a full picture of significant palaeochannels since the breadth of the survey did not enable their courses to be traced effectively and with any confidence. This area was also characterised by the presence of very extensive areas of medieval ridge and furrow earthworks which in themselves will have a masking effect on earlier features. Furthermore, the preservation of such features highlights the good preservation of earthworks and thus by implication below ground archaeological deposits in these areas.

It is therefore concluded that any future studies of this type in the Lower Severn Valley should ensure that the entire valley floor is covered, especially where undertaken near a confluence, and also that the benefits of the mapping are reduced where deep and extensive alluvium is present and/or where large areas of ridge and furrow are present. Despite the difficulties inherent in characterising and studying these 'masked' areas, it is only through mapping them that the areas affected and the 'knowledge gaps' they create can be properly identified and means sought to assess their potential. Here, the evidence from extensively revealed areas of the sub-alluvial landscape such as quarry operations can provide is highly important. These provide a means of assessing their potential character and demonstrate the potential importance of remains which might be 'masked' within such landscapes (e.g the nationally important Grooved Ware pit deposits recorded at Clifton; Mann and Jackson 2009). Additionally, approaches which have been extensively tested in other river catchments need to be adopted (e.g. predictive modelling and the use of specialist remote sensing and augering to develop sub-surface mapping).

This project enabled the correlation within a GIS of the newly mapped landform units and cultural features with data derived from existing sources such as Historic Environment Records. This has provided a better understanding of the likely archaeological resource present within the pilot study areas. The resultant examination of relationships between major landform units and the known archaeological resource was shown to have a good potential for identifying trends and correlations such as might be used to develop predictive models. As noted previously, such correlations have been observed in other catchments (Passmore *et al.* 2002; OA North and the University of Liverpool 2007; Howard *et al.* 2008; Waddington 2008; Passmore and Waddington 2009) but this study confirms the potential of this approach in the Lower Severn Valley, identifying associations between elements of the archaeological resource and certain landforms. This has also further demonstrated the artificial 'blanks' in the record created by alluvial 'masking', a problem previously highlighted for the Lower Severn aggregate producing areas (Jackson and Dalwood 2007; Mullin 2008) and within comparable river valley studies elsewhere (*e.g.* Bapty 2008; Howard *et al.* 2008).

It has not been possible within the confines of this project to develop any predictive models; however, in the medium to long term it is hoped that sufficient LiDAR derived mapping of geomorphological landforms in the Severn Valley will ensue, thus enabling the potential of combining this with other information sources to be realised. Such outcomes would be of considerable potential value in strategic decision making and in further refining which prospection techniques might be most appropriately employed when evaluating or mitigating future mineral (and other) development applications. In the meantime, accessioning of the newly mapped information onto the county HERs will provide an important new resource in delivering more effective management and protection of deposits in the two study areas, as well as highlighting the value of developing comparable resources for the remainder of the catchment.

5.2.2 The use of desk-based analysis in identifying and assessing palaeochannels

The use of historic map analysis in identifying and tracing palaeochannels and other features has proved to be a rapid and cost effective tool in the Lower Severn Valley in both study areas. This has enabled the enhancement of features recorded through the LiDAR analysis but more importantly has also mapped features not readily identifiable or not visible at all, on the LiDAR mapping.

These features have a high potential for containing well-preserved organic deposits suitable for palaeoenvironmental analysis and reconstruction, examination of which can provide detailed data on inter-related patterns of former climate and landscape change, as well as human impact on the latter. As a result, a largely desk-based methodology was trialled for assessing the potential of both palaeochannels and other features (such as ponds and mill leats). This also proved to be rapid and cost effective, leading to identification of 25 areas of high potential. Further, the integration of this and other environmental data into HERs using an approach previously developed in Worcestershire was extended into the pilot area in Gloucestershire, demonstrating the potential of making this information available though the HER. Accessioning of such information provides an important new resource since it enables the more effective management and protection of these deposits which are often either not recorded or very poorly represented and thus can easily be overlooked during the planning process.

5.2.3 The use of OSL and radiocarbon dating in developing floodplain geochronologies

The pilot dating studies undertaken have provided dating for phases of terrace formation, Holocene alluvial accumulation and palaeochannel incision and abandonment, showing both OSL and radiocarbon dating to be effective tools in developing geochronologies within this particular river valley.

The pilot has shown that both the terrace units and overlying alluvial horizons present within the Lower Severn are suited to OSL dating. There appears to be no geologically inherited cause of systematic error and they have sufficient datable mass; errors are therefore likely to be associated with partial bleaching and bioturbation, and vary from sample to sample. This technique should therefore be exploited to re-evaluate the terrace chronologies established for the Severn and develop understanding of patterns of later prehistoric, Roman and medieval alluviation in this region which has good archaeological records for these periods.

The occurrence of partially bleached samples at Frampton and Clifton has suggested that future work should employ single-grain approach for Terraces 1 and 2, while the divergent dosimetry approach has been shown to be valuable. The latter could be capitalised upon by either profile dosimetry or the sampling of multiple samples and dating of only those with significantly different mean dose rates.

Radiocarbon dating of a complex sequence of organic palaeochannel deposits within an area also tested by OSL dating of associated terrace units has largely validated the OSL age estimates. The work has also confirmed that dating of terrestrial plant macrofossils rather than bulk organic sediment samples is likely to obtain the most reliable chronology for organic-rich palaeoenvironmental sequences, though the cautionary example provided by Howard *et al* (2009) should be noted. However, bulk organic sediment samples can potentially be of value especially for more recent sequences which include horizons which do not provide appropriate terrestrial plant macrofossils and where Bayesian modelling is utilised.

5.3 Improving baseline information

5.3.1 Geomorphological landform units and cultural features

Landform units identified and mapped primarily comprised terrace units, terrace edges, alluvial accumulations, and palaeochannels. Of these, the mapping of terrace units and extents has proved to provide greater resolution and accuracy than is available through the BGS (the previous best source of mapping). However, it is through the mapping of probable palaeochannels and other features of high palaeoenvironmental potential that the project has made the most significant contribution to baseline information. These include Holocene palaeochannels, incised into the lower terraces, and potentially earlier palaeochannels, present on the upper terraces. These palaeochannels (both Holocene and those of potentially pre-Holocene date) have a high potential to contain well-preserved palaeoenvironmental and geoarchaeological deposits. As previously noted, ideally these should be cored to prove their identification as palaeochannels; however, two examples have been confirmed in this study by previous work (at Ashmoor Common, Brown 1982; and within Clifton Quarry, Head 2007; Fig 11). Both contain well-preserved organic sequences and in the case of that investigated in the quarry is closely associated with significant cultural activity on the channel bank (Mann and Jackson forthcoming; Brown *et al* forthcoming). As a result of the mapping undertaken by the project, the courses of these two channels have now been more fully mapped, enabling both the channel deposits and potential cultural associations to be more effectively managed in the future.

Mapped cultural features mainly comprised surviving earthworks relating to cultivation (ridge and furrow), watermeadows and other water management features but also included a number of enclosures, building platforms and settlement features. Although significant elements of the ridge and furrow and watermeadow systems had previously been identified in both study areas, largely through aerial photographic mapping, the project has considerably enhanced understanding of the extents and character of these features. Enhanced understanding of a deserted medieval village and several later settlement features was also provided, but perhaps most significant discoveries are the two earthwork-defined, enclosures masked beneath woodland on low hilltops in the Clifton study area. Morphologically these appear most likely to represent previously unknown Iron Age or Romano-British settlements, especially the elongated enclosure with an apparent internal sub-division recorded in Frieze Wood. Since both have been identified through surviving earthworks, indications are that preservation of these sites is very good and, although untested, these both appear to represent important new discoveries with a high archaeological potential.

This new mapping has been deposited with both county HERs providing an important and accessible addition to the known archaeological resources within both study areas, for both cultural and geomorphological features.

5.3.2 Developing chronologies

As described above, optical dating proved to be effective in dating both gravel terrace and alluvial units, providing a series of age estimates which, although accompanied by analytical caveats, were on the whole consistent with their relative stratigraphic positions. Whilst anticipated ages were achieved for most of the units investigated, as discussed above a series of four dates from terrace deposits at Ball Mill, Grimley provided a major disagreement with the existing understanding of the terrace chronology suggesting an early Devensian (MIS5a-d) as opposed to the anticipated late Devensian date (MIS2). Further importance lies in the fact that at the previously estimated date these deposits were assessed to have very low archaeological and Quaternary research potential (Buteux, Keen and Lang 2005, 37) but at this revised date they could theoretically contain Middle or Upper Palaeolithic artefacts. This work has therefore delivered important new information on a major element of terrace chronology, information which potentially requires reconsideration of the conditions under which the terrace formed as well as potential archaeological associations of these deposits.

The radiocarbon dating programme undertaken was also successful and has suggested two phases of organic channel fill accumulation at this location, one during the late third millennium BC and the other in the first millennium AD. These phases of deposition are separated by a phase of alluvial deposition which OSL dating places during the middle of the first millennium BC, while the later organic accumulation is sealed by a further phase of alluvial deposition which OSL dating indicates was being laid down during the later part of the 8th century AD. This confirms patterns of channel incision, abandonment and alluviation observed elsewhere in the Severn Valley, as through previous work in the Clifton area (Brown 1982, 1983; Head 2005, 2007) and further afield as at Ripple (Brown 1982; 1983). These indicate that the mid to late Holocene (ca 4500 yr BP to 2500 yr BP) was a period of major floodplain and river channel change during which overbank deposition and vertical accretion of fine grained sediments accelerated. This phenomenon has been widely noted in the Midlands and is liable to have resulted in gradual reduction of floodplain relief and other changes initially in the lower parts of the floodplain and then at a later date on higher areas (Brown and Keough 1992). It has been suggested that, whilst there are indications of hydrological change preceding this, the primary cause of the metamorphosis was an increase in fine sediment supply during the later Holocene which can probably be related in part to woodland clearance and cultivation. This process was first proposed in the Severn Valley by Shotton (1978) and it is suggested that this resulted in the development of an imbalance in channel bed and flood plain aggradation rates resulting in relative incision Brown and Keough 1992). Much of the evidence for the chronology of this metamorphosis has derived from dating of organic fills within abandoned palaeochannels such as those examined here. This project has therefore extended that work and most significantly has demonstrated that OSL dating can effectively date associated alluvial horizons; dating the alluvium that separated the two abandoned channel fill sequences to the first millennium BC and that sealing them to the later 8th century AD. The latter alluvial deposit is a distinct, reddish brown coloured alluvium which is widely present in the Severn Valley. This has long been anticipated on the basis of dating of cultural remains (both pre- and post-dating the alluvium) and dated organic sequences to be of early medieval origin. Through demonstrating this date to be correct the project has now confirmed that cultural deposits of pre-8th century date are liable to be masked below this material wherever it is present.

5.4 Other project outcomes

As well as trialling techniques and providing enhanced baseline information for the Lower Severn Valley, the project also had a number of other objectives which it has delivered and which are not readily covered in the two previous sections.

From the outset, the project aimed to provide information, feedback and guidance to HERs, minerals operators, planners, archaeological organisations and other stakeholders, thus ensuring the future delivery of consistent, proportionate, and evidence-based approaches to archaeological investigation and mitigation within the Severn Valley. This had the aim of ensuring that the project addressed some of the principal objectives identified in the guidance set out in the *Mineral Extraction and Archaeology: A Practice Guide* produced by the Minerals Historic Environment Forum (MHEF 2008).

This has been achieved in a number of ways. Firstly this report and the mapped deposit models and accompanying information have been deposited with the respective HERs for Gloucestershire and Worcestershire. This means that project data is readily accessible to all stakeholders. It will also serve to raise awareness of the distinct character and archaeological potential of the mineral producing areas of the valley and highlight effective techniques for use in investigation of the landscape of this river valley.

This will be of considerable value for the following processes:

- Defining the scope of archaeological input to strategic planning and development frameworks (LDFs, MDFs and LDDs);
- Scoping development briefs for individual quarry applications;
- Use in producing Environmental Impact Assessments and Environmental Statements undertaken in support of planning applications (where required); and
- Designing appropriate, effective and targeted programmes of evaluation and mitigation.

Secondly, web-based information provided through the ADS and the project partner websites allied to production of two academic papers will ensure that the project results reach a wider audience than is liable to be achieved through deposition with the HERs. The academic papers will especially focus on presenting those techniques have proved to be most effective in the Severn Valley and will also highlight the ready availability of the information and mapping produced through the HERs. One of the papers will also present the results of a project undertaken in 2007/8 at Wellington Quarry in the Lugg Valley, Herefordshire which provides a case study for the successful application of these techniques within the commercial sphere as required as part of the development control process.

Thirdly, the Wellington case study and the principles and benefits of applying this methodological approach in the Severn Valley and wider West Midlands region have been highlighted within a paper given at two of the four workshops (*Mineral Extraction and Archaeology: Using the Practice Guide*) organised in 2010 by MIRO (Minerals Industry Research Organisation) on behalf of English Heritage. These workshops were designed to promote the use of the 2008 Minerals and Historic Environment Forum publication *Mineral Extraction and Archaeology: A Practice Guide*. These workshops attracted an audience which comprised not only archaeologists (contractors, consultants and curators) but also a significant number of mineral planning officers, mineral operators, estate managers and mineral planning consultants, thus reaching a wide range of stakeholders.

6. Future research and development

Potential further stages for the project (for which a funding source has yet to be identified), are outlined below. These would build on the enhanced evidence and knowledge base established for the Lower Severn Valley by this and other recently completed ALSF projects, thereby supporting development of future research initiatives and feeding into the research cycle for Britain’s longest river.

Proposed stages encompass extension of the mapping and deposit modelling beyond the two pilot study areas already examined and the further development of the prospection ‘tool kit’ through the testing of applicable field techniques. Such work would have the aim of providing mapping and deposits modelling for the whole of the Lower Severn Valley and of ‘ground truthing’ and enhancing models developed though the mapping work and further ‘sharpening’ prospection techniques.

This could be undertaken as a single project or through a series of interlinked initiatives with the overarching aim of contributing to the continued development of prospection techniques and geomorphological research within the Lower Severn Valley.

Proposed elements would include:

- Extension of the mapping and modelling approaches successfully developed during this pilot study across either the entire area (or further selected areas) of the Lower

Severn Valley, thereby providing a consistent baseline resource for either the entire area or areas identified as most under threat from aggregate extraction or other major developments;

- Further development of the prospection 'tool kit' through the testing of applicable field techniques within the two pilot study areas to 'ground truth' and enhance models developed though the mapping work, and to test the Severn Valley models against established models from other large river valleys. This would support the effective and consistent application of prospection and mitigation techniques, especially within aggregate producing areas, and provide improved baseline data underpinning planning decisions developed both strategically and in relation to individual applications;
- Further examination of distributions of cultural evidence against geoarchaeological and palaeoenvironmental mapping (landform units) and models to update elements of the aggregates resource assessments and other research frameworks, and to improve predictive modelling of the archaeological resource within the Lower Severn Valley, thereby reducing risk to both the archaeological resource and potential developers;
- Further detailed palaeoenvironmental analysis and reconstruction (including of the palaeochannel deposits dated through this project), and provision of further guidance on the palaeoenvironmental potential associated with the terraces and floodplain of the Lower Severn Valley;
- The development of further recommendations as to the possible directions of future archaeological research in relation to the terraces and floodplain of the Lower Severn.
- Provision of one or more Severn Valley conferences/seminars (to follow that successfully held in 2008) highlighting the results of new work in the Lower Severn Valley and associated catchments such as the Lugg, Wye, Worcestershire/Warwickshire Avon and Frome.

7. Conclusions and recommendations

The project set out with two principal aims, namely:

- to develop investigative approaches (EH Objective 1D, Research programme D1) for this poorly understood, major river catchment; and
- to improve baseline information (EH Objective 1A, Research programme A1).

These aims have been met, the project results making an important contribution to methodological approaches for investigating archaeological and geomorphological deposits in the Lower Severn Valley, as well as making an important contribution to the knowledge base for the active aggregate extraction landscapes of this area, one of the last major UK valley floors to still hold significant aggregate resources.

The resultant information will considerable benefit to minerals operators in the region by enhancing the quality, consistency and reliability of the baseline data available through the county HERs; data which is used by archaeological planning officers in developing regional mineral development frameworks (LDFs) and determining individual aggregate extraction applications.

The results also highlight the archaeological potential and complexity of this poorly understood landscape and will support provision of effective, consistent, appropriate and cost effective evaluation and other mitigation strategies in relation to future aggregate applications. The importance of developing improved and more effective prospection techniques and predictive models has been emphasised in recent years at both Ryall and Clifton Quarries where PPG16 Assistance has been required to support mitigation work relating to commercial mineral extraction programmes.

The project has enabled the development of a more effective 'toolkit' which can be widely applied during prospection, mitigation design and research. Three techniques have proved particularly effective and recommended for widespread adoption within the Lower Severn Valley and other comparable river catchments. These are:

1. The mapping and analysis of geoarchaeological features (landform units) using Digital Surface Models derived from Environment Agency LiDAR surveys. The latter are readily available (http://www.geomatics-group.co.uk/GeoCMS/Order.aspx) and can be used in conjunction with the cost-effective mapping approaches and pro-forma developed during this project. These allow ready transfer and use of the resultant information within Geographic Information Systems based within Historic Environment Records.

2. The mapping and environmental assessment of palaeochannels and other features with high organic potential using historic maps. Again the resultant data can be structured as during this particular project to enable the ready transfer and use of resultant information within Historic Environment Records

3. The use of Optically Stimulated Luminescence and radiocarbon dating techniques to develop and test geochronological models for terrace formation, and to date Holocene alluvial deposition and phases of palaeochannel incision and abandonment.

8. Bibliography

(Please note: Most Worcestershire Historic Environment and Archaeology Service reports have been published in digital format through our online library service http://www.worcestershire.gov.uk/home/wccindex/archeo_dr_list-public.htm)

Adamiec, G, and Aitken, M J, 1998 Dose-rate conversion factors: new data, *Ancient TL*, **16**, 37-50

Agersnap-Larsen, N, Bulur, E, Bøtter-Jensen, L, and McKeever, S W S, 2000 Use of the LM-OSL technique for the detection of partial bleaching in quartz, *Radiation Measurements*, **32**, 419-25

Aitken, M J, 1998 *An introduction to optical dating: the dating of Quaternary sediments by the use of photon-stimulated luminescence*, Oxford University Press

Bailey, R M, Singarayer, J S, Ward, S, and Stokes, S, 2003 Identification of partial resetting using D_e as a function of illumination time, *Radiation Measurements*, **37**, 511-18

Baker, S, 2006 Trent Valley: Palaeochannel Mapping from Aerial Photographs, Research report for Trent Valley GeoArchaeology, Nottingham, Trent and Peak Archaeological Unit, http://ads.ahds.ac.uk/catalogue/archive/palaeo_eh_2006/overview.cfm.

Baker, S, 2007 The palaeochannel record in the Trent Valley UK: contributions towards cultural heritage management, *Internet Archaeology*, **20**, http://intarch.ac.uk/journal/issue20/baker_index.html.

Banerjee, D, Murray, A S, Bøtter-Jensen, L, and Lang, A, 2001 Equivalent dose estimation using a single aliquot of polymineral fine grains, *Radiation Measurements*, **33**, 73-94

Bapty, I, 2008 *Lower Lugg floodplain. Archaeological mitigation review*, Herefordshire Archaeology Report, **243** (EH PNUM 3336), http://ads.ahds.ac.uk/catalogue/archive/lugg_eh_2007

Barber, A, and Watts, M, 2008 Excavations at Saxon's Lode Farm, Ripple, 2001-2: Iron Age, Romano-British and Anglo-Saxon rural settlement in the Severn Valley, *Transactions of the Worcestershire Archaeological Society*, 3 series, **21**, 1-90

Barton, R N E *et al*., 1995 Wye Valley Caves Project: investigations at King Arthur's Cave and Madawg Rock Shelter. In Lewis, G S, and Maddy, D, (eds) *The Quaternary of the South Midlands and the Welsh Marches. Field Guide*. London, Quaternary Research Association.

Bateman, M D, Frederick, C D, Jaiswal, M K, Singhvi, A K, 2003 Investigations into the potential effects of pedoturbation on luminescence dating, *Quaternary Science Reviews*, **22**, 1169-76

Bayliss, A, Cook, G, Bronk Ramsey, C, van der Plicht, J, and McCormac, F G, 2008 *Radiocarbon Dates from Samples Funded by English Heritage under the Aggregates Levy Sustainability Fund 2004–7*, Swindon: English Heritage

Berger, G W, 2003 Luminescence chronology of late Pleistocene loess-paleosol and tephra sequences near Fairbanks, Alaska, *Quaternary Research*, **60**, 70-83

Berger, G W, Mulhern, P J, and Huntley, D J, 1980 Isolation of silt-sized quartz from sediments, *Ancient TL*, **11**, 147-52

Boismier, B, 2002 Lynford Quarry, A Neanderthal butchery site, *Current Archaeology* **182,16**, 53-8

Bøtter-Jensen, L, McKeever, S W S, and Wintle, A G, 2003 *Optically Stimulated Luminescence Dosimetry*, Elsevier, Amsterdam

Bøtter-Jensen, L, Mejdahl, V, and Murray, A S, 1999 New light on OSL, *Quaternary Science Reviews*, **18**, 303-10

Bowen, D Q (ed.), 1999 *A Revised Correlation of Quaternary Deposits in the British Isles.* Geological Society Special Report, **23**, London

Bridgland, D R, 1994 *Quaternary of the Thames,* Geological Conservation Review Series, **7**, Chapman and Hall, London

Bridgland, D R, Westaway, R, Howard, A J, Innes, J B, Long, A J, Mitchell, W A, White, M J, and White, T S, in press The role of glacio-isostasy in the formation of post-glacial river terraces in relation to the MIS 2 ice limit: evidence from northern England, *Proceedings of the Geologists Assoc*

Brock, F, Higham, T, Ditchfield, P, and Bronk Ramsey, C, 2010 Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU) *Radiocarbon*, **52**(1), 103–12

Bronk Ramsey, C, 1995 Radiocarbon calibration and analysis of stratigraphy, *Radiocarbon*, **36**, 425–30

Bronk Ramsey, C, 1998 Probability and dating, *Radiocarbon*, **40**, 461–74

Bronk Ramsey, C, 2001 Development of the radiocarbon calibration program, *Radiocarbon*, **43**, 355–63

Bronk Ramsey, C, 2008 Deposition models for chronological records, *Quaternary Science Reviews*, **27**(1-2), 42–60

Bronk Ramsey, C, 2009 Bayesian analysis of radiocarbon dates, *Radiocarbon*, **51**, 337–60

Bronk Ramsey, C, Higham, T, and Leach, P, 2004 Towards high precision AMS: progress and limitations, *Radiocarbon*, **46(1)**, 17–24

Brown, A G, 1982 Human impact on former floodplain woodlands of the Severn, in M Bell and S Limbrey (eds), *Archaeological Aspects of Woodland Ecology*, British Archaeological Reports, International Series, **146**, 93-105

Brown, A G, 1983 Floodplain deposits and accelerated sedimentation in the lower Severn basin, in K J Gregory (ed), *Background To Palaeohydrology*, Wiley, Chichester, 375-98

Brown, A G, 1984 The Flandrian vegetation history of Hartlebury Common Worcestershire, *Proc Birmingham Natural History Soc*, **25**, 89-98

Brown, A G, 1987 Holocene floodplain sedimentation and channel response of the lower river Severn, UK, *Zeitscrift fur Geomorphologie N F*, **31**, 293-310

Brown, A G, 1991 Hydrogeomorphology and palaeoecology of the Severn basin during the last 15,000 years: orders of change in a maritime catchment, in K J Gregory, L Starkel and J B Thornes (eds.) *Fluvial Processes in the Temperate Zone During the Last 15,000 Years*, Wiley, Chichester, 147-69

Brown, A G, 2004a *Regional Variations in Aggregate-Related and Valley Archaeology (PNUM 3350)*, Position Paper for English Heritage, London

Brown, A G, 2004b *Aggregate-Related Archaeology in England: A Review (PNUM 3350)*, Position Paper for English Heritage, London

Brown, A G, 2009 *The Environment and Aggregate-related Archaeology,* Oxbow Books & Heritage Marketing and Publications, Oxford

Brown, A G, and Keough, M, 1992 Holocene floodplain metamorphosis in the Midlands, United Kingdom, *Geomorphology*, **4**, 433-45

Brown, A G, Howard, A, Jackson, R, Mann, A, and Roberts, T, and Toms, P S, in prep Pleistocene Fluvial Geology and Geomorphology of the Lower Severn Valley, UK, *Quaternary Science Reviews*

Brown, A G, Basell, L S, Toms, P S, Bennett, J, Hosfield, R T, and Scrivener, R C, 2010 Later Pleistocene Evolution of the Exe Valley: A Chronstratigraphic Model of Terrace Formation and its Implications for Palaeolithic Archaeology, *Quaternary Science Reviews*, **29 (7-8)**, 897-912

Brown, A G, Carey, C, Challis, K, Howard, A, and Cooper, L, 2005 *Predictive modelling of multi-period geoarchaeological resources at a river confluence*, Phase 1 Report (PNUM 3357), http://ads.ahds.ac.uk/catalogue/archive/trentsoar_eh_2008/downloads.cfm

Brown, A G, Carey, C, Challis, K, Howard, A, Kincey, M, Tetlow, E, and Cooper, L, 2007 *Predictive modelling of multi-period geoarchaeological resources at a river confluence*, Phase II Report (PNUM 3357), http://ads.ahds.ac.uk/catalogue/archive/trentsoar_eh_2008/downloads.cfm

Brown, A G, Hatton, J, Pearson, L, Roseff, R, and Jackson, R, 2005 The Severn-Wye Revisited: Lateglacial-Holocene Floodplain Palaeoenvironments in the Lugg Valley, in D N Smith, M B Brickley, and W Smith (eds.) *Fertile Ground. Papers in Honour of Susan Limbrey*, Symposia for the Association of Environmental Archaeology, **22**, Oxbow Books, Oxford, 16-29

Bryant, V, and Pearson, E, 2004 *A model for accessing environmental evidence through Historic Environment Records*, Worcestershire Historic Environment and Archaeology Service, Paper presented for an e-conference on Archaeological Science Data and the SMR/HER, held on 17th of January 2004 by the Forum for Information Standards in Heritage (FISH), available at https://www.jiscmail.ac.uk/cgi-bin/webadmin?A2=ind05&L=FISH&D=0&H=0&O=T&T=0&P=35074

Burn C R, 1990 Implications for palaeoenvironmental reconstruction of recent ice-wedge development at Mayo, Yukon territory, *Permafrost and Periglacial Processes*, **1**, 3–14

Buteux, S T E, Keen, D H, and Lang, A T O, 2005 *The Shotton Project. Resource Assessment*, University of Birmingham: Birmingham Archaeology

Carey, C J, and Howard, A H, 2008 *Wellington Quarry Moreton-on Lugg extension. Geoarchaeological assessment*, VISTA Centre, University of Birmingham, client report for WCC

Carey, C J, Brown, A G, Challis, K C, Howard, A, and Cooper, L, 2006 Predictive modelling of multi-period Geoarchaeological Resources at a River Confluence, *Journal of Archaeological Prospection*, **13**, 241-50

Challis, K C, 2006 Airborne laser altimetry in alluviated landscapes, *Archaeological Prospection*, **13**, 103-27

Challis, K, 2004 *Trent Valley GeoArchaeology 2002. Component 2b LiDAR Terrain Models*, Trent Valley Geoarchaeology Research Report, York, York Archaeological Trust, http://www.tvg.bham.ac.uk/lidar.pdf?bcsi_scan_A6AF5382CFDFA77B=jUj87SGAE+nnx+4cSo6YZCgAAAD/xXsW:1

Challis, K, Kokalj, Z, Kincey, M, Moscrop, D, and Howard, A J, 2008 Airborne lidar and historic environment records, *Antiquity*, **82 (318)**, 1055-64

Chiverrell, R C, Foster, G C, Thomas, G S P, Marshall, P and Hamilton, D, 2008 Robust chronologies for landform development, *Earth Surface Processes and Landforms (2008)*

Dawson, M R, and Bryant, I D, 1987 Three-dimensional facies geometry in Pleistocene outwash sediments, Worcester, UK, in F G Etheridge (ed.) *Recent Developments in Fluvial Sedimentology*, Society of Economic Palaeontologists and Mineralogists Special Publication **39**, 191-6

DCLG, 2010 *Planning Policy Statement 5: Planning for the historic environment,* Department for Communities and Local Government

DCLG, DCMS and EH, 2010 *PPS5 Planning for the historic environment: historic environment planning practice guide.* Department for Communities and Local Government/Department for Culture, Media and Sport/English Heritage

Duller, G A T, 2003 Distinguishing quartz and feldspar in single grain luminescence measurements, *Radiation Measurements*, **37**, 161-5

Duller, G A T, 2008 *Luminescence dating: Guidelines on using luminescence dating in archaeology*, English Heritage, http://www.english-heritage.org.uk/upload/pdf/luminescence_dating.pdf?1251999658

Earle, S, 2009 Testing the chronostratigraphy of the River Severn's terraces using optically stimulated luminescence dating, unpublished BSc thesis, University of Gloucestershire

Elrington, C, and Herbert, N, (eds.), 1972 *A History of the County of Gloucester, Westbury and Whitstone Hundreds*, HMSO

English Heritage, 2004 River and estuary of the Severn – proposals for grant-funded historic environment research, unpublished typescript

English Heritage, 2006 *Advice and guidance to users on laser scanning in archaeology and architecture*, http://www.english-heritage.org.uk/upload/pdf/publishing-3d-laser-scanning-reprint.pdf?1251999713

English Heritage, 2008 *SHAPE 2008. A strategic framework for Historic Environment activities and programmes for English Heritage*, English Heritage

English Heritage, 2010 *The light fantastic. Using airborne LiDAR in archaeological survey*, English Peritage Publishing

Flatman, J, Short, J, Doeser, J, and Lee, E (eds.), 2008 *ALSF Dissemination Project 2002-7 Benchmark Report: Sustainable heritage – Aggregates extraction and the historic environment*, London: UCL Centre for Applied Archaeology, on behalf of English Heritage

Fulford, M, and Nichols, E (eds.), 1992 *Developing landscapes of lowland Britain: the archaeology of the British gravels: a review*, Society of Antiquaries, London

Galbraith, R F, 1990 The radial plot: graphical assessment of spread in ages, *Nuclear Tracks and Radiation Measurements*, **17**, 207-14

Galbraith, R F, Roberts, R G, Laslett, G M, Yoshida, H, and Olley, J M, 1999 Optical dating of single and multiple grains of quartz from Jinmium rock shelter (northern Australia): Part I, Experimental design and statistical models, *Archaeometry*, **41**, 339-64

Gardiner, C, 1932 Recent discoveries in the Stroud Valley, *Proceedings of the Cotteswold Naturalists Field Club*, **XXIV (3)**, 163-80

Garwood, P, (ed) 2007 *The Undiscovered Country. The Earlier Prehistory of the West Midlands*, The Making of the West Midlands. Vol, **1**, Oxbow

Gregory, K J, Starkel, L, and Thornes, J B, (eds.) 1991 *Fluvial Processes in the Temperate Zone During the Last 15,000 Years*, Wiley, Chichester

Harris, C, and Murton, J, 2005 Experimental simulation of ice-wedge casting: processes, products and palaeoenvironmental significance, *Geological Society, London, Special Publications,* **242**, 131-43

Harry, D G, and Gozdik, J S, 1988 Ice wedges: Growth, thaw transformation, and palaeoenvironmental significance, *Journal of Quaternary Science*, **3**, 39-55

Head, K, 2005 Pollen remains, in T M Vaughan, *Archaeological Evaluation at Clifton Quarry, Severn Stoke, Worcestershire*, Worcestershire Historic Environment and Archaeology Service, internal report, **1369**

Head, K, 2007 *Environmental remains from a palaeochannel investigated at Clifton Quarry, Severn Stoke, Worcestershire*, Worcestershire Historic Environment and Archaeology Service, internal report, **1529**

Hosfield, R T, Brown, A G, Basell, L S, Hounsell, S, and Young, R, 2006 *The Palaeolithic Rivers of South-West Britain (PNUM 3847)*, Final Report Phases I & II, University of Reading and University of Exeter, http://ads.ahds.ac.uk/catalogue/archive/proswb_eh_2007

Howard, A J, Bridgeland, D R, Knight, D, McNabb, J, Rose, J, Shreve, D C, Westaway, R, and White, T S, 2007 The British Pleistocene fluvial archive; East Midlands drainage evolution and human occupation in the context of the British and NW European record, *Quaternary Science Reviews*, **26**, 2724-37

Howard, A J, Brown, A G, Carey, C J, Challis, K, Cooper, L P, Kincey, M, and Toms, P, 2008 Archaeological resource modelling in temperate river valleys: a case study from the Trent Valley, UK, *Antiquity*, **82 (318)**, 1040-54

Howard, A J, Gearey, B R, Hill, T, Fletcher, W, and Marshall, P, 2009 Fluvial sediments, correlations and palaeoenvironmental reconstruction: the development of robust radiocarbon chronologies, *Journal of Archaeological Science*, **36**, 2680-88

Hubble, J H, 1982 Photon mass attenuation and energy-absorption coefficients from 1keV to 20MeV, *International Journal of Applied Radioisotopes*, **33**, 1269-90

Huntley, D J, Godfrey-Smith, D I, and Thewalt, M L W, 1985 Optical dating of sediments, *Nature*, **313**, 105-7

Hurst, D, and Miller, D, 2008 *River Severn bank-side survey. Worcester to Tewkesbury (PNUM 5301)*, WCC Historic Environment and Archaeology Service for English Heritage, http://ads.ahds.ac.uk/catalogue/archive/severnbank_eh_2008

Hütt, G, Jaek, I, and Tchonka, J, 1988 Optical dating: K-feldspars optical response stimulation spectra, *Quaternary Science Reviews*, **7**, 381-6

Jackson, M L, Sayin, M, and Clayton, R N, 1976 Hexafluorosilicic acid regent modification for quartz isolation, *Soil Science Society of America Journal*, **40**, 958-60

Jackson, R, and Dalwood, H, 2007 *Archaeology and aggregates in Worcestershire: a resource assessment and research agenda (PNUM 3966)*, WCC Historic Environment and Archaeology Service, Internal report, **1477**, http://ads.ahds.ac.uk/catalogue/archive/worcsagg_eh_2007

Jackson, R, and Miller, D, in press *Wellington Quarry, Herefordshire (1986-96). Investigation of a landscape in the Lower Lugg Valley*, Oxbow Books

Lowe, J J, and Walker, M J C, 2000 Radiocarbon dating the last glacial-interglacial transition (14C ka BP) in terrestrial and marine records: the need for new quality assurance protocols, Radiocarbon, **42**, 53-68

Maddy, D, Bridgland, D R, and Westaway, R, 2001 Uplift-driven valley incision and climate controlled river terrace development in the Thames Valley, UK, *Quaternary International*, 79, 23–36

Maddy, D, English Midlands, in D Q Bowen (ed.) 1999 *A Revised Correlation of Quaternary Deposits in the British Isles*, Geological Society Special Report, **23**, 28-44

Maddy, D, Green, C P, Lewis, S G, and Bowen, D Q, 1995 Pleistocene geology of the Lower Severn valley, *UK Quaternary Science Reviews*, **14**, 209-22

Maddy, D, Keen, D H, Bridgeland, D R, and Green, C P, 1991 A revised model for the Pleistocene development of the River Avon, Warwickshire, *Journal of the Geological Society of London*, **148**, 473-84

Mann, A, and Jackson, R, 2009 *Archaeological watching brief and contingency excavation at Clifton Quarry, Severn Stoke, Worcestershire (PNUM 5379)*, Historic Environment and Archaeology Service, Worcestershire County Council, Internal Report, **1612**

Mann, A, forthcoming *Excavation of an early to Middle Iron Age settlement at Clifton Quarry, Severn Stoke, Worcestershire (PNUM 5714)*, Historic Environment and Archaeology Service, Worcestershire County Council, Internal Report,

Markey, B G, Bøtter-Jensen, L, and Duller, G A T, 1997 A new flexible system for measuring thermally and optically stimulated luminescence, *Radiation Measurements*, **27**, 83-9

Mejdahl, V, 1979 Thermoluminescence dating: beta-dose attenuation in quartz grains, *Archaeometry*, **21**, 61-72

MHEF (Minerals and Historic Environment Forum), 2008 *Mineral extraction and archaeology: a practice guide*, HELM, English Heritage

Miller, D, Darch, E, and Griffin, L 2001 *Evaluation (stage 2) at land north of Clifton Quarry, Severn Stoke and Kempsey, Worcestershire*, Historic Environment and Archaeology Service, Worcestershire County Council, Internal Report, **945**

Mook, W G, 1986 Business meeting: recommendations/resolutions adopted by the twelfth International Radiocarbon Conference, *Radiocarbon*, **28**, 799

Mullin, D, 2008 *The aggregate landscape of Gloucestershire. Predicting the archaeological resource (PNUM 3346)*, GCC Archaeology Service for English Heritage; http://ads.ahds.ac.uk/catalogue/archive/gloucsaggs_eh_2008

Mullin, D, in press A Round Barrow Cemetery in the Severn Vale: Richards Atkinson's excavations of five ring ditches at Netherhills, Frampton on Severn, 1948 and their archaeological context, *Transactions of the Bristol and Gloucestershire Archaeological Society*

Murray, A S, and Olley, J M, 2002 Precision and accuracy in the Optically Stimulated Luminescence dating of sedimentary quartz: a status review, *Geochronometria*, **21**, 1-16

Murray, A S, and Wintle, A G, 2000 Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol, *Radiation Measurements*, **32**, 57-73

Murray, A S, and Wintle, A G, 2003 The single aliquot regenerative dose protocol: potential for improvements in reliability, *Radiation Measurements*, **37**, 377-81

Murray, A S, Wintle, AG, and Wallinga, J, 2002 Dose estimation using quartz OSL in the non-linear region of the growth curve, *Radiation Protection Dosimetry*, **101**, 371-4

Murray, A.S, Olley, J M, and Caitcheon, G G, 1995 Measurement of equivalent doses in quartz from contemporary water-lain sediments using optically stimulated luminescence, *Quaternary Science Reviews*, **14**, 365-71

OA North and the University of Liverpool, 2007 *ALSF Aggregate extraction in the Lower Ribble Valley*, Final report submitted to English Heritage (ALSF PNUM 3928), http://ads.ahds.ac.uk/catalogue/archive/ribble_eh_2007

Olley, J M, Caitcheon, G G, and Murray, A S, 1998 The distribution of apparent dose as determined by optically stimulated luminescence in small aliquots of fluvial quartz: implications for dating young sediments, *Quaternary Science Reviews*, **17**, 1033-40

Olley, J M, Caitcheon, G G, and Roberts R G, 1999 The origin of dose distributions in fluvial sediments, and the prospect of dating single grains from fluvial deposits using - optically stimulated luminescence, *Radiation Measurements,* **30,** 207-17

Olley, J M, Murray, A S, and Roberts, R G, 1996 The effects of disequilibria in the Uranium and Thorium decay chains on burial dose rates in fluvial sediments, *Quaternary Science Reviews*, **15**, 751-60

Olley, J M, Pietsch, T, and Roberts, R G, 2004 Optical dating of Holocene sediments from a variety of geomorphic settings using single grains of quartz, *Geomorphology*, **60**, 337-58

Passmore, D G, and Waddington, C, 2009 *Managing archaeological landscapes in Northumberland: Till Tweed Studies*, **1**, Oxford: Oxbow books

Passmore, D G, Waddington, C, and Houghton, S J, 2002 Geoarchaeology of the Milfield Basin, Northern England; towards an integrated archaeological prospection, research and management framework, *Archaeological Prospection*, **9**, 71-91

Pawley, S M, Toms, P S, Armitage, S J, Rose, J, 2010 Quartz luminescence dating of Anglian Stage fluvial sediments: Comparison of SAR age estimates to the terrace chronology of the Middle Thames valley, UK, *Quaternary Geochronology*, **5**, 569-82

Prescott, J R, and Hutton, J T, 1994 Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations, *Radiation Measurements*, **23**, 497-500

Reimer, P J, Baillie, M G L, Bard, E, Bayliss, A, Beck, J W, Blackwell, P G, Bronk Ramsey, C, Buck, C E, Burr, G S, Edwards, R L, Friedrich, M, Grootes, P M, Guilderson, T P, Hajdas, I, Heaton, T J, Hogg, A G, Hughen, K A, Kaiser, K F, Kromer, B, McCormac, G, Manning, S, Reimer, R W, Remmele, S, Richards, D A, Southon, J R, Talamo, S, Taylor, F W, Turney, C S M, van der Plicht, J, and Weyhenmeyer, C E, 2009 INTCAL09 and MARINE09 radiocarbon age calibration curves, 0–50,000 years cal BP, *Radiocarbon*, **51**(4), 1111–50

Scott, E M, 2003 The third international radiocarbon intercomparison (TIRI) and the fourth international radiocarbon intercomparison (FIRI) 1990–2002: results, analyses, and conclusions, *Radiocarbon*, **45**, 135–408

Shotton, F W, 1978 Archaeological inferences from the study of alluvium in the lower Severn-Avon Valleys, in S Limbrey and I G Evans (eds.), *Man's Effect on the Landscape: The Lowland Zone*, Council for British Archaeology, Research Report, **21**, 27-32

Singhvi, A K, Bluszcz, A, Bateman, M D, Someshwar Rao, M, 2001 Luminescence dating of loess-palaeosol sequences and coversands: methodological aspects and palaeoclimatic implications, *Earth Science Reviews*, **54**, 193-211

Slota Jr, P J, Jull, A J T, Linick, T W, and Toolin, L J, 1987 Preparation of small samples for ^{14}C accelerator targets by catalytic reduction of CO, *Radiocarbon*, **29**, 303–6

Smith, B W, Rhodes, E J, Stokes, S, Spooner, N A, 1990 The optical dating of sediments using quartz, *Radiation Protection Dosimetry*, **34**, 75-8

Smith, M J, Rose, J, and Booth, S, 2006 Geomorphological mapping of glacial landforms from remotely sensed data: An evaluation of the principal data sources and an assessment of their quality, *Geomorphology*, **6** (1-2), 145-65

Spooner, N A, 1993 The validity of optical dating based on feldspar, unpublished D.Phil. thesis, Oxford University

Stuiver, M and Kra, R S 1986 Editorial comment, *Radiocarbon*, **28**(2B), ii

Stuiver, M, and Polach, H A, 1977 Reporting of ^{14}C data, *Radiocarbon*, **19**, 355–63

Stuiver, M, and Reimer, P J, 1986 A computer program for radiocarbon age calculation, *Radiocarbon*, **28**, 1022–30

Stuiver, M, and Reimer, P J, 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program, *Radiocarbon*, **35**, 215–30

Sworn, S, and Jackson, R, 2008 *Archaeological evaluation of land south of Moreton Camp, Wellington Quarry, Marden, Herefordshire: interim report*, WCC Historic Environment and Archaeology Service, Internal report, **1605**

Templer, R H, 1985 The removal of anomalous fading in zircons, *Nuclear Tracks and Radiation Measurements*, **10**, 531-7

Thomas, J, 1999 *Understanding the Neolithic*, Routledge

Toms, P S, Brown, A G, Basell, L S, and Hosfield, R T, 2008 *Palaeolithic Rivers of South-West Britain Optically Stimulated Luminescence dating of Residual Deposits of the Proto Axe, Exe, Otter and Doniford,* Scientific Dating Report, English Heritage Research Department Report Series, **2. 2-2008**, English Heritage, Portsmouth

Vandeputte, K, Moens, L, and Dams, R, 1996 Improved sealed-tube combustion of organic samples to CO_2 for stable isotope analysis, radiocarbon dating and percent carbon determinations, *Analytical Letters*, **29**(15), 2761–73

Vaughan, T, 2005 *Archaeological evaluation at Clifton Quarry, Severn Stoke, Worcestershire*, Historic Environment and Archaeology Service, Internal Report, **2449**

Walker, M J C, Bryant, C, Coope, G R, Harkness, D D, Lowe, J J, and Scott, E M, 2001 Towards a radiocarbon chronology of the Late-Glacial: sample selection strategies, Radiocarbon, **43**, 1007-1021

Wallinga, J, 2002 Optically stimulated luminescence dating of fluvial deposits: a review, *Boreas* **31**, 303-22

Ward, G K and Wilson, S R, 1978 Procedures for comparing and combining radiocarbon age determinations: a critique, *Archaeometry*, **20**(1), 19–31

Wenban-Smith, F, 2010 Early Devensian (MIS 5) occupation at Dartford, southeast England, *AHOB Conference April 8th-10th, Abstracts*

White, T S, Bridgland, D R, Howard, A J, and White, M J, 2007 *The Quaternary of the Trent Valley and Adjoining Regions: Field Guide*, Quaternary Research Association, London

Wills, L J, 1938 The Pleistocene development of the Severn from Bridgenorth to the sea, *Quarterly Journal of the Geological Society of London*, **94,** 161-242

Wintle, A G, 1973 Anomalous fading of thermoluminescence in mineral samples, *Nature*, **245**, 143-4

Xu, S, Anderson, R, Bryant, C, Cook, G T, Dougans, A, Freeman, S, Naysmith, P, Schnabel, C, and Scott, E M, 2004 Capabilities of the new SUERC 5MV AMS facility for ^{14}C dating, *Radiocarbon*, **46**, 59–64

Zimmerman, D W, 1971 Thermoluminescent dating using fine grains from pottery, *Archaeometry*, **13**, 29-52