Killerby Geoarchaeological and Palaeoenvironmental Analysis

Northwest facing section of kettle hole KB5 sediments

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1 INTRODUCTION

This report presents the results of the geoarchaeological assessment and palaeoenvironmental analysis of landforms and sediment units in the western part of the Killerby West part of Killerby Quarry, North Yorkshire, that took place in Autumn 2017 (Fig. 1.1). Preliminary geoarchaeological assessment conducted by Archaeological Research Services Ltd at Killerby have developed and tested a classification of landform elements and archaeological associations through a combination of (i) desk-based analysis of map, aerial photographic and documented geomorphological and geological material, and (ii) sediment coring and palaeoenvironmental analyses (Waddington and Passmore 2008). This latest piece of work presents an enhanced classification of landform elements that draws on newly available LiDAR data and a programme of field mapping, survey, test pit assessment and the excavation of an enclosed wetland basin or 'kettle hole' deposit.

Geoarchaeological landform elements and archaeological associations at Killerby may now be assessed in the context of a comprehensive study of Late Quaternary environmental change for the Swale-Ure Washlands region (Bridgland *et al*., 2011). This locates the Phase 1 extraction area at Killerby in the northern part of the Leeming Moraine, an arcuate ridge *c*.36-40m in elevation that extends for 7km south of Catterick along the route of the A1. This new study confirms Frost's (1998) interpretation of the moraine as reflecting the local readvance of ice extending east from Wensleydale into the Swale lowlands during the Last Glacial Maximum (LGM). At Killerby the highest relief of the moraine is formed by ridges and mounds of till and glacial sand and gravel up to 55m OD. These are inset with terraces of glaciofluvial and fluvial sand and gravel at *c*.45-50m OD, and low-lying terraces, depressions and alluvial valley floors at *c*.38-42m OD which reflect localised reworking and incision by meltwater during deglaciation. The overall form of the moraine complex was therefore established by the climatic amelioration of the Windermere Interstadial *c*.15,000-11,500 BC and has since experienced relatively little geomorphological modification. However, slope processes and flooding during the Holocene are liable to have locally reworked and(or) buried archaeological material and features developed on this landscape, while poorly-drained depressions and valley floor environments have accumulated locally and preserved organic-rich sedimentary sequences including peat. These localities have a high potential for preserving a wide variety of archaeological materials *in-situ*, but also record the localised activities of former communities as expressed in the palaeoenvironmental record of vegetation changes.

The aims of the 2017 assessment are as follows:

(i) To conduct detailed field mapping and evaluation of sedimentary sequences in the Phase 1 extraction area, with a particular focus on those parts of the landscape scheduled for initial development of quarry access and facilities.

(ii) To produce an updated and higher-resolution classification of landform elements and archaeological associations for the Phase 1 extraction area.

(iii) To undertake palaeoenvironmental analysis of sediments infilling two kettle-holes in the western part of the study area identified in previous evaluations (Waddington and Passmore, 2008); sediment cores KB5 and KB15 as well as a low-lying depression identified here as KB6.

A full archaeological investigation and excavation of the kettle hole KB5 was also undertaken alongside palaeoenvironmental analysis (Hunter and Waddington 2018).

2 METHODS

2.1 Field mapping and survey

In addition to the desk-based resources used in previous assessments (Waddington and Passmore 2008), this evaluation has benefitted from the availability of open-access LiDAR data (Environment Agency) and survey-grade GPS receivers. LiDAR data at 2m resolution is available for the entire Phase 1 extraction area with the exception of a small (*c*.300m^2) locality in the southwest part of the Extraction Area near Broadclose Cottage. Field mapping was conducted with reference to Bridgland *et al's* (2011) large-scale geomorphological map and a LiDAR-derived DSM of the study area, augmented with GPS data points where appropriate; mapping sought to identify and delimit major landform elements on the basis of their geomorphological origin and potential for preserving sedimentary sequences of archaeological and palaeoenvironmental value.

2.2 Analysis of sedimentary sequences

Existing sedimentary records for the Phase 1 extraction have been augmented by assessment of selected sedimentary sequences by means of machine-dug test pits. Assessment trenches were excavated into two kettle holes (KB5 and KB15) down to basal glacial clay. These assessment trenches were excavated by a machine using a toothless bucket (see Hunter and Waddington 2018 for further details). A test pit was also excavated by hand in a low-lying depression (KB6) in order to compare palaeoenvironmental and sedimentary sequences with those of kettle holes KB5 and KB15, and identify whether potential exists here for survival of archaeological remains. The sample trenches of KB5 and KB15, as well as the test pit in KB6, exposed continuous sedimentary sequences which provided the opportunity for palaeoenvironmental analysis.

Monolith samples were taken from the exposed sequences of kettle holes KB5 and KB6, as well as the low-lying depression KB15. These were taken in order to provide samples for palaeobotanical recovery, palynological investigation, and radiocarbon dating. Five 50cm and two 25cm monoliths were taken from KB5, two 50cm monoliths from KB5, and two 50cm monoliths from KB6. These monoliths were targeted at organic sedimentary units which would provide optimum potential for palaeoenvironmental analysis. The organic-rich sedimentary units within KB5 had 40L of bulk sample taken from each during the archaeological excavation (Hunter and Waddington 2018) in order to provide further material to be processed for recovery of palaeobotanical remains and identifiable fragments of waterlogged wood.

2.3 Palaeoenvironmental Analysis

The sedimentary sequences present at Killerby were sampled, assessed, and analysed in order to understand the palaeoenvironmental history of the site. These sequences contain palaeoenvironmental records that reflect the post-glacial environmental change which occurred in the region and provide the backdrop for eventual human occupation. The kettle hole KB5 formed the main focus of investigation as this was viewed as being likely to contain the most complete record of palaeoenvironmental change, and on excavation proved to contain in situ archaeological remains of various periods stratified throughout its fills. Palaeoenvironmental analysis would allow for placing this past human activity within the context of land use, vegetation and climatic change. This human occupation is reflected through in-situ archaeological features and finds recovered during excavation dating from the Mesolithic, Neolithic, and Bronze Age. Particularly notable was the waterlogged timber platform extending across part of the kettle hole, several pits, an in situ timber post and areas of burning, together with clusters of chipped flint artefacts and cattle teeth (see Hunter and Waddington 2018). Pollen profiles were produced which record changes to local vegetation as a response to both the changing climate, as well as nearby human activity and water conditions within the feature. Botanical macrofosssils were recovered which reflect local vegetation which existed adjacent to and within the kettle hole.

Bulk samples of waterlogged organic material from the kettle hole KB5 were taken from organic sedimentary units. These were taken during the excavation phase at KB5. 5L of bulk-sample were taken from the two upper organic-rich units (1006 and 1008) and from the lower organic-rich units (1026, 1025, and 1011) during excavation. The lowermost organic-rich unit (1022) had a 1cm-thick bulk-sample extracted directly from Monolith Sample 1, taken from the exposed section of KB5, which was processed for botanical macrofossils. These waterlogged bulk-samples were processed using the method described by Kenward *et al.* (1980) where a gentle disaggregation of material is achieved by wash-over followed by sieving into 5mm, 2mm, 1mm, 500µm, and 300µm size fractions. All identifiable palaeobotanical remains and waterlogged wood fragments from these fractions were counted.

Plant macrofossil identification was undertaken using a low-power binocular microscope (x40). Plant macrofossil identification utilised plates and guides from Martin and Barkley (2000) and Cappers *et al.* (2006). Plant macrofossil nomenclature follows Stace (1997). Transparent sections were cut from pieces of waterlogged wood which had a size of >2mm using a razor blade. Sections were cut on the tangential, transverse, and radial planes. These could then be identified using a high power Leica GXML3030 binocular microscope (up to x600). Species identification was undertaken using plates and guides from Scoch *et al.* (2004) as well as comparison with a modern reference library held by ARS Ltd.

Pollen samples were taken from the sedimentary units contained within the monolith sample tins in 1cm thick sections. For KB5, the organic units (1026, 1025 and 1011, and 1008 and 1006) were focused on for sampling, and four samples were taken from each grouping at regular intervals so as to maximise consistency. In addition to these, a single sample was taken from the lowermost sedimentary unit (1022), the clay unit (1027), and the silty clay unit (1010) respectively. Samples were also taken from the margins of KB5 in order to identify localised differences in pollen deposition, as well as characterising sedimentary units which were only present at the margins.

Pollen samples were also taken from KB6 and KB15, with a single sample being taken from each major sedimentary unit. These pollen samples would permit characterisation of the low-lying depression KB6, as well as comparison of both KB6 and KB15 to KB5.

These sediment samples were submitted to the School of Geosciences at Aberdeen University for pollen extraction and slide preparation, using the method described below:

Pollen Extraction Methodology

(1) Sampling a standard volume of sediment (1ml)

(2) Adding two tablets of the exotic clubmoss *Lycopodium clavatum* to provide a measure of pollen concentration in each sample

(3) Deflocculation of the sample in 1% Sodium pyrophosphate

(4) Sieving of the sample to remove coarse mineral and organic fractions (>125µ)

(5) Acetolysis

(6) Removal of finer minerogenic fraction using Sodium polytungstate (specific gravity of 2.0g/cm^3)

Each stage of the procedure was preceded and followed by thorough sample cleaning in filtered distilled water. Quality control was maintained by periodic checking of residues, and assembling sample batches from various depths to test for systematic laboratory effects. Two *Lycopodium* tablets (batch number 3862) per sample were added prior to extraction for the purposes of calculating pollen concentrations as described by Stockmarr (1971). The evaluation count was undertaken using a Leica DME compound microscope at magnifications of x100 and x400. A standard evaluation count of the area of 40mm x 20mm cover slip was employed with the intent of identifying and recording the presence of pollen palynomorphs. The counts given include exotic (*Lycopodium*) grains, as well as non-terrestrial grains so as to show pollen concentrations and potential vegetation composition. Pollen identification utilised plates and guides from Moor *et al.* (1991). Microscope slides were then prepared using silicone fluid as a mounting medium.

In order to provide a chronology for the major sedimentary units and the environmental/climatic changes which influenced their formation, samples from both KB5 as well as the low-lying depression KB6 were selected for radiocarbon dating. Where possible, botanical macrofossil samples which were present at significant stratigraphic boundaries were selected for dating. Attempts were made to apply dendrochronological analysis to four pieces of excavated waterlogged wood from kettle hole KB5. In the absence of botanical macrofossils or waterlogged wood, and where absolute dating was deemed necessary, bulk sampling was undertaken. Dates were calibrated using the latest version of OxCal (Bronk Ramsey 2009) and all given dates in the report are at 95.4% probability.

Microcharcoal counts on pollen slides were undertaken along a single horizontal transect through the widest part of the pollen slide. Counts were made up to 800 microcharcoal fragments, and for higher counts the number was noted as being in excess of 800.

Small quantities of beetle sclerites were unintentionally recovered during bulk sample processing and though noted were not identified. These may provide potential for future analysis.

3 Results of geomorphological mapping and investigation of sedimentary sequences

The mapping and survey prompted a revision of the original landform element classification for Killerby as follows:

1a: Late Devensian tills and glacial sand and gravels

1b: Late Devensian glaciofluvial sand and gravel

1c: Late Devensian river terraces

1d: Late Devensian / Holocene lower slopes and enclosed basins

1e: Late Devensian / Holocene low terraces

1f: Late Devensian / Holocene valley floors

2a: Holocene alluvial valley floors

2b: Holocene palaeochannels

2c: Late Devensian and Holocene basin and kettle hole deposits (peat)

Each of these classifications is described below together with a summary of their archaeological associations.

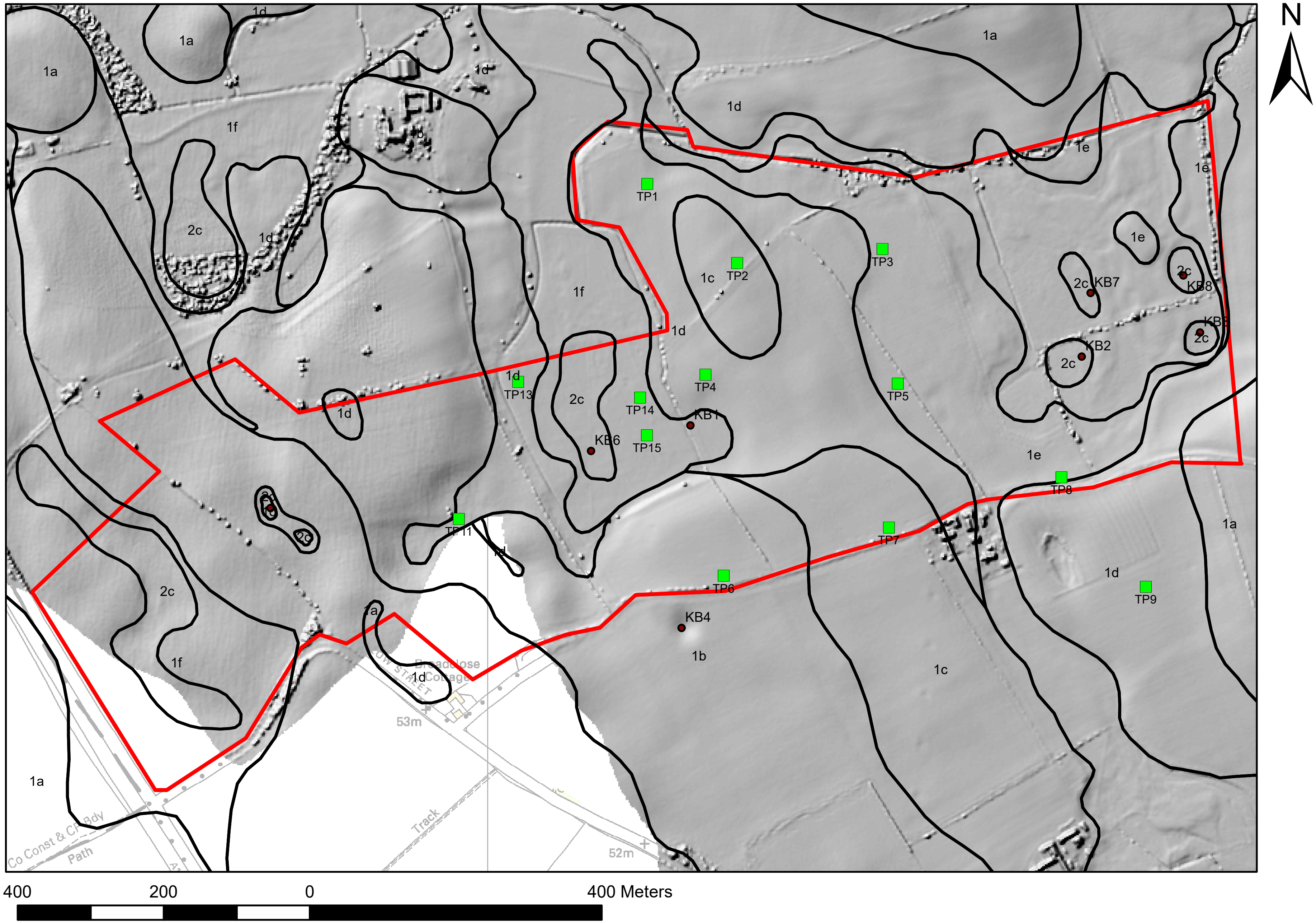


Fig. 3.1: Map of Phase 1 Extraction Area showing LiDAR-derived digital elevation model, landform elements and location of test-pits (TP1-15) and sediment cores (KB1-8)

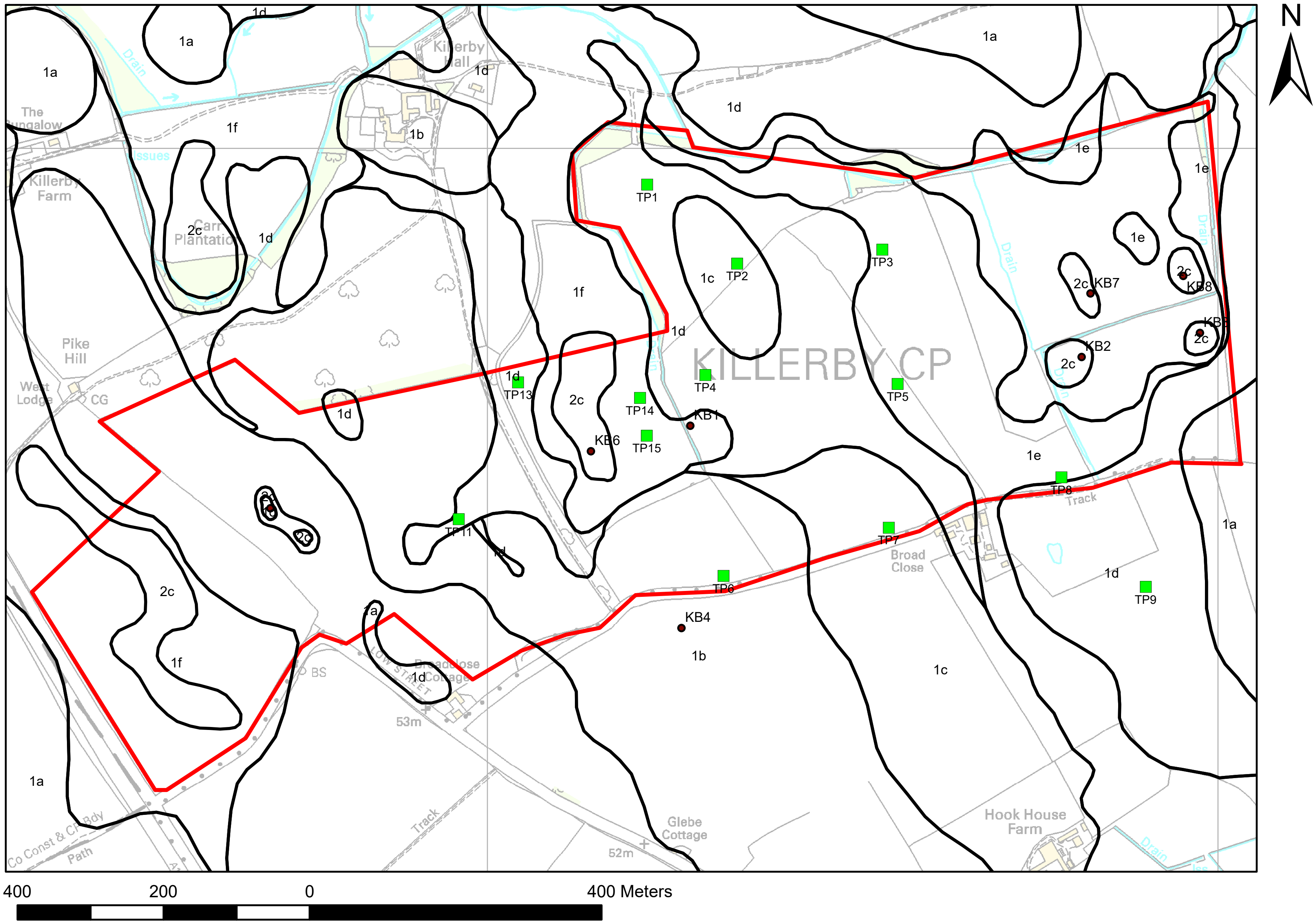
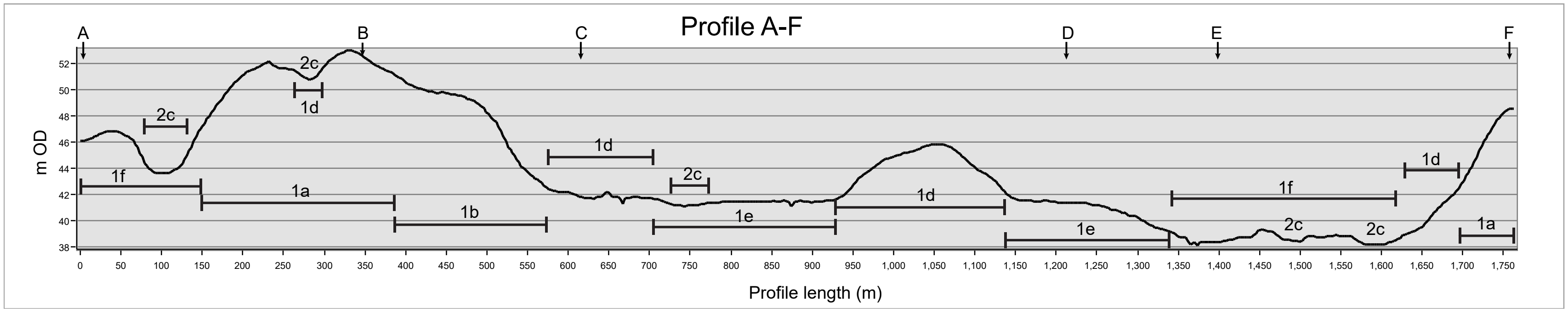


Fig. 3.2: Map of Phase 1 Extraction Area showing Ordnance Survey map detail, landform elements and location of test-pits (TP1-15) and sediment cores (KB1-8)



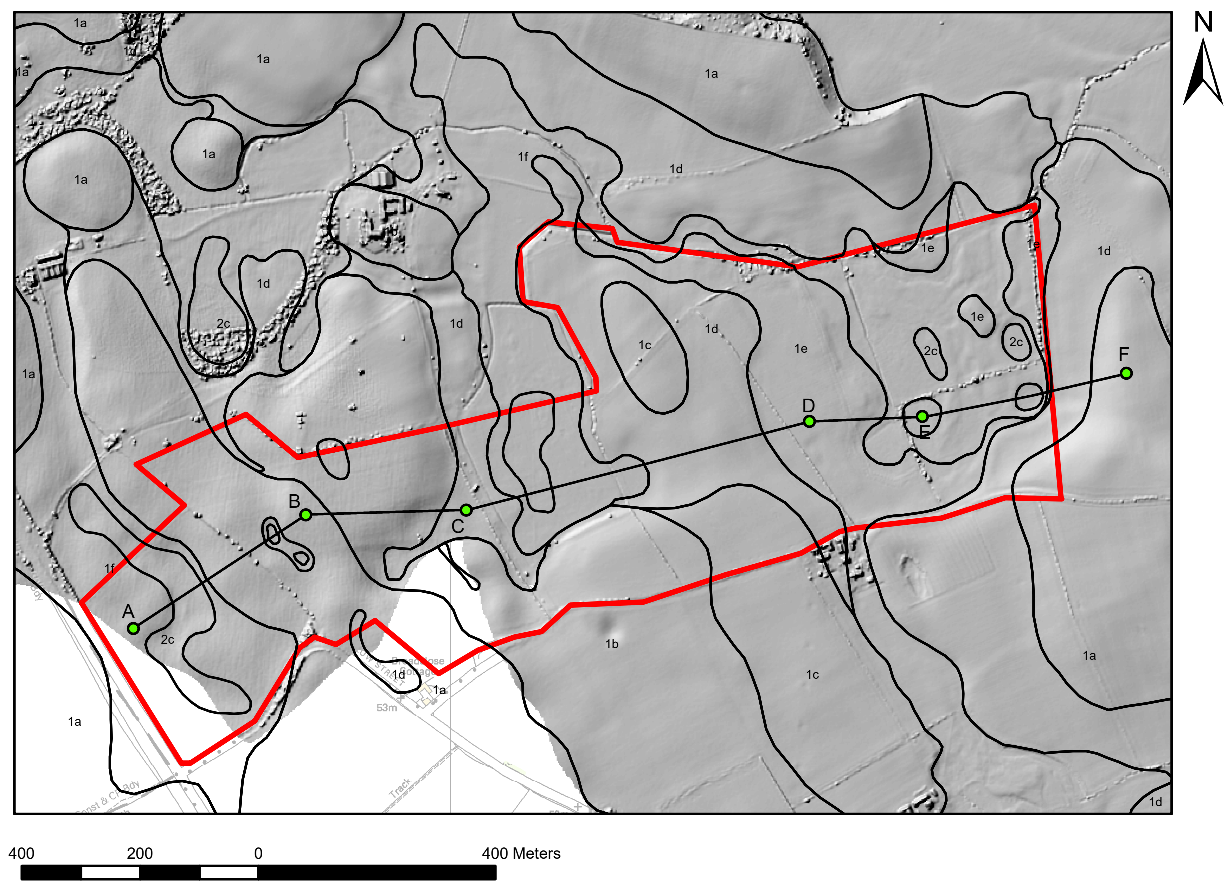


Fig. 3.3: (Top) Surface cross-profile A-F showing landform element classifications; (Bottom) Map of Phase 1 Extraction Area showing location of Profile A-F

3.1 1a: Late Devensian tills and glacial sand and gravels

Late Devensian tills and glacial sands and gravels constitute the highest landsurfaces in the Killerby area and are present in the western part of the Phase 1 Extraction Area as an elongate, hummocky ridge parallel to the A1 and reaching elevations between 50-55m OD (Figs. 3.1 – 3.3). Here they form part of the northern extension of the Leeming Moraine complex and are amongst the oldest of the landform elements identified in the study area. The ridge is locally inset by shallow (c.1-2m) enclosed basins (Landform Element 1d – see below) and kettle holes (2c) which have experienced accumulation of sediment during the Holocene, and lower slope facets are also liable to have experienced localised colluviation. In general, however, 1a landforms are likely to have experienced relatively little Holocene geomorphological activity.

Archaeological associations (where present) can be expected to be developed at or near the surface. No earthworks have been recorded to date, but widespread chipped lithic scatters were documented during 2008 (Waddington and Passmore 2008) and there remains the potential for mixed age buried sites (likely truncated by ploughing) which have not yet manifested as cropmarks.

3.2 1b: Late Devensian glaciofluvial sand and gravel

Late Devensian glaciofluvial sand and gravel deposits are widespread in the study area as hummocky and locally terraced terrain that typically lie between 53-40m OD. In the Phase 1 Extraction Area these units form gently undulating surfaces that lie adjacent to, and inset below till deposits with a maximum elevation of *c*.50m OD (Figs. 3.1 – 3.3). The hummocky relief of these landform elements suggests they were formed (at least in part) as kamiform ice-contact meltwater deposits during Late Devensian de-glaciation of the area, together with local re-working of (1a) deposits. Landform element 1b surfaces also feature occasional shallow enclosed basins and channel-like depressions (Landform Element 1d – see below), and colluviation is likely to have accumulated on lower slope facets. The sedimentary sequence of the main 1b surface has been assessed by TP6 and (to the south of the extraction area boundary) TP10. These reveal sandy soils and subsoils up to 1m thick overlying variable thicknesses of inorganic sandy gravel and gravelly sand to a recorded depth of 4.5m (TP6) and nearly 6m (TP10) (Figs. 3.4). Sediments in TP6 also feature 0.9m of clean, well-sorted and occasionally cross-bedded sands and both sequences contain thin beds and lenses of inorganic clayey silt and silty clay (Fig. 3.4).

Archaeological associations are similar to those described for Landform Element 1a, and these surfaces also feature widespread lithic scatters (Waddington and Passmore 2008). Potential cropmark evidence of an undocumented site and a WW2 bomb crater has been recorded on this surface immediately to the south of the extraction area boundary (Waddington and Passmore 2008)

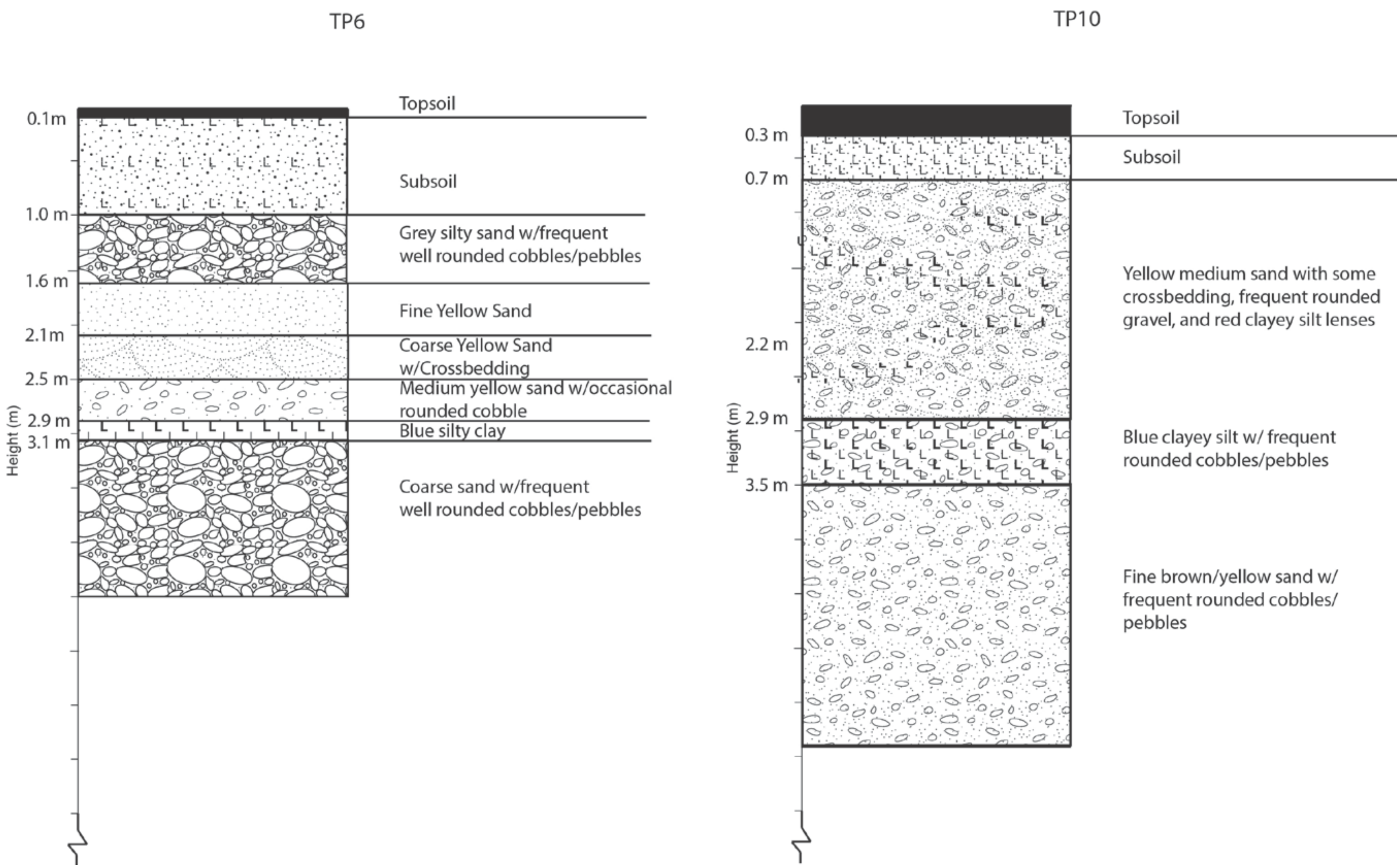


Figure3.4: Sediment logs of TP6 and TP10.

3.3 1c: Late Devensian river terraces

Late Devensian river terrace deposits in the Phase 1 Extraction Area form low-relief or gently sloping landsurfaces that are most extensively developed in a terrace unit that lies inset below the 1b landsurface immediately west of Broad Close Farm (Figs. 3.1 – 3.3). This terrace forms part of an extensive area of river terrace deposits formed along the outer edge of the Leeming Moraine south to Leeming Bar and are associated with a former meltwater-fed river system that probably dates to the early stages of deglaciation (Bridgland *et al*., 2011). In the study area the terrace surface has an elevation of 47m OD and a sedimentary sequence exposed by TP7 (Fig 3.5). Sediments in this test pit were excavated to a depth of 2.3m and exhibit a similar depositional sequence to that revealed in TP6 (Fig 3.4), being capped by 1.2m of sandy soil and subsoil and dominated by inorganic sands and coarse sandy gravels.

A further upstanding and elongate mound 150m to the north of the main 1b surface reaches a maximum elevation of 47m OD and is provisionally also interpreted as a Late Devensian river terrace remnant left isolated by subsequent erosion (Figs. 3.1 – 3.3), although a glaciofluvial (1b) origin cannot be discounted at this stage. TP2 revealed a sedimentary sequence comprising 0.9m of topsoil and gravelly subsoil that overlie three repeating bodies of fining-upward sediment parcels, each *c*.2m thick and comprising basal sandy well-rounded gravels that are capped by silty clay and finally clean, cross-bedded sands (Fig. 3.5). These sediments are consistent with fluvial deposition, most probably in the context of an aggrading, multiple-channel system with high rates of sediment supply.

Archaeological associations

Archaeological associations are similar to those described for Landform Element 1a, and both surfaces feature abundant lithic scatters (Waddington and Passmore 2008).

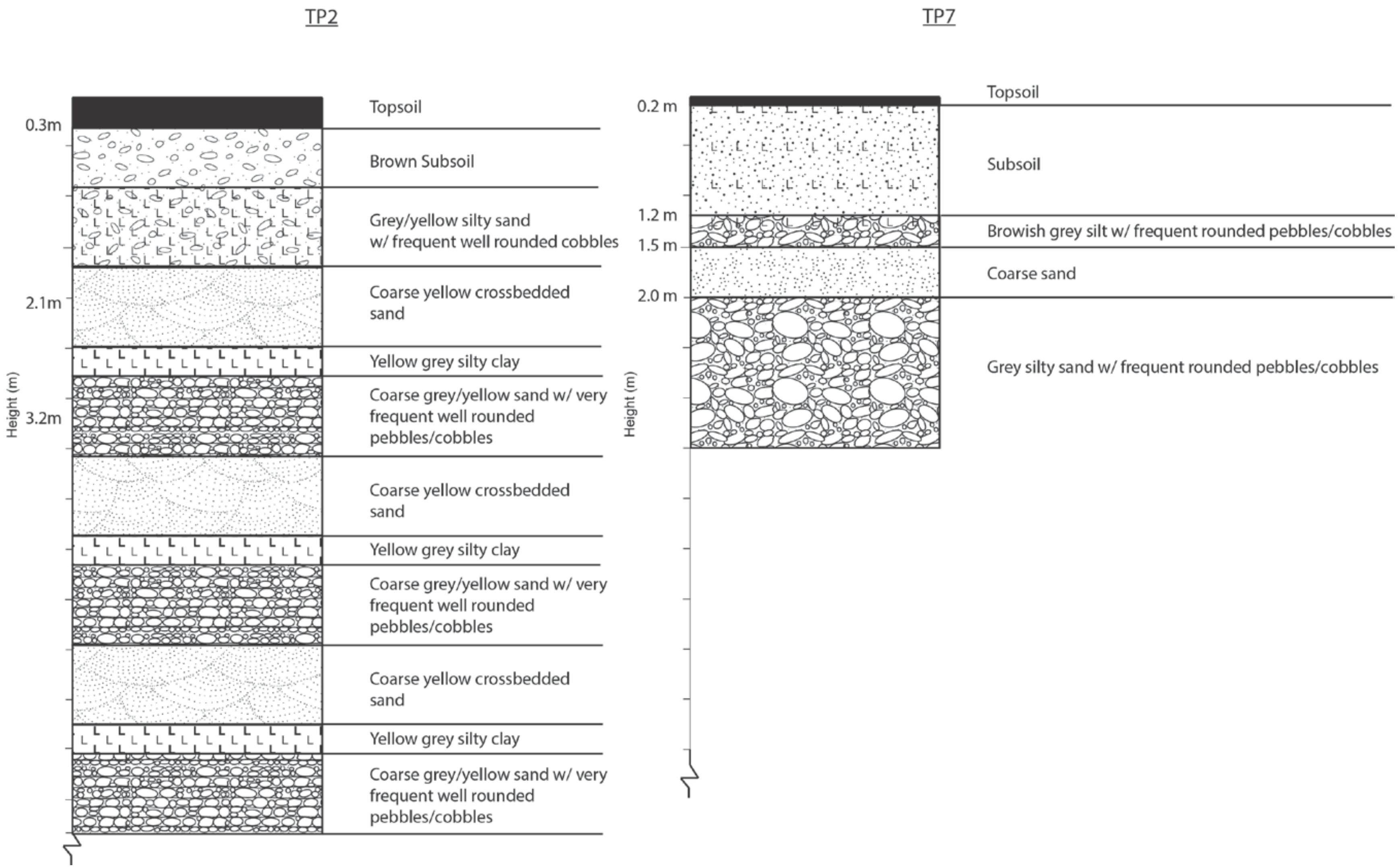


Figure3.5: Sediment logs of TP2 and TP7.

3.4 1d: Late Devensian / Holocene lower slopes and enclosed basins

Landform Element 1d represents the relatively shallow, concave lower slopes of Landform Elements 1a-d and localities with shallow enclosed basins and channel-like depressions cut into their surfaces (Figs. 3.1 – 3.3). The latter features are likely to have originated through localised ice-block melt and meltwater flow during or shortly after deposition of tills and glacial- and glaciofluvial sands and gravels. A channel-like depression of this classification is developed on the relatively high-elevation 1a surface in the extreme western part of the Extraction Area and hosts two smaller (2c) kettle-type depressions that are described below. Slope units may extend up to *c*.46m OD, but locally they extend to low-relief surfaces as low as 39m OD that fringe Late Devensian / Holocene low terraces (1e), valley floors (1f) and enclosed basin and kettle hole deposits (2c).

Landform element 1d units originated as isostatic uplift during the later stages of deglaciation promoted fluvial incision and lowering of the landscape along drainage networks. They have been mapped and differentiated here on account of the likelihood that these surfaces have accumulated (at least locally) deposits of Holocene sediment. However, and in contrast to the enclosed basins classified as Landform Element 2c (see below), they lack surface evidence of persistent wetland conditions that are liable to permit long-term preservation of organic-rich sediments.

Sedimentary sequences associated with 1d landforms have been exposed in TP1, 4, 9, 11 and 13 (Fig 3.6). TP1 and 4 (Fig. 3.6) are located on the lower slopes of upstanding river terrace (1d) deposits in the central part of the Extraction Area. Sequences in TP1 and 4 are broadly similar in their upper 3m (TP 4 terminating at this depth), having relatively thin (50-70cm) and gravelly soil and subsoils overlying well-rounded gravels in a silty sand matrix (Fig 3.6). In TP1 these coarse sediments overlie 0.7m of silty clay before passing abruptly to coarse sandy gravels with a maximum recorded depth of 7m (Fig 3.6). Test Pit 9 is located 150m south of the Phase 1 Extraction Area but associated with an extensive and continuous lower slope facet of relatively high-elevation (48m OD) till (1a) deposits forming the eastern margin of the extraction area (Fig 3.6). Sediments exposed here show the uppermost 3.6m to comprise coarse sands and gravel with a thin (0.7m) subsoil and soil cap. Below 3.6m these coarse sediments overlie 0.4m of well-sorted, crossbedded sand, 1.2m of laminated grey clay and then 1.3m of blue silty clay to the maximum recorded depth (Fig 3.6).

Test Pit 11 (Fig 3.6) is located in a small valley fill cut into glaciofluvial sands and gravels (1b) in the western part of the Extraction Area. The lower part of the fill between 1.7 and 4m shows a fining-upward sequence of silty rounded gravels, gravelly silt and a thin (0.3m) bed of clayey silt. This sequence is buried by 0.9m of clean, cross-bedded medium sand that in turn is overlain by 0.3m of poorly-sorted gravelly sandy silt. The sequence is capped by 0.5m of sandy soil and subsoil (Fig 3.6). At 42m OD TP13 is the lowest elevation pit on 1d landform elements and exposes sediments forming the uppermost 2.7m of a low, gently sloping terrace flanking the Late Devensian / Holocene valley floor (1f – see below) in the central part of the Extraction Area

(Figs. 3.1 – 3.3). Sediments here form a fining-upward sequence of silty sandy clay, 0.5m of laminated clay and 0.8m of marl below a thin (0.3m) topsoil (Fig 3.6).

Generally coarse-grained sedimentary sequences in TP1, 4, 9 and the lower part of 11 are consistent with deposition in till or glacial- and glaciofluvial contexts and in none of these pits (with the possible exception of sediments above 0.8m in TP11) are the uppermost sediments suggestive of thick accumulation of Holocene colluvium in their immediate localities. A glaciolacustrine and(or) glaciofluvial origin may also be inferred for relatively well-sorted fine sediments below 3.6m in TP9, between 0.8m and 2.0m in TP11 and the lower part of TP13.

Archaeological associations

Archaeological associations are similar to those described for Landform Element 1a, but with some local possibility of colluvial and – in the lowest elevation areas – alluvial burial. Abundant lithic scatters have been recorded on 1d surfaces (Waddington and Passmore 2008).

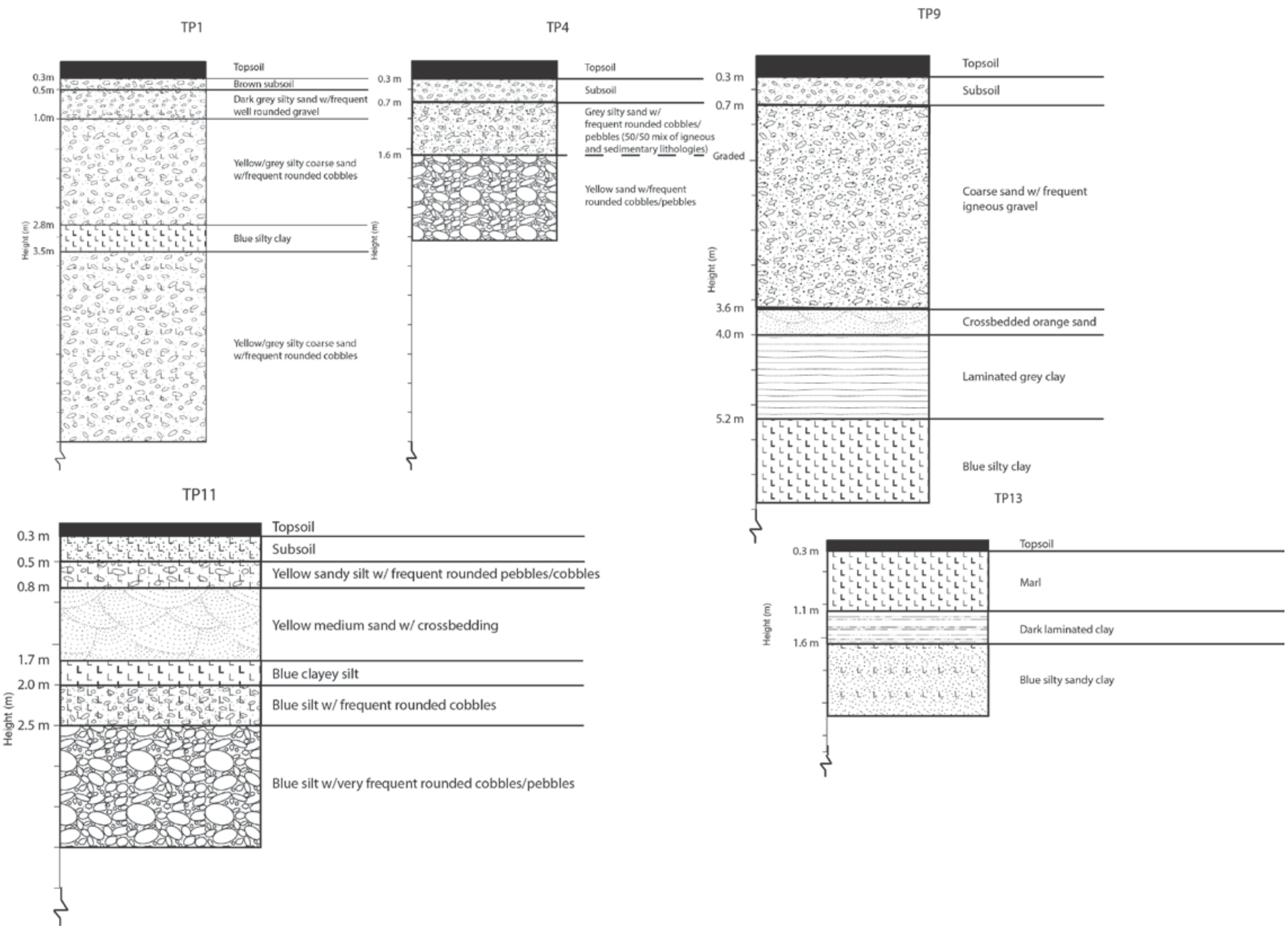


Figure3.6: Sediment logs of TP1, TP4, TP9, TP11, and TP13.

3.5 1e: Late Devensian / Holocene low terraces

Late Devensian / Holocene low terraces have been mapped in the eastern part of the Phase 1 Extraction Area where they lie between 40-42m OD and flank the low elevation (<40m OD) Late Devensian / Holocene valley floors (1f) (Figs. 3.1 – 3.3). These are flat or gently sloping terraces that are interpreted as localised alluvial reworking and deposition in the low-lying parts of the Leeming Moraine complex during the later stages of deglaciation. Their surfaces, however, may have been subject to localised Holocene colluviation from adjacent higher glacial and glaciofluvial landforms, and alluviation from local tributary streams and possibly also larger flood incursions from the Swale.

Test pits TP3 and 5 reveal sediments comprising the largest and highest terrace of this group to be capped by a thicker sequence of fine sediment than recorded in 1a-d, respectively 3.2m (TP3) and 2.5m thick (TP5), and dominated by silty sands (Fig 3.7). Test Pit TP5 was terminated at 2.5m, but TP3 was excavated to 6.5m in depth through grey silty sands with frequent well-rounded (fluvial) gravels. Test Pit 8, located on the rising southern margin of this terrace near Broad Close Farm (Fig 3.7), revealed a thinner (0.65m) topsoil and silty clay marl subsoil overlying 1.25m of gravelly silty clay (Fig 3.7). These relatively coarse and poorly-sorted sediments may reflect, at least in part, colluvial (or ploughzone) input from the adjacent (1d) slope unit. Below these coarse sediments is a thin (0.3m) bed of silty clay that in turn overlies at least 1.3m of sandy well-rounded (fluvial) gravels.

Archaeological associations

Archaeological associations are similar to those described for Landform Element 1a, but with the possibility of colluvial and – especially in the lowest elevation areas – alluvial burial. In contrast to 1a-d landscapes only occasional surface artefacts were recovered from 1e surfaces, most likely reflecting the combination of burial and the tendency to avoid these low-lying, wetter landscapes for settlement.

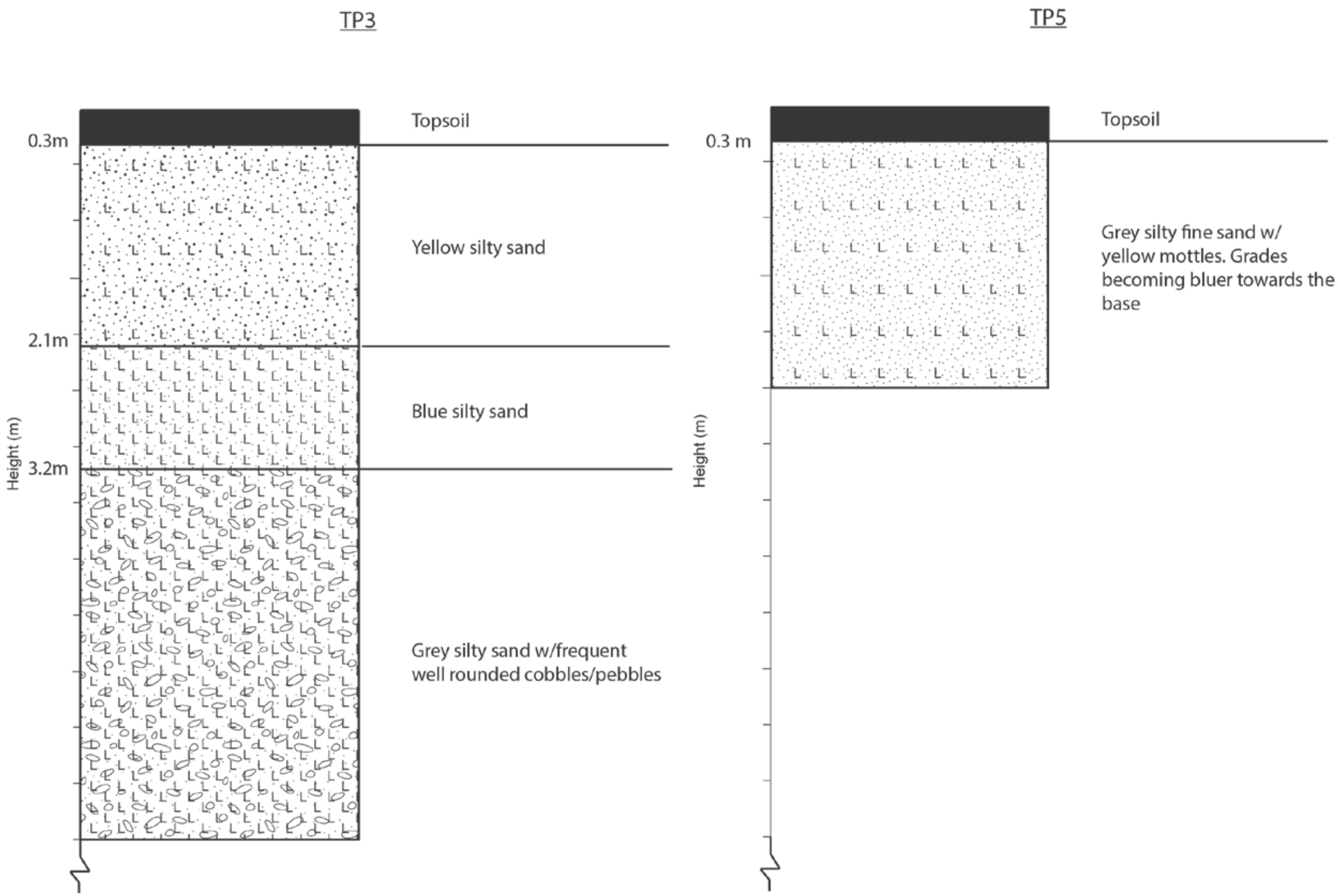


Figure3.7: Sediment logs of TP3 and TP5.

3.6 1f: Late Devensian / Holocene valley floors

Late Devensian / Holocene valley floors have been mapped as discrete low-relief surfaces in the western, central and eastern parts of the Phase 1 Extraction Area (Figs. 3.1 – 3.3). They lie at elevations of 46m, 42m and 39m OD, respectively, and form part of a larger and partially connected valley network centered on Killerby Hall. A modern system of drainage ditches connects the valleys floors below 42m and flows out of the northeast corner of the extraction area as a tributary of Fiddale Beck (Fig. 3.2). These low-lying landscapes are interpreted as reflecting the final large-scale meltwater downcutting and drainage of this part of the Leeming Moraine complex. Downcutting is likely to have been promoted by the combination of isostatic uplift and low base levels controlled by the Swale valley during the later stages of deglaciation, with local irregularities reflecting delayed melt-out of isolated blocks or areas of wasting ice, allied possibly with localised subsidence.

Test Pits 14 and 15 assessed valley fill sediments in the central part of the Extraction Area (Figs. 3.1 – 3.3). The latter sequence comprised a thin topsoil and 35 cm of marl that overlay poorly-sorted gravelly silty clay to a depth of 2.2 m (Fig 3.8). A similar sequence was revealed by TP14 except here a bed of silty clay (65 cm thick) separated the marl and coarser basal sediments (Fig 3.8). Neither sequence featured organic inclusions, but organic-rich Late Devensian and Holocene basin and kettle hole deposits (2c) are located within these valley floor areas (see below) and previous large-scale geomorphological mapping (Waddington and Passmore 2008) has described extensive areas of peat infilling these parts of the Killerby landscape. Accordingly, while 1f landform units have been strongly conditioned by late Devensian geomorphological events, they are likely to have accumulated variable thicknesses of sediment during the Holocene. Deposits may include colluvial sediments near valley side margins and alluvial spreads from local streams and, in the low-lying eastern valley floor, possibly also from Swale-derived flood events. There is a high probability of good organic preservation in these poorly drained environments and especially in small basins and palaeochannels that have yet to be mapped in detail.

Archaeological associations

Archaeological associations are similar to those described for Landform Element 1e, but with the increased likelihood of local peat formation and generally good organic preservation. Surface artefacts are absent from these valley floors in the central and eastern parts of the Extraction Area, but have been recorded across higher elevation valley floor units in the western area where there are no active stream networks and limited prospects for Holocene alluviation.

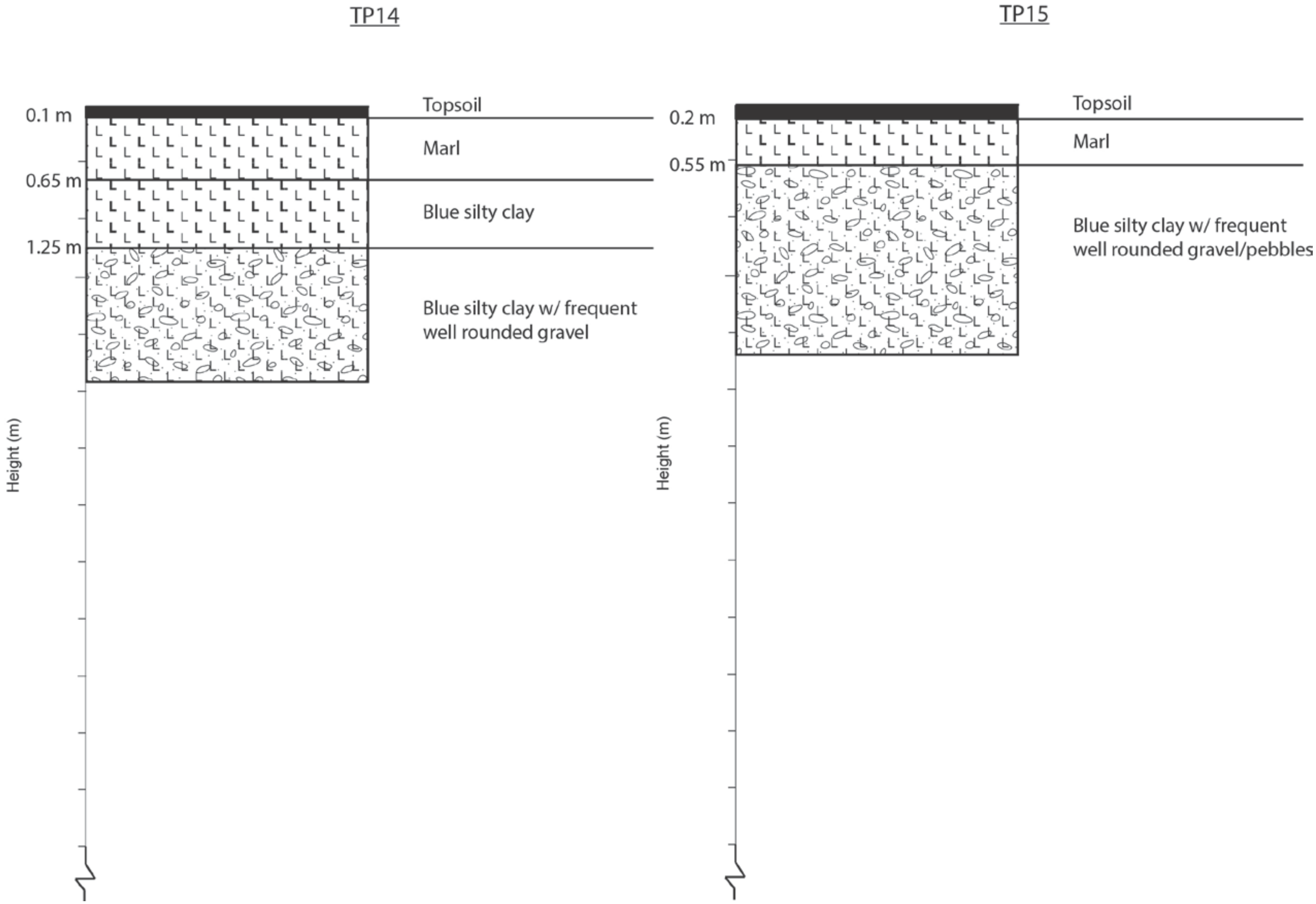


Figure3.8: Sediment logs of TP14 and TP15.

3.7 2a: Holocene alluvial valley floors

(See previous reports (Waddington and Passmore 2008) – *no further work undertaken on these landform elements during this phase)*

3.8 2b: Holocene palaeochannels

(See previous reports (Waddington and Passmore 2008) – *no further work undertaken on these landform elements during this phase)*

3.9 2c: Late Devensian and Holocene basin and kettle hole deposits (peat)

Enclosed basins and smaller sub-circular depressions have been mapped in both low-lying (1f) and high-elevation (1a/d) parts of the Phase 1 Extraction Area (Figs. 3.1 – 3.3). They are interpreted as reflecting the melt-out of ice blocks (e.g. kettle holes) and associated subsidence during regional de-glaciation and have persisted to the modern day as poorly-drained sediment sinks with distinctive vegetation assemblages. They are differentiated here on account of having a proven or high-probability of preserving organic-rich sedimentary sequences of Holocene and, in some localities, Late-glacial age.

In the eastern part of the Extraction Area several low-lying depressions have been previously cored and found to preserve variable thicknesses of peat and organic-rich sediment (Cores KB2,3, 7 and 8; Waddington and Passmore 2008) with basal dates as early as 8230-7750 cal BC (KB2), 9450-9140 cal BC (KB3) and 12850-12000 cal BC (KB8). On the relatively high-elevation 1a ridge in the western part of the Extraction Area a depression / kettle-hole has also been previously demonstrated to preserve a sequence dating to at least 9660-9240 cal BC (KB5; Waddington and Passmore 2008); this latter sequence has been excavated as part of the current phase of work and this excavation is reported on separately (Hunter and Waddington 2018). Earlier evaluation by ASUD (Archaeological Services, University of Durham, 2007) in the extreme western part of the Extraction Area has also demonstrated organic-rich deposits dating back to the Lateglacial period in cores taken from a shallow channel-like depression (Fig.3.1).

Archaeological associations

Archaeological associations are similar to those described for Landform Element 1f, but with the increased likelihood of – and locally proven - peat formation and generally good organic preservation. Potential for in situ and waterlogged archaeological remains dating back to the Late Glacial and the early-mid Holocene.

Surface artefacts are absent from these valley floors in the central and eastern parts of the Extraction Area, but have been recorded across higher elevation valley floor units in the western area where there are no active stream networks and limited prospects for Holocene alluviation.

4 Sedimentology and Stratigraphy of Kettle Holes KB5 and KB15, and Low Lying Depression KB6

4.1 Kettle Hole KB5

The kettle holes KB5 and KB15 represent large ovular depressions towards the southwest area of Killerby Quarry. Although these features have not been conclusively defined as kettle holes, they are clearly small, localised wetland basins inset within upper Devensian stadial till. It is unlikely that these depressions represent cryogenic landforms such as pingos or palsas, due to the lack of the raised rim or rampart around the depression (Gurney *et al.* 2010). They are very likely to represent relict hollows of ice melt-out and so will be referred to as kettle holes for the purposes of this analysis. Both kettle holes had sample trenches excavated through the width of them until glacial till was reached. Sedimentary sequences were exposed in section which displayed what appeared to be a complete sediment stratigraphy which proceeded from the Devensian stadial period until the present day. Though both sedimentary sequences appeared very similar and likely reflected the same palaeoenvironmental fluctuations, the sequence was best represented and preserved in the larger of the two features KB5. It is for this reason, as well as the archaeological remains described in Hunter (2018), that KB5 was chosen for a more complete excavation and palaeoenvironmental analysis.

Henceforth all given depths for KB5 refer to depth below the surface at which the trench was stripped to. Immediately overlying the glacial till (1080) at a depth of 2.39m was a grey moderately organic gravel (1022) that graded into a series of three highly organic sedimentary units (1026, 1025, and 1011) at 2.06m. Unit (1026) was an organic-rich clay/silt that extended from 2.06m-1.75m depth, unit (1025) was a fibrous humic peat which extended from 1.75m-1.64m depth, and unit (1011) was an organic-rich clay that spanned 1.64m-1.55m depth (Fig. 4.1). These three lower organic units were separated by two distinct thick clay layers (1027 and 1010) (Fig. 4.1). The clay unit (1027) had a lower boundary of 1.55m and an upper boundary of 1.22m where it graded into the silty clay (1010) (Fig. 4.1). The silty clay (1010) extended upwards to a depth of 1.06m where a sharp upper boundary separated it from a further two organic-rich 'upper' stratigraphic units (1008) and (1006) (Fig. 4.1). At the margins of the kettle hole a thin lens of fine grey sand (1009) underlay these 'upper' two organic units (1008) and (1006) (Fig. 4.1). The two upper organic sediment units (1008 and 1006) were somewhat difficult to distinguish in the centre of the kettle hole as two discrete units, however could more easily be seen as being discrete towards the margins where they are separated by in-wash sediments (Figs. 4.2, 4.3). During the archaeological excavation (Hunter and Waddington 2018) organic-rich sediment (1008) was further split into 'a' and 'b' sub-units. The upper sub-unit (1008a) of organic-rich sediment (1008) was identified as being a slightly more clay-rich organic sediment compared to the lower sub-unit (1008b) which was slightly siltier. This palaeoenvironmental sampling/processing only allocated samples to the two sub-units of (1008) and (1006) based on stratigraphic position. At the base of organic rich sediment (1008) (which is equivalent to 1008b) a significant arrangement of oak wood that extended for around 90.79m^2 was uncovered, and had been preserved through waterlogging. This wood was composed of 34 counted individual pieces, some of which measured *c.*10m in length, with two long pieces positioned exactly parallel to each other and others criss-crossing so as to build up layers of timber that rested directly atop the underlying clay (1010) to form a made timber 'platform' (see Hunter and Waddington 2018). The wood was poorly preserved and may have undergone extensive pre-depositional rotting prior to being buried and preserved, masking any tooling marks which may have been present. A number of chipped lithics were recovered from within and upon the oak platform (see Section 7: Lithic Assessment in Hunter and Waddington 2018 for details), together with a few fragmentary cattle teeth. A single posthole containing the remains of a large oak post was identified dug into the underlying clay layer (1010). This oak post possessed a tip which had been fashioned through two tangential cuts, undoubtedly evidence of anthropogenic modification. Small pieces of human-split hazel (*Corylus avellana L.*) and willow (*Salix* sp.) roundwood had been wedged between the post and the posthole edge to secure it in an upright position. See Hunter and Waddington (2018) for more details on the archaeological finds recovered from KB5. A brown silty clay lens (1007) separates organic sediment units (1008) and (1006) at the northeast margin of the kettle hole (Figs. 4.2, 4.3), whereas they are separated by dark grey clay sedimentary units (1028) and (1029) at the south western margin (Fig. 4.2). Overlying the upper two sub-divided organic sediment units (1008) and (1006) are two poorly sorted clayey silt layers (1014) and (1005) and two sandy silt units (1004) and (1003) (Fig. 4.1).

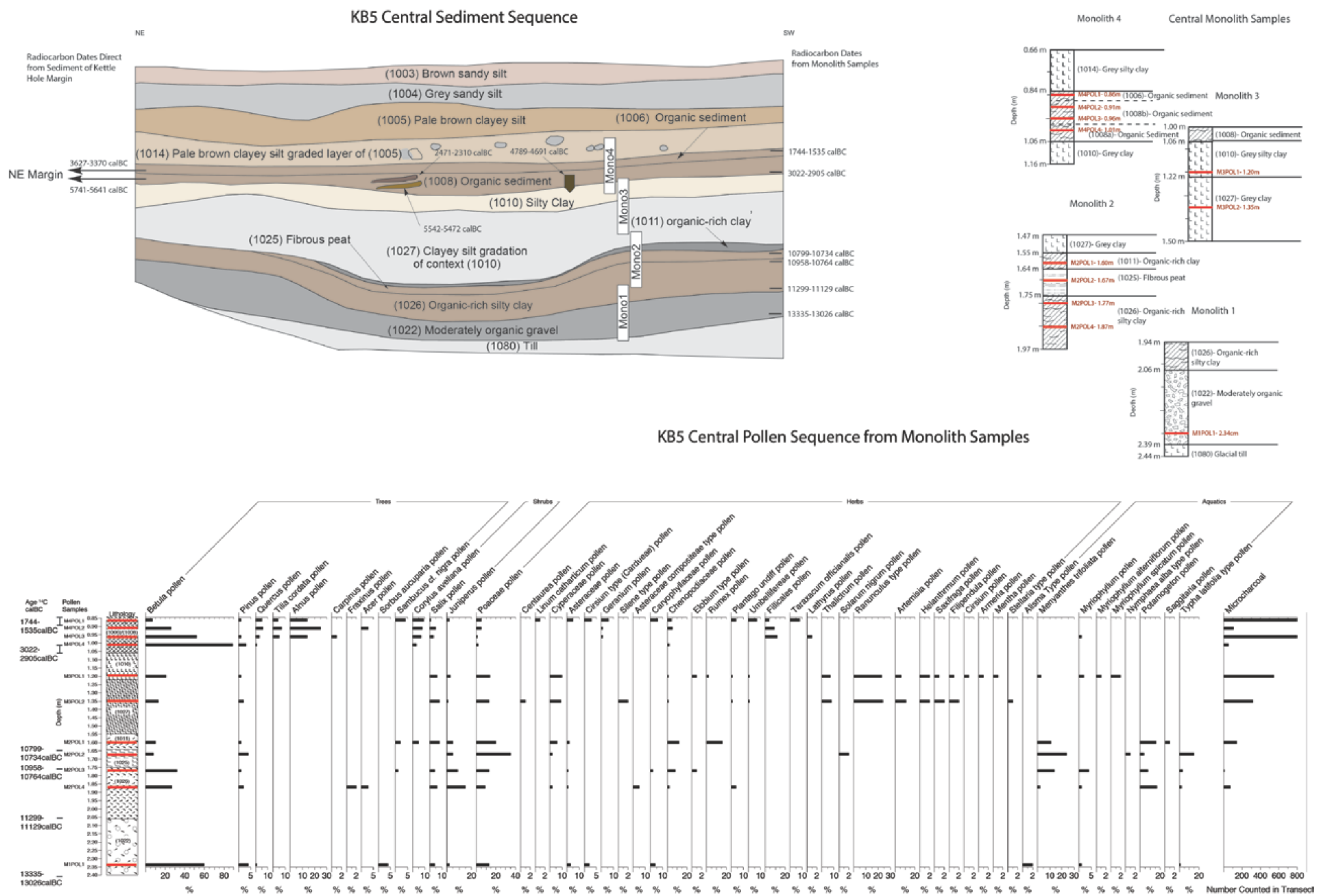


Figure 4.1: KB5 central sediment sequence, associated monolith sample locations, palynology results, and radiocarbon date locations.

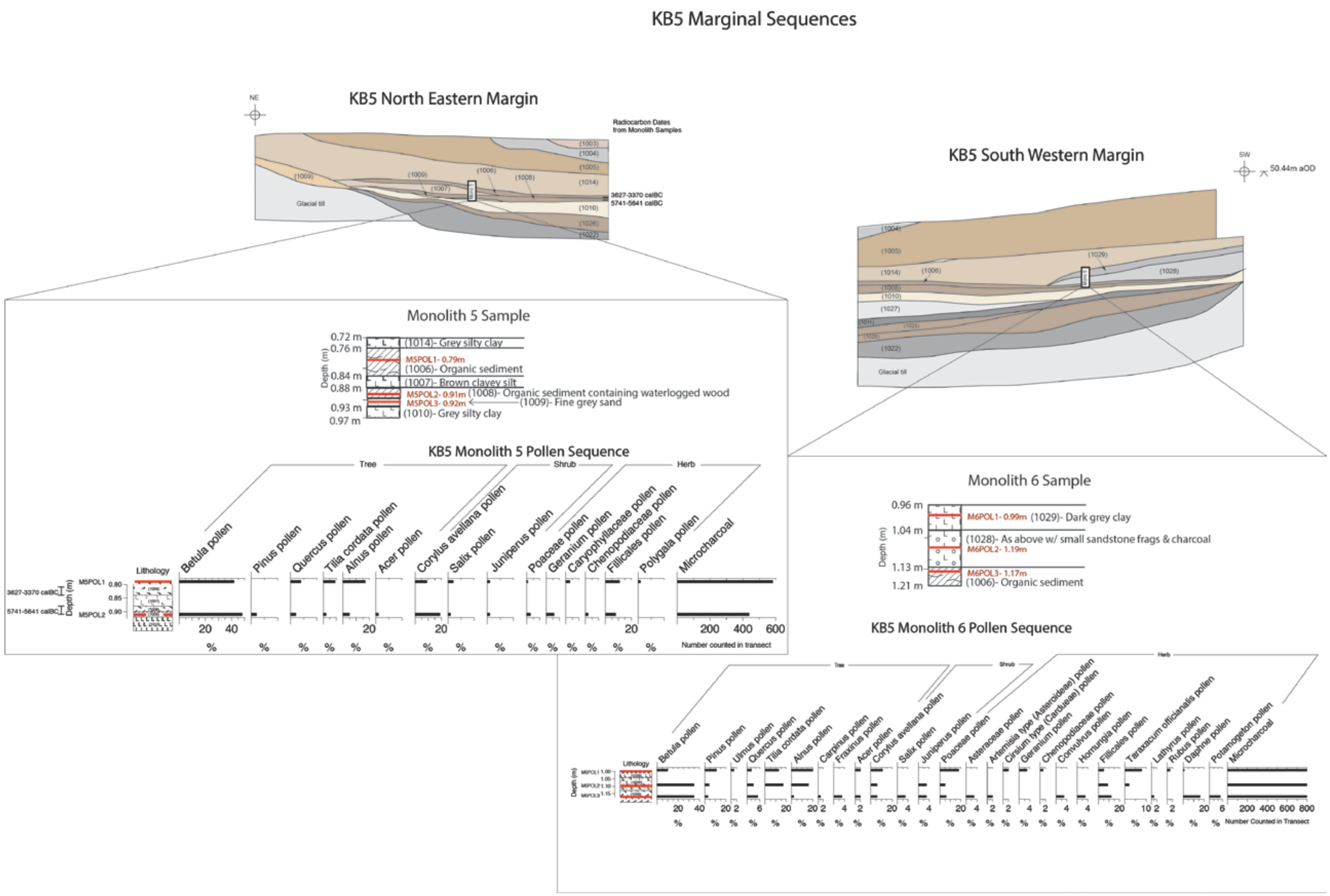


Figure 4.2: KB5 marginal sediment sequences, associated monolith sample locations, palynology results, and radiocarbon date locations.

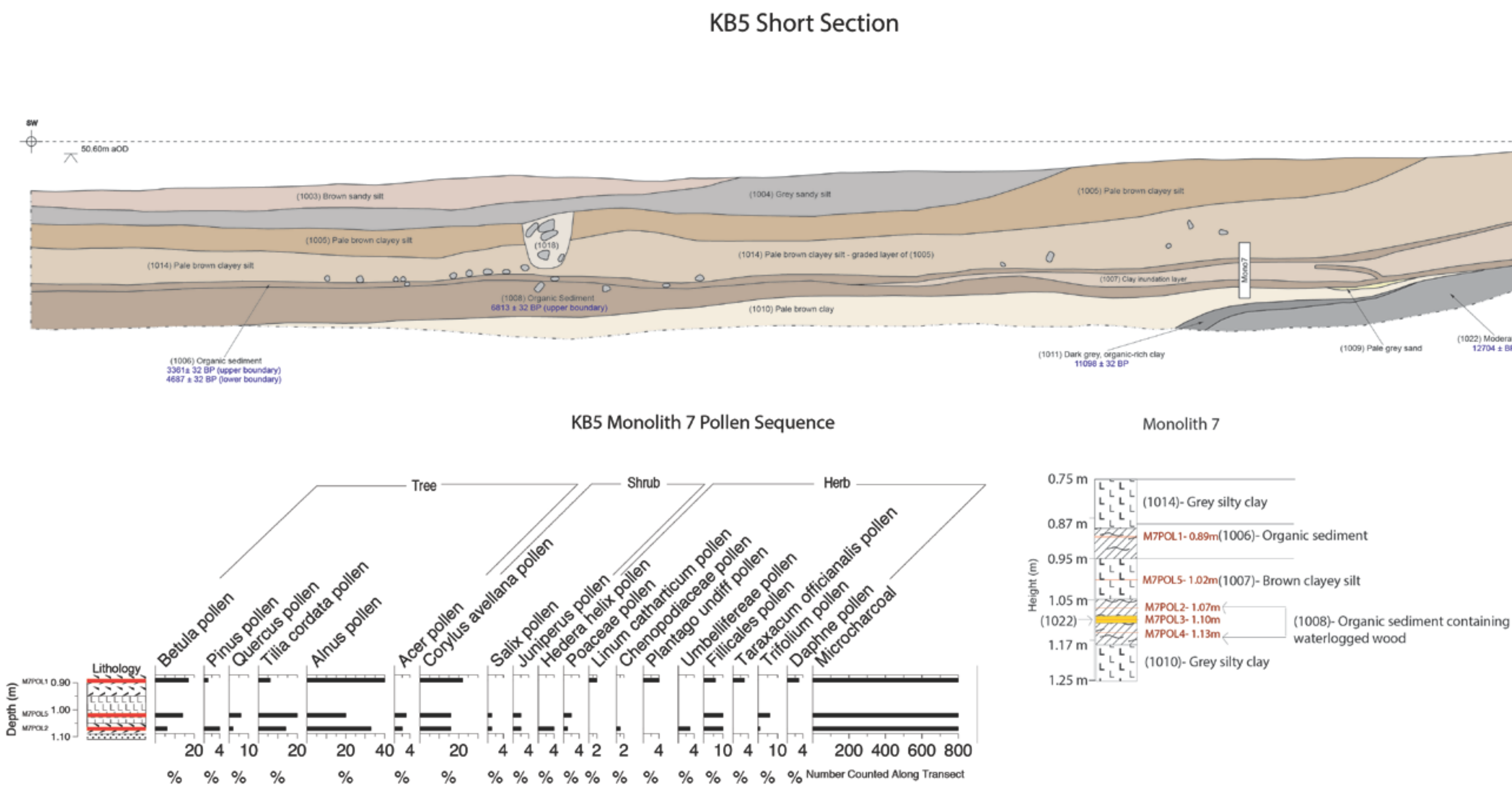


Figure 4.3: KB5 south-east facing sediment sequence, associated monolith sample locations, palynology results, and radiocarbon date locations.

4.2 Kettle Hole KB15

KB15 contained a stratigraphy which roughly mirrored that of KB5. All depths given for KB15 refer to depth below modern ground surface. Immediately overlying the glacial clay (2010) was a lower organic sediment (2009) which almost entirely lacked clastic material and had a lower boundary at 2.38m depth. This lower organic layer (2009) had an upper boundary with a homogenous, massive clay unit (2011) at 2.22m depth. This homogenous massive clay (2011) extended upwards where it had a sharp upper boundary with an upper organic layer (2007) at 2.18m, averaging a thickness of 0.04m. This upper organic sediment (2007) contained a small number of rounded gravel clasts and was very slightly more clay-rich than the lower organic sediment (2009). A grey clay silt (2006) overlay the upper organic sediment (2007) at a depth of 2.08m, after which a series of poorly sorted highly clastic silt units (2003), (2005), (2002), and (2001) extended upwards to the current land surface. The very poorly sorted silt (2002) contained a large quantity of farm debris in the form of broken pottery, glass, timber *etc*. and comprises a recent dump of farm waste (see Hunter and Waddington 2018). A Victorian field drain trench with a field drain at the base (see Hunter and Waddington 2018) has truncated the poorly sorted, highly clastic silt units (2001), (2002), (2005), (2003), and (2006). This sequence is illustrated alongside monolith sample locations and palyonolgy results in Fig. 4.4.

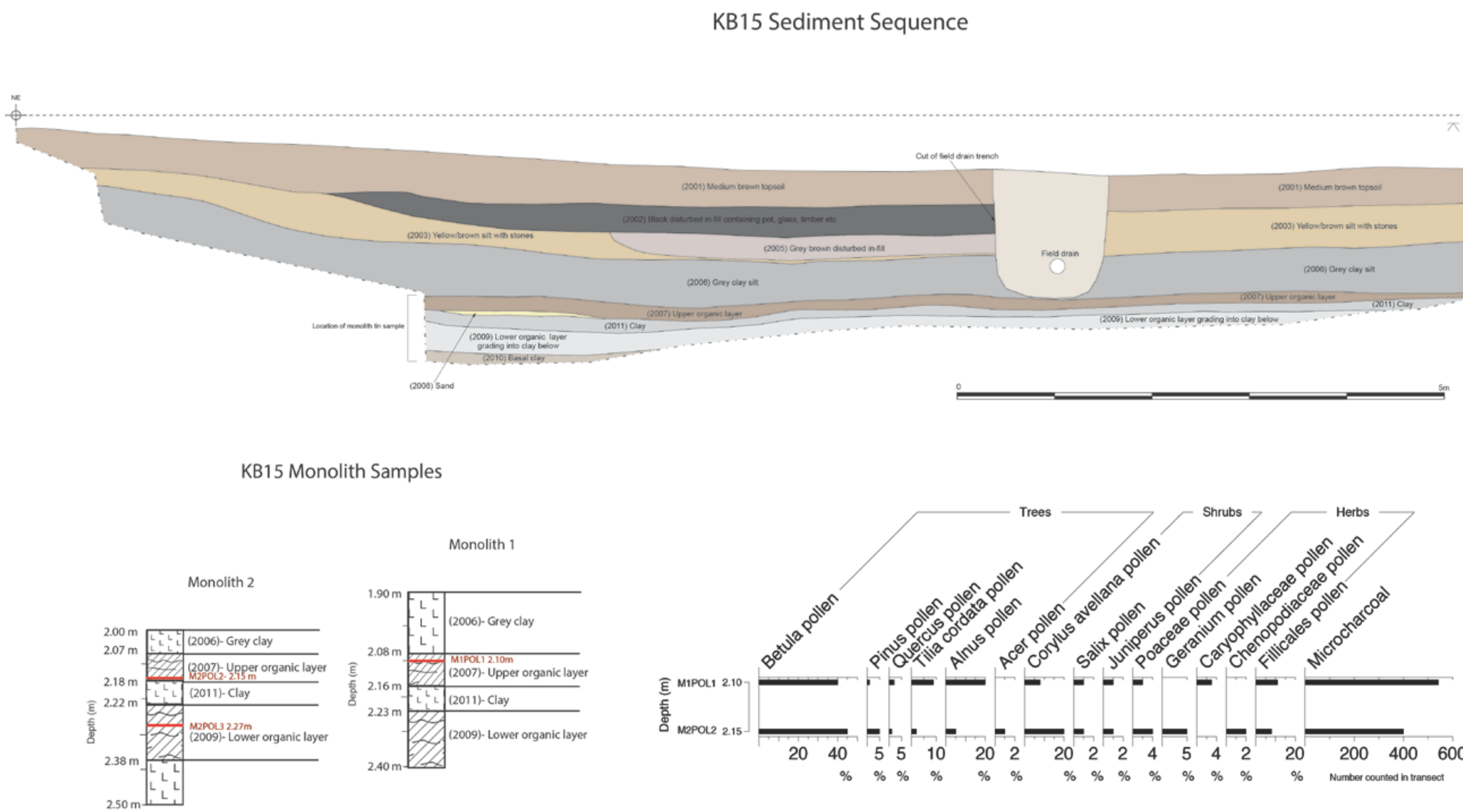


Figure 4.4: KB15 sediment sequence, associated monolith sample locations, palynology results, and radiocarbon date locations.

4.3 Low-lying depression KB6

The test pit, hand excavated into the low-lying depression KB6 revealed a sequence which contained clearly separated sedimentary units. This is shown in Fig 4.6 along with monolith sample locations and palynology results.

Figure 4.5: Monolith 1 (50cm length) taken from KB6 illustrating the distinctiveness of the five sediment units (left to right: (6005), (6004), (6003), (6002), and (6001)).

The lowermost sediment in KB6 was the glacial clay (6005) which formed the basal sediment of this depression. Immediately overlying the basal glacial clay (6005) was a dark brown/black peat (6004) containing significant quantities of well-humified organic matter. The peat unit (6004) and the basal glacial clay (6005) were separated by a very sharp, distinctive boundary at a depth of 1.03m. The peat unit (6004) extended to a depth of 0.97m whereupon the pale yellow fine clayey sand (6003) began. This fine clayey sand (6003) contained frequent small (<1cm) aquatic mollusc shells, was highly calcareous, and was well-sorted. Possible laminations are observable in (6003), however these are relatively indistinct and could be better identified (or disproven) through micromorphological analysis. The fine clayey sand (6003) had, to a limited extent, mixed with the underlying peat (6004) at the lower 0.97cm depth boundary, and to a greater extent with the overlying organic-rich clay (6002) at the upper 0.88m depth boundary. The organic-rich clay (6002) which overlay the fine clayey sand (6003) extended upwards to 0.83m where the clay content gradually reduced to the point where the sediment had become a dark brown/black peat (6001). This peat (6001) extended from a depth of 0.83m upwards to the current land surface

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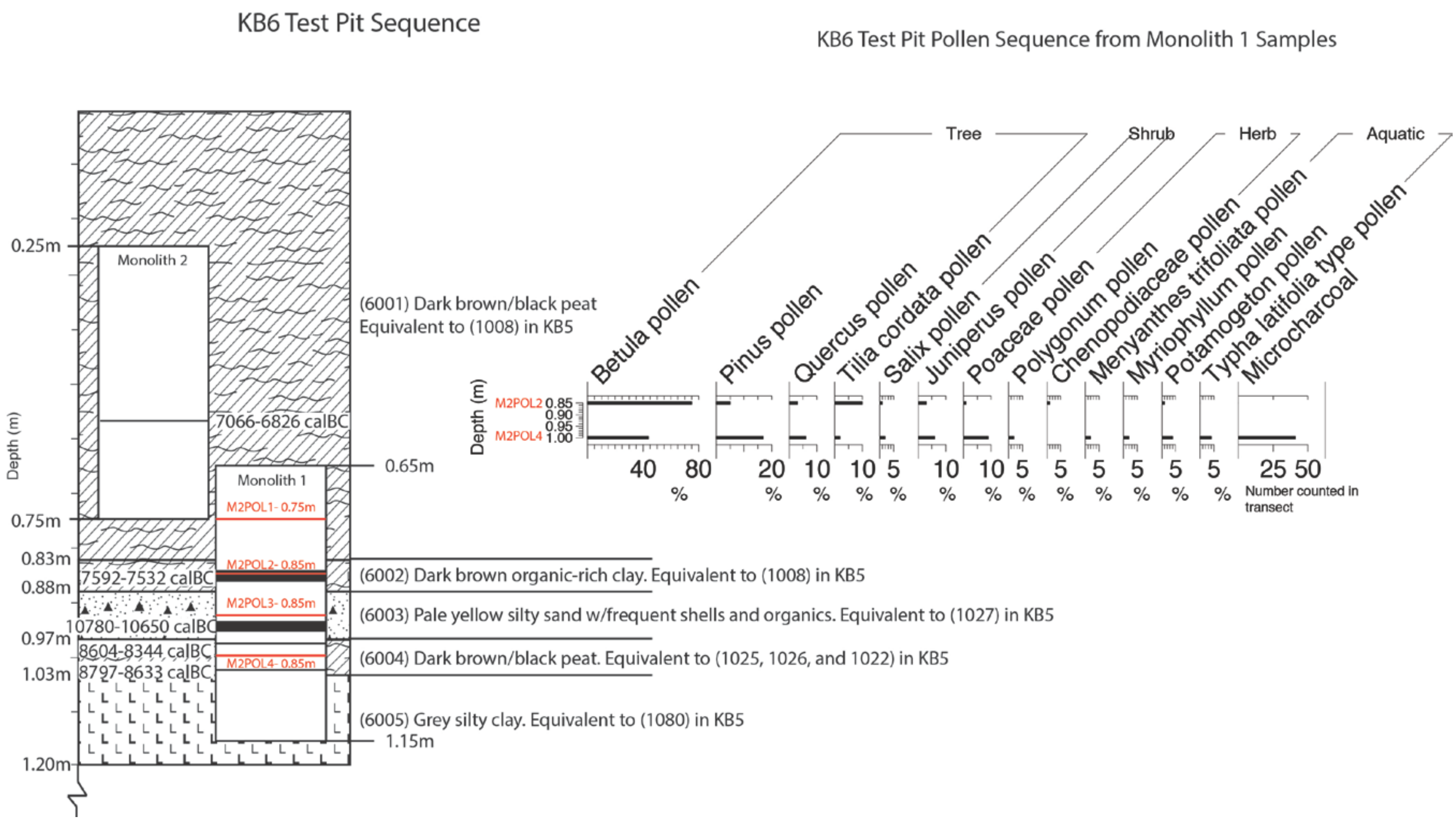

Figure 4.6: KB6 sediment sequence, associated monolith sample locations, palynology results, and radiocarbon date location.

5 RESULTS OF PALAEOENVIRONMENTAL AND 14C ANALYSES

5.1 Radiocarbon Dating

The results of radiocarbon dating are provided in Table 1.

Laboratory Number	Dating ID	Context No.	Sample	δ13C (‰)	Radiocarbon Age (BP)	Calibrated Date Range (2σ, 95.4% confidence)
SUERC-79310 (GU47405)	KB5.7a	1016	Waterlogged hazel from pit containing limestone blocks within (1008)	-26.9	2837±32	1109-912 calBC
SUERC-79309 (GU47404)	KB5.6a	1013	Waterlogged oak from circular pit within (1008)	-28.8	3200±32	1529-1414 calBC
SUERC-79296 (GU47393)	KB5.1	1006	Bulk organics from top of (1006)	-28.6	3361±32	1744-1538 calBC
SUERC-79307 (GU47402)	KB5.4a	1045	Maloideae charcoal from burnt deposit (1045)- within (1006) at margin	-26.2	3405±32	1864-1623 calBC
SUERC-80721 (GU48309)	KB5.10a	1037	Waterlogged oak (*Quercus sp.*) wood platform	-26.5	3910±20	2471-2130 calBC
SUERC-79411 (GU47394)	KB5.2	1008	Bulk organics from bottom of (1008)	-28.7	4350±24	3022-2905 calBC
SUERC-79308 (GU47403)	KB5.5a	1034	Oak charcoal from burnt deposit (1034)- within (1006) at margin	-25.7	4425±32	3325-2923 calBC
SUERC-79297 (GU47395)	KB5.3	1006	Bulk organics of Monolith 5 just above (1007)	-28.6	4687±32	3627-3370 calBC
SUERC-80723 (GU48311)	KB5.12a	1020.5	Waterlogged hazel (*Corylus avellana*) wood post packing	-29.6	5863±23	4789-2691 calBC
SUERC-80722 (GU48310)	KB5.11a	1065	Waterlogged oak (*Quercus sp.*) wood platform	-28.6	6540±25	5542-5472 calBC
SUERC-79298 (GU47396)	KB5.4	1008	Bulk organics of Monolith 5 just below (1007)	-28.3	6813±32	5741-5641 calBC

SUERC-79299 (GU47397)	KB5.5	1011	Indet lignous material from top of (1011)	-24.6	11098±32	11122-10890 calBC
SUERC-79300 (GU47398)	KB5.6	1025	Menyanthes trifoliata (bogbean) from top of (1025)	-25.0	10809±32	10799-10734 calBC
SUERC-79304 (GU47399)	KB5.7	1026	Menyanthes trifoliata (bogbean) from top of (1026)	-26.3	10956±32	10958-10764 calBC
SUERC-79305 (GU47400)	KB5.8	1026	Menyanthes trifoliata (bogbean) from bottom of (1026)	-26.4	11132±32	11299-11129 calBC
SUERC-79306 (GU47401)	KB5.9	1022	Sorbus aucuparia (Rowan) seeds from bottom of (1022)	-9.5	12704±32	13335-13026 calBC
			KB6			
Laboratory Number	**Dating ID**	**Context No.**	**Remains**	**δ13C (‰)**	**Radiocarbon Age (BP)**	**Calibrated Date Range (2σ, 95.4% confidence)**
SUERC-79314 (GU47407)	KB6.1	6001	Bulk organic material from uppermost peat (6001)	-27.1	8029±32	7066-6826 calBC
SUERC-79315 (GU47408)	KB6.2	6002	Bulk organic material from peat (6002)- Uppermost part of this layer	-28.4	8519±32	7592-7532 calBC
SUERC-79316 (GU47409)	KB6.3	6003	Bulk material taken from upper boundary of marl layer (6003)	-21.7	10713±32	10780-10650 calBC
SUERC-79317 (GU47410)	KB6.4	6004	Bulk organic material from upper boundary of lowermost peat (6004)	-25.1	9257±32	8604-8344 calBC
SUERC-79318 (GU47411)	KB6.5	6004	Bulk organic material from lower boundary of lowermost peat (6004)	-25.2	9438±32	8797-8633 calBC

Table 1: Radiocarbon dating results of material from KB5 and KB6. Anomalous results are highlighted in red indicating samples that are evidently anomalous for the positions from which they were taken.

Two results, highlighted in red, are evidently anomalous for the positions they were sampled from and are therefore excluded from further analysis. They represent ages which are older than material stratigraphically lower down the sequence. The anomalous date from KB5 of 11122-10890 calBC (11098±32 BP, SUERC-79299(GU47397)) was acquired from indeterminate fragments of wood which were recovered from the organic-rich sediment unit (1011). It is likely that these fragments are of a very mature tree, which contained a large in-built radiocarbon age (see Schiffer 1986; Gavin 2001). The anomalous date of 10780-10650 cal BC (2σ, 10713±32 BP, SUERC-79316 (GU47409)) from KB6 was a bulk sample taken from the upper boundary of a sandy marl layer (6003). It is possible that the high concentration of $CaCO3$ in this unit could be inducing a freshwater reservoir effect that is causing an erroneously old date (see Philippsen 2013).

Two attempts to date bovine teeth recovered from the organic rich sediment (1008b) were unsuccessful due to a lack of datable collagen.

6 BOTANICAL MACROFOSSILS AND PALYNOLOGY

6.1 KB5 Results

The waterlogging of the organic-rich sedimentary units in kettle hole KB5 preserved organic material which was recovered through bulk sampling and analysed. The results of this analysis are summarised in Tables 2 and 3.

Context No.	1008a	1008a	1008a	1008a	1008b	1008b	1008b	1008b
Description	Extensive ligneous/charred content				Extensive ligneous/charred content			
Flot mesh size	5mm	2mm	1mm	500um	5mm	2mm	1mm	500um
Plant Macrofossils								
Wild seeds								
Brassica rapa (field mustard)		7	13					
Sambucus nigra seed (elder)		1	4					
cf. Sambucus nigra berry (elderberry)			2					1
Carex sp. (sedge)							2	

Table 2: Recovered palaeobotanical macrofossils from the upper organic sedimentary unit (1008a) and (1008b).

Context No.	1011 (159-164cm)	1011 (159-164cm)	1011 (159-164cm)	1011/1025 (164-169cm)	1025 (169-174cm)	1026 (174-179cm)	1026 (179-184cm)	1026 (184-189cm)	1022 (2.36m depth)
Flot mesh size	1mm	2mm	500um	500um	500um	500um	500um	500um	500um
Plant Macrofossils									
Wild seeds									
Menyanthes trifoliata (bogbean)	4	25	1	3	36	9	3	9	
Andromeda polifolia (bog rosmary)	4		2						
Campanulape rsicifolia (peach-leaved bellflower)								2	
Myosotis cf. scorpioides (water forget-me-not)	1	2							
Fallopia sp./Persicaria sp. (knotweed)	67	11	3			1		3	
Comarum palustris (purple marshlock)	22	8	14					1	
Betula pubescens (moor birch)	3	2	1						
Carex sp. (sedge)				2					
Sorbus aucuparia (rowan)									29
Chenopodium sp. (goosefoot)				1					
Coleoptera	-								
Staphylinideae elytra	1								
Carabinae elytra	1	1	1						
Indet. pronotum	-		2						

Table 3: . Recovered palaeobotanical macrofossils from the lower organic units. These samples were taken in 5cm intervals from a test-pit dug into the kettle hole sediments for bulk-sample extraction. The depths given are depth below ground level where the bulk-sample was extracted.

The preservation of pollen grains was good throughout all samples from KB5, KB15, and KB6. Very few crumpled or damaged palynomorphs were observed, with those that were often still identifiable. The organic-rich sedimentary units (1026, 1025, 1022, 1008, and 1006) contained particularly abundant concentrations of pollen palynomorphs (Figs. 4.1, 4.2, 4.3). Inorganic sedimentary units, predictably, contained lower concentrations. There were however, generally still sufficient quantities to make the required 100 identifications at each sample level (Figs. 4.1, 4.2, 4.3, 4.4, and 4.6). The following names of floral species are given in Latin; however the common names are given in Table 4.

The lowermost pollen sample (M1POL1) was taken from the grey moderately organic gravel unit (1022). This pollen profile suggests an initial high in *Betula* populations, as well as the presence of *Pinus* and moderate numbers of *Sorbus aucuparia*. Limited numbers of shrub-type palynomorphs were encountered in the form of *Salix* and *Juniperus*, alongside herbaceous pollen types Poaceae, Asteraceae, *Cirsium*-type, and Caryophyllaceae. The 1cm thick sample obtained from the monolith yielded 29 rowan tree (*Sorbus aucuparia*) seeds. Rowan is a hardy, robust tree which is native to the UK and commonly found at high altitudes. This contrasts greatly with the relatively low-lying landscape species of the present day. A radiocarbon date of 13335-13026 cal BC (12704 ±32 BP, SUERC-79306 (GU47401)) for a rowan seed taken from the base of this sedimentary unit indicates that the formation of (1022) began during the final stage of the Devensian.

The organic units overlying (1022) displayed a marked change in the sedimentary and palaeoenvironmental sequence. M2POL4 within the organic-rich silty clay (1026) displayed a very low concentration of birch pollen, along with a drop in pine and disappearance of rowan. Tree palynomorphs are represented by deciduous tree species *Quercus*, *Fagus*, *Fraxinus*, and *Acer*. Notably high concentrations of shrub-type pollen palynomorphs are present in this sample primarily in the form of *Corylus*, but also *Salix* and *Juniperus*. Herbaceous palynomorphs are present in the form of *Asteraceae compositeae-type*, Cyperaceae, Chenopodiaceae, and *Plantago-undiff*. Aquatic pollen becomes present primarily through *Potamogeton*, though also with small numbers of *Menyanthes trifoliata*, *Myriophyllum*, and *Typha latifolia-type*. Relatively small numbers of microcharcoal are observable. M2POL3 shows a reduction in the deciduous tree species and shrub-type pollen, alongside a rise in birch. The concentration of herbaceous-type pollen decreases slightly from M2POL4, whilst an increase in aquatic-type pollen is observable. An increase in proportions of *Menyanthes trifoliata* and *Myriophyllum* is visible, as well as a reduction *Potamogeton*. A bogbean (*Menyanthes trifoliata*) seed taken from the base of this sedimentary layer (and therefore the uppermost boundary for the underlying moderately organic gravel unit (1022)) provided a date of 11299-11129 cal BC (11132±32 BP, SUERC-79305 (GU47400)) which represents the early Winderemere lateglacial Interstadial. A date of 10958-10764 calBC (10956±32 BP, SUERC-79304 (GU47399)) was acquired for a bogbean seed at the uppermost boundary of (1026). Organic-rich clay (1026) contained a number of aquatic specie seeds. The most abundant of these were 21 bogbean seeds, as well as four knotweed (*Fallopia sp./Persicaria sp.*) seeds of an indeterminate specie, two peach-leaved bellflower seeds (*Campanula persicifolia*), and one purple marshlock (*Comarum palustris*) seed.

The next organic layer, which formed more of a peat, was (1025) which was visibly composed of thin discrete layers of compacted organic material interspersed with a high concentration of bogbean seeds. The pollen sample M2POL2, taken from this unit, shows a drop in birch, whilst showing a rise in juniper and grass pollen. There is an increase in *Typha latifolia-type* pollen and a further rise in *Menyanthes trifoliata* pollen. The sample taken from the test pit of fibrous peat unit (1025) yielded 36 bogbean seeds. Radiocarbon dating of a bogbean seed from the uppermost boundary of this unit provided a date of 10799-10734 cal BC (10809±32 BP, SUERC-79300 (GU47398)).

M2POL1 was taken from the uppermost of these 'lower organic units' (1011). This pollen sample displayed an increase in *salix* pollen, alongside a small increase in elder (*Sambucus nigra*) and *Corylus*. A moderate decrease in Poaceae pollen could be observed, as well as an increase in Cyperaceae, Asteraceae, *Chenopodium*, and a distinct inclusion of *Rumex*. The samples which were taken exclusively from organic rich clay (1011) were the most abundant in botanical macrofossils out of all sampled sedimentary units. These contained 81 knotweed seeds, 44 purple marshlock seeds, 30 bogbean seeds, 6 bog rosemary (*Andromeda polifolia*) seeds, 6 moor birch seeds (*Betula pubescens*), 3 water forget-me-not seeds, two sedge seeds, and a single goosefoot seed. Relatively small concentrations of microcharcoal were noted within the pollen samples taken from these organic-rich layers.

The two clay/silty clay strata which overlie the three lower organic layers (1026, 1025, and 1011) represent a notable interruption in organic production within the kettle hole. The lower of these two units (1027) is a massive, clayey silt which grades into (1010) which contains a slightly more clayey fraction. A pollen sample (M3POL2) was taken mid-way through (1027) to characterise the local vegetation when this unit was deposited. Another pollen sample was taken just above the graded boundary between (1027) and (1010) in order to observe whether any vegetational change had occurred following the introduction of a silty element. The pollen sequence of M3POL2 contains a moderate concentration of *Betula* pollen, as well as minor quantities of *Pinus* and *Salix.* Both units contained large quantities of herbaceous pollen palynomorphs, with many being associated with tundra conditions. M3POL2 contained high quantities of Poaceae*, Ranunculus,* and *Artemisia*, and small numbers of *Centaurea,* Cyperaceae*, Silene-type, Thalictrum,* Chenopodiaceae*, Plantago-undiff,* Umbelliferae*, Helanthrmum, Saxifragia, Filipendula,* and *Stellaria-type*. M3POL1 is similar to M3POL2, though with an increase in *Betula* and a small decrease in *Pinus* and *Salix.* M3POL1 also contained similarly high quantities of herbaceous pollen, though with a slight reduction in some of the more tundra-type pollen species. These were high quantities of Poaceae*, Ranunculus, Thalictrum,* and *Artemisia*, and small quantities of Cyperaceae, Chenopodiaceae*, Elobium-type, Rumex, Plantago-undiff, Umbelliferae, Thalictrum, Helanthrmum, Saxifraga, Filipendula,* and the introduction of *Cirsium, Armeria,* and *Mentha*. Also introduced are small numbers of aquatic pollen palynomorphs in the form of *Menyanthes trifoliata, Myriophyllum, Myriophyllum alterniflorum,* and *Myriophyllum spicatum.* A relatively high and notable quantity of microcharcoal was present in M3POL2, which increased for M3POL1.

Pollen samples were taken from monoliths which cover both central and marginal locations of the uppermost organic sedimentary units (1008) and (1006). The central monoliths contain the thickest expression of these organic sediments; however it is difficult to distinguish between the two. The uppermost pollen sample (M4POL1) is sampled from (1006) and the three below (M4POL2, M4POL3, and M4POL4) are from (1008). The lowest central pollen sample (M4POL4) was almost entirely composed of *Betula* pollen, along with a minor quantity of *Pinus*. *Betula* pollen then consistently and severely declines upwards through these uppermost organic strata as it is succeeded by rising numbers of *Tilia* and particularly *Alnus* which peaks in M4POL2. Herbaceous-type palynomorphs are relatively limited in number, other than a steadily declining population of *Filicales*. This characteristic rise in *Alnus* and *Tilia*, as well as the presence of *Betula* pollen is also reflected by the marginal pollen samples from Monolith 5 (M5POL1, M5POL2) and Monolith 6 (M6POL1, M6POL2, and M6POL3).

The uppermost pollen sample, M4POL1, from (1006), shows a notable change in the pollen sequence. A notable reduction in tree-type pollen palynomorphs is observable (other than the inclusion of a small quantity of *Sambucus* pollen), along with a large increase in herbaceous-type pollen palynomorphs. These herbaceous-types are in the form of *Asteraceae*, *Cirsium-type, Cardueae*, geranium, Caryophyllaceae, *Plantago-undiff*, *Umbelliferae*, and *Taraxacum officianalis*.

M6POL3, taken from the uppermost area of (1006) at the southwestern margin of the kettle hole, has a similar display of low concentrations of tree-type pollen palynomorphs and high concentrations of herbaceous-type pollen palynomorphs. The numbers of alder and lime pollen are comparably low in this profile, yet birch is high, contrasting somewhat with what was located in the central sequence in M4POL1. It is possible that this marginal pollen sample represents a more localised pollen signal which differs from the central sequence. M6POL1, taken from a dark grey clay marginal inclusion (1029) immediately overlying the organic sediment (1006), also displays a similar pollen profile to M4POL1. However, it also displays a rise in *Poaceae* pollen unlike M4POL1.

The pollen sequence recovered from monolith 7 (Fig. 4.3) displays a similar floral composition to the equivalent expressions of (1008) and (1006) to Monoliths 4 and 5 from the opposite section (Figs. 4.1 and 4.2); *Betula, Alnus, Tilia,* some *Quercus,* and some *Corylus*. However, there is a greater *Alnus* and *Corylus* concentration than any of the other stratigraphically equivalent sections of (1008) and (1006). Unfortunately the lower two samples (M7POL3 and M7POL4) from monolith 7 did not contain sufficient recoverable pollen to undertake palynological analysis.

Abundant (>800 fragments) quantities of microcharcoal was present in M4POL3 and M4POL1. Microcharcoal was also highly abundant in the marginal pollen samples, as shown in the following Fig 6.1

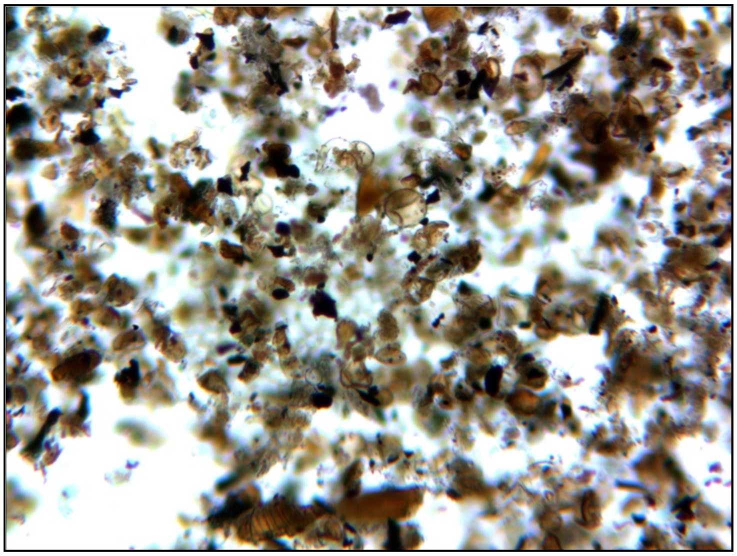 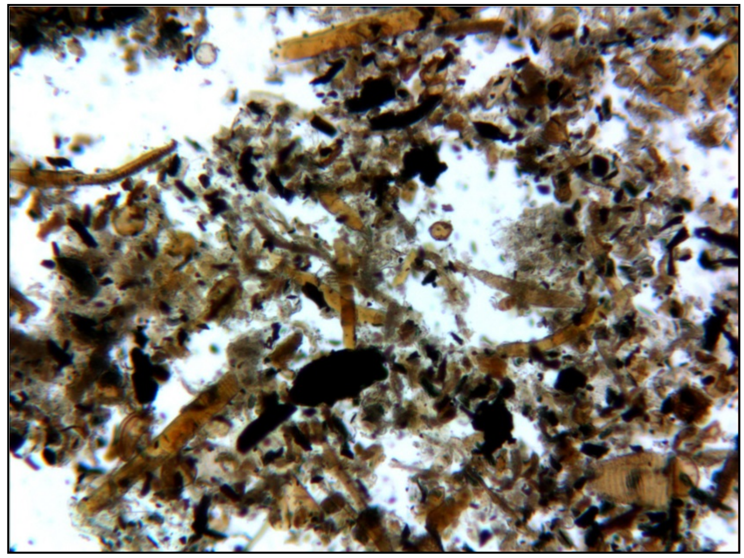

Figure 6. 1: Abundant microcharcoal concentrations recovered from the central pollen sample M4POL1 (left) and M6POL2 (right) from monoliths 4 and 6 (Figs 4.1 and 4.2).

The failed pollen samples M5POL3 was extracted from the fine sand unit (1009) which was present in both sections of the excavation trench at the northeastern margin of the kettle hole.

Bulk samples which were taken for recovery of botanical macrofossils were extracted during the archaeological excavation of KB5. The bulk samples taken from both the upper (1008a) and lower (1008b) sub-units of organic sediment (1008) contained significant quantities of ligneous and charred organic content. Despite this significant concentration of organic material, there were surprisingly few recovered botanical macrofossils. These were almost entirely from the (1008a) fraction of the organic unit and were primarily field mustard (*Brassica rapa*), alongside five elderberry (*Sambucus nigra*) seeds, and two intact elderberries. In the lower fraction (1008b) there were two sedge (*Carex sp.*) seeds, as well as a single elderberry.

6.2 KB15 Results

Only two (M1POL1 and M2POL2) of the three pollen samples taken from KB15 yielded sufficient quantities of recoverable pollen. These two pollen samples were extracted from the upper organic sediment (2007), with the third failed sample (M2POL3) being from the lower organic sediment (2009). M2POL2 has a tree-type pollen palynomorph assemblage composed of a large *Betula* percentage, along with small numbers of *Pinus, Quercus, Tilia,* and *Alnus*. Alongside this is a moderate number of *Corylus,* and small number of *Salix* and *Juniperus* shrub-type pollen palynomorphs. There are some herbaceous species present in M2POL2; small quantities of Poaceae*,* geranium*,* Chenopodiaceae*,* and *Filicales*. M2POL1 differs somewhat from M2POL2 in that although there is a similar quantity of *Betula* pollen, there is a distinctive increase in *Tilia* and *Alnus* alongside a decrease in *Corylus*. A large quantity of microcharcoal is present in both M2POL2 and a slightly larger quantity in M2POL1, mirroring results from KB5.

6.3 KB6 Results

Out of the four pollen samples taken from KB6, only two contained sufficient quantities of recoverable pollen for analysis. These were M2POL4 which was the pollen sample which characterised the lower dark brown/black peat (6004) and M2POL2 which characterised the organic-rich clay (6002).

M2POL4 yielded a sequence characterised by relatively high proportions of *Betula* and *Pinus*, as well as smaller quantities of *Quercus* and a very small number of *Tilia* pollen palynomorphs. A small quantity of *Salix* and *Juniperus* was also present. A relatively limited number of herbaceous pollen palynomorphs were recovered primarily in the form of Poaceae, but also a small number of *Polygonum*. A variety of aquatic pollen was present in M2POL4, represented by *Menyanthes trifoliata, Myriophyllum, Potamogeton,* and *Typha latifolia-type* pollen. A moderate quantity of microcharcoal is present in M2POL4.

M2POL2 yielded a large quantity of *Betula* pollen, as well as a moderate quantity of *Tilia*, and a smaller number of *Pinus* and *Quercus* tree-type pollen. There appears to be a reduction of shrub, herbaceous, and aquatic pollen palynomorphs compared with M2POL4. There is no microcharcoal present in M2POL2.

Latin Name	Common Name
Trees	
Betula	Birch
Alnus	Alder
Betula	Birch
Carpinus	Hornbeam
Pinus	Pine
Quercus	Oak
Sambucus cf. nigra	Black elder
Sorbus aucuparia	Rowan
Tilia cordata	Lime
Shrubs	
Corylus avellana	Hazel
Juniperus	Juniper
Salix	Willow

Herbs	
Armeria	Thrift
Artemisia	Mugwort
Asteraceae	Daisy family
Asteraceae compositeae type	Daisy type
Caryophyllaceae	Pink/Carnation family
Centaurea	Knapweed
Chenopodiaceae	Goosefoot family
Cirsium	Plume Thistle
Cirsium type (Cardueae)	Plumeless Thistle
Cyperaceae	Sedge
Elobium type	Willowherb
Fillicales	Fern
Geranium	Cranesbills
Helianthemum	Sunrose
Lathyrus	Legume family
Linum catharticum	Purging flax
Metha	Mint
Plantago	Plantain/Fleawort
Poaceae	Grass
Rumex	Dock
Saxifraga	Rockfoil
Silene type	Catchfly
Stellaria type	Chickweed
Taraxacum officianalis	Common dandelion
Thalictrum	Meadow-rues
Aquatics	
Alisma type	Water-plantain
Menyanthes trifoliata	Bogbean
Myriophyllum	Watermilfoil

Myriophyllum alterniflorum	Alternate watermilfoil
Myriophyllum spicatum	Spiked milfoil
Nymphaea alba type	Water-lily
Potamogeton	Pond weed
Saggitaria	Arrowheads
Typha latifolia type	Bulrush

Table 4: Latin names of floral species/genera/families and corresponding English 'common' names.

7 DENDROCHRONOLOGY

Ian Tyers

7.1 Summary

Five oak timbers from the 2017 excavations at Killerby Quarry were selected for dendrochronological analysis. The sampled timbers were from a large assemblage of timbers located in a Quaternary-Holocene kettle-hole. None of these timbers cross-matched each other or to dated or undated reference sequences. Several of these samples were from exceptionally slow grown trees, this perhaps reflecting the environmental conditions in the vicinity of the kettle-hole.

7.2 Methodology

Each sample was assessed for the wood type, the number of rings it contained, and whether the sequence of ring widths could be reliably resolved. For dendrochronological analysis samples usually need to be oak (*Quercus* spp.), to contain 50 or more annual rings, and the sequence needs to be free of aberrant anatomical features such as those caused by physical damage to the tree whilst it was still alive. Standard dendrochronological analysis methods (see e.g. English Heritage 1998) were applied to each suitable sample. A surface equivalent to the original horizontal plane of the parent tree was prepared on each sample with a sequence of increasingly fine bladed tools; surform or plane, Stanley blades, medical scalpel blades, razor blades. This is usually undertaken whilst the samples are frozen as they are not solid enough to take a sharp edge in ordinary circumstances. Their sequences of ring widths were revealed by this laborious preparation method, and once thawed out they could be assessed again for suitability. The complete sequence of the annual growth rings in the suitable samples were then measured to an accuracy of 0.01mm using a micro-computer based travelling stage. The sequences of ring widths were then plotted onto semi-log graph paper to enable visual comparisons to be made between the sequences and reference data. In addition cross-correlation algorithms (e.g. Baillie and Pilcher 1973) were employed to search for positions where the ring sequences were highly correlated. Highly correlated positions were checked using the graphs and where these were satisfactory, these locations were used to identify the calendar dates of the measured series.

Tree-ring analysis usually dates the rings present in some timbers within an assemblage of material. The interpretation of these dates relies upon the nature of the final rings in the sequence. Oak timber contains two types of wood, heartwood and sapwood, the latter is on the outside of the tree and thus contains the most recent growth rings, this material is softer and is not always preserved under archaeological conditions. If the sample ends in the heartwood of the original tree, a *terminus post quem (tpq)* date for the felling of the tree is indicated by the date of the last ring plus the addition of the minimum expected number of sapwood rings which are missing. This *tpq* may be many decades prior to the actual date that a tree was felled, particularly where poor preservation or other loss of outer heartwood has occurred. Where some of the outer sapwood or the heartwood/sapwood boundary survives on the sample, a date range for the felling of a tree can be calculated by using the maximum and minimum number of sapwood rings likely to have been present. For dated samples where the bark edge survived intact, a precise date for the felling of the tree can be directly identified from the date of the last surviving ring.

7.3 Results

The Killerby site was a kettle-hole feature which contained a sedimentary sequence stretching from the Late Glacial through into the early/middle Holocene. It contained a surface upon which a large quantity of waterlogged timber appeared to have been deliberately placed extending out from the kettle-hole margins towards the centre (Luke Parker pers comm). Examination of this material suggested most of it was oak, and in somewhat degraded condition. These timbers were assessed for their dendrochronological potential, the five sampled timbers were the only ones identified with potential, the rest of the assemblage appeared to have no further dendrochronological potential. The selected dendrochronological material comprised samples from five oak (*Quercus* sp.) timbers. Cross-sections were obtained wherever possible from the optimum location for outermost rings or sapwood survival from these timbers. All of the timbers contained suitable tree-ring sequences for analysis. The five timbers were each measured successfully (Table 5).

Timber	**Size (mm)**	**Rings**	**Sap**	**Growth mm/yr**	**Result**	**Interpretation**
1003 SF051	195 x 75	48	-	1.56	not dated	-
1020.1	210 x 195	254	H/S?	0.73	not dated	-
1030 SF654	180 x 180	182	54	0.38	not dated	-
1074 SF185	110 x 95	107	35+*10*	0.64	not dated	-
2009	150 x 150	105	H/S?	0.92	not dated	-

Table 5: Details of the five dendrochronological samples from Killerby Quarry, North Yorkshire. Samples are oak (*Quercus* spp). Note: H/S? ends at possible transition of heartwood/sapwood, *+10* additional unmeasured sequence of rings, in this case crushed sapwood

No relative cross-matching was found between the measured samples. This probably indicates they were derived from different trees and potentially from different periods. Comparisons with reference data, and individual timber sequences from the British Isles and elsewhere identified that none of these samples strongly matched to dated or undated data from other sites.

It was recognised beforehand that it was a relatively unpromising assemblage. The long potential period of origin and the paucity of geographically nearby contemporaneous sequences suggested it was unlikely that the material would be able to provide absolute dates. The intended purpose of the tree-ring analysis was to assist with any future radiocarbon programme on these timbers.

Although they appear to be stratigraphically related the tree-ring sampled material cannot be demonstrated to be co-eval by dendrochronology. It is appropriate to consider radiocarbon strategies for identifying if they are co-eval or spread across several millennia, although the stratigraphic positioning makes the latter scenario unlikely. If they are exceptionally early in date, as is likely given their stratigraphic position, these timbers could be from beyond the extent of the national tree-ring sequence (4989 BC for England), though they ought to lie within the tree-ring derived part of the northern hemisphere radiocarbon calibration curve (~12000 BC).

Most oaks in woodland grow at 1 to 1.5mm/year, and open conditions can accelerate growth to 3-5mm/year. The extraordinarily distressed or moribund form of the sequences present within the Killerby trees indicate they are not datable timbers by conventional dendrochronology. Sample (1030) is growing on average at less than 0.4mm/year for nearly two centuries and both (1003) and (1020) have a peculiar burst of a decade of fast growth between otherwise moribund slow growth, (1020) notably having one ring nearly 5mm wide within a 250 year sequence otherwise averaging 0.7mm/year. All these are atypical events within oak tree-ring sequences. Their presence here strongly argues for the material coming from a perturbed growing environment.

All except (1003) have sapwood, or retain likely edge of sapwood, and each of these would therefore produce a radiocarbon date of some interpretative value. Outermost heartwood decade radiocarbon samples from the four excluding (1003) would identify how spread out across their potential period they are or potentially clarify if they are likely to be co-eval. The latter finding would indicate their tree-ring sequences are too distressed or moribund even to cross-match locally. For this limited aim there is no significant technical benefit to be gained from multiple samples, or wiggle matching. Obviously consideration of the overall project aims and some appropriate advice should be sought regarding the overall radiocarbon dating programme. These tree-ring samples can provide sufficient raw material from their outermost heartwood rings for radiocarbon sub-sampling, and they can be stored pending any radiocarbon sampling decision.

The 254- and 182-year sequences obtained from 2 of the KIL17 samples are both relatively long lived for oak, and as long as they are not hopelessly localised in character both may cross-match as individual series to nearby and contemporaneous reference data in due course. An extensive search of other undated prehistoric series has failed to identify any other analysed material they cross-match with. Providing these series with radiocarbon dates will assist long term projects involving searching for the framework datasets that will underpin improvements or extensions to the national tree-ring sequence.

The nationally recommended guidance for dendrochronology projects (English Heritage 1998) is to undertake sampling and analysis of assemblages that comprise groups of contemporaneous timbers, and this is a particularly appropriate for all pre-Roman material due to the weak points within the national reference sequence and the vast time span involved. The tree-ring analysis of prehistoric timber is most likely to prove successful when large assemblages of contemporaneous oak trees are recovered.

Analysing small numbers of perhaps non-contemporaneous timbers will inevitably have a poor success rate. The Killerby assemblage unfortunately contains relatively small numbers of suitable timbers, and they seem to contain distressed tree-ring sequences that may be extremely localised in character.

8 SYNTHESIS

8.1 KB5

The grey moderately organic-rich gravel (1022) immediately overlying the glacial clay is of very late Devensian and very early Windermere interstadial age (i.e. spanning the Glacial/Late glacial transition). Seeds and pollen of rowan, as well as relatively high proportions of birch and pine pollen were present within this sedimentary unit. The rowan is most likely to be within the immediate vicinity of the kettle-hole, owing to the presence of abundant seeds. These are all hardy, often high-altitude, colonising tree species. Rowan in particular generally prefers cool, high-altitude habitats, far different to the present landscape which suggests that the environment was cooler than the present day. A modern day comparison of similar tree composition could be the Calendonian forest now found in Northern Scotland. These trees may represent the forests which gradually began to colonise the highly active Post Glacial landscape, following glacial retreat. The date of 13335-13026 cal BC (12704 ±32 BP, SUERC-79306 (GU47401)) for a rowan seed recovered from near the base of (1022) indicates that this gravel began to be deposited during the late Devensian stadial with the sedimentary unit spanning the final stages of the Devensian and the transition into the early part of the Windermere Interstadial. Forest compositions similar to those identified in M1POL1 are indeed common in Britain during the very early Windermere Interstadial (Ingrouille 1995). The poorly sorted and abundant gravel which form (1022) are a reflection of the highly active and unstable landscape of the late Devensian/early Windermere transition period. Recoverable pollen and palaeobotanical macrofossils within very early Windermere interstadial or Devensian stadial sediments of the Swale-Ure region has not been encountered prior to this study (Bridgland *et al.* 2011).

Increased vegetation growth led to the formation of a succession of organic strata and likely reflects the ameliorating climate of the mid-late Windermere interstadial. A radiocarbon date from a bogbean recovered in the lowermost centimetre of the organic-rich silty clay (1026) provided a date of 11299-11129 cal BC (11132±32 BP, SUERC-79305 (GU47400))The variety of macrofossils and aquatic-type pollen palynomorph seeds from the lower three organic units (1026, 1025, and 1011) illustrates what was a vibrant community of marshy-habitat/pond-side flora (particularly flowering plants) which grew in the ameliorating climate within and around the kettle hole. The waterlogged seeds are all suggestive of a marsh/bog environment. The bogbean, bog rosemary, water forget-me-not, and purple marshlock are flowering plants commonly found in bog or pond-side habitats. Similarly, moor birch, goosefoot, and sedge are also amenable to boggy environments. The pollen suggests a relatively high proportion of aquatic pollen, particularly bogbean and pondweed, and is indicative of the kettle hole itself being filled with water. There was likely a small pond within the kettle hole which existed through the deposition of (1026), (1025), and (1011). It is possible that the water level of the pond fluctuated. Although (1026) is relatively organic-rich, there is still a silty component to the sediment. Additionally, there is a reduction in pond weed pollen. Pond weed generally requires water depths of deeper than 1m and the reduction in pollen may be an indication of reducing water levels. The increase in bogbean pollen and macrofossils likely reflects its replacement of pond weed as the pond weed numbers decrease through decreasing water levels. It may have been that the kettle hole would have been filled with relatively deeper water through the deposition of the organic-rich silty clay unit (1026), with a progression into a shallower, marshier environment at the point when (1025) was formed. This appears to have reversed during the formation of (1011) where the minor silty component becomes present again, alongside an increase in pond weed pollen and decrease in bogbean pollen and macrofossils. Speculation can be made about the cause for this fluctuating water level. Though it could simply be a result of localised hydroseral succession, it could also be due to the increased aridity that would occur during the Older Dryas. Indeed, the radiocarbon dates of 10958-10764 cal BC (10956±32 BP, SUERC-79304 (GU47399)) and 10799-10734 cal BC (10809±32 BP, SUERC-79300 (GU47398)) which bracket this fluctuation would correlate with it occurring during the Older Dryas. There is the notable presence of microcharcoal in these organic layers (1011, 1025, and 1026). This is possibly an indication of nearby human activity, or natural fires in the locality. The quantity of microcharcoal is suggestive that the former scenario is more likely and could indicate human presence as early as the Windermere interstadial.

The inorganic sedimentary units (1027) and (1010) demonstrate a termination of the vibrant aquatic and pond side floral communities which characterised the lower pre-Holocene organic-rich strata. The switch to a clay and then silty clay sedimentary deposition is suggestive of a change from the stable, amenable climatic conditions which was conducive for organic production, towards a less stable climatic regime. Indeed, the pollen indicates a high percentage of herbaceous taxa which is indicative of the nearby landscape being open and relatively unforested at this time. The herbaceous taxa present are highly typical of the open tundra-type landscape of the Younger Dryas (notably *Thalicrum,* Cyperaceae*, Rumex,* and *Saxifraga)*. The climate in this phase was also relatively dry (Lowe *et al.* 1994) which is reflected through the presence of *Artemisia* which is one of the most characteristic features of this period (Bridgland *et al.* 2011, 251). The lower *Betula* and slightly higher *Pinus* and herbaceous pollen palynomorphs within M3POL2 compared to M3POL1 may indicate a cooler, earlier period within this stadial. The increased microcharcoal counts within M3POL1 and M3POL2 are again, possibly indicative of local human activity. There is also likely an element of the increased aridity of the Younger Dryas creating additional potential for natural fires; however the counts of microcharcoal are high enough that it is more likely to be predominantly created by anthropogenic activity.

The recommencement of organic material accumulation following the transition from the silty clay unit (1010) into the organic sediment (1008) indicates a stabilisation of the environment following the instability of the Younger Dryas and reflects the Younger Dryas-Holocene transition. The initial high concentration of birch pollen in M4POL1 indicates birch woodland colonising the area around the kettle hole during the initial formation of the organic sediment (1008b) at the beginning of the Holocene. The composition of this woodland appears to have altered through the formation of (1008b) by the steady replacement of birch by what was to become dense deciduous forest composed primarily of alder and lime, as well as oak. This rise in alder pollen palynomorphs, is likely indicative of the well-known 'alder rise' phenomenon which frequently occurs in Mesolithic pollen sequences. The alder rise is characterised by a spatially and temporally erratic spread northwards in alder populations from the southeast of England and is viewed as occurring from around 8000BP (Tallantire 1992) but potentially as early as 8500BP (Chambers and Price, 1985). The proliferation of alder in Northern Britain is generally understood as having occurred by around 7000-6500 BP (Bennett and Birks, 1990) and is tied to the termination of relatively dry conditions which characterised the Boreal pollen-chronozone (Tallantire 1992). This spread of alder is frequently observed as occurring contemporaneously with the growth of lime populations (e.g. Brown 1988). Lime is often viewed as a warmth-demanding species which becomes an important component of the primary woodland cover in the early-mid Holocene (Grant *et al.* 2011).

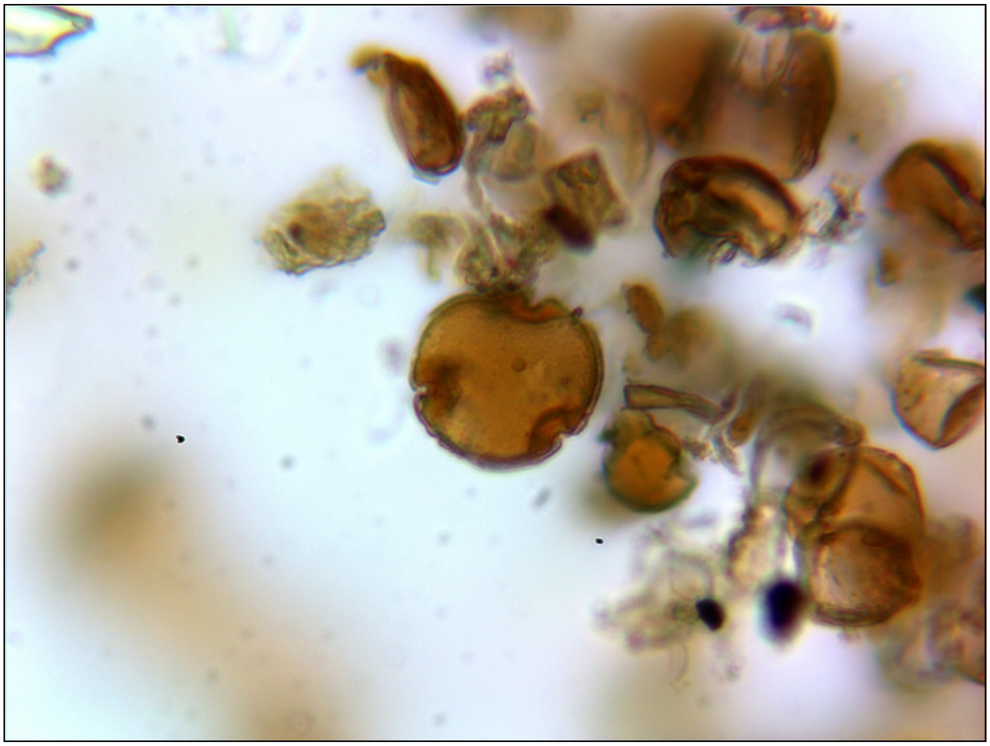

Figure 8.1: A *Tilia* pollen grain recovered from the central pollen sample M4POL2 taken at x400 magnification.

The distinction between the two sub-units of (1008) was not visible in the monolith samples from which pollen extraction was undertaken. However, based on their position M4POL4 likely represents the lower sub-unit (1008b) and M4POL3 and M4POL2 have been allocated to the upper sub-unit (1008a). This gains more confidence by the fact that M4POL4 is characterised by high *Betula* populations, and M4POL3 and M4POL2 are characterised by the presence of *Alnus* and *Tilia* which corresponds with the known climatic changes that occur from the early-mid Holocene.

M4POL1, extracted from (1006) indicates a drop in tree-type pollen and a growth in herbaceous-type pollen palynomorphs. This could possibly result from localised tree felling during the early Holocene. It is notable that while herbaceous species are replacing trees, *poaceae* (grass) is not one of them. It is possible that deliberate burning of tree cover to promote the growth of browse and graze for wild ungulates was taking place as implied by both the microcharcoal and the reduction in tree cover. This is supported by the presence of cattle teeth which were recovered during the archaeological excavation (see Hunter and Waddington 2018) from within KB5. The presence of marginal sedimentary influxes in the form of (1007), (1028), and (1029) also supports a scenario whereby destabilisation around the margins of the kettle hole was taking place as a result of localised tree clearance. The land clearance likely resulted in nearby soil destabilisation which resulted in sedimentary runoff into the kettle hole, leading to these influx deposits.

M6POL1, which is stratigraphically the uppermost pollen sample taken from unit (1026) which post-dates (1006) which has a radiocarbon date of 1744-1538 cal BC (3361±32 BP, SUERC-

79296 (GU47393)) associated with its upper limit, displays a relative high in grass pollen. This is the first conclusive evidence within the pollen profile for cultivation taking place in the vicinity of the kettle hole, and given its stratigraphic position indicates it occurred sometime shortly after 1744-1538 cal BC, during what was likely the middle-later Bronze Age.

There is a lack of earlier Holocene dates recovered for these upper organic sediments (1006 and 1008) which is notable. The earliest date thus far for organic unit (1008) is 5741-5641 cal BC (6813 ±32 BP, SUERC-79298 (GU47396)) from a bulk sample which was taken at the base of (1008) at the margin of the kettle hole. Though it may be that there is a hiatus in sediment formation, it is more likely that the lack of early-Holocene dates is a result of using bulk-sampling in order to acquire dates for the organic sediments (1008b). Indeed, the lower radiocarbon date of 5741-5641 cal BC (6813±32 BP, SUERC-79298 (GU47396)) from a bulk sample taken from the base of (1008b) at the NE margin of KB5 and a radiocarbon date acquired from a bulk sample taken at the upper boundary of organic sediment (1006) of 1744-1538 cal BC (3361±32 BP, SUERC-79296(GU47393)) suggests a relatively significant quantity of time which is represented by just 22cm of organic sediment (1008b, 1008b and 1006). It seems likely that organic formation did occur from the end of the Younger Dryas and through the early/mid Holocene, however the organic sediments (1006) and (1008) have been highly compressed. Considering the period before the Alder Rise (7000-6500 BP; Bennett, Birks, 1990) is observable within the KB5 palynology sequence, it is likely that in reality organic formation of (1008) has extended prior to the earliest acquired bulk sample date of 5741-5641 cal BC (6813±32 BP, SUERC-79298 (GU47396)). It is clear therefore that this compression has prevented the necessary bulk sample radiocarbon chronology strategy from acquiring accurate dates from the Early Holocene and Holocene/Younger Dryas transition at the base of (1008b).

An upper (1037) and lower (1065) piece of oak wood were taken from the wooden platform and radiocarbon dated, alongside waterlogged hazel roundwood post-packing for a set oak post (1020.5). This hazel roundwood surrounded a post which had been sharpened at its base. The date of 2471-2310 cal BC (3910±20 BP, SUERC-80721 (GU48309)) for the uppermost wood on the platform (1037) and the date of 5542-5472 cal BC (6540±25 BP, SUERC-80722 (GU48310)) from the lower (1065) wood in the platform indicates a significant age range for the wood comprising the platform, suggesting human use of this pond and possibly the platform over a long period. The date of 4789-4691 cal BC (5863 BP±23, SUERC-80723 (GU48311)) for the hazel post-packing shows that when the post was inserted into the underlying sediment, the wood platform was already present and had been for at least several hundred years which again testifies to repeated use of the pond and platform area. The three dates from the top and base of the timber platform and the inserted timber post indicate that at least three episodes of human activity occurred in this part of the pond spanning a period from the Late Mesolithic through to the end of the Neolithic.

The relatively small size of kettle hole KB5 is useful regarding the reliability of the microcharcoal record. The relatively small microcharcoal source area, as well as the greatly simplified taphonomy allows a much clearer attribution of microcharcoal concentrations to nearby human agency (Innes and Simmons 2000). Although major microcharcoal trends can be viewed as accurate, one should be wary of developing too precise an interpretation of human occupational patterns particularly with the sampling resolution that is utilised at Killerby (Innes *et al.* 2004). This said, in pollen samples M2POL3 and M2POL1, the abundance of microcharcoal is such that the likelihood is that humans were undertaking burning activities in the area immediately surrounding the kettle hole and this correlates with the evidence for human activity in units (1008). Initial nearby human activity is indicated by the spike in microcharcoal quantities in M4POL2, followed by a brief reduction in microcharcoal in M4POL3. It could be interpreted that this may be an indication of a brief absence of nearby humans; however developing an interpretation at this relatively small temporal scale is difficult. The upper part of the sequence contains a very large abundance of microcharcoal in M4POL1, which becomes increasingly abundant within the pollen samples taken from overlying sedimentary influx deposits. The microcharcoal in the upper part of the pollen sequence could even be micro-fragments of the same material which was burned next to the kettle hole in the charcoal deposits described in Hunter and Waddington (2018). As aforementioned, the microcharcoal concentrations present in the samples from monoliths 2 and 3 suggest that humans were possibly present during the Winderemere interstadial, were likely present during the Younger Dryas, and were certainly present during the early and mid-Holocene. This human presence displays a great deal of resilience through periods of major climatic and environmental change which is being similarly reflected in other recent studies, such as the latest findings from Star Carr (Milner *et al.* 2018)

A small (around 2cm thick), fine sand unit (1009) was present at the northeastern margin of KB5. The sand matrix of the unit appeared fine enough to be aeolian and likely represents a very brief period of wind-blown sedimentary influx at the kettle hole margin. It appears to have been deposited uniformly in a single event, without evidence of reworking. Stratigraphically, it is deposited beneath (1008) and so predates the aforementioned anthropogenic tree clearance which is expressed in M4POL1. This suggests that rather than indicating localised landscape destabilisation due to human activity, it is instead suggestive of a natural process which led to a brief period of destabilisation. It is difficult to identify whether this represents a larger-scale environmental event, or a more localised phenomenon. Stratigraphically (1009) overlies the Younger Dryas clay-rich sediments of (1027) and (1010), and underlies the mid-Holocene organic sediment (1008b).

The following sequence of clayey silt/sandy silt strata overlying the upper organic sediments (1008) and (1006) are viewed as being successions of more modern Holocene sedimentary deposition which have been greatly influenced by agricultural processes. The pale brown clay silt layers of (1005) and (1014) are notably poorly sorted, containing numerous angular clasts. These palaeosol layers are likely the result of anthropogenic deposition which was undertaken within KB5 as an attempt to terrestrialise the landform in order to provide more suitable land for agriculture and bring the area of the kettle hole into arable agricultural production.

8.2 KB15

The stratigraphy of KB15 appears to mirror that of KB5. Particularly clear in both KB5 and KB15 is the sequence of basal glacial clay (1080 and 2010), lower organic sediment (1026, 1025 and 1011, and 2009), inorganic clay (1027 and 1010, and 2011), and upper organic sediment (1008 and 1007, and 2007). Purely on the basis of stratigraphic correlation between KB15 and KB5, it appears that the lower organic sediment (2009) represents the Windermere Interstadial and the homogenous, massive clay (2011) represents the Younger Dryas.

Stratigraphically, it can be also observed that the upper organic sediment (2007) is equivalent to (1008a) and (1008b), but this correlation can also be made palynologically. M2POL2 is similar to M4POL4 in that there is a relatively high concentration of *Betula* pollen. They do differ in that M2POL2 in KB15 contains a much greater quantity of *Corylus* pollen. The M2POL2 sequence is quite typical of a Holocene sequence (Bridgland *et al.* 2011) but considering the lack of a notable *Alnus* or *Tilia* population at the sampled point in this unit it is more likely that this part of the unit is of a similar pre-Alder Rise age to M4POL4 in (1008b) of KB5.

M1POL1 does contain the aforementioned *Alnus* and *Tilia* signal and therefore this part of the sequence is likely to be post-Alder Rise, equating the upper part of (2007) to (1008a) of KB5.

The microcharcoal concentrations in M2POL2 and M2POL1, which mirror those found in KB5, are more widely indicative of human occupation in the area of both kettle holes

8.3 KB6

The two pollen samples of KB6 (M2POL4 and M2POL2) contain significant quantities of *Betula*, as well as the presence of *Quercus* and *Tilia* which is indicative of an early Holocene sequence. The bulk-sample radiocarbon dates support this, where 8797-8633 cal BC (9438±32 BP, SUERC-79318 (GU47411)) and 8604-8344 cal BC (9257±32 BP, SUERC-79317 (GU47410)) for the lower dark brown/black peat (6004), 7592-7532 cal BC (8519±32 BP, SUERC-79315 (GU47408)) for the dark brown organic-rich clay (6002), and 7066-6826 cal BC (8029±32 BP, SUERC-79314 (GU47404)) are all early Holocene dates. This illustrates that around half of the KB6 sediment sequence is between 8797-8633 cal BC (9438±32 BP, SUERC-79318 (GU47411)) at 1.02m, and 7066-6826 cal BC (8029±32 BP, SUERC-79314 (GU47404)) at 0.52m. This would suggest that the 52cm of sediment between these two dates only represents around 1800 years of deposition. This therefore indicates that the Early Holocene in this sediment sequence is particularly pronounced, and that the mid to late Holocene of KB6 has experienced a reduction in organic peat accumulation. The lowermost radiocarbon date of 8797-8633 calBC (9438±32 BP, SUERC-79318 (GU47411)), as well as an early Holocene pollen sequence of M2POL4 in (6004) immediately above the basal clay (6005) would also suggest that either there is a hiatus in sediment formation during the late-glacial Windermere and Younger Dryas periods, or these sediments have been removed (if ever present) through subsequent erosion. The latter scenario may be supported by the sharpness of what may be an erosive boundary between basal glacial clay (6005) and lower dark brown/black peat (6004), however further indication of this extensive sedimentary erosion is not present. Another possibility is that the clay (6005) was mistakenly identified as basal and is instead representative of the Younger Dryas. It could be that the actual glacial sediment lies at a greater depth below what was excavated in the test pit within KB6.

The aquatic-type pollen palynomorphs from M2POL4 sampled from lower dark brown/black peat (6004) suggests that during the early Holocene the low lying depression KB6 contained a standing body of water with a depth of at least 1m (as suggested by the *Potamogeton* pollen). This water body was primarily surrounded by trees; primarily *Betula*, but also some *Pinus* and a small number of deciduous woodland species such as *Quercus* and *Tilia.* It should be noted that, though likely present in the area, the pollen likely exaggerates the actual representation of *Pinus* in the landscape, as *Pinus* pollen palynomorphs are well known for being particularly far-travelled (i.e. Simmons and Innes 1981).

The excellent survival and stratigraphic integrity of early Holocene sediments in KB6 is notable and assists in filling in detail for this important period given that it is represented by only a very thin part of a heavily compressed peat layer in KB5 (ie. unit 1008b). Understanding the early Holocene and associated land use and landscape change can be addressed by a more detailed palaeoenvironmental investigation of the extensive early-Holocene sediment units of KB6. Additionally, further investigation should address the question of whether the 'basal' clay (6005) is actually the lowermost clay unit and if there in fact lays deeper sediments which cover the Glacial/Lateglacial Interstadial.

The well-sorted fine clay sand (6003) with frequent aquatic mollusc shells represents a notable interruption of organic sediment within the low-lying depression KB6. That this sediment is well-sorted and lacking in clastic material suggests that a high-energy influx of material is unlikely and instead represents a more prolonged, lower-energy process. The high calcium carbonate content of the fine clay sand (6003) was likely precipitated from the pond water by high organic productivity within the depression during the early Holocene coupled with the alkaline geology. This sedimentary unit is very similar to the marl deposits encountered within the Vale of Pickering (Lincoln *et al.* 2017; Candy *et al.* 2017). This calcium carbonate could indicate that the water level had risen following the deposition of the dark brown/black peat (6004) and enabled the authigenic calcium carbonate production of (6003).

Pollen sample M2POL2, extracted from (6002) displays a large increase in *Betula* population as well as an increase in *Tilia* pollen compared with M2POL4 from (6004). Alongside this is a notable decrease in herbaceous and aquatic pollen palynomorphs. That aquatic pollen is still present (notably a very small number of *Potamogeton*) suggests that KB6 still represents a standing water body at this time, although the tree pollen suggests that nearby woodland (particularly *Betula* woodland) has expanded. The increase in woodland populations and particularly the increase in *Tilia* could indicate somewhat warmer conditions than in M2POL4. The resumption of organic production within the dark brown organic-rich clay (6002) may indicate a fall in water level which prevented the formation of the authigenic calcium carbonate which characterises the fine clay sand (6003).

The dark brown/black peat (6001) is without the clay component of the dark brown organic-rich clay (6002) and shows an increase in organic content. It is possible that these two charcteristics may be suggestive of hydroseral succession causing a progression into a marshier environment along with a reduction in water level.

9 Recommendations for assessment on route of quarry conveyor (2019-2020)

Several areas of particular geoarchaeological potential have been identified along the proposed corridor to be stripped in advance of the quarry conveyor construction between the Swale crossing and the Plant Site area in 2019/2020. Figure 9.1 below shows the route of the conveyor as it extends across the northeast part of the Extraction Area before turning north towards the main Holocene valley floor and the River Swale.

In the northeast part of the Extraction Area the conveyor route traverses 1e surfaces (Late Devensian / Holocene low terraces) and low-lying 1f surfaces (Late Devensian / Holocene valley floors) and crosses at least one well-developed palaeochannel (Fig. 5.1) associated with drainage of the former lateglacial basin. On the main Holocene valley floor (landform element 2c) to the north of the Phase 1 Extraction Area the conveyor line crosses at least two major Holocene palaeochannels (landform element 2d), respectively investigated by geoarchaeological assessment cores KB10 (with a basal sedimentary sequence dated to *c*. cal AD 560-770) and KB14 (dated to *c*.400-200 cal BC) (Fig. 8.1; Waddington and Passmore 2008).

Given the proven or high potential for organic-rich sediments of palaeoenvironmental interest in these areas the following evaluations are recommended:

(i) Detailed geomorphological mapping of palaeochannels and floodplain depressions within the conveyor strip area via a combination of desk-based (LiDAR) analysis and ground survey.

(ii) Machine trenching of channel cross-sections and test-pitting of other depressions identified in (i).

(iii) Recording of sedimentary sections exposed by (ii) and sampling of organic-rich sequences for palaeoenvironmental analyses and ^{14}C dating.

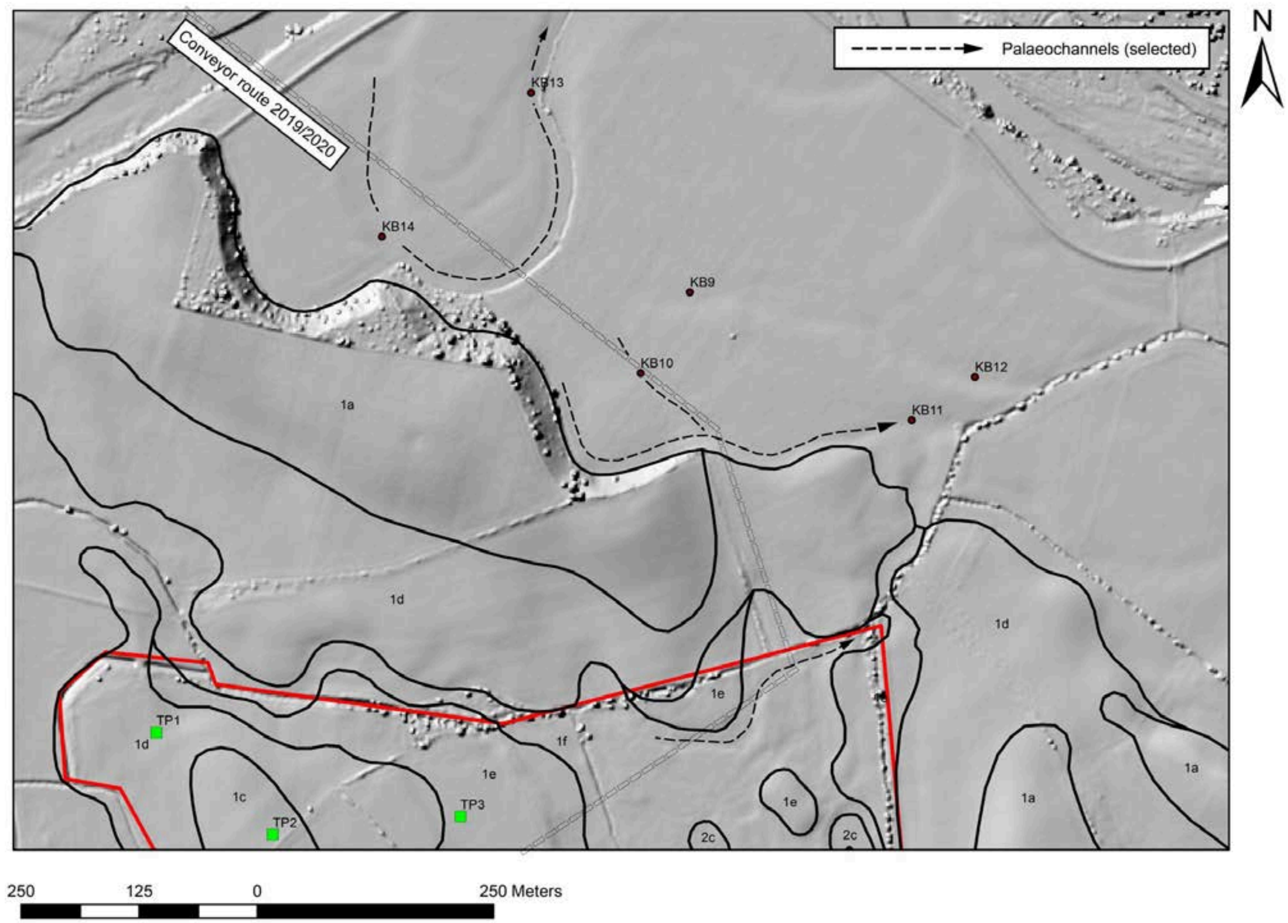

Figure 9.1: Map of Phase 1 Extraction Area (Northeast Corner) and valley floor to north and east showing route of conveyor (scheduled for 2019/2020) and selected major palaeochannels (see text for details).

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