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Whitemoor Haye Quarry, Alrewas, Staffordshire
(NGR: SK 173 127)

Assessment report on scientific investigations funded by the Aggregates Levy Sustainability Fund (ALSF) through a grant administered by English Nature

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The Whitemoor Haye Woolly Rhino Site

Whitemoor Haye Quarry, Alrewas, Staffordshire
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Assessment report on scientific investigations funded by the Aggregates Levy Sustainability Fund (ALSF) through a grant administered by English Nature

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Edited by Simon Buteux

1. Introduction and non-technical summaries Simon Buteux

1.1 Content and purpose of the report

The following section (Section 2) of this report provides a description of the discovery of an extraordinarily well-preserved partial skeleton of a woolly rhinoceros at Whitemoor Haye Quarry in Staffordshire and subsequent preliminary investigations at the find spot. Section 3 describes the results of a more intensive scientific fieldwork investigation, part funded by an ALSF grant administered by English Nature. Sections 4 to 11 provide detailed technical assessments by thirteen specialists – leaders in their fields – of the range of material and evidence recovered. These specialist assessments also detail the scientific work recommended for the full analysis of this material, which has enormous potential. Section 12 provides a less technical overview of the recommended scientific analyses, with layman's descriptions of the scientific principles underlying each investigative technique, and explanations of contribution the various analyses will make to understanding of the woolly rhinoceros, its date, diet, evolutionary relationships and the environment in which it lived and died.

Subsequent sections outline the contributors to the recommended scientific analyses and their role within the project (Section 13), provide a consolidated list of the tasks necessary to complete the scientific analysis and bring the work to publication (Section

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14), and provide synopses of the proposed content of both a scientific and a popular publication (Sections 15 and 16).

Four appendices provide (1) a programme for the project in the form of a chart, (2) a list of the samples taken for environmental analyses, (3) a summary with examples of the very extensive international media coverage of discovery of the woolly rhino and the ALSF-funded investigations, and (4) a detailed budget for the scientific analyses and publication in both scientific and popular formats.

The purpose of this report is four-fold:

- to provide and interim statement on the discovery of the woolly rhinoceros and the results of subsequent investigations, in fulfilment of the terms of the ALSF grant (English Nature ALSF grant no: IW/2002/127).

- to provide a detailed assessment of the scope for further scientific analyses, together with a justification for carrying out these analyses, in accordance with the goals stated in the initial ALSF grant application.

- to provide details of the proposed publications, scientific and popular, to arise from the scientific analyses.

- to provide a fully detailed task list, budget and programme for analysis and publication, both scientific and popular, as the basis for a second ALSF grant application.

1.2 <u>Summary of the discovery and subsequent investigations</u>

In September 2002, a machine operator working at the Lafarge Whitemoor Haye sand and gravel quarry in Staffordshire pulled up in his machine bucket the skull, lower jaw and most of the other bones representing the front part of a woolly rhinoceros. The bones were in a very good condition and represent the best preserved example of a woolly rhino found in Britain this century and perhaps the most important find of a fossil mammal from the Ice Age made in this country since the 1960s.

The quarry notified archaeologists from Birmingham University of the find and a preliminary, one-day investigation of the find spot and its environs was carried out. This investigation was carried out by a team of specialists from the Natural History Museum and several universities. The investigation found the remains of further Ice Age mammals and established the presence of well-preserved contemporary plant and insect remains.

A second, more systematic and detailed, scientific investigation was carried out over a one-week period in late October 2002. This investigation was part funded by an ALSF grant administered by English Nature. The purpose of this second investigation was to search for the remaining (back) half of the woolly rhino skeleton, to make a detailed search for the bones of other Ice Age mammals, to take systematic samples of the deposits containing preserved plant remains (both macroscopic remains and pollen) and insect remains, to record and interpret the geological context of the finds and samples, and to take samples for the purpose of scientific dating.

Although the back half of the woolly rhino was unfortunately not found, the investigations at the site, in combination with earlier discoveries, recovered the remains of three further woolly rhinos together with bones of mammoth, horse, bison, reindeer and wolf. Numerous samples were taken containing the rich remains of insects (especially beetles) and plants typical of Arctic tundra conditions. With further analysis, taken together with the evidence from geology and soils, these remains offer a unique opportunity to undertake a remarkably detailed reconstruction of the environment in which the rhino lived and died.

1.3 Summary of the potential for further scientific analyses

The potential for further scientific analyses falls into two broad categories: analysis of the woolly rhino itself and reconstruction of the broader Ice Age environment of the find.

The woolly rhinoceros

Due to exceptional preservation of the partial woolly rhino skeleton it should be possible, amongst other things, to:

- Study the diet of the rhino from plant remains preserved within its teeth.
- Make inferences about the climate in which it lived by means of stable isotope analysis of bone mineral and dental enamel (this and other methods of scientific analysis are explained in layman's terms in Section 12).
- Determine the evolutionary relationships of the rhino by means of osteocalcin and mitochondrial DNA sequencing.
- Date the rhino by means of radiocarbon dating.

The broader environment

With further analysis, the remarkable assemblage of mammalian and insect faunas and plant remains recovered in association with the rhino, together with analysis of the geology and soils, should enable amongst other things:

- Detailed reconstruction of temperature and climate from the insect remains.
- Detailed reconstruction of the environment, and environmental change, from a combination of the mammalian, insect and plant remains, geology and soils.

- Dating of the assemblages and geological sequence by means of biostratigraphical analysis and optical dating (see Section 12 for non-technical explanation).

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Several of the techniques of scientific analyses proposed are at the cutting edge of research while others are more established. Overall, the scientific potential of the Whitemoor Haye Woolly Rhino Site lies in the diversity of scientific analyses which are possible, and the ways in which different scientific techniques of analysis will complement and inform each other. For example, two methods of studying the evolutionary relationships of the woolly rhino are proposed (osteocalcin and mitochondrial DNA sequencing), and three dating techniques (radiocarbon, optical dating and biostratigraphical analysis).

The discovery of the Whitemoor Haye woolly rhino and the subsequent investigations generated substantial international media interest. The proposed further scientific analyses offer possibilities for similar levels of interest in both scientific circles and more widely, providing once again a high profile for the ALSF grants scheme.

1.4 Outline of proposals for publication

The Whitemoor Haye woolly rhino and the fieldwork investigations following its discovery have generated great interest both in the specialist scientific community and amongst the wider public (see Appendix 3: Publicity). It is proposed that publication of the results of the investigations and subsequent scientific analyses reflects both this scientific and more general interest.

Two principal publications are therefore suggested, one a paper in an appropriate scientific journal and the other a popular publication in short book or booklet form. The popular publication will be an accessible means to demonstrate the value of the ALSF scheme and, by putting the woolly rhino find in its wider context, will highlight the riches hidden away in sand and gravel quarries across the country.

2. Background: discovery, preliminary investigations and conservation Simon Buteux and Gary Coates

On 3rd of September 2002, Ray Davies, a machine operator working at the Lafarge Whitemoor Haye sand and gravel quarry in Staffordshire, pulled up in his machine bucket the skull, lower jaw and most of the other bones representing the anterior part of a woolly rhinoceros, *Coelodonta antiquitatis*. The bones were in a very good state of preservation and had evidently been at least in partial articulation prior to their disturbance by the machine bucket. Mr Davies, realising the potential importance of the find, recovered the bones as carefully as the circumstances allowed.

The quarry notified Birmingham University Field Archaeology Unit (BUFAU) of the find. On behalf of Lafarge Aggregates Limited, the University has, since 1997, been undertaking archaeological investigations at the quarry in advance of gravel extraction. These investigations are being carried out as a condition of the planning permission for sand and gravel extraction, but the find of the woolly rhinoceros falls outside the remit of these investigations and Lafarge Aggregates' funding responsibilities.

The partial rhinoceros skeleton was handed over to Gary Coates of Birmingham University, director of the archaeological investigations at Whitemoor Haye, who established the circumstances of the discovery, marked the reported find spot and recovered by hand excavation some further bones of the skeleton. The bones were transported to Birmingham University for safe keeping, and were wrapped in black plastic to slow down the drying-out process; they were not washed. Andrew Currant, Curator of Quaternary Mammals at the Natural History Museum was informed of the find in late September, and with Dr Danielle Schreve of Royal Holloway, University of London, inspected the finds at Birmingham University and visited the find spot.

At the find spot of the rhinoceros some further fragments of the skeleton were recovered, and it was also noted that rich organic deposits, containing well-preserved plant macrofossils and beetle remains, were associated with the find. Preliminary samples of these deposits were taken. Given the apparently cold environment represented by remains at the site, and the presence of elements like the hyoid bones of the throat that are usually not preserved, it is likely that the skeleton was initially buried as a frozen carcass.

The quality of preservation of the rhinoceros bones was exceptionally good. It seemed likely that it should prove possible to obtain a radiocarbon date on the bones, look for DNA, carry out stable isotope analyses and perhaps even recover plants remains from between the teeth, but only if the material could be prevented from drying out too fast. Despite the precautions being taken, it was clear that the bones of the rhino were beginning to dry and that cracking and distortion was beginning to occur. It was therefore decided, with the agreement of Lafarge, that the bones should be transferred to the Natural History Museum for stabilization and urgent conservation. The remains were transferred to London on 25th September.

Given the possibility that the remainder of the rhinoceros skeleton survived *in situ* adjacent to the original find spot, the quality of the associated organic deposits, and the need to establish the stratigraphic position of the find in the sequence of fluvial deposits, a small-scale investigation of the site was undertaken on 4th October, with the permission of Lafarge Aggregates, who kindly made available a machine for a few hours. Participating in the investigation were Gary Coates and Kate Bain (Birmingham University – archaeologists), Andrew Currant (Natural History Museum – palaeontologist), Dr Danielle Schreve (Royal Holloway – palaeontologist), Professor David Keen (Coventry University – Quaternary specialist), Professor Susan Limbrey (Birmingham University – soil scientist), Dr David Smith (Birmingham University – palaeoentomologist), Dr Andy Howard (geomorphologist) and Dr Mike Field (University of Cambridge - palaeobotanist).

The one-day investigation failed to recover the posterior part of the rhino skeleton, although three further vertebrae and a metacarpal from the skeleton were recovered from spoil, as well as additional remains of a second woolly rhino and mammoth. A machine-excavated section helped to establish the sedimentary context, and further samples were taken for associated plant macrofossils and beetle remains. In the area around the rhino find spot, on the irregular surface which had been left following the extraction of the overlying gravels, further animal remains were picked up, including a wolf limb bone, part of a horse femur and a shed reindeer antler.

Despite its limitations, the one-day investigation clearly established the richness of the deposits in terms of vertebrate remains, associated plant macrofossils and beetles, and the palaeogeographical and sedimentary context. It was clear that more in-depth on-site investigations were required and an application was made to English Nature to fund these excavations through a grant from the Aggregates Levy Sustainability Fund (ALSF). The grant was awarded on 22nd October 2002 (Ref: IW/2002/127) and the bulk of the fieldwork was carried out during the week 28th October – 1st November 2002.

3. The ALSF-sponsored investigations Simon Buteux, Gary Coates, Andy Currant and Danielle Schreve

These investigations were carried out by broadly the same team of specialists who conducted the original one-day investigation, with the addition of further archaeological assistance from the University of Birmingham and a specialist in optically stimulated luminescence (OSL) dating, Dr Phillip Toms of the Geochronology Laboratories of the University of Gloucestershire.

Initial inspection of the fluviatile sequence at the site revealed a bipartite upper unit of massive to poorly bedded gravels (3-4 m thick), underlain by a lower unit of well-bedded sands (*c.* 2 m thick) (see Section 4 below for detail). Bone appeared to be concentrated in the lower sands, particularly in basal hollows overlying the Triassic marl bedrock.

The exact site of the rhinoceros find could not be clearly established, although the presence of a scatter of unstratified bones belonging to the same animal within a relatively confined zone indicated an approximate area worthy of intensive investigation. It was therefore decided to use a mechanical digger to clear the area and to work through the remaining *in situ* Pleistocene sediments left at the base of the sequence on the pit floor to search for the remainder of the skeleton. The skill of the machine drivers operating in the pit allowed work to proceed in a controlled and systematic manner and an area of approximately 50 x 30m was stripped right down to the terrace base. Numerous other faunal specimens were recovered from within the lower sands (often associated with coal-rich seams) and from gravels immediately overlying bedrock but the remainder of the rhinoceros skeleton was unfortunately not found.

A search was made of the accessible parts of the pit floor in the area around the original find and along the east - west axis of the pit. Any *in situ* finds were recorded in three dimensions and unstratified material was also collected. Some distance to the east, the dorsal part of another woolly rhinoceros skull (SF 6) was found in the spoil from a drainage trench. It seemed likely that this skull had also originated from quite close to the base of the sequence.

The geological sequence was studied and recorded in a series of exposures (see Section 4, below). Eight sediment samples, four from the Upper Sands and Gravels and four from the Lower Sands and Gravels were collected for the purposes of OSL dating (see Section 11, below). A systematic programme of sampling for ancient pollen, insect and plant macrofossils was carried out, with the samples being related to the geological sequence (see Appendix 2).

4. Geological context Andy Howard

4.1. <u>Introduction</u>

The River Tame is one of the major tributaries of the Trent catchment, draining the area to the east of Birmingham before entering the Trent near Alrewas (Staffs.). Historically, Quaternary research along the Tame Valley has been limited, with the majority of studies concerning Pleistocene fluvial history and environmental change undertaken on the terrace sediments of the Trent and its tributaries downstream of Burton-on-Trent (e.g. Clayton 1953; Brandon and Sumbler 1988; Brandon and Sumbler 1991). Vertebrate faunas documented by this work include Ipswichian remains from the terrace deposits of the River Derwent near Derby (Bembrose & Deeley 1896; Jones and Stanley 1974) and pre-Ipswichian fauna from the Balderton Sand and Gravel near Newark on Trent (Lister and Brandon 1991). In the Tame Valley, Coope and Sands (1966) recorded fossiliferous insect remains from two localities: Minworth and Whitacre Heath. These faunas were recovered from lenses of peaty sand at the interface of the sand and gravel and Mercia Mudstone bedrock. Organic material from this study yielded a radiocarbon date of 32160 ± 1780-1450 years BP and the insect remains suggested that the local environment had a mean annual air temperature of around -2°C.

4.2. <u>Whitemoor Haye Quarry</u>

4.2.1. *Stratigraphy*

The quarry is situated on a low terrace of the River Tame, approximately 2 km upstream from the contemporary confluence with the Trent. Exposures of sand and gravel indicate a bipartite sequence of deposits comprising an upper unit of massive to poorly bedded gravels (3-4m thick), underlain by a lower unit of well-bedded sands (*c*.2m thick). These lower sands contain too much clay and silt for industrial purposes and therefore it is only the upper gravels which are of economic importance and are extracted at this site. This bipartite sequence rests on the undulating rockhead surface of the Mercia Mudstone

Group (red mudstones and marls of Triassic age), which is demonstrably lower in the central part of the current quarry area, probably due to fluvial scour and channelling. The lower unit, which appears to occupy this channel, has yielded a significant number of vertebrate remains.

4. 2.1.1. The Lower Sand

The lower unit predominantly comprises a sequence of well-sorted sands occupying a series of stacked channels, with some thin interbedded units of massive gravel (comprising local Triassic 'Bunter Pebble Bed' quartzite and quartz; now part of the Sherwood Sandstone Group). Internally, these sand-filled channels exhibit well developed bedding structure including both planar and trough cross bedding and ripple lamination. Internal structure is commonly picked out by fragments of coal deposited along foresets. Individual trough foresets are up to *c.*0.5m high with planar foresets up to 0.3m high. Erosion and multiple reactivation are common features of the channel units, suggesting frequent changes in both flow strength and current direction. Measurement of palaeocurrent (from foresets and imbrication) indicated no uniform flow direction. Thin organic rich units (0.01-0.1m thick) of macroscopic plants remains and other material formed small lenses within the sands or more continuous drapes over pre-exiting bedforms and suggests both periods and areas of lower energy flow across the floodplain.

Although, no evidence of cold-climate periglacial structures was noted within the lower sands in the immediate vicinity of the main concentration of vertebrate remains, an organic channel beneath the 'upper gravels' (Profile 4; Fig. 4) displayed evidence for a 'frozen' contact with the lower sands and ice related deformation. Elsewhere, frozen blocks of sand and gravel were noted within the lower sand (Candy, pers. comm.), and may have been incorporated into these sandy channels by the undercutting of frozen channel banks by the river. Ventifracts (wind polished rocks) were also observed across the quarry floor and are a common feature of periglacial environments.

The identification and sampling of a small organic channel (*c.*2m wide) demonstrably incised into the base of the Mercia Mudstone close to the main concentration of bones (Profile 5; Figure 5) should provide important information on local conditions during their deposition.

4.2.1.2. The Upper Gravel

The upper unit, which is 3-4m thick, is characterised by stacked sequences of massive to poorly sorted, coarse, clast supported gravels (individual beds up to 1m thick). The composition of the gravels is predominantly locally derived quartzite and quartz (from the Bunter Pebble Beds). These gravels were interspersed by thin (0.2-0.4m thick) units of sand either overlying the gravels or forming small (slough) channels. Internally, the sands were either structureless, rippled or cross bedded. Palaeocurrent direction measured from foresets or imbricated clasts indicated a wide spread of palaeoflows. No organic rich beds were noted within the unit. The top 1m of the upper gravel was clay-enriched and included matrix-supported friable pebbles of quartzite and sandstone, suggesting weathering of this upper surface. The base of the 'weathered' zone appeared coincident with a level of sediment deformation in the form of three V-shaped depressions, each approximately 1 m wide and 1.5 m deep. These depressions were infilled with sands and pea gravel and had weathered contacts with the surrounding upper gravel. These deformation features could not be traced between sections or identified upon the stripped surface of the quarry and are therefore not considered to represent ice wedge casts. However, they are considered to be of periglacial origin and are interpreted as 'fossil' ground ice depressions, which developed locally, where water accumulated and froze at low points in the topography. Subsequent thaw and infilling by the surrounding sediments created the features observed today.

4.2.2. *Environmental Setting*

4.2.2.1. The Lower Sands

Sedimentological evidence indicates that the lower sands were deposited in a braided river system in a series of broad shallow channels (10s of metres in diameter and probably between 1-2m deep). Multiple reactivation and erosion of individual channel bedforms and changes in bedform type (i.e. tough to ripple bedded) suggest frequent changes in flow velocity and volume (discharge). The variability of palaeocurrent direction suggests that flow was frequently switching between braided channels. Organic remains and more extensive clay drapes suggest that there were periods of quiescence and areas of floodplain where finer-grained sediments were deposited, probably across bar surfaces and within abandoned braid-channels away from the main channel belt. Examples of frozen sediment entrained within these sandy channels and frozen sediment contacts suggest that the River Tame was probably operating under a periglacial climatic regime.

4.2.2.1.1. The origin of the vertebrate remains

The partially articulated skeleton of the woolly rhinoceros (and other associated faunal material), which appears to be intimately associated with this lower sand unit may have been incorporated within this braided stream environment under a number of scenarios.

- The animal may have become stuck and died within a 'quicksand' at the edge of a channel whilst feeding.
- The animal may have been cut off on part of the floodplain and died as a result of increased stream flow in the valley bottom (e.g. floods associated with spring snowmelt).
- The bones may be locally reworked from other parts of the floodplain environment.

The excellent preservation and part articulation of the bone material suggests that reworking from other parts of the floodplain is the least likely scenario for the Whitemoor Haye vertebrate fauna. The periglacial nature of the climate suggests that any skeletons deposited on the floodplain would have been quickly frozen and buried beneath sandy sediments. Whilst freezing may have helped preserved some of the material in a semi-articulated form, it may also have allowed fluvial processes to scour away parts of the skeleton (although part of the carcass could equally have been removed by scavengers).

4.2.2.2. The Upper Gravels

The upper gravels were also deposited under braided river conditions, although sediment supply had become coarser (perhaps reflecting the onset of full glacial conditions?). The gravels were deposited as a series of large bars within a braided river system with sandy units aggraded over the bar top (during periods of high discharge) or within secondary (slough) channels flowing around the bar edges. Periglacial processes were still important within this environment as demonstrated by the evidence of local ground ice features.

4.2.2.3. Organic deposits

Organic deposits were observed and sampled from the interface of the rockhead and lower sand (Profile 5; Fig. 5), the interface between the lower sand and upper gravel (Profile 4; Fig. 4) and from isolated organic clasts in the lower sand adjacent to the semi-articulated skeleton. Analysis of these remains should provide a detailed picture of the local environment of Whitemoor Haye.

4.3. <u>Recommendations for future work</u>

Sedimentological observations in the field have provided a valuable insight into the environment in which the Whitemoor Haye vertebrate fauna was deposited. Further analyses which would contribute to the aims of the project are:

- The fossiliferous lower sand appears to occupy a channel incised into the rockhead of the Mercia Mudstone. Channelling is a common feature of such soft substrates and may have been exacerbated in this confluence zone, where the discharge was high and the substrate was frozen. Analysis of borehole data for the entire quarry area and modelling of the rockhead surface within a GIS framework may help to identify other fossiliferous channels within present and future extraction areas and therefore allow the targeting of areas for future monitoring.

- Due to the proximity of the sediments to the confluence of the Tame and Trent, it is unclear which river aggraded the fossiliferous deposit. Elucidation of this question may help to prospect for further fossilferous localities. The provenance of the sediments might be investigated in three ways:

    1. Where coarse sediments occur in the lower sands, they appear 'in the field' to have a similar lithological signature to the upper gravels. Analysis of lithological composition can provide a range of information about the provenance and age of deposits. Samples of material from both

the lower sand and upper gravel have been recovered and should by analysed in the laboratory to determine their lithological composition.

2. Particles of coal were abundant within the lower sand, usually deposited along foresets. Analysis of microfossils from this coal may help to determine its source. The analysis can be carried out by the British Geological Survey (BGS).

3. Heavy mineral analysis of the sand fraction (XRF and XRD analysis). This work can be carried out by the BGS.

- The organic deposits at Whitemoor Haye at the base of the Mercia Mudstone appear to be in a similar stratigraphic position and are probably of broadly similar age to those recorded by Coope and Sands (1966) further upstream in the Tame Valley at Minworth and Whitacre Heath. Coope and Sands (1966) believed that these organic units were part of a 'continuous bed affected by periglacial processes'. It is therefore probable and certainly possible that the sediments at Whitemoor Haye and those recorded elsewhere within the Tame Valley form part of a wider, potentially mappable lithostratigraphic unit. A number of quarries are now open both up- and downstream of Whitemoor Haye and these quarries should be inspected to record the deposits and recover any fossil remains. This work will be carried out under the aegis of the ALSF-funded 'Shotton Project' through a grant administered by English Heritage.

5. Assessment of vertebrate remains Andy Currant and Danielle Schreve

5.1 Introduction

The Late Pleistocene fluviatile sands and gravels laid down by the River Tame yielded the remains of fossil mammals attributable to the Middle Devensian (marine oxygen isotope stage [MIS] 3, c. 60-25 ka B.P.). The most significant find is the well preserved anterior part of what appears to have been an articulated skeleton of a woolly rhinoceros (*Coelodonta antiquitatis).* Woolly rhinoceros material is relatively common at sites of this age across Britain but it is rarely so well preserved and is usually heavily gnawed by spotted hyenas. The discovery of an articulated skeleton is relatively unusual in Pleistocene deposits of any age but particularly so in this part of the country, where vertebrate remains are encountered only infrequently. For these reasons, the Natural History Museum expressed an interest in acquiring the material for the National Collection.

5.2 Preliminary species list

The preliminary mammalian species list from Whitemoor Haye is as follows:

Carnivora
cf. *Canis lupus* Linné, 1758, wolf
Proboscidea
Mammuthus primigenius (Blumenbach, 1803), woolly mammoth
Perissodactyla
Equus ferus Boddaert, 1785, horse
Coelodonta antiquitatis (Blumenbach, 1807), woolly rhinoceros
Artiodactyla
Rangifer tarandus (Linné, 1758), reindeer
Bison priscus Bojanus, 1827, bison

5.3 Comments on the partial rhinoceros skeleton and other vertebrate material

To date, 33 separate elements have been identified from the partial rhinoceros skeleton. These include the cranium and lower jaw, some of the vertebrae and ribs, a single shoulder blade and the major parts of the anterior limbs. Although the pelvis and hind limbs were not found during the recent investigations, two elements of the posterior skeleton were recovered in the same area as the front part, namely the last lumbar vertebra and the last rib on the right side. In the absence of the remainder of the skeleton, this would suggest that either the posterior part had been removed by quarrying at an earlier stage and had been destroyed, or that the skeleton had become dispersed in antiquity. The recovery of two almost perfect ribs, seemingly part of the articulated skeleton, 100-150m to the north-west of the rhino site, may support the latter hypothesis. However, a number of features of the partial skeleton all point to the very rapid burial of a (probably frozen) carcass. These include the excellent preservation of the bone surface, the presence of the fragile stylohyoid bones, the occurrence of dental calculus (normally removed by transport) and the preservation of plant remains in the fossae of the upper dentition. It is therefore suggested that if disarticulation of the skeleton had occurred, the posterior part of the carcass was re-exposed after deposition and was subsequently dispersed by fluvial activity, whereas the anterior part remained undisturbed.

Based upon the material collected thus far, it is apparent that at least four individuals of woolly rhinoceros are preserved at the site and that remains of this species are most abundant within the faunal assemblage. While Whitemoor Haye is not the only site to have several rhinos preserved in a relatively small area, such sites are not particularly common and of these the Whitemoor Haye material is by far the best preserved.

The remainder of the faunal assemblage shows a range of preservational states, some notably different from the rhinoceros skeleton and including quite badly abraded material. Preservation of bones within a normally acidic environment is unusual and requires further investigation (see Section 10 below).

5.4 Preliminary age and environment inferred from the vertebrate assemblage

The composition of the vertebrate assemblage from Whitemoor Haye fits well with the Pin Hole mammal assemblage-zone of Currant and Jacobi (2001), correlated with MIS 3 of the deep ocean record. MIS 3 (the Middle Devensian in Britain) represents the warmest part of the last cold stage and is characterised by rapid (often millennial-scale) climatic oscillations (see chart below). In the GISP2 ice-core (Grootes *et al.*, 1993), numerous abrupt alternations are apparent between excursions 6-7°C warmer than the intervening cold episodes (the so-called 'Dansgaard-Oeschger interstadial events'), which towards the end of MIS 3 equalled those of the last glacial maximum. The impact of these sharp climatic fluctuations on the landscape, vegetation and fauna remains poorly understood and interpretation has been hampered by the lack of a reliable absolute chronology. However, what is clear is that the mosaic environment of this period, generally termed 'mammoth steppe', was highly diverse and capable of supporting a wide range of large herbivores. Habitat diversity was maintained by the grazing actions of the animals themselves and it is anticipated this is will be reflected in both the flora from Whitemoor Haye and the coleopteran assemblage, most notably by a diverse dung beetle fauna. The Whitemoor Haye site therefore represents one of the best opportunities to study the mammoth steppe and its mammalian fauna in Britain.

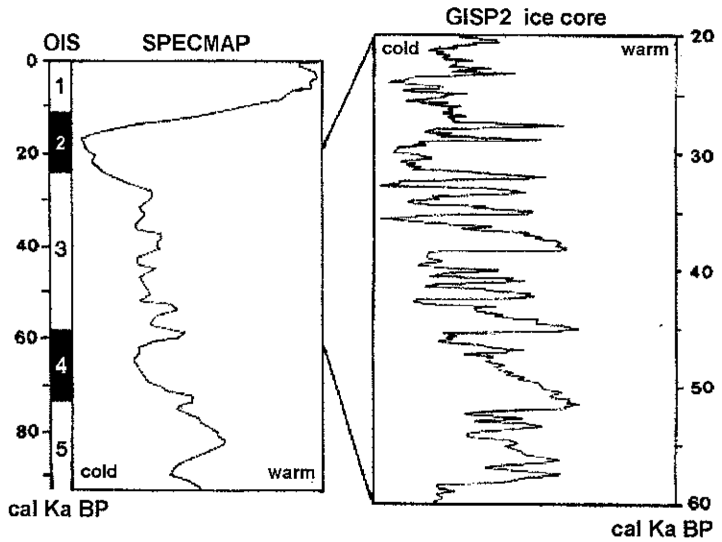

Chart: Detail from the GISP2 core of rapid climatic oscillations during OIS 3, shown against the SPECMAP stacked marine $\delta^{18}O$ record (adapted from The Stage Three project website: http://www.esc.cam.ac.uk/oistage3)

5.5 Recommendations for future work

- Complete description of all vertebrate remains recovered from the site, including body part and side, identification to generic or species level wherever possible, calculation of numbers of individuals and comments on state of preservation.

- Detailed analysis of the partial rhinoceros skeleton, including full description and measurements (where appropriate) of all elements preserved, estimation of age (and possibly sex) of the individual, comments on the preservation and taphonomy of the remains and comparison of the Whitemoor Haye *Coelodonta* remains with other British woolly rhinoceros populations.

- Photography and drawing of representative parts of the skeleton for publication. Photography to be carried out in the Natural History Museum photo studio. Drawings to be made by D. Schreve or draughtsman as required.

- Reconstruction of palaeodiet of *Coelodonta*, based upon analysis of dental calculus and identification of plant remains preserved within dentition. It may prove possible to examine microwear on the teeth, which would also further this line of investigation.

- Examination of all material for evidence of human, carnivore or other modification (cutmarks, deliberate fracturing of fresh bone, gnawmarks) and pathologies.

- Reconstruction of palaeoenvironment and climate as indicated by the mammalian remains and assessment of any evidence for seasonality (e.g. shed reindeer antlers).

- Establishment of the age of the mammalian assemblage through biostratigraphical analysis, comparison with other British and NW European last cold stage faunas and integration of ^{14}C and OSL age-estimations.

- Submission of samples for radiocarbon dating at the Oxford Radiocarbon Accelerator Unit, University of Oxford. The age-estimations will be obtained as a by-product of the biomolecular analyses outlined below.

- Biomolecular analysis of the woolly rhinoceros. The discovery of a well-preserved partial skeleton of a woolly rhinoceros from the Middle Devensian offers a remarkable opportunity to apply modern biomolecular analysis to material from an open site well below the limit of permafrost. The phylogenetics of the Rhinocerotidae are complex, and a skeleton from such a southern site at this period is most unusual, since as stated above, most UK material is degraded. The possibility that the specimen was rapidly buried as a frozen carcass implies ideal conditions for long-term biomolecular preservation. During the Holocene, deep burial (below 4m from the ground surface) will have thermally damped the sample and based upon thermal age calculations (14k years @ 10°C), the sample should be within rage of all three major molecular approaches: palaeodietary and palaeotemperature analyses based upon collagen stable isotopes, mitochondrial DNA sequencing and protein (osteocalcin) sequencing – the latter a new method only reported for the first time in December 2002 (Nielsen-Marsh et al., 2002). These analyses will be undertaken in several stages:

Stage 1: Bone characterization (Dr Matthew Collins and Dr Christina Nielsen Marsh, University of Newcastle)

Initially the bone will be characterized using a series of basic screening techniques. Specifically these are:

- Insoluble collagen – this material will be used for $\delta^{13}C$ and $\delta^{15}N$ analysis (see section on stable isotopes).
- FT/IR Splitting Factor and carbonate phosphate ratio
- Mercury Intrusion Porosimetry

Stage 2: Collagen analysis (Dr Matthew Collins, University of Newcastle)

Collagen will be prepared for $\delta^{13}C$ and $\delta^{15}N$ analysis (see stable isotopes, below), and collagen helix examined under TEM. The purity of the collagen will be established by chiral amino acid analysis at the University of Newcastle and the purified collagen sent to the Oxford Radiocarbon Accelerator Unit for ^{14}C dating.

Stage 3: Osteocalcin sequencing (Dr Christina Nielsen Marsh, University of Newcastle)

Osteocalcin sequencing will be conducted at Newcastle University. Samples of species of both African and Asian rhinoceroses will be sought for comparison (currently there are no rhino sequences on GenBank). Briefly, a small sample of EDTA decalcified rhinoceros bone powder will be purified over a fresh C-18 gravity column. The osteocalcin eluent will then be run on a MALDI-TOF (Matrix-assisted laser desorption/ionisation-time of flight) mass spectrometer to establish the presence of the A mass at approximately 5500. If a peak is present, this will then be digested with trypsin and a peptide mass map generated. The variable N-terminus will be sequenced using MALDI-TOF-TOF. The osteocalcin sequence of the woolly rhinoceros will be compared with that of extant representatives.

Stage 4: DNA sequencing (supervised by Prof. Alan Cooper, University of Oxford)

Mitochondrial DNA will be extracted and amplified from the woolly rhinoceros bones using PCR and specific primers, in the Henry Wellcome Ancient Biomolecules Centre at Oxford University. The DNA will be contrasted with sequences of the extant rhino species (from GenBank) to analyse the evolution of this group. Control region sequences will be used to examine the relationship of the Whitemoor Haye specimen with other European *Coelodonta*, including a Russian permafrost-preserved *Coelodonta* currently being sequenced at the University of Copenhagen. The possibility also exists for the genetics of the plant material present in the teeth of the Whitemoor Haye specimen, as well as the dental calculus on the teeth, to be studied.

- Stable isotope analysis (Dr Mike Richards, Bradford University)

  Oxygen isotopes from bone mineral and dental enamel reflect the oxygen isotope values of the water that a mammal consumes. In species that are considered to be non-migratory, such as the woolly rhinoceros, changes in oxygen isotope values through time may reveal the changing climate in a specific region. Stable isotopes of nitrogen and carbon from bone collagen may also provide information about climate variation.

6. Assessment of the insect faunas Steve Brooks, Russell Coope, Malcolm Greenward, Emma Paddock and David Smith

6.1 Introduction

Insect remains are one of the key techniques used in the reconstruction of climate and temperature during the Quaternary (Buckland and Coope 1991, Elias 1993). The accuracy of the insects as sensitive temperature indicators has been proven clearly (Walker and Lowe 1997). Insect remains can also provide information intrinsic to the detailed reconstruction of the local environment, vegetation cover and water conditions associated with geological and archaeological deposits (Buckland and Coope 1991, Elias 1993).

A number of samples associated with the remains of the woolly rhinoceros of Middle Devensian date were collected from Whitemoor Haye and were clearly rich in insect remains. Though a number of insect faunas have been studied from the period between 50 and 30,000 years BP, their occurrence is still limited when compared to later oxygen isotope stages. Insect studies are much more limited in number from this period of the Devensian as compared to the subsequent Late Glacial and Holocene (Coope 1987).

Detailed studies of the insect remains from Whitemoor Haye have the potential, therefore, to help increase the accuracy of the temperature curve and climatic reconstruction for this period of the Middle Devensian. Equally, by reconstructing the local landscape and river conditions existing at the time, the insect remains may elucidate the depositional processes of the mammal fauna.

6.2 On-site investigation

Samples containing insect faunas were recovered from a number of organic clast deposits associated with the location of the original rhino find. In addition, stratigraphically continuous sequences of samples were taken from two palaeochannel deposits within the lower sands (Profiles 4 and 5; see Section 4.2.11 above and Appendix 2). The samples collected were all approximately 40 litres in volume.

Initial examination on-site clearly demonstrated the insect remains were well preserved. A representative selection of the samples taken from the clasts associated with the site of the rhino find and the two palaeochannels have been paraffin floated using the method first described by Coope and Osborne (1968) and later elaborated by Kenward *et al.* (1980). Insect remains were sorted from the resulting flot with X10 – 40 binocular microscopes. During the sorting it was clear that faunas of the following taxa of insects were present:

1. Coleoptera (beetles)
2. Tricoptera (caddis flies)
3. Chironomidae (non-biting midges)
4. Hemiptera (true bugs)
5. Hymenoptera (bees, wasps, ants, etc)

This report presents an initial assessment of the potential of the Coleoptera, Tricoptera and Chironomidae to aid with reconstruction of the prevailing climate and environment associated with the rhino find at Whitemoor Haye.

6.3 The Coleoptera Russell Coope and David Smith

This order of insects has been used to produce a number of paleoclimatic curves for the Quaternary (Coope 1977; Atkinson *et al.* 1987). The technique is dependent upon using the modern temperature and precipitation range of the insect ecology derived from zoogeographic studies. The modern method uses a combination of the 'Range Overlap' method developed by Coope (1959) and the 'Mutual Climatic Range' programme of Atkinson *et al.* (1987). In terms of climate and temperature reconstruction, the accuracy of the method has been shown to compare well with the ice core data (Walker and Lowe 1997).

The faunas recovered are well preserved, relatively diverse and contain enough individuals to be considered as representative. A number of the faunas from a range of the samples have been provisionally assessed and identified by Professor Russell Coope.

Even from preliminary examination it is clear that the faunas recovered contain a large number of species that are no longer encountered as part of the British entomological fauna. These are all species that are associated today with high Arctic tundra or Alpine conditions. Typical indicators of these climatic and environmental conditions are *Pycnoglypta lurida* (Gyll.) and *Eucneocosum bracypterum* (Grav.), which are the two most common species in the faunas. In addition, a number of ground and water beetles encountered at Whitemoor Haye now appear to have geographic distributions limited to the high Arctic and eastern Siberia. Examples of these species are *Helophorus obscurellus,* now found only to the east of the Kanin Penisula in arctic Russia, and *Helphorus articus*, a predominantly North American species with a small number of isolated populations in the Kamchatka peninsula of eastern Siberia (Coope 1994). Similarly *Octhebius kaninensis* exists today only as a small population breeding in pools in the tundra of the Kalin peninsula. Also representative of this aspect of the fauna are *Diaceila polita, Diacela arctica* and *Heloboraephilus nordenskioeli,* all species of insect with distributions limited to the tundra landscapes of Northern Scandinavia and Siberia (Coope 1994). It is estimated that one third of the species present in the fauna fall into this 'exotic' grouping.

This preliminary study indicates that, in terms of temperature reconstruction, we may possibly be looking at July mean temperature of 10 degrees centigrade and January mean temperatures as low as -15 degrees centigrade. The accuracy of this temperature reconstruction would be considerably improved by total identification and investigation of these insect faunas. This would allow an accurate reconstruction of temperature and climate using the Mutual Climatic Range programme (Atkinson *et al.* 1987).

Several fossil elements encountered are not identifiable to species level. These require further investigation and identification using the Natural History Museum collections. It is suspected these fossil elements are potentially from taxa which are 'exotic' and therefore they have an important role to play in climatic reconstruction. In particular, a wide range of *Aphodius* dung beetles were encountered. At present these taxa cannot be identified to species but past experience suggests that they may be particularly vital as palaeoclimatic indicators (Coope 1973; 1994).

In terms of landscape reconstruction the species of beetle present suggest the existence of a tundra scrub with sand and gravelly ground. This is suggested by species of ground beetle such as *Amara quenseli* and A. *artica.* Equally, the wide range of other ground beetles, chrysomelid "leaf beetles" and curculionid "weevils" should enable an accurate reconstruction of the nature of local ground conditions and vegetation. Several water beetles encountered are particularly associated with specific fluvial conditions. The species encountered tend to be typical of slow flowing and usually vegetated waters. The distinctive fauna of elmid 'riffle beetles' associated with fast flowing waters are missing. A further investigation of this latter aspect of the fauna may help with the understanding of the deposition of the large mammal material.

6.4 Chironomids Steve Brooks

Chironomids are excellent indicators of environmental conditions and provide information about temperature and water conditions, including pH, trophic status, and depth. With H.J.B. Birks, Steve Brooks has recently developed a chironomid-mean July air temperature inference model with a root mean squared error of prediction of ±1.0°C. Combined with the data gathered from the beetles, the application of this model to the faunas recovered from the Whitemoor Haye rhino site should provide an accurate temperature reconstruction.

The preliminary results of approximately 120 chironomids from Profile 4, and 60 chironomids from Profile 5 are presented. This material had been passed over a 150 micron mesh sieve during the processing for Coleoptera and Tricoptera, rather than the 95 micron usually used for chironomids. All the head capsules recovered were as a result at the large end of the usual chironomid size spectrum. In most samples I would expect chironomids of this size to represent only about 10-20% of the total count. There is a high diversity of Chironomini genera from Profile 4, but such taxa usually represent only about 40% of the total fauna. This leads to the conclusion that the samples are not representative of the whole chironomid assemblage.

However, the high diversity and numbers of even these large midges in the samples suggest that the sediments hold a rich chironomid fauna and would merit further examination using different sorting techniques. I would expect that the yield of smaller specimens would be increased, and the sample to be more representative of the true assemblage, by deflocculating the sediment with hot KOH, rather than paraffin floatation, and sieving through a 90 µm sieve. Only relatively small amounts of sediment can be treated in this way but given the high abundance of midges in the samples this method may be efficient.

The samples were dominated by *Chironomus anthracinus*-type, a taxon typical of warm eutrophic conditions. The other taxa in the samples also suggest temperate, eutrophic conditions, although both *Stictochironomus* and *Corynocera ambigua* have cooler temperature optima than the other taxa in the samples. The mean July air temperature at this site is tentatively reconstructed at around 11-12°C.

6.5 Trichoptera (caddis flies) Malcolm Greenward

In terms of their modern ecology caddis flies are thought to be very sensitive indicators of water conditions, especially in terms of pH, flow rates and pollution quality. Several species are also associated with different forms of vegetation communities in water bodies. At present the caddis are an underused resource in terms of both archaeological and geological investigation and interpretation. Their role as indicators of temperature and climate has not been investigated.

Small spot samples (0.1 litres volume) of organic silts were processed from two samples from Whitemoor Haye. Both yielded well-preserved cuticular fragments (frontoclypeal apotome, pro- and mesonotal plates) from larval caddis flies.

The recognised taxa are all cased caddis flies:

1. *Brachycentrus subnubilus* Curtis
2. *Apatania sp.*
3. *Phryganea* c.f. *bipunctata*
4. *Anabolia nervosa* (Curtis)
5. *Ecclisopteryx guttulata* (Pictet)
6. unidentified members of the Stenophylacini.

The assemblage suggests a fairly still, possibly deep, vegetated water-body but with some indication of flowing water. *Phryganea* cf *bipunctata*, *Anabolia nervosa*, *Brachycentrus subnubilus* and Stenophylacini all construct larval cases using plant fragments at some stage of their life cycle, whereas *Apatania* sp. and *Ecclisopteryx guttulata* all construct cases from mineral grains.

Brachycentrus subnubilus is a filter feeder, trapping food particles carried in the water flow on hairs on the front legs. This species often attaches its cases to stands of plants in the main current of the channel.

The apparent mixture of taxa representing both still and flowing water condition could also have arisen by overbanking at times of high flows and depositing flowing water taxa into ponded depressions. A predominance of still water taxa, together with numbers of chironomids and beetles of the genus *Helophorus* (common in grassy pools), supports this interpretation.

The present distribution of both *Apatania* sp. and *Ecclisopteryx guttulata* in the UK is predominant in streams, often close to springs in Scotland and northern England. This and the presence of many other taxa as yet unidentified (i.e. not in the modern UK fauna), suggests that the climate condition may have been cooler than that of the present day. The identified elements recovered should be studied further and compared to the caddis faunas of Fennoscandia and further east. The recovery and study of caddis fly faunas from Whitemoor Haye has the potential to lead to the establishment of a temperature range overlap method for the interpretation of climate using caddis flies. This approach will be strengthened by the ease of comparison with the information derived from the Coleoptera at Whitemoor Haye.

6.6 Recommendations for future work

It is clear that the insect remains present in the material from Whitemoor Haye have the potential to provide three areas of information that are important to the understanding of the rhino find:

1) climatic and temperature reconstructions
2) the nature of the surrounding local landscape and vegetation
3) reconstruction of the water conditions and fluvial activity associated with the deposition of the large mammal remains

In addition, this will be the first time that climate, landscape and fluvial conditions have been reconstructed using the three insect taxa in parallel. This comparison of the relative strengths of the three techniques may produce results that have a high degree of impact in the development of this area of research.

It is therefore recommended that:

- the Coleoptera are identified to species level where possible from all samples. The fauna should be analysed against the existing temperature curves reconstructed by the Mutual Climatic Range method.

- the Tricoptera should be identified to species as far as is applicable from all samples. Data on the modern distribution and temperature ranges of the species recovered should be collated and used to developed a temperature range overlap method for this order.

- the Chironomidae should be identified to species level whenever possible from all samples. The faunas should be extracted from unprocessed material so that the smaller elements can be recovered. The fauna should be analysed against existing temperature inference models.

7. Assessment of plant macrofossils Mike Field

7.1 Sampling, preparation & analysis

A bulk sample was taken from the spot where the first woolly rhino remains were discovered. The bulk sample was carefully taken from the thin, dark coloured, organic sediment horizon that occurred in the mineralogenic deposits. This layer was sampled for plant macrofossil analysis because many fossil leaves could be seen in it with the naked eye during the digging. Analysis of the sample began with a subsample of 200 cm^3 being taken and then disaggregated in cold water. This subsample was then washed through a nest of sieves. The smallest sieve mesh was 150 μm. Macroscopic plant remains were picked from the resulting residues using a low-power binocular microscope and identification of the fossils was accomplished by comparison with modern reference material. The nomenclature follows Tutin *et al.* (1964-1993).

7.2 Presentation of data

The assemblage is displayed in the table below. Only presence or absence is noted for this assessment. The taxa are sorted into habitat classifications in order to aid interpretation and reconstruction of past vegetation and palaeoenvironment. The categories are deliberately kept broad to reduce the possibility of taxa falling into a number of the habitat classifications. The aquatic group contains taxa that can only be described as obligate aquatic plants.

Table: Plant macrofossil assemblages from Whitemoor Haye Quarry
(a - achene, bin - biconvex nutlet, ca - capsule, cal - calyx, cary - caryopsis, fr - fruit, l - leaf, mg - megaspores, lf - leaf fragment, ps - piece of stem, trn - trigonous nutlet).

Tundra	
Betula nana	lf
Dryas octopetala	lf
Salix herbacea	l
Grassland, open, bare and disturbed ground	
Armeria maritima	cal
Linum perenne	s
Potentilla anserina	a
Silene maritima	s
Taraxacum officinale	a
Viola subgenus *Melanium* sp(p).	s
Aquatic	
Myriophyllum spicatum	fr
Potamogeton fresii	fr
Potamogeton sp(p).	fr
Ranunculus subgenus *Batrachian* sp(p).	a
Unclassified	
Carex sp(p).	bin
	trn
Gramineae sp(p).	cary
Pre-Pleistocene structures	mg
Musci sp(p).	ps
Salix sp(p).	ca

7.3 Vegetation and environment

The subsample yielded relatively undiverse assemblages with only 17 plant taxa recorded. The plant macrofossils indicate that a variety of habitats existed in the vicinity of the site where deposition took place.

Areas existed around the site of deposition where a tundra type vegetation occurred that consisted of dwarf arctic-alpine plants. Only two fragments of the characteristically strongly crenate leaves of *Betula nana* were recovered, possibly suggesting that dwarf birch was not as abundant in the source vegetation as other dwarf tree taxa represented. However, it has been noted that the macroscopic remains of *Betula nana* are rarely found in abundance in British Pleistocene sediments (West 2000). The dominant dwarf tree taxon recorded was *Salix herbacea,* with many of its leaves recovered. West (2000) comments that *Salix herbacea* prefers open habitats with fresh and basic soils, often subject to solifluction, and that this species is particularly associated with late snow patches. *Dryas octopetala* was probably found growing within this dwarf wood. There is the possibility that in an open, treeless landscape some of these leaves may have been blown some distance before deposition took place. The taphonomic processes that acted upon the leaf component of the assemblage is uncertain and, therefore, the precise location of the source plants in relation to the site of deposition is difficult to determine.

The most abundant fossil type in the assemblage investigated were the calyces of *Armeria maritima*. Today this is a polymorphic species that has a wide circumpolar and boreal range, thus making it unsuitable for the reconstruction of past ecological or climatic conditions.

A grassland, open and disturbed ground habitat is evident by the presence of Gramineae, *Linum perenne*, *Potentilla anserina* and *Taraxacum officinale*. This component suggests that conditions near to the site of deposition were relatively dry and calcareous, and that disturbance of the grassland may have exposed bare soil in places. Erosion of the underlying deposits may have been the source of the Pre-Pleistocene megaspores that were recorded. The disturbed areas may have been formed by bank collapse at the margins of the channel or by the movement of large animals to and from the waterbody. It is possible that the plants that produced the *Viola* subgenus *Melanium* seeds also inhabited the grassy or disturbed areas. The soil profile may have been slightly saline in places. This conclusion comes from the fact that both *Potentilla anserina* and *Silene maritima* can tolerate a degree of soil salinity.

Waterside and damp ground taxa are not recorded suggesting that no marginal reedswamp existed at the channel edge.

Only four aquatic taxa are recorded. They suggest deposition took place in relatively shallow water, probably less than 1.5 metres deep, with still or slow flowing water. Preston (1995) notes that *Potamogeton friesii* prefers calcareous water that is often eutrophic. The occurrence of *Myriophyllum spicatum* would also suggest alkaline water conditions with a mesotrophic to eutrophic nutrient status. The presence of *Ranunculus* subgenus *Batrachian* achenes indicates that the water surface was covered, in places, by patches of water buttercup. However, the difficulty of making species identifications of the achenes makes this fossil record of limited value in palaeoecological reconstructions.

Prevailing climatic conditions at the time of deposition were arctic in nature. All of the species recorded have part of their present day range close to the arctic circle (Hultén, 1950; Hultén & Fries, 1986; Jalas & Suominen, 1972; Meusel & Jäger, 1965 & 1978). Any more precise interpretation of the climatic conditions at the time of deposition is difficult from the palaeobotanical data because, as West (2000) comments, it requires not only an understanding of the biological evidence (i.e. taxonomy, phytogeography, biology of individual species, and taphonomy), but also the geological evidence for climate.

7.4 Age of the sediments, correlation with other sites and duration of deposition

Further studies may provide more data that will allow an age determination from the plant macrofossil data, but at the moment no age can be suggested. The only conclusion that can be made is that the fossiliferous sediments were deposited during a cold stage or a stadial event. The fossiliferous samples occurred in narrow lenses that would suggest that deposition was rapid.

7.5 Recommendation for further work

It is recommended that full analysis is undertaken of the plant macrofossils in all the samples taken during the on-site investigations. This will include analysis of samples collected from the Lower Sands (Profiles 4 and 5) in addition to further work on the samples collected from the vicinity of the original woolly rhino find. This further analysis, in combination with the further study of the plant pollen, the insects remains, the vertebrate fauna and other palaeoenvironmental and dating analyses, will contribute to a full analysis and reconstruction of the environmental sequence.

8. Potential for stable isotope analysis of wood macrofossil samples Ian Candy

Preserved wood was taken from four sample points within the Quaternary deposits of the Whitemoor Haye quarry. The samples were taken from sediments occurring at the base of the sequence, within scour pits at the Quaternary/Triassic contact, within the middle of the succession, within fine-grained "ponded water" deposits, and at the top of the sequence from preserved root mats. A fourth sample was taken from fine-grained sediments from deposits within which the woolly rhinoceros remains are thought to have occurred. The material sampled comprised a range of plant remains including root, leaf, stem and twig fragments. The material was in a range of preservations states but for the purpose of this study, the densest, least decayed material was taken, with the aim of sampling wood with the best-preserved isotopic signature.

The study of the stable isotopic content of wood within Quaternary deposits is, at the current time, in its infancy. Plants naturally fractionate stable carbon isotopes, preferentially uptaking ^{12}C rather than ^{13}C. Plant values for ^{13}C range between –25 and –35 ‰ compared to approximately -8 ‰ for atmospheric CO_2 (Lajtha & Marshall, 1994). As the degree of fractionation is significantly affected by climate related factors such as temperature and precipitation, the ^{12}C:^{13}C ratio within fossil wood can give a broad indication of the prevailing climate. Although establishing a direct link between the ^{12}C:^{13}C ratio and quantitative climate values is problematic, the samples taken throughout the sequence could provide an indication as to whether the climate was warming or cooling during the deposition of the Whitemoor Haye sequence. Combining this isotopic evidence with pollen and beetle records could provide an important record of the climatic conditions that existed during and after the burial of the rhino remains. The significance of the results obtained from the Whitemoor Haye wood samples depends upon; 1) the degree of diagenetic alteration of the isotopic signature, and 2) the range of species sampled within each sub-sample.

The study carried out will be a pilot study to see if meaningful results may be derived from the Whitemoor Haye samples and how they compare with the other more traditional palaeoecological records. The samples will be completely dried and then analysed on the Isochrone NA1500 elemental analysis at the Department of Geology, Royal Holloway, University of London.

9. Assessment of pollen James Greig

9.1 Summary

The samples assessed show that pollen is preserved in sufficient quantity and quality to demonstrate open, probably arctic conditions when the material was buried. The potential for further more detailed analysis is demonstrated

9.2 Sampling

Two channel fills, Profiles 4 and 5, were sampled, as were a number of other features of the area in which the partial skeleton of the woolly rhinoceros was found.

The two profiles, 4 and 5, were sampled for pollen at intervals of 5 cm by David Smith. Of these, an organic-looking example from each section was chosen for this assessment, from Profile 4 at a depth of 55cm and from Profile 5 at 40cm.

9.3 Method of analysis

The two pollen samples were processed using the standard method; about $1cm^3$ subsamples were dispersed in dilute NaOH and filtered through a 70æm mesh to remove coarser material, which was then scanned under a stereo microscope. The finer organic part of the sample was concentrated by swirl separation on a shallow dish. Fine material was removed by filtration on a 10æm mesh. The material was acetolysed to remove cellulose, stained with safranin and mounted on microscope slides in glycerol jelly. Counting was done with a Leitz Dialux microscope. Identification was using the writer's pollen reference collection, seen with a Leitz Lablux microscope. Standard reference works were used, notably Faegri and Iversen (1989) and Andrew (1984).

9.4 Results

The nomenclature and order of the taxa follow Bennett (1994) and Kent (1992) respectively. The pollen types have been listed in taxonomic order according to Kent (1992).

Spores			
Profile	4	5	
Sample depth	55	40	Common name
Sphagnum	2	1	sphagnum moss
Pollen			
Pinus	-	1	pine
Ranunculus-tp.	-	4	buttercup, crowfoot
Thalictrum	1	-	rue
Quercus	3	-	oak
Betula	1	8	birch
Corylus	-	1	hazel
Caryophyllaceae	2	-	stitchwort family
Apiaceae	+	1	umbellifers
Plantago lanceolata	-	1	ribwort plantain
Plantago major/media	-	2	hoary plantain
Cirsium-tp	1	-	thistles
Lactuceae	-	2	a group of composites
Aster-tp	1	1	daisies etc
Artemisia	2	1	mugwort
Cyperaceae	30	17	sedges
Poaceae	20	28	grasses
Total pollen	63	68	

The material from Profile 4 (55 cm) was a fine organic silt and sand, and a Caryophyllaceae seed and a moss fragment was noticed in the coarse sieving residue. The material from Profile 5 (40 cm) was highly organic, consisting of rather amorphous coarse organic material among which a seed of *Taraxacum* sp. (dandelion) was noticed in the coarse sieving residue.

9.5 Discussion

The pollen counts for assessment purposes were quite small and they therefore represent outline information only at this stage. The spectrum from each sample was basically similar, so they can be discussed together. Poaceae (grass) and Cyperaceae (sedges etc.) pollen was the most numerous. A range of herb pollen types was present such as *Ranunculus* (buttercup), *Thalictrum* (rue), Caryophyllaceae (stitchworts etc), *Plantago* (plantain), Apiaceae (umbellifer family), *Artemisia* (mugwort), *Cirsium* tp. (spear thistles), *Aster* type (daisies etc.) and Lactuceae, a large group of composites which includes *Taraxacum* (dandelion), of which a seed was found.

There was only a little tree and shrub pollen, including *Betula* (birch), with a trace of *Pinus* (pine) and in 4/55 cm *Quercus* (oak). Spores of *Sphagnum* were present.

The environment indicated by the pollen spectra is a largely open one with grasses, sedges and a range of herbs, while birch as the main tree or shrub suggests rather cold conditions.

The pollen and plant macrofossil records seem to complement each other quite well, and lead to similar conclusions about the nature of the landscape with birch and mainly open herbaceous plant cover. Some taxa show up better as macrofossils and others, such Poaceae and Plantago, show up better as pollen. More overlap between the macrofossil and pollen floras can be expected when larger floras have been investigated.

9.6 Recommendation for further work

The pollen is well enough preserved and abundant enough to make more work worthwhile. More detailed counts can be obtained and the taxa identified more exactly. In addition, examining more samples will determine whether there is any temporal variation through the profiles.

10. Potential for soil studies Susan Limbrey

Potential for soil and related studies focuses on two aspects:

- Environmental conditions
- Bone preservation

10.1 Environmental conditions

To complement the plant macrofossil, pollen and insect studies, micromorphological study of what may be transient soils - rather than purely depositional entities - is proposed. Where organic material has been preserved on the gentle sloping channel edges, and overlies thin grey, clay-rich material, a humic gley soil is suggested (these are referred to as 'drapes' in Section 4 above). This implies sub-aerial conditions prevailing for long enough for a plant community to become established and deposit residues which humify and form a thin organic horizon and induce iron reduction in the subjacent mineral material. These 'soils' have been preserved mainly at two levels: on a gravel spread immediately overlying the Mercian Mudstones, and patchily at a higher level, where they may be associated with the partial rhino skeleton.

Samples were taken of the lowest of these 'soils', and at two levels higher up in Profile 6. A block of sediment enclosing organic laminae in sand overlying another of them was taken from close to the rhino find spot. It is proposed examine them by soil micromorphology to look for specifically pedological, as distinct from sedimentological, features. These organic horizons have also been sampled for pollen analysis.

10.2 Bone preservation

The soil profile exposed in the quarry edge indicates a history of podzolisation, the B horizon of a strongly developed iron-humus podzol being preserved below the depth to which ploughing during and since reclamation from heathland (whose existence is confirmed by the placename) has reached. Such reclamation, and maintenance for a recent history of productive arable agriculture, will have involved massive incorporation of fertilisers: dung and lime, and more recently lime and NPK. Podzolisation, which may have developed under forest in the early post-glacial, and by analogy with the history of heathlands in lowland Britain was probably well established in the first millennium BC, results from low base reserve in the soil parent materials and involves extreme acidification as the soil develops.

The extent to which extreme acidification extends below the metre or so depth at which deposition of iron and humus in the B horizon occurs, is variable. The leaching and iron/humus deposition can extend in tongues to greater depth, following root channels. Such tongues are present at Whitemoor Haye, within the gravels and the sands.

Samples were taken from Profile 6, fairly close to the principal rhino location, and covering sediment types inferred from field observation and from the material adherent to the skull to be comparable to those in which the partial skeleton lay. pH readings lie within the range 5.1 to 5.6 in the sands, which is moderately acid in soil terms, but fall to the extremely acid levels of 3.0 to 3.8 in the layer containing the 'soil'. At the bottom of the section a 'soil' occurs just above a basal gravel; pH is 4.8, with 5.2 in subjacent sand.

Further samples were taken from a lump of sediment including laminated sand and organic matter, a substantial layer of plant material, a 'soil' and a thin gravel, with some iron oxide cementing, which was collected from immediately adjacent to the rhino find location, and thought to be at a similar level. pH readings of 2.9, 3.0 and 3.0 were obtained from the organic material, clayey layer and gravel respectively

A sample of sand from within the nasal cavity of the rhino skull gives a pH reading of 3.6. This could be taken to confirm that the skeleton lay at the level of the 'soil' within the sands, rather than at the base of the sands.

Preservation of bone and tooth even for short periods under such acid conditions requires a protective process. Reducing conditions that ensured the preservation of plant and insect remains would also promote survival of the proteinaceous material around the rhino's teeth, but most of the bone material, and parts of the teeth, do not have a protein covering. The bones are, however, heavy and in places conspicuously impregnated with iron oxides and/or other iron compounds. Some of the isolated bones are heavy and black, suggesting iron sulphide. High available sulphur is indicated by the H_2 S smell of the organic materials. Iron-phosphate-organic complexes may also be involved.

Whatever the materials which have replaced, protected or encapsulated bone and tooth, the dynamics of the preservation processes must be considered. Once buried, so long as sub-zero mean annual temperatures prevailed, preservation was ensured, so it is interstadial and post glacial conditions that introduce potential leaching of bone in sands and gravels. The pH of the deposits might have been around neutral to start with, acidity increasing as soils developed. Localised stagnation in channels at the base of the deposits and containing organic debris would produce the necessary reducing environment for mobility of iron, and the possibility of its deposition in bone, but above the level of the highest inter-channel rise of Mercian Mudstone lateral water flow would maintain oxygen levels, apart from in the localised organic channel deposits at higher levels. None of those seen in this part of the site appeared to be big enough to hold a rhinoceros, and the iron in and on parts of the skull is in oxide form. Bone destruction must be slow enough for replacement minerals to replicate bone mineral or to infill porosity; destruction of collagen by hydrolysis and biological attack leaves carbonate susceptible to dissolution, and it is only close to neutral that phosphate is mobilised as it switches between stable forms. Absorption of fluoride, to form fluorapatite, which is a more stable mineral than apatite, and replacement of calcium by uranium from groundwater may also increase stability.

It is therefore hypothesised that slow replacement processes took place under near neutral pH; reducing conditions set up locally in stagnant patches provided a supply of mobile iron to be incorporated into bone structure, as oxide, sulphide, or in phosphatic complex depending on the immediately local pH and redox conditions, possibly with further, and slower, stabilising process involving fluorine and uranium in the groundwater. To test this hypothesis it is proposed that chemical analysis of samples of bone and tooth be carried out, from the rhino itself, by inconspicuous drilling, or from separate finds covering the same range of material and colour, to determine content of calcium, phosphorus, iron, sulphur, fluorine, uranium, carbon and nitrogen. (F and U concentrations in groundwater should be available from the BGS.)

11. Optical dating sampling and assessment of potential Phillip Toms

11.1 Summary of sample collection

Eight sediment samples (field prefix code OSL WH) were collected within opaque plastic tubing forced into Profiles 10 (OSL WH 10/1 through to OSL WH 10/4) and 6 (OSL WH 6/1 through to WH 6/4) for the purpose of optical dating. The table below shows the depth of the samples relative to the surface of the excavation. The tubes were sealed with clingfilm in order to preserve water content, the proportion of which bears a direct relationship on the rate of dose exposure in and around the sediment samples. The sample cavity was then extended for the purpose of *in situ* gamma spectrometry in order to gain a measure of gamma dose contributions to the sediment sample whilst buried and accurately account for potential heterogeneity in the gamma dose field. Loose sediment samples were collected from the rear of this extended cavity and double-bagged. The comparability of water content measurements from these samples with those obtained from the dating sample will be examined to ensure that the assessment of present water content is not affected by evaporation from the excavated face of each section.

	Field Code
	OSL WH 10/4
Section 10	OSL WH 10/3
Upper Sands and Gravels	OSL WH 10/2
	OSL WH 10/1
	OSL WH 6/4
Section 6	OSL WH 6/3
Lower Sands and Gravels	OSL WH 6/2
	OSL WH 6/1

Location of optical dating samples

11.2 Statement of potential

The accurate determination of the age of a sedimentary event by luminescence dating principally rests upon the reduction of the datable luminescence signal through exposure to sunlight and, once buried, subsequent accumulation of this signal through exposure to natural ionizing radiation. The total luminescence signal accrued is a measure of the total dose exposure, an equivalent dose (D_e) value being generated through calibration of the luminescence produced per unit dose by measurement of luminescence response to known amounts of laboratory β-radiation (derived from intercomparison with the 'Hotspot 800' ^{60}Co γ-source, National Physical Laboratory, UK). Ages are obtained by dividing D_e by a value of dose rate exposure, generally acquired through an assessment of the concentrations of the radioisotopes ^{40}K, ^{238}U and ^{232}Th within and around the sediment samples and calculation of cosmic dose on the basis of sample depth and geographical location. Optical dating (Huntley *et al.* 1985) refers to the process of signal stimulation in the laboratory and is the logical extension to its progenitor, thermoluminescence dating, when dating materials originally reset by sunlight.

The datable luminescence signal in this study will be harnessed from fine sand-sized quartz isolated by physical and chemical methods. The primary motive in using this minerogenic dosimeter is that its datable signal is highly stable over the Quaternary period, which contrasts with the anomalous fading of this signal observed for other naturally ubiquitous minerals such as feldspar and zircon (Wintle 1973; Templer 1985). The D_e value will be determined through a modified version of the Single-Aliquot Regenerative-dose (SAR) protocol outlined by Murray and Wintle (2000) in order to accurately correct for changes in luminescence response to laboratory dose induced by irradiation and heating treatments, a necessary part of the D_e acquisition process.

The dose rate value has already been determined in part on site. *In-situ* measurements of gamma dose contributions to each sample from the surrounding sediment were made using an EG&G μNOMAD portable NaI gamma spectrometer calibrated at RLAHA, Oxford University, UK. Neutron Activation Analyses (NAA) will be performed by Becquerel Laboratories, Australia, upon sub-samples of 'tubed' material to determine the local beta contributions. The absorption coefficient of the present water content for each sample will be incorporated within the dose rate calculation. Temporal variations in water content are limited by porosity, however saturated volume was probably only achieved during the period of deposition. This sedimentary phase was brief compared to the period of burial, therefore it is assumed that present water contents reflect the long term average and that a relative uncertainty of 50% in these estimates is sufficient to account for any potential seasonal variation in sediment moisture. Estimations of cosmic dose will follow the calculations given by Prescott and Hutton (1994).

The primary source of inaccuracy in luminescence ages obtained from fluvial depositional contexts similar to Whitemoor Haye is the presence of residual datable signals subsequent to burial, due to exposure to an attenuated spectrum and/or period of sunlight, generating age overestimates. D_e (t) plots incorporating the SAR protocol proposed by Bailey (in press) exploit the existence of signal accumulation sites (traps) within minerogenic dosimeters where stored pre-depositional signals are reduced (or bleached) with different efficiency for a given wavelength of light. These plots will be used to identify the occurrence of grains partially bleached at the point of burial within each sample. Mean D_e values for each sample will be based upon D_e determined from 12 aliquots. Where this process of signal analysis evidences partial bleaching, a maximum age will be calculated through rejection of data from those aliquots indicating the presence of grains that were partially bleached.

It is anticipated that optical dating at Whitemoor Haye will:

1) test the accuracy of the biostratigraphic MIS 3 age assignment (c. 60-25 ka BP) of the deposits,
2) further refine the chronology of the sedimentary evolution, and
3) provide absolute chronometry through measurement of a datable signal independent of that used in radiocarbon dating, thereby generating a potential means of verification in age assignment by the geochronometric methods employed.

12. Overview of proposed scientific analyses Simon Buteux

The Whitemoor Haye woolly rhinoceros partial skeleton is the best preserved example of a woolly rhinoceros to be discovered in Britain this century, and one of the most important finds of a Pleistocene mammal made in the country since the 1960s. The completeness and quality of preservation of the skull and anterior post-cranial bones enable a range of scientific analyses – many at the cutting edge of research – to be carried out on the remains. These analyses will be aimed at determining the date, diet, environment and – most importantly – phylogeny (evolutionary relationships) of the rhino.

The scientific importance of the find is greatly enhanced by the fact that the circumstances of its discovery allowed detailed investigation of its context. Although unfortunately the posterior part of the skeleton was not recovered, this investigation resulted in the recovery of the remains of three other woolly rhinos together with the remains of woolly mammoth, horse, reindeer, bison and wolf. Also of great importance was the survival, in a remarkably good state of preservation, of plant and insect remains associated with the vertebrate faunal assemblage, enabling detailed reconstruction of the climate and environment. In addition, it was possible to study the geological context of the remains, and thus to examine the circumstances of their deposition and preservation.

Taken together, the wide range of the evidence thus available provides in general one of the best opportunities to study the Ice Age 'mammoth steppe' landscape of the Middle Devensian in Britain, and in particular to study one of its most fascinating inhabitants, the woolly rhinoceros. Furthermore, because such a diverse range of evidence is available, bearing on the age of the deposits, the climate, the environment and the landscape, it is possible to make detailed comparisons between the different strands of evidence and contribute to the evaluation and development of the various techniques of analysis.

12.1 Analyses of the woolly rhinoceros partial skeleton

Analyses of the partial skeleton will include:

- Detailed metrical analysis of the skeleton, enabling estimation of the age and possibly the sex of the individual, and shedding light on the circumstances of its deposition and preservation. Such analysis will also enable systematic comparison with other British woolly rhinoceros populations.

- Analysis of the dental calculus, microwear analysis on the teeth and identification of plant remains preserved within the dentition, enabling reconstruction of diet.

- Stable isotope analysis of the bone mineral and dental enamel. The varying proportions of the stable isotopes (variant forms of the atom) of oxygen, nitrogen and carbon preserved in bone can shed light on past climate and climate change. The proportion of the different isotopes – which have different atomic weights –

present in the environment and absorbed into bone is in part temperature and climate dependent. For example, in cold periods the proportion of the lighter isotope of oxygen, oxygen 16, to the heavier isotope, oxygen 18, is lower because the lighter isotope is preferably evaporated in water and becomes literally locked up in the ice caps. Because living creatures absorb oxygen in one way or another, the proportion of oxygen 16 to oxygen 18 in their tissues is a proxy indicator of the climate at the time the creature died.

- Osteocalcin sequencing. This is a very new analytical technique which can help to reveal the evolutionary relationships of the woolly rhino, for example with living African and Asian rhinoceroses. Ostecalcin is the second most abundant protein in bone after collagen. As a result of genetic mutation, the structure – sequence – of the osteocalcin molecule changes through time. By measuring the degree of similarity between the osteocalcin sequences in different specimens the degree of relatedness between the specimens can be estimated – the greater the similarity the closer the relationship.

- Mitochondrial DNA sequencing. This is a somewhat more established technique for determining evolutionary relationships, but still at the forefront of scientific research. Mitochondrial DNA is found outside the cell nucleus in each cell of an animal; it is only inherited through the female line thus escapes the 'shuffling' that occurs in nuclear DNA as a result of the mating of a male and female, each contributing half of their nuclear DNA in a largely random manner to their offspring. As a consequence, mitochondrial DNA changes through time as individuals within a population diverge, generation upon generation, only as a result of genetic mutation and natural selection. Parts of the mitochondrial genome, including the so-called 'control region', do not code for genes, and thus are unaffected by natural selection; the changes that occur in the sequence of DNA in these regions are the result of random mutations building up through the generations. Comparison of the DNA sequences in such regions between individuals and species thus provides a measure of their degree of evolutionary relatedness.

  The mitochondrial DNA sequence established for the Whitemoor Haye woolly rhino can be compared with sequences from modern rhinos as well as with a Russian permafrost-preserved example currently being sequenced at the University of Copenhagen.

  Osteocalcin sequencing and mitochondrial DNA sequencing are complementary approaches to assessing the evolutionary relationships of the Whitemoor Haye rhino, each with its particular limitations and biases. Comparison of the two techniques promises to be particularly enlightening and make a major contribution to scientific research.

- Radiocarbon dating. Radiocarbon dating of purified collagen extracted from the partial rhino skeleton will provide one method of attempting to determine the date of the skeleton. The principle of radiocarbon dating depends on the fact that at the time of death of the animal the proportion in the bone of the unstable – radioactive – isotope of carbon, carbon 14, to the stable isotope, carbon 12, mirrors that in the surrounding environment. However, at death the radioactive isotope, carbon 14, starts to decay at a known rate. Thus measuring the proportion of surviving carbon 14 to carbon 12 provides an estimate of the age of the bone.

However, there are severe limitations to the accuracy of radiocarbon dating as a means to date the Whitemoor Haye rhino. At an estimated age of between 60,000 and 30,000 years old the Whitemoor Haye rhino lies at the limits of the effectiveness of the radiocarbon technique. First, at an age such as this the amount carbon 14 surviving in the bone will be very small indeed – nearly all of it will have decayed – making measurement of its proportion to carbon 12 difficult and potentially inaccurate. Second, it has for several decades been realised that the proportion of carbon 14 to carbon 12 in the atmosphere has fluctuated through time. This means that to obtain an accurate radiocarbon date, the dates have to be 'calibrated' against dates for organic materials obtained by other means, for example tree-ring dating. Unfortunately, there are no reliable methods to calibrate radiocarbon dates as old as that anticipated for the woolly rhino, so a date obtained by the radiocarbon method will need to be compared with dates obtained by other means (below).

12.2 Analyses of the whole vertebrate faunal assemblage

Analyses of the whole vertebrate faunal assemblage will include:

- Complete description of all vertebrate remains recovered from the site to enable identification to generic or species level wherever possible, calculation of numbers of individuals and comments on state of preservation.

- Examination of all material for evidence of human, carnivore or other modification (cutmarks, deliberate fracturing of fresh bone, gnawmarks) and pathologies.

- Reconstruction of palaeoenvironment and climate as indicated by the mammalian remains and assessment of any evidence for seasonality (e.g. shed reindeer antlers).

- Estimation of the age of the mammalian assemblage through biostratigraphical analysis. The composition of the mammalian fauna present during the Ice Age fluctuated with the changing climate and environmental conditions, with different animals coming and going, evolving and going extinct. Systematic comparison of faunal assemblages from different sites enables the assemblages to be slotted into an overall sequence – a technique known as biostratigraphical analysis. In favourable circumstances, an estimation of the 'absolute' - that is 'colander' –

date can be obtained for some assemblages by means of a range of scientific dating techniques; similar assemblages are assumed to be of a similar date.

Detailed comparison of the Whitemoor Haye assemblage with other British and NW European last cold stage faunas will enable an estimation of the date of the assemblage through biostratigraphical analysis (it is a preliminary application of this approach that has enabled a rough date for the assemblage to be suggested). The estimated date obtained by means biostratigraphical analysis can then be compared with dates obtained by the other – independent - techniques of radiocarbon dating (above) and optical dating (below).

12.3 Analyses of the insect remains, plant remains, geology and soils

Preliminary assessment has shown that detailed analyses of the insect and plant remains will enable reconstruction of the climate and environment at and around the time the woolly rhinoceros died. They may also contribute to an estimate of the age of the deposits.

- Climate. Particular species of insect can be very sensitive to temperature, only able to survive in a narrow range climatic conditions. The temperature ranges and climatic conditions in which such insects flourish today provide a guide to temperature and climatic conditions in the past where the remains of these insects are found. For example, some of the insect species from Whitemoor Haye are only found today in the high Arctic and eastern Siberia. Through systematic and statistical analysis of the modern ranges of the insects found at Whitemoor Haye detailed inferences can be made about the climatic conditions which prevailed. These techniques are well established for coleoptera (beetles) and have more recently been refined for chironomids (midges). However, the range and preservation of insect remains at Whitemoor Haye also offers the opportunity to extend this approach to the trichoptera (caddis flies) and develop a 'temperature range overlap method' for this order as well.

  Of course, plants are sensitive to climate conditions also and can contribute to the reconstruction of climate and temperature. This is a complementary approach to that provided by the insects, although on the whole a more coarse-grained one. An experimental approach to climate reconstruction using plant remains will involve stable isotope analysis of wood samples. The principles of stable isotope analysis have been outlined above (Section 12.1). In the case of the wood samples it will be the ratio of carbon 12 to the heavier carbon 13 that will be measured; this ratio is affected by climatic factors such as temperature and precipitation. Changes in the ratio through a series of samples taken in stratigraphic sequence should provide evidence of whether the climate was warming or cooling.

- Environmental reconstruction. Many species of insects feed on particular foods and are associated with very particular environments, for example fast-flowing or slow-flowing waters, 'open' or more vegetated ground, and so forth. For example, the assemblage of trichoptera (caddis flies) suggests the presence mainly of still, vegetated water conditions but with some water flowing. This is important for the reconstruction of the river system and the conditions in which the mammal remains became deposited. Amongst the beetle remains a wide range of dung beetles were encountered; the dung presumably derived from the large numbers of animals, woolly rhinoceros and mammoth amongst them, which came down to the water to drink.

Analysis of the plant remains will also enable detailed reconstruction of the environment; both dry-land and aquatic taxa are present. The plant remains survive in two forms, as the macroscopic remains of plants and as microscopic pollen grains. These two lines of evidence complement each other, some taxa being represented better by macrofossils and others by pollen; in addition the pollen, especially the wind-borne pollen, provides evidence of a wider environment than the more localised evidence provided by the macroscopic remains. Furthermore, the stratigraphic sequence of pollen samples collected will provide evidence of changes in the environment through time.

Further analysis of the geological context of the finds and of the transient soils associated with the animal and plant remains will also contribute to environmental reconstruction. Through studying borehole records a wider picture of the Ice Age landscape and ancient river channels can be built up, while analysis of microfossils preserved in fragments of coal amongst the deposits will shed light on their origin. The detailed composition and structure (micromorphology) of the soils can be analysed by making thin sections of the soils and examining these through a microscope. The micromorphology of the soils will provide information on the environmental conditions which gave rise to their development.

12.4 Dating

Three methods of scientific dating will be employed.

- Radiocarbon dating
- Biostratigraphic dating
- Optical dating

The first two of these methods has been described above. The limitations of radiocarbon dating in the present context have been stressed, and given the relative small species list biostratigraphic dating is likely to be coarse focussed. Optical dating represents a third, independent method which may be used to date not the faunal and floral samples themselves, but the sequence of sands and gravels in which they were deposited.

Optical dating depends on the fact that quartz grains in the sands and gravels contain defects in their crystal structure which capture electrons disrupted from their stable atomic position by ionising radiation from radioisotopes of elements (mainly uranium, thorium and potassium) that occur naturally in the geological deposit. These 'electron traps' are emptied, or 'bleached' after only a few seconds to minutes of exposure to sunlight, such as occurs during water transportation of the sands and gravels. Once the quartz grains are laid down and buried in the aggrading sediment, however, the electrons start to accumulate again. The total number of electrons accumulated whilst buried should be in proportion to the total dose received. Measurement of electrons accumulated is made indirectly through exposure of the isolated quartz grains to controlled laboratory lighting and measuring the luminescence emitted by the sample, a phenomenon resulting from the recombination of the trapped electrons into their stable atomic position. This process is known as optically stimulated luminescence (OSL).

In order to calculate the age of the sample the total dose of radiation is divided by the annual dose of radiation occurring in the deposit. The annual dose is calculated through an assessment of the concentrations of the radioisotopes of uranium, thorium and potassium within and around the sample, and calculation of the cosmic dose on the basis of sample depth and geographical location.

A principal source of inaccuracy in optical dating derives from the possibility that the water-transported quartz grains may not have received sufficient exposure to sunlight to completely empty the 'electron traps' in the crystal lattice, i.e. the grains may be only partially 'bleached'. This can result in overestimates of age. However, techniques have recently been developed to identify partially bleached grains, which may then be eliminated from the analysis. Furthermore, the samples were taken in stratigraphic sequence and should thus produce a chronological sequence of dates; this also helps the identification of 'rogue' dates.

While all the three dating techniques to be used at Whitemoor Haye have limitations, they are all founded on different principles and will thus provide independent but complementary estimates of the date of the Whitemoor Haye woolly rhinoceros and the associated deposits. As in the reconstruction of the rhino's evolutionary relationships, the climate and the environment, this is the strength and principal justification of using multiple techniques.

13. Contributors to full analysis and their roles

Contributor	Institution	Role
British Geological Survey	British Geological Survey	Heavy Mineral Analysis of the sand fraction in the Lower Sands to help determine origin of deposits
Dr Steve Brooks	Department of Entomology, Natural History Museum	Analysis of Chironomids (non-biting midges) as contribution to inferences about environmental conditions
Mr Simon Buteux	Institute of Archaeology and Antiquity, University of Birmingham	Project management; authorship of 'contextual' sections of scientific report; co-authorship of popular publication, editing
Dr Ian Candy	Department of Geography, Royal Holloway, University of London	Stable isotope analysis of wood macrofossils as experimental contribution to climatic analysis
Mr Gary Coates	Institute of Archaeology and Antiquity, University of Birmingham	Authorship of 'contextual' sections of scientific report
Dr Matthew Collins	University of Newcastle	Bone characterisation and collagen analysis of woolly rhino as contribution to reconstruction of palaeodiet and palaeotemperature
Prof Russell Coope	School of Geography Earth and Environmental Sciences, University of Birmingham	Analysis of Coleoptera (beetles) as contribution to inferences about environmental conditions and climate
Prof Alan Cooper	University of Oxford	Mitochondrial DNA sequencing of woolly rhino to analyse its phylogenetic (evolutionary) history
Mr Andy Currant	Department of Palaeontology, Natural History Museum	Description of vertebrate remains; detailed analysis of partial rhinoceros skeleton and reconstruction of palaeodiet; analysis of vertebrate remains as contribution to inferences about environmental conditions, climate and seasonality; dating of mammalian assemblage through biostratigraphical analysis; co-ordination of biomolecular analysis and radiocarbon dating of woolly rhino; co-authorship of popular publication, editing
Mr Nigel Dodds	Institute of Archaeology and Antiquity, University of Birmingham	Illustration for popular publication, including reconstruction of the Ice Age landscape at Whitemoor Haye
Dr Mike Field		Analysis of plant macrofossils as contribution to inferences about environmental conditions and climate
Mr Simon Fitch	Institute of Archaeology and Antiquity, University of Birmingham	Analysis of borehole data and modelling of rockhead surface within GIS framework for whole quarry area to identify other potential fossiliferous palaeochannels
Dr Malcolm Greenward	Department of Geography, Loughborough University	Analysis of Trichoptera (caddis flies) as contribution to inferences about environmental (notably water) conditions, and as a potential climatic indicator
Dr James Greig	Institute of Archaeology and Antiquity, University of Birmingham	Analysis of pollen as contribution to inferences about environmental conditions and climate

Dr Andy Howard		Further sedimentological analysis, including analysis of borehole data for whole quarry area to identify other potential fossiliferous palaeochannels; lithological analysis of coarse sediments in Lower Sands as contribution to inferences about the provenance and age of deposits
Prof Susan Limbrey	Institute of Archaeology and Antiquity, University of Birmingham	Micromorphological analysis of soils as contribution to inferences about environmental conditions; studies using elemental analysis of bone samples to determine factors leading to bone preservation
Dr Christiana Nielson Marsh	University of Newcastle	Bone characterisation of woolly rhino; osteocalcin sequencing to analyse phylogenetics (evolution) of the rhino
Oxford Radiocarbon Accelerator Unit	University of Oxford	Radiocarbon dating of woolly rhino partial skeleton
Ms Emma Paddock	Institute of Archaeology and Antiquity, University of Birmingham	Processing of Coleoptera (beetle) assemblages for analysis
Photographer	Natural History Museum	Photography of partial rhinoceros skeleton for publication
Dr Mike Richards	University of Bradford	Stable isotope analysis (oxygen, nitrogen and carbon) of bone from the woolly rhino as contribution to inferences about climatic variation
Ms Bryony Ryder	Institute of Archaeology and Antiquity, University of Birmingham	Preparation of site illustrations for scientific report and popular publication
Dr Danielle Schreve	Department of Geography, Royal Holloway, University of London	Description of vertebrate remains; detailed analysis of partial rhinoceros skeleton and reconstruction of palaeodiet; analysis of vertebrate remains as contribution to inferences about environmental conditions, climate and seasonality; dating of mammalian assemblage through biostratigraphical analysis; co-ordination of biomolecular analysis and radiocarbon dating of woolly rhino; illustration of partial rhinoceros skeleton for publication; co-authorship of popular publication; editing
Dr David Smith	Institute of Archaeology and Antiquity, University of Birmingham	Analysis of Coleoptera (beetles) as contribution to inferences about environmental conditions and climate
Dr Mike Stevenson	Palynology Section, British Geological Survey	Analysis of microfossils in coal fragments in Lower Sands to help determine origin of deposits
Dr Phillip Toms	Geochronology Laboratories, University of Gloucestershire	Optical dating of sediments as contribution to assessment of age of deposits

14. Task list for full analysis and publication

Task Group A: Description of excavation results; regional context; editing; project management (Tasks 1-5)

Task No.	*Task*	*Personnel*	*Days*
1	Full description of excavation results	Buteux Coates	3 2
2	Set findings in regional context	Buteux	5
3	Illustrations for excavation and regional context	Ryder	5
4	Editing of full scientific report	Buteux	5
5	Project management	Buteux Coates	15 3

Task Group B: Geological context (Tasks 6-12)

Task No.	***Task***	***Personnel***	***Days***
6	Analysis of borehole data	Howard	2
7	Modelling of rockhead/palaeochannels	Fitch	5
8	Analysis of lithological composition of deposits	Howard	1
9	Analysis of microfossils in coal particles	Stevenson (BGS)	N/A
10	Heavy Mineral Analysis of sand fraction	BGS	N/A
11	Inspection of local quarries for fossil remains	*Fieldworker*	15
12	Compile/edit geological report	Howard	1

Task Group C: Analyses of woolly rhinoceros and other vertebrate remains (Tasks 13-22)

Task No.	*Task*	*Personnel*	*Days*
13	Description and analysis of vertebrate remains	Currant Schreve	10 10
14	Reporting on vertebrate remains	Currant Schreve	5 5
15	Illustration of partial rhino skeleton	Schreve	5
16	Photography of partial rhino skeleton	NHM	N/A
17	Rhino bone characterisation	Collins Neilson Marsh	1 1
18	Rhino bone collagen analysis	Collins	2
19	Radiocarbon dating	ORAU	N/A
20	Osteocalcin sequencing	Neilson Marsh	5
21	DNA sequencing	Cooper	5
22	Stable isotope analysis	Richards	5

Task Group D: Analyses of insect remains (Tasks 23-25)

Task No.	*Task*	*Personnel*	*Days*
23	Analysis of Coleoptera		
	Processing of remaining samples	Paddock	4
	Identification of faunas	Smith/Coope	15
	Report writing and collating	Smith	5
24	Analysis of Tricoptera		
	Processing and identification of faunas	Greenward	15
25	Analysis of Chrionomidae		
	Processing and identification of faunas	Brookes	15

Task Group E: Analyses of floral remains (Tasks 26-28)

Task No.	*Task*	*Personnel*	*Days*
26	Full analysis of plant macrofossils	Field	30
27	Stable isotope analysis of preserved wood	Candy	7
28	Full analysis of pollen samples	Greig	18

Task Group F: Soil studies and optical dating (Tasks 29-30)

Task No.	*Task*	*Personnel*	*Days*
29	Micromorphological analysis of soils	Limbrey	12
30	OSL dating	Toms	14

Task Group G: Preparation of popular booklet/book (Tasks 31-33)

Task No.	*Task*	*Personnel*	*Days*
31	Writing of first draft	Buteux	15
		Currant	15
		Schreve	15
32	Prepare illustrations	Dodds	15
33	Editing of first draft	Buteux	10

15. Publication synopsis, scientific report

Title: 'A Middle Devensian partial skeleton of woolly rhinoceros (*Coelodonta antiquitatis)* from Whitemoor Haye, Staffordshire and the reconstruction of its Pleistocene environment'

Steve Brooks, Simon Buteux, Ian Candy, Gary Coates, Matthew Collins, Russell Coope, Alan Cooper, Andy Currant, Mike Field, Simon Fitch, Malcolm Greenward, James Greig, Andy Howard, Susan Limbrey, Christiana Nielson Marsh, Mike Richards, Danielle Schreve, David Smith, Mike Stevenson and Phillip Toms

Introduction (Buteux, Coates)

Geological context (Howard)
- Analysis of microfossils (Stevenson)
- Soils (Limbrey)
- Deposit modelling (Fitch)

Vertebrate remains (Currant, Schreve)
- Bone characterisation (Collins, Nielsen Marsh)
- Collagen analysis (Collins)
- Osteocalcin sequencing (Nielsen Marsh)
- Mitochondrial DNA sequencing (Cooper)
- Stable isotope analysis (Richards)

Insect remains (Brooks, Coope, Greenward, Smith)
- Coleoptera (Coope, Smith)
- Chironimidae (Brooks)
- Trichoptera (Greenward)

Plant macrofossils (Field)
- Stable isotope analysis of wood macrofossils (Candy)

Pollen analysis (Greig)

Dating (Currant, ORAU, Schreve, Toms)
- Biostratigraphic analysis (Currant, Schreve)
- Radiocarbon dating (ORAU)
- Optical dating (Toms)

Environmental reconstruction and discussion (various authors)

16. Publication synopsis, popular booklet/book

Title: 'Hunting the Woolly Rhino – secrets from England's gravel quarries'

Simon Buteux, Andy Currant and Danielle Schreve

Chapter 1: 'Something big came up in my bucket'

(An account of the discovery of the Whitemoor Haye rhino.)

Chapter 2: Scientists and journalists: the search for the other half

(An account of the ALSF-funded investigations and the media coverage.)

Chapter 3: Bones, molecules and atoms

(The scientific study of the rhino skeleton, including analysis of its evolutionary relationships by means of DNA analysis and other methods.)

Chapter 4: Ice Age Alrewas

(A reconstruction of the environment in which the rhino lived and died, based on the wide range of evidence available.)

Chapter 5: The life and death of the woolly rhino

(This chapter broadens the focus to look at what is known of woolly rhinos from throughout the world, including examples preserved in the Russian permafrost. It will explore the evolution of the rhino, its characteristics and lifestyle, and the reasons for its extinction – including hunting by humans.)

Chapter 6: The hunt goes on

(This chapter takes a broader look at the range of fossil evidence from the Ice Age that has been - and remains to be - discovered in England's quarries. This includes evidence for the activities of Neanderthals and other ancient humans. The chapter will stress the positive contribution that quarrying and the aggregates industry have made in the search to discover England's Ice Age past. It will also highlight the way that ALSF funding has helped in this search. Particular examples will include the excavation of the Neanderthal mammoth butchery site at Lynford Quarry in Norfolk and the work of the 'Shotton Project' which, with the aid of ALSF funds, is exploring the gravel quarries of the Midlands for more Ice Age remains and engaging schools and the wider public in this quest.)

17. Project programme and budgets

Appendix 1 shows the project programme in the form of a chart. The overall programme is designed to be completed by the end of February 2002 to accord with the current round of ALSF funding. Due to the time constraints, it is unlikely to be possible to achieve publication of either the scientific report or the popular book/booklet within this time frame, although full, illustrated, edited drafts of both will be submitted. Printing and publication of the popular book or booklet could either be subsidised to maximise its distribution, in which case a further grant application would be necessary in the 2004/5 financial year, or offered to a commercial publisher.

Four 'milestones' are identified in the project programme at quarterly intervals in order to enable clear external monitoring of the progress of the project and as a basis for staged payments.

Separate budgets are set out in Appendices 4 and 5 for the scientific analysis and for the preparation of the text and illustrations for the popular book/booklet. No costs are included for the costs of printing and publication of the popular book/booklet .

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Appendix 2: List of environmental samples taken

Sampling on 4th October 2002

Eight samples for environmental analysis were taken during the intial one-day investigation following the discovery of the rhinoceros partial skeleton.

Samples 1-6 were taken during excavation by the mechanical excavator in the area associated with the rhinoceros partial skeleton. All samples were located three dimensionally. Sample 3 was taken solely for macroscopic plant remains.

Sample 7 came from an isolated buttress left by the mechanical excavator. It consisted of a series of thin 'drapes' of organic matter on the edge of a relict channel.

Sample 8 came for an area of organic 'mat' towards the centre of Profile 1.

Sampling on 1st November 2002

Profile 5

This consisted of a small channel cut into the bedrock. Both sides of the channel were marked by gravel 'lag' deposits. The bottom fills of the channel consisted of alternating layers of black silty sands and well-preserved 'mats' of plant material. These wqere overlain by clean organic sands and subsequently by gravels. The profile was recorded and drawn to scale.

Pollen
Small spot samples were taken for pollen analysis in 5cm intervals down the face of the profile.

Insect and plant macro fossils
Four samples of approximately 20-litres each were taken from each of the 'contexts' identified within the profile. This series is labelled "S5(context type)".

Profile 4

This was a long longtidudinal cross-section of a channel below the Upper Gravels. The channel was filled with a black, organic silty sand with occasional inclusions of clean sand. The material within the channel appeared to be very heterogeneous in nature.

Pollen
Fifteen pollen samples were taken at 5cm intervals down the face of the profile.

Insect and plant macrofossils
Six 20-litre samples of material were taken for insect and plant macrofossil analysis. Given the heterogeneous nature of the material it was decided to sample at 10cm intervals down the face of the profile (sampling started 10cm lower than the pollen). This series is labelled "S4 1-6".

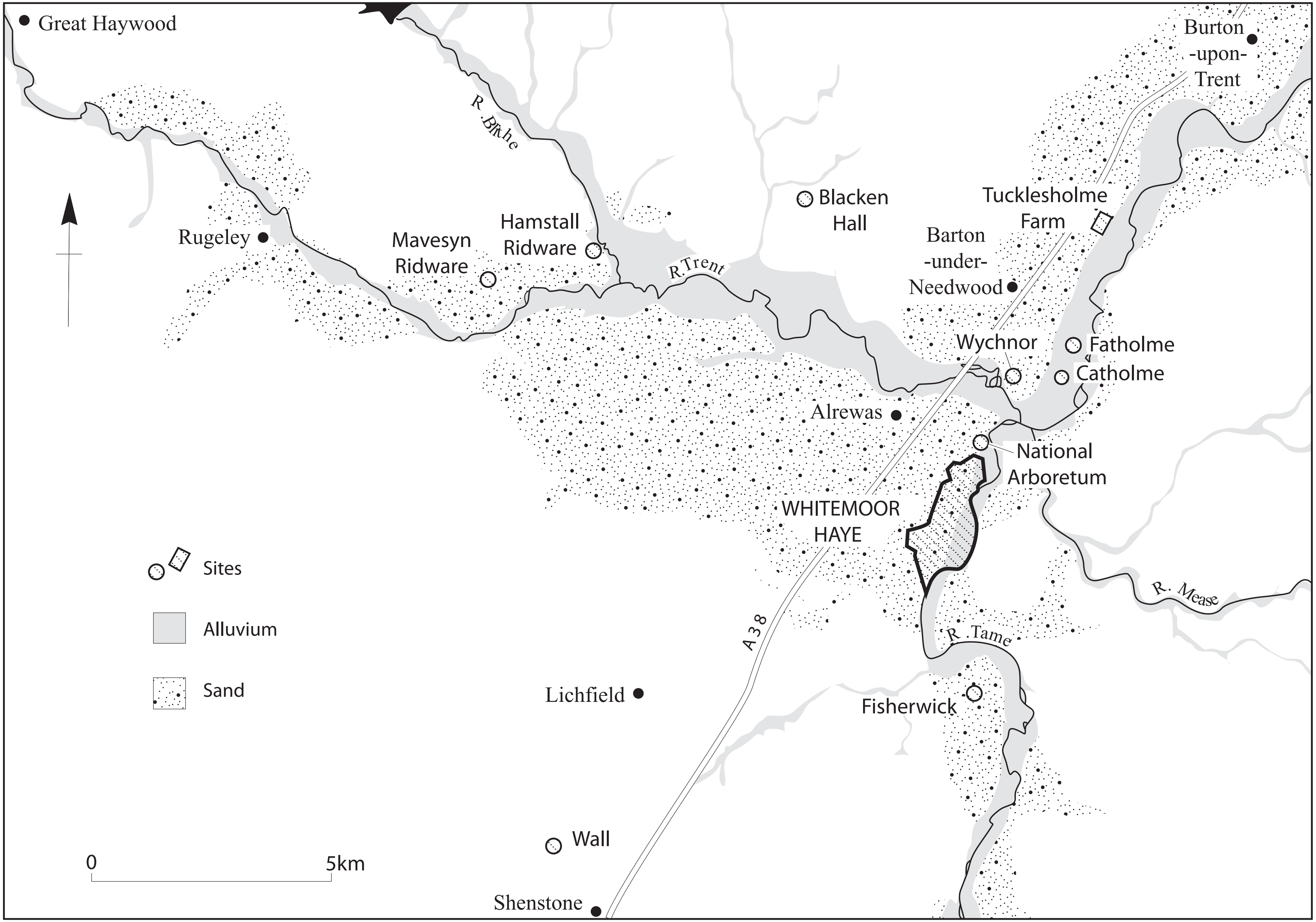


Fig.1 Site Location and Local Geology

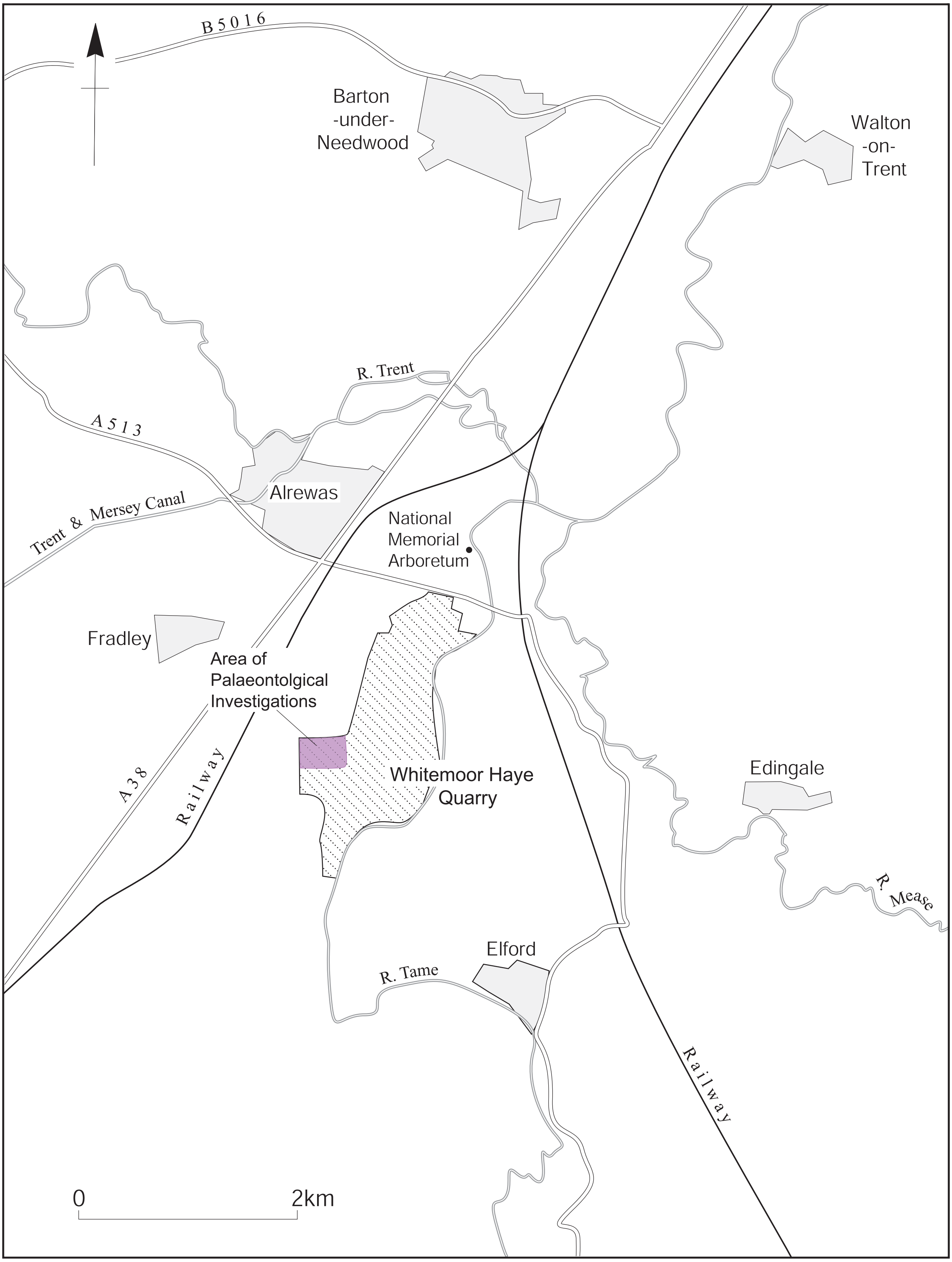


Fig.2 Area of Palaeontological investigations.

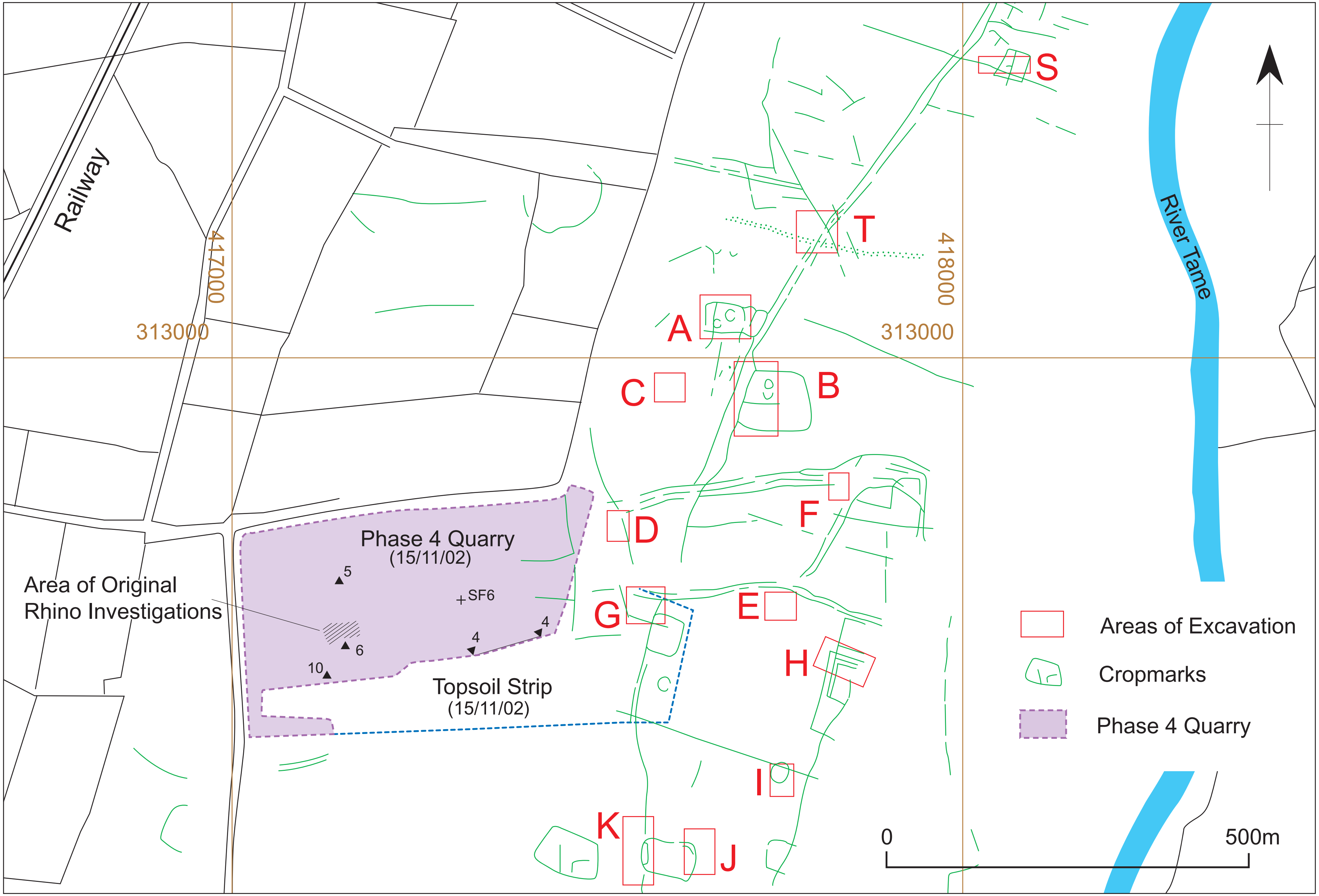
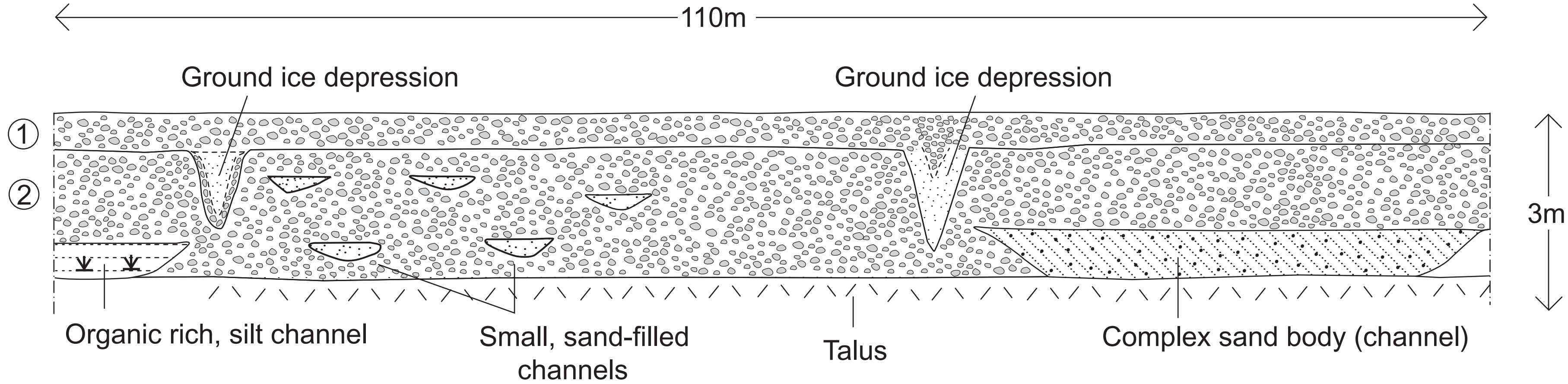


Fig.3 Area of Palaeontological Investigations showing location of rhino find and recorded profiles.



① Clay-rich gravel (weathered zone), massive, clast-supported

② Massive, clast-supported gravel

Fig.4 Profile 4: Schematic section.

① Pebbly sand
② Massive, medium to coarse gravel
③ Bedded sand, organic/humic towards base
④ Fibrous peaty silt with sandy beds
⑤ Channel lay
⑥ Massive, medium to coarse gravels
⑦ Bed rock (Mercia Mudstone)

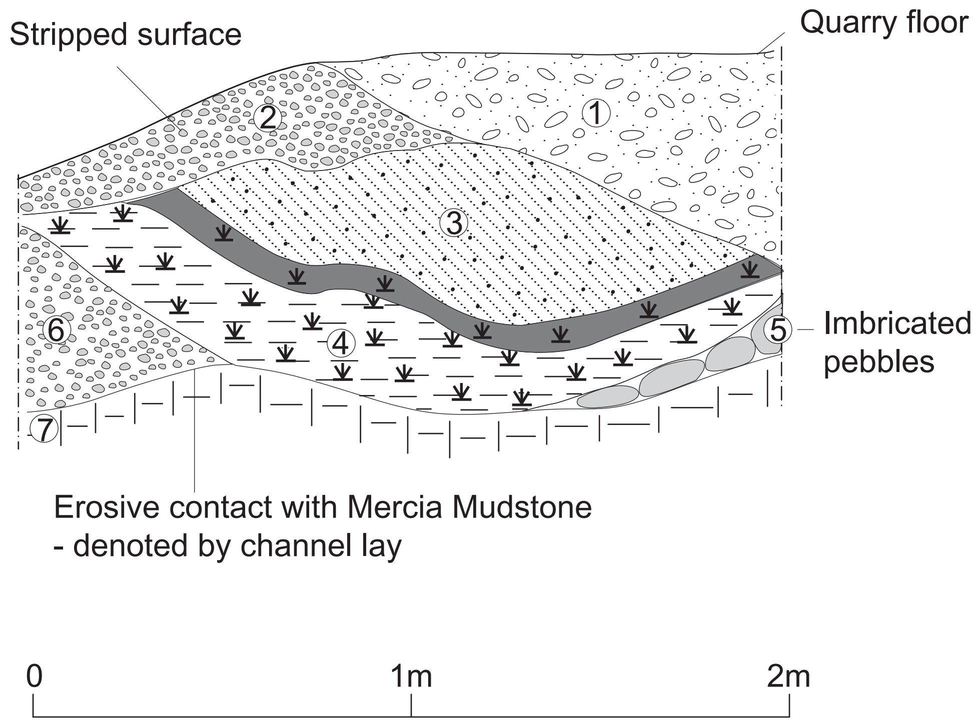


Fig.5 Profile 5: Schematic section

① Pebbly sand

② Complex, multiply-stacked units of sand infilling a number of channels

③ Clay 'drapes'

④ Channel lays (coarse pebble layers) denoting channel bases

Coal

⊗ OSL dating samples, No's 1-4

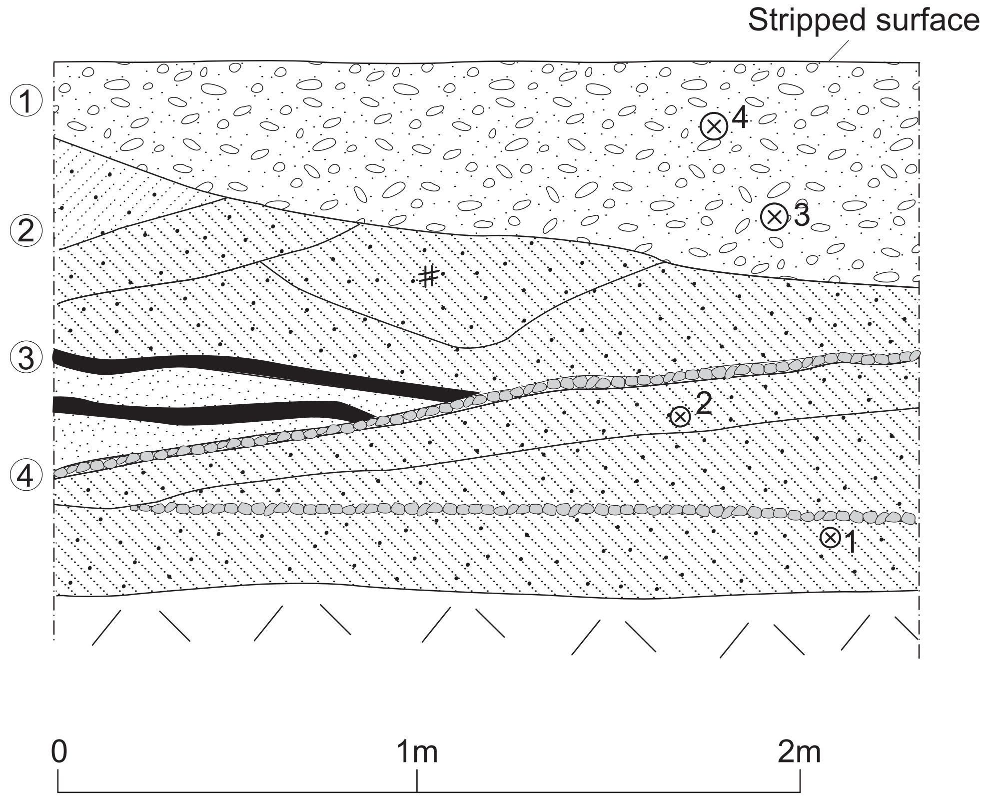


Fig.6 Type section of Lower sands.