Killerby Quarry Geoarchaeological Study

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Contents

1 Executive Summary 1
2 Introduction 3
3 Methodology 4
3.1 Field Mapping and Survey 4
3.2 Sedimentary Analysis 5
3.3 Kettle Hole Excavation 5
3.4 Laboratory Analysis of Pollen and Plant Macrofossils 6
4 Results 6
4.1 Landform Element 1a: Late Devensian Till, and Glacial Sand and Gravel 12
4.2 Landform Element 1b: Late Devensian Glacio-Fluvial Sand and Gravel 14
4.3 Landform Element 1c: Late Devensian River Terraces 18
4.4 Landform Unit 1d: Late Devensian/Holocene Lower Slopes and Enclosed Basins 20
4.5 Landform Element 1e: Late Devensian / Holocene Low Terraces 23
4.6 Landform Element 1f: Late Devensian / Holocene Valley Floors 27
4.7 Landform Units 2a and 2b: Holocene alluvial valley floors and Holocene palaeochannels 34
4.8 Landform Element 2c: Late Devensian and Holocene basin and kettle hole deposits (peat) 41
5 Discussion of Killerby in a Regional Context 52
6 References 56

List of Figures

Figure 1. LiDAR derived local relief model of the Killerby site.. 7
Figure 2. LiDAR derived local relief model of the southern area of Killerby Quarry. 8
Figure 3. LiDAR derived local relief model map of the northern area of Killerby Quarry. 9
Figure 4. LiDAR derived local relief model map of the north-western area of Killerby Quarry. 10
Figure 5. A simplified deposit model visualising the overall topography and dominant sediment types of the southern area of the site 11
Figure 6. Sediment log of KB24.. 14
Figure 7. Sediment logs of KB4, KB16, and KB17.. 16
Figure 8. Sediment logs of TP6 and TP10. 17
Figure 9. Sediment logs of TP2 and TP7. 19
Figure 10. Sediment logs of TP1, TP4, TP9, TP11 and TP13.. 22
Figure 11. Sediment logs of KB23 24
Figure 12. Sediment logs of TP3 and TP5. 25
Figure 13. Sediment log of TP8 and KB18... 26
Figure 14. Sediment logs of TP14 and TP15. 29
Figure 15. Sediment logs of KB1, TP16, and KB19 30
Figure 16. Sediment logs of KB20, KB21, and KB22 31
Figure 17. Sediment logs of KB25, KB26, and KB27 32
Figure 18. Sediment log of the BGS borehole SE29NE23. 33
Figure 19. Holocene palaeochannels of the river Swale within the Holocene alluvial valley floor area 35
Figure 20. Holocene palaeochannels (Landform Elements 2a and 2b) on the opposite side of the river Swale in the area of Ellerton Quarry. 36
Figure 21. Sediment logs of KB9, KB10 and KB11.. 39
Figure 22. Sediment logs of KB12, KB13 and KB14.. 40
Figure 23. Sediment logs of BGS borehole SE29NE18. 41
Figure 24. Identified kettle-like depressions (2c) within the eastern depression of the quarry's plant site. 42
Figure 25. Monolith of the sediment sequence extracted from KB6 43
Figure 26. Stratigraphy of the KB6 sequence. 44
Figure 27. Sediment logs of KB2 and KB3.. 46
Figure 28. Sediment logs of KB7 and KB8. 47
Figure 29. Stratigraphy and location of pollen samples from the central area of the kettle hole KB5 sequence.. 49
Figure 30. Stratigraphy and location of pollen samples from the margin of the kettle hole KB5 sequence.. 50
Figure 31. Regional palaeoenvironmental summary.. 54

List of Tables

Table 1. Core and test pit coordinates. KB denotes core location, TP denotes test-pit location...... 5
Table 2. Killerby Quarry radiocarbon dates 13

1 Executive Summary

Project Name:	*Killerby Quarry Geoarchaeological Study*
Site Code:	*KIL19*
Planning Authority:	*North Yorkshire County Council*
Geology:	*Devensian till overlying Brotherton formation limestone*
NGR:	*SE 26651 95936*
Date of Report:	*July 2019*

This report presents a geoarchaeological synthesis of results from a recent survey undertaken in 2019 alongside all previous geoarchaeological and palaeoenvironmental studies from the Killerby Quarry site (Waddington 2008, Hopla and Gearey 2009, and Parker et al. 2018). This current geoarchaeological understanding of the site will be amended in further studies as development of the quarry progresses.

The site is located to the south-east of Catterick, North Yorkshire and to the immediate south of the River Swale. On the opposite northern bank of the River Swale is Tarmac's Ellerton Quarry. Current land-use of the area is predominantly agricultural in addition to the gravel quarrying. The site is centred at SE 26651 95936 and has a topography composed of pronounced undulations which vary between 38m and 55m aOD as a result of glacial and post-glacial formation processes. The solid geology of the area comprises Carboniferous Millstone Grit and Permian Magnesian Limestone, which is overlain by glacial till and glacio-fluvial sands/gravels, alongside in-filled ice-wastage features and wetland basins. The northeastern portion of the site possesses a complex sequence of intercutting fluvial palaeochannels which reflect former watercourses of the River Swale.

The site contains extensive sedimentary records and geomorphological features which were formed by depositional processes from the end of the Devensian until the present day. These processes reflect environmental changes which would have formed the backdrop of human occupation in the area. This occupation is illustrated by a detailed excavation of kettle hole (KB5), located on a plateau at the south-west of the site, which uncovered a complex deposit sequence spanning the end of the Devensian to the modern period (Hunter and Waddington, 2018). Within these sediments, remarkable evidence for a Late Mesolithic timber platform alongside associated Mesolithic flints and cattle teeth was uncovered and interpreted as being used for the processing and curing of wild cattle skins.

The sedimentary record at Killerby is one of the most complete for the entire Swale-Ure region. The lowermost sediment studied within kettle-hole KB5 represent some of the earliest fossil-bearing sediment within the region and covers an important climate transition at the end of the last ice age. Further sediments cover the climate amelioration of the Windermere Interstadial period, resembling other regional sequences (Bridgland et al. 2011). Holocene sediments are particularly well represented within the numerous organic-rich sediments which can be found at Killerby- particularly within two wetland basins located in *the west and east of the southern portion of the site. The eastern wetland basin in particular contains extensive peat deposits which reach over 4m deep and potentially constitute some of the longest Holocene palaeoenvironmental archives for the Swale-Ure region.*

2 Introduction

2.1 This report presents the results of geoarchaeological assessment and analysis for Killerby Quarry, North Yorkshire and represents the latest phase of work which builds on the several preceding assessments of the site (Waddington and Passmore 2008, Hopla and Gearey 2009, and Parker *et al.* 2018). This study has utilised a combination of desk-based analysis of map, aerial photographic, documented geomorphological and geological material, and LiDAR data, supported by a program of sediment coring (eg. Waddington and Passmore 2008), and hand and machine-assisted test-pitting, together with controlled excavation of a kettle hole depression (see Hunter and Waddington 2018; Parker *et al.* 2018). This approach enabled the identification and characterisation of distinct geoarchaeological landform elements alongside archaeological associations. Particular focus was given towards identifying low-lying, poorly-draining wetland areas which provide the greatest potential for organic preservation and act as records of past localised environmental change and human activity. These wetlands also represent areas of high potential for the preservation of a wide range of archaeological remains *in-situ* which can then be placed within the wider context of environmental change. The study concludes by placing the results of this geoarchaeological investigation into the broader context of the comprehensive study of regional Late Quaternary environmental change for the Swale-Ure Washlands region (Bridgland *et al.* 2011).

2.2 The southern portion of the site is located at the northern part of the Leeming Moraine, a glacial landform *c.*36-50m in elevation which extends for 7km south of Catterick along the route of the A1 (Bridgland *et al*., 2011). This moraine was created by local readvance of glacial ice during the Last Glacial Maximum (LGM). This moraine dominates the south of the Phase 1 extraction area, being up to 55m OD, and is formed from undulating masses of glacial sand and gravel. This moraine is inset with terraces of glacio-fluvial and fluvial sand and gravel, and low-lying terraces, depressions, and alluvial valley floors which represent localised reworking and incision by deglacial and Holocene processes. Poorly-drained depressions in these low-lying parts of the landscape have provided ideal locations for the accumulation of organic-rich sediments and peats within which archaeological remains are proven to exist (Hunter and Waddington 2018). The area in the north-eastern portion of the site, adjacent to the River Swale contains extensive well-preserved palaeochannels reflecting former (Holocene) courses of the River Swale. These palaeochannels form complex networks of cross-cutting meanders, the deepest of which contain organic-rich sediments conducive to palaeoenvironmental reconstructions as well as archaeological preservation.

3 Methodology

3.1 Field Mapping and Survey

3.1.1 Open-access LiDAR data was available for the entirety of the site at 2m resolution (with the exception of *c*.300m^2 in the southwest part of the site near Broadclose Cottage) and at 0.5m resolution for areas extending *c*.220m on either side of the current River Swale. Geomorphological mapping was conducted in the first instance as a desk-based exercise with reference to British Geological Survey (BGS) superficial geology maps, Bridgland *et al's* (2011) large-scale geomorphological map and a LiDAR-derived digital surface model (DSM) of the study area. A local relief model was generated from the LiDAR data in order to highlight topographical features. These maps were then subjected to field verification and augmentation using survey-grade GPS. Further visualisations were developed using the 'Rockworks' geological modelling software package. Mapping sought to identify and delimit major landform elements on the basis of their geomorphological origin, morphostratigraphic relationships and potential for preserving sedimentary sequences of archaeological and palaeoenvironmental value. This also provided the basis for prioritising areas for sediment coring and test-pitting in order to establish the depth and character of organic- and organic-rich sediments.

3.1.2 The coordinates of core and test pit locations are given in Table 1 below.

Test Pit/Core Number	Easting	Northing
KB1	426277	495620
KB2	426813	495714
KB3	426975	495747
KB4	426265	495343
KB5	425747	495467
KB6	426141	495585
KB7	426825	495801
KB8	426952	495825
KB9	426783	496418
KB10	426731	496332
KB11	427018	496282
KB12	427085	496328
KB13	426615	496330
KB14	426457	496477
KB15	425702	495507
KB16	426184	495252
KB17	426256	495186
KB18	426496	496008
KB19	426348	495976
KB20	426613	495946
KB21	426824	495937

KB22	426922	495938
KB23	427059	426257
KB24	427273	495662
KB25	426717	495665
KB26	426741	495691
KB27	426710	495801
TP1	426217	495950
TP2	426341	495842
TP3	426539	495861
TP4	426336	495701
TP5	426551	495683
TP6	426322	495414
TP7	426548	495480
TP8	426784	495549
TP9	426892	495395
TP10	426396	495153
TP11	425959	495492
TP13	426041	495679
TP14	426207	495658
TP15	426217	495606
TP16	426093	495884

Table 1. Core and test pit coordinates. KB denotes core location, TP denotes test-pit location.

3.2 Sedimentary Analysis

3.2.1 A program of test-pitting and hand-coring was utilised in order to characterise the sedimentary composition of the major landform elements, and in particular to test for preservation of organic- and organic-rich sediment. This analysis utilised the results of fifteen machine-excavated and one hand-excavated test pits (TP1-16), twenty seven hand-operated gouge auger core locations (KB1-27) and two BGS boreholes. Machine-assisted test-pitting was primarily utilised for characterising the major landform elements which were likely to contain significant sand and gravel deposits, whereas hand-dug test-pits and hand-operated gouge auger coring was used to investigate areas which were viewed as likely to contain organic-rich sediments. Test-pits were excavated until glacial sedimentary deposits were reached, whereas gouge auger cores extended until either glacial or glacio-fluvial sand and gravel deposits were reached. Sediment cores and test-pits were logged on-site. Peaty and organic-rich sediments were periodically sampled for evaluation of pollen preservation and character, and also for radiocarbon dating samples.

3.3 Kettle Hole Excavation

3.3.1 Detailed archaeological and palaeoenvironmental analysis of a kettle hole (KB5) revealed extensive sedimentary sequences which provided a record for long-term palaeoenvironmental change and in-situ archaeology representing past human activity here (see Parker *et al.* 2018; Hunter and Waddington 2018). A machine-excavated trench was placed across the width of kettle hole KB5, reaching down to basal glacial clay. Stratigraphic recording and palaeoenvironmental sampling of the exposed section was undertaken, following which a full palynological and palaeobotanical analysis revealed a palaeoenvironmental record spanning from the late Devensian period through to the present day.

3.4 Laboratory Analysis of Pollen and Plant Macrofossils

3.4.1 Palynological and palaeobotanical macrofossil analyses were undertaken on bulk and monolith column samples extracted from the sequences of kettle holes KB5 and KB15, and from KB6. Bulk samples of waterlogged organic material were taken from organic sedimentary units within exposed sequences. Pollen samples were taken from the sedimentary units contained within the monolith sample tins in 1cm thick sections. For a detailed methodology on the palaeoenvironmental analysis of the kettle holes KB5, KB15, and KB6 see Parker *et al.* (2018).

3.4.2 A total of twelve pollen subsamples were also taken from sampling locations KB2, KB3, KB5, KB8, KB10, KB11, and KB14. Pollen preparation followed standard techniques including potassium hydroxide (KOH) digestion, hydrofluoric acid (HF) treatment and acetylation (Moore *et al.,* 1991). At least 125 total land pollen grains (TLP) excluding aquatics and spores were counted for each sample.

4 Results

A total of nine landform elements have been identified and classified at 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)

These are shown in Figures 1-4 along with the locations of BGS boreholes and the array of test pits and sediment cores conducted for the Killerby Geoarchaeological Study. Each of the Landform Elements are described below together with a summary of their archaeological associations. A simplified deposit model was constructed in order to present a visualisation of the overall relief of the southern portion of the site and to illustrate the location of organic-rich sediments (Figure 5).

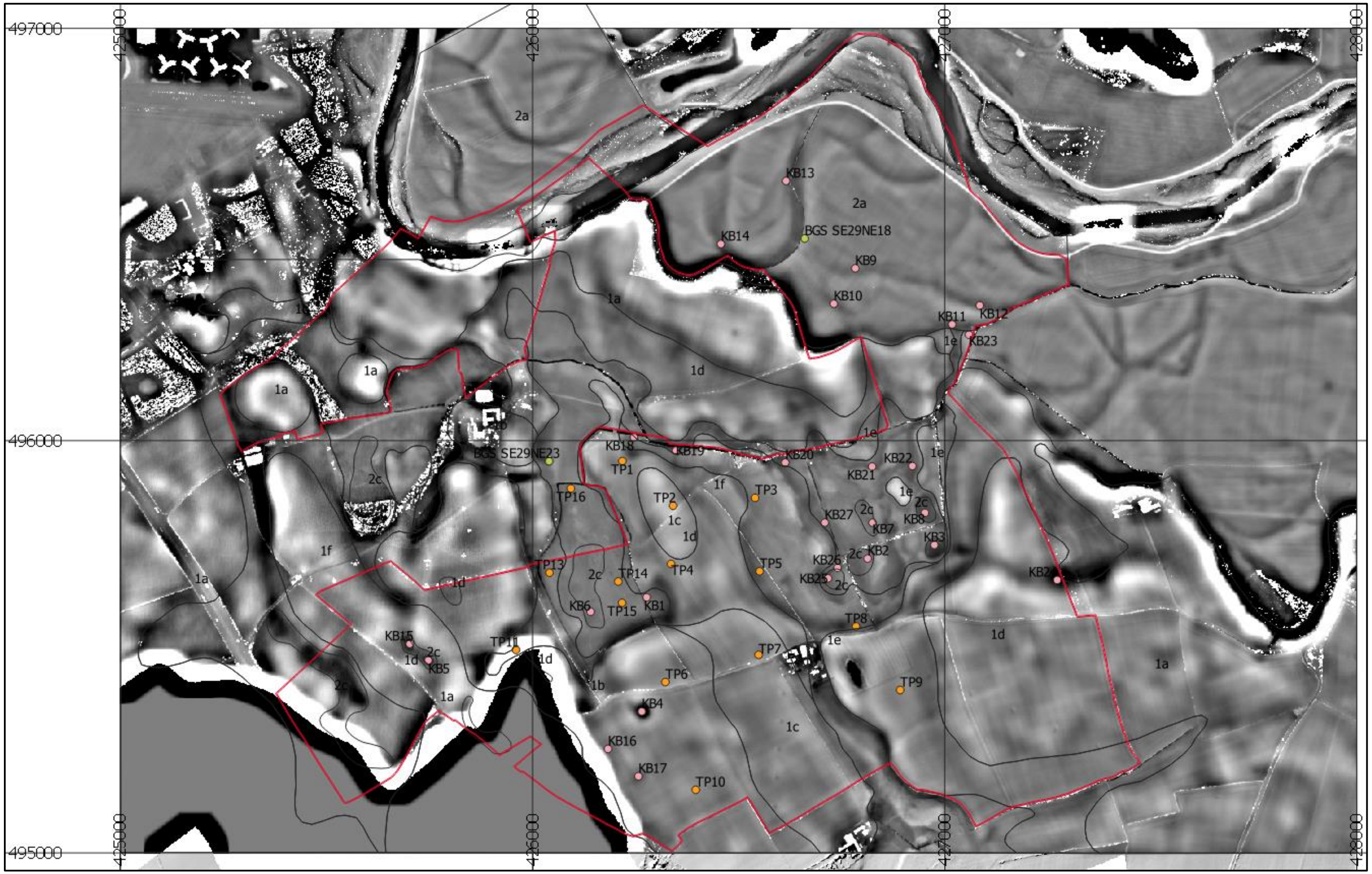

Figure 1. LiDAR derived local relief model of the Killerby site. The site boundary is delineated by the red line. Pink dots which are labelled with KB'x' are core locations, orange dots which are labelled with TP'x' are test-pit locations, and green dots labelled with BGS'x' are BGS borehole locations.

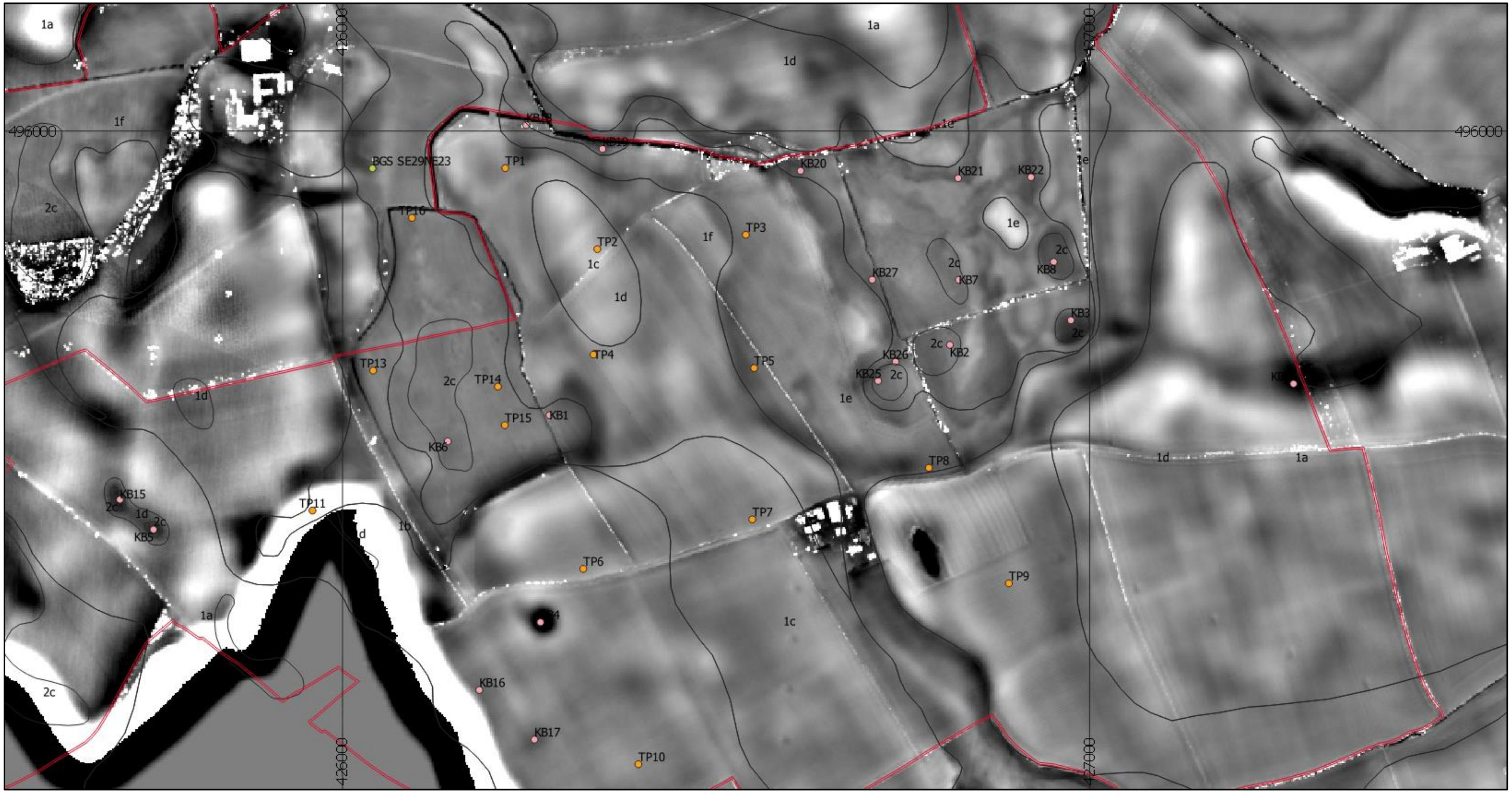

Figure 2. LiDAR derived local relief model of the southern area of Killerby Quarry. The site boundary is delineated by the red line. The black contours denote boundaries for landform elements. Pink dots which are labelled with KB'x' are core locations and orange dots which are labelled with TP'x' are test-pit locations.

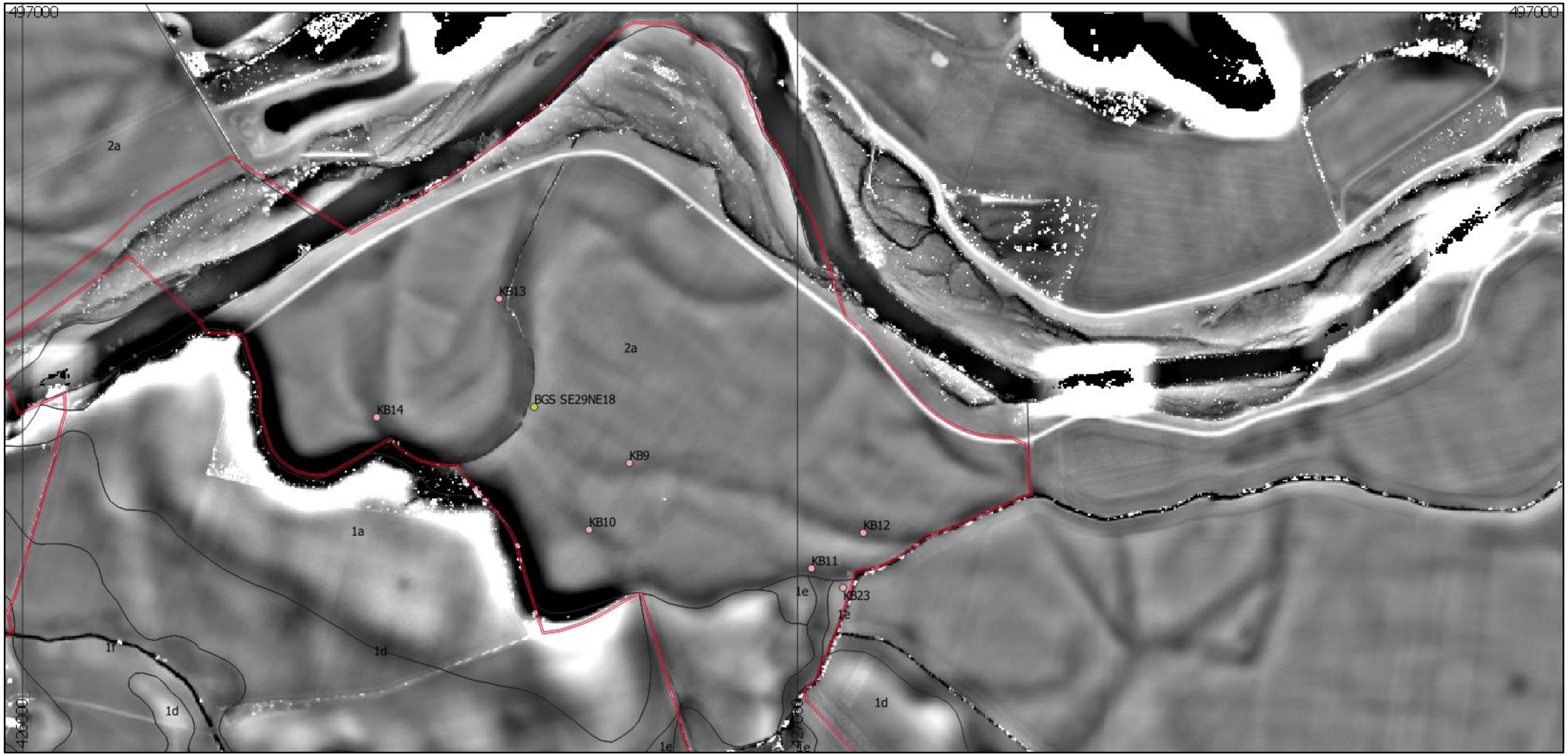

Figure 3. LiDAR derived local relief model map of the northern area of Killerby Quarry. The site boundary is delineated by the red line. The black contours denote boundaries for landform elements. Pink dots which are labelled with KB'x' are core locations, orange dots which are labelled with TP'x' are test-pit locations, and green dots labelled with BGS'x' are BGS borehole locations.

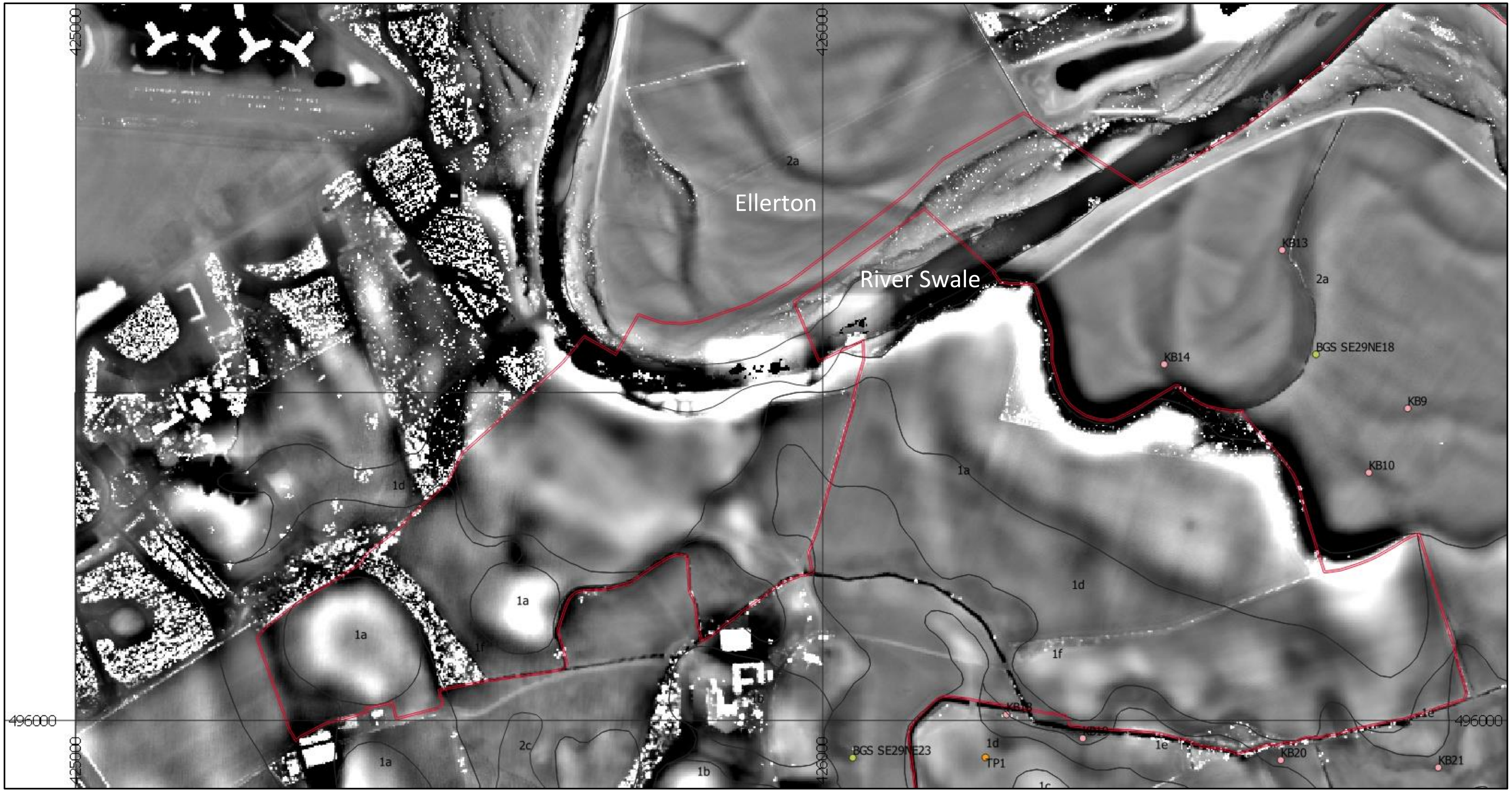

Figure 4. LiDAR derived local relief model map of the north-western area of Killerby Quarry including the planned conveyor route across the river Swale to Ellerton Quarry. The site boundary is delineated by the red line. The black contours denote boundaries for landform elements. Pink dots which are labelled with KB'x' are core locations, orange dots which are labelled with TP'x' are test-pit locations, and green dots labelled with BGS'x' are BGS borehole locations.

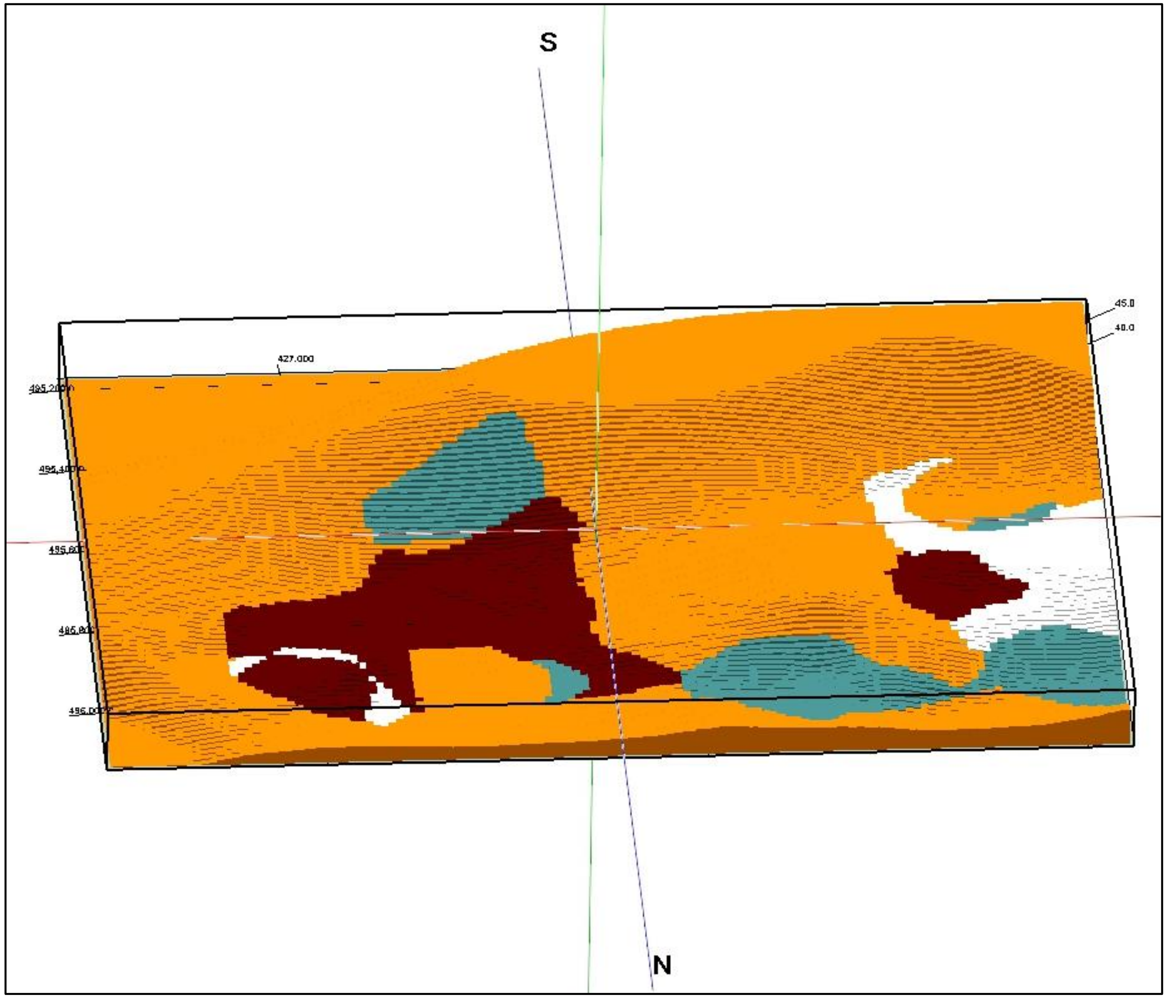

Figure 5. A simplified deposit model visualising the overall topography of the southern area of the site (Figure 2), as well as the dominant sediment types which are present. Orange defines sand/gravel, light blue defines silt/clay sediment, red-brown defines peat and organic-rich sediment, and white defines marl. Note the main eastern and western wetland basins containing organic-rich sediment. Also note orientation- north is towards the bottom, south is towards the top.

Radiocarbon dates from core samples, the kettle hole KB5, as well as the monolith samples from KB6 are given below in Table 2.

Laboratory Number	Dating ID	Context No.	Sample	δ13C (‰)	Radiocarbon Age (BP)	Calibrated Date Range (95.4% confidence)
SUERC-26092 (GU-199946)	1.42m	KB2	Bulk peat	-28.9	8845±60	8230-7750 calBC
SUERC-26093 (GU-19947)	2.30m	KB3	Bulk peat	-33.1	9800±65	9450-9140 calBC
SUERC-26094 (GU-19948)	1.52-57m	KB5	Bulk peat	-29.3	3040±45	1420-1130 calBC
SUERC-26095 (GU-19949)	2.31-52m	KB5	Bulk peat	-27.9	9885±65	9660-9240 calBC
SUERC-26096 (GU-19950)	2.30m	KB8	Bulk peat	-24.1	12325±80	12850-1200 calBC
SUERC-26097 (GU-19951)	1.55m	KB10	Bulk peat	-29.4	1395±45	560-770 calAD
SUERC-26098 (GU-19952)	1.12m	KB11	Bulk peat	-29.5	1505±45	430-650 calAD
SUERC-26102 (GU-19953)	1.64m	KB14	Bulk peat	-29.3	2240±45	400-200 calBC
KB5 Kettle Hole						
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-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-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 (95% 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 2. Killerby Quarry radiocarbon dates. Dates in red writing are viewed as being erroneous as a result of either being intrusive material (SUERC-79299, KB5.5) or due to the effects of hard water error (SUERC-79316, KB6.3) and so are disregarded from the discussion.

4.1 Landform Element 1a: Late Devensian Till, and Glacial Sand and Gravel

4.1.1 Late Devensian tills and glacial sands and gravels constitute the highest land surfaces 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 50-55 m OD (Figure 2). 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.* 1-2 m) 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 and are capped by relatively thin and inorganic fine-grained soil and subsoil sedimentary sequences. For example, at the western end of the site sediment core KB24 has revealed a 0.65 cm thick sandy silt unit which overlies (glacio-fluvial) sands and gravels (Figures 1, 2, and 6).

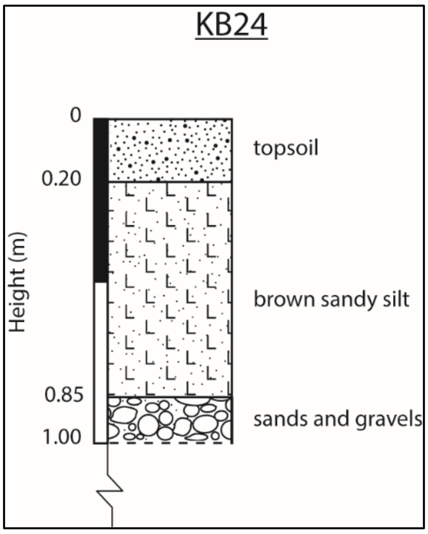

Figure 6. Sediment log of KB24.

4.1.2 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 have been documented across these surfaces being mostly of Mesolithic, and occasionally Neolithic, age (Waddington 2008). There remains the potential for mixed age truncated sites (likely truncated by ploughing) surviving as buried remains which have not manifested as cropmarks.

4.2 Landform Element 1b: Late Devensian Glacio-Fluvial Sand and Gravel

4.2.1 Late Devensian glacio-fluvial sand and gravel deposits are widespread in the study area as hummocky and locally terraced terrain that typically lies between 40-53 m OD. In the southern portion of the site these units form gently undulating surfaces that lie adjacent to, and inset below, till deposits with a maximum elevation of *c.* 50 m OD (Figure 2). The hummocky relief of these landform elements suggests they were formed (at least in part) as kamiform ice-contact meltwater deposits during Late Devensian deglaciation of the area, together with local reworking 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 occurred 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 (Figure 8). TP6 and TP10 reveal sandy soils and subsoils up to 1 m thick overlying variable thicknesses of inorganic sandy gravel and gravelly sand to a recorded depth of 4.5 m (TP6) and nearly 6 m (TP10) (Figure 8). Sediments in TP6 also feature 0.9 m of clean, well-sorted and occasionally cross-bedded sands and both sequences contain thin beds and lenses of inorganic clayey silt and silty clay.

4.2.2 Three topographic depressions in the south-west part of the site were also subjected to sediment coring in order to test for the presence of organic formations within Landform Element 1b. Core KB4 was located in a discrete sub-circular depression around 100m south east of the turning onto the original Killerby Hall access road (Figure 7) and was intended to establish whether the depression was a kettle-hole or a bomb crater associated with the airfield to the north. This core was terminated on sand and gravel within 0.3m of the surface and, given also extensive gravelly topsoil evident in the vicinity, suggests the feature is a bomb crater. Sediment cores KB16 and KB17, located just over 100m directly south of the turning onto the original Killerby Hall access road (Figure 2 and 7) reveal a sandy silty loam with frequent pebbles and gravels of up to 1.44 m (KB16) and 2.50 m (KB17). The sandy silty loam overlies medium silty sand in KB16 and a clayey silt unit in KB17.

4.2.3 Archaeological associations for Landform Element 1b are similar to those described for Landform Element 1a, and these surfaces also feature widespread surface lithic scatters of predominantly Mesolithic, and occasional Neolithic age (Waddington 2008). Potential cropmark evidence for undocumented linear archaeological features have been recorded on this surface immediately to the south of the part of the site (Waddington 2008). There remains the potential for other mixed age truncated sites (likely truncated by ploughing) surviving as buried remains which have not manifested as cropmarks.

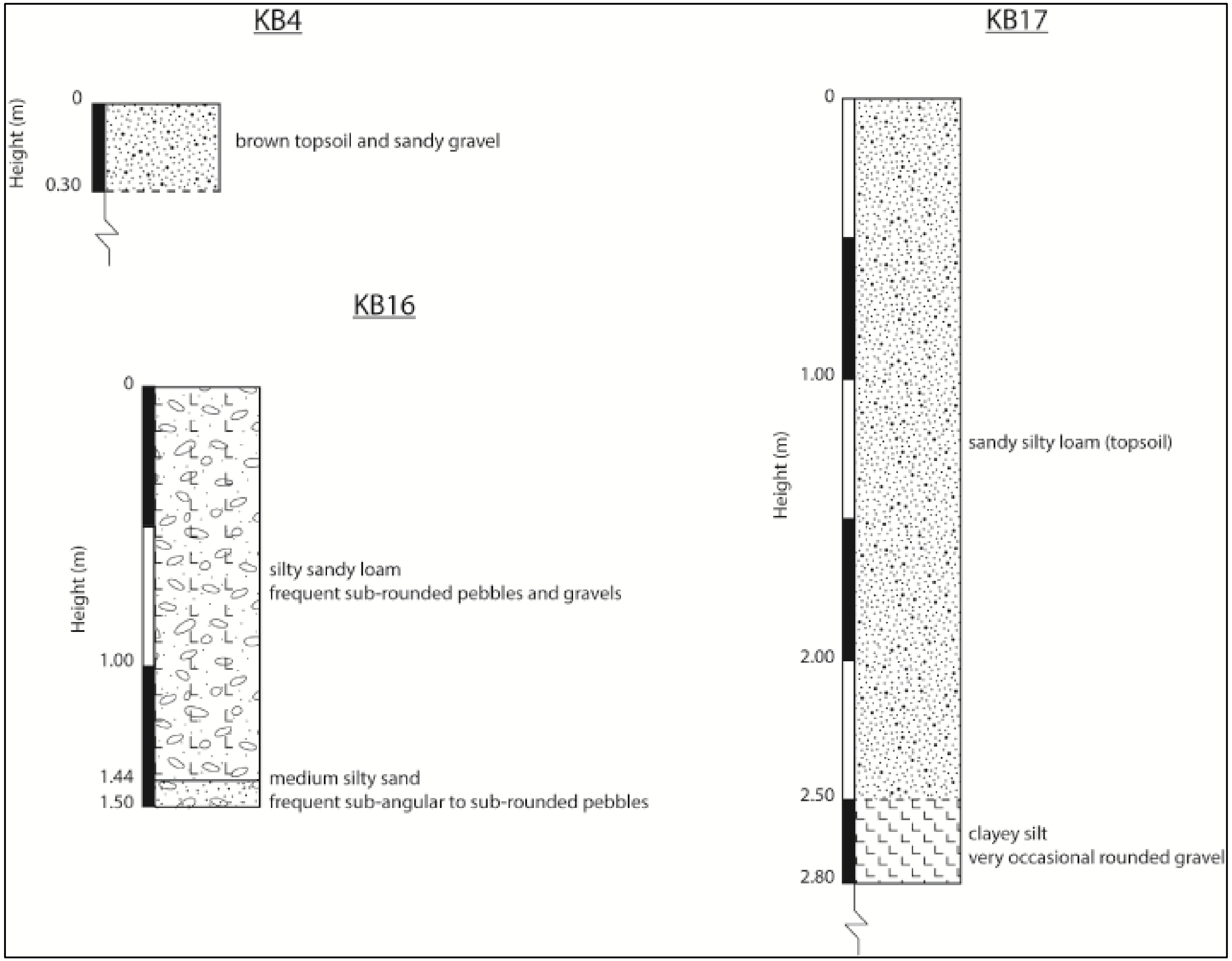

Figure 7. Sediment logs of KB4, KB16, and KB17.

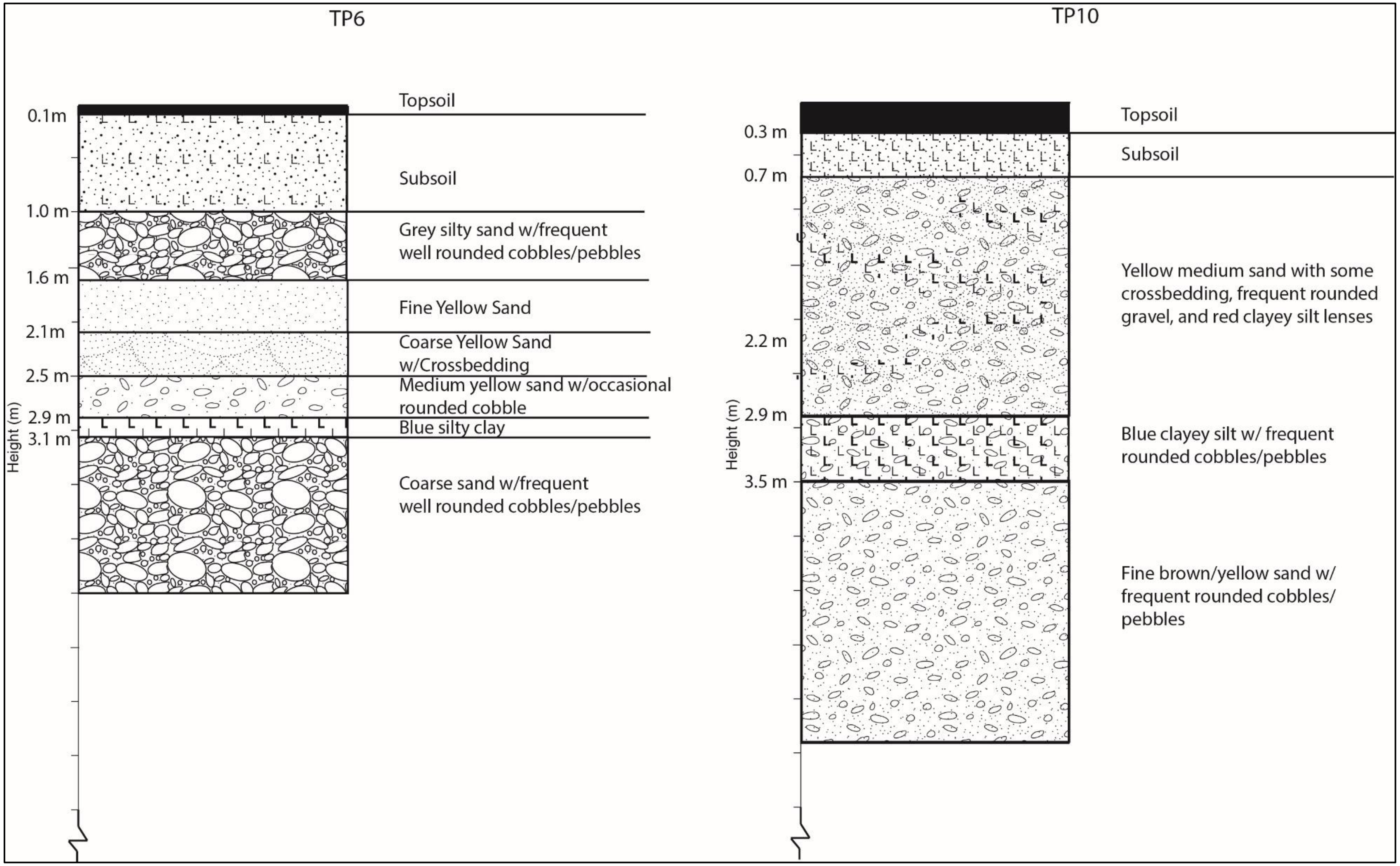

Figure 8. Sediment logs of TP6 and TP10.

4.3 Landform Element 1c: Late Devensian River Terraces

4.3.1 Late Devensian river terrace deposits in the southern portion of the extraction area form low-relief or gently sloping land surfaces that are most extensively developed in a terrace unit that lies inset below the 1b land surface, immediately west of Broad Close Farm (Figure 2). 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 that 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 47 m OD and a sedimentary sequence shown by TP7 (Figures 1, 2, and 9). Sediments in this test pit were excavated to a depth of 2.3 m and exhibit a similar depositional sequence to that revealed in TP6, being capped by 1.2 m of sandy soil and subsoil and dominated by inorganic sands and coarse sandy gravels.

4.3.2 A further upstanding and elongate mound 150 m to the north of the main 1b surface reaches a maximum elevation of 47 m OD and is provisionally interpreted as a Late Devensian river terrace remnant left isolated by subsequent erosion (Figure 2), although a glacio-fluvial (1b) origin cannot be discounted. TP2 revealed a sedimentary sequence comprising 0.9 m of topsoil and gravelly subsoil that overlie three repeating bodies of fining-upward sediment parcels, each *c*. 2 m thick and comprising basal sandy well-rounded gravels that are capped by silty clay and finally clean, cross-bedded sands (Figures 2 and 9). These sediments are consistent with fluvial deposition, most probably in the context of an aggrading, multiple channel system with high rates of sediment supply.

4.3.3 Archaeological associations are similar to those described for Landform Element 1a, and both surfaces feature abundant lithic scatters of mostly Mesolithic and occasionally Neolithic material (Waddington 2008).

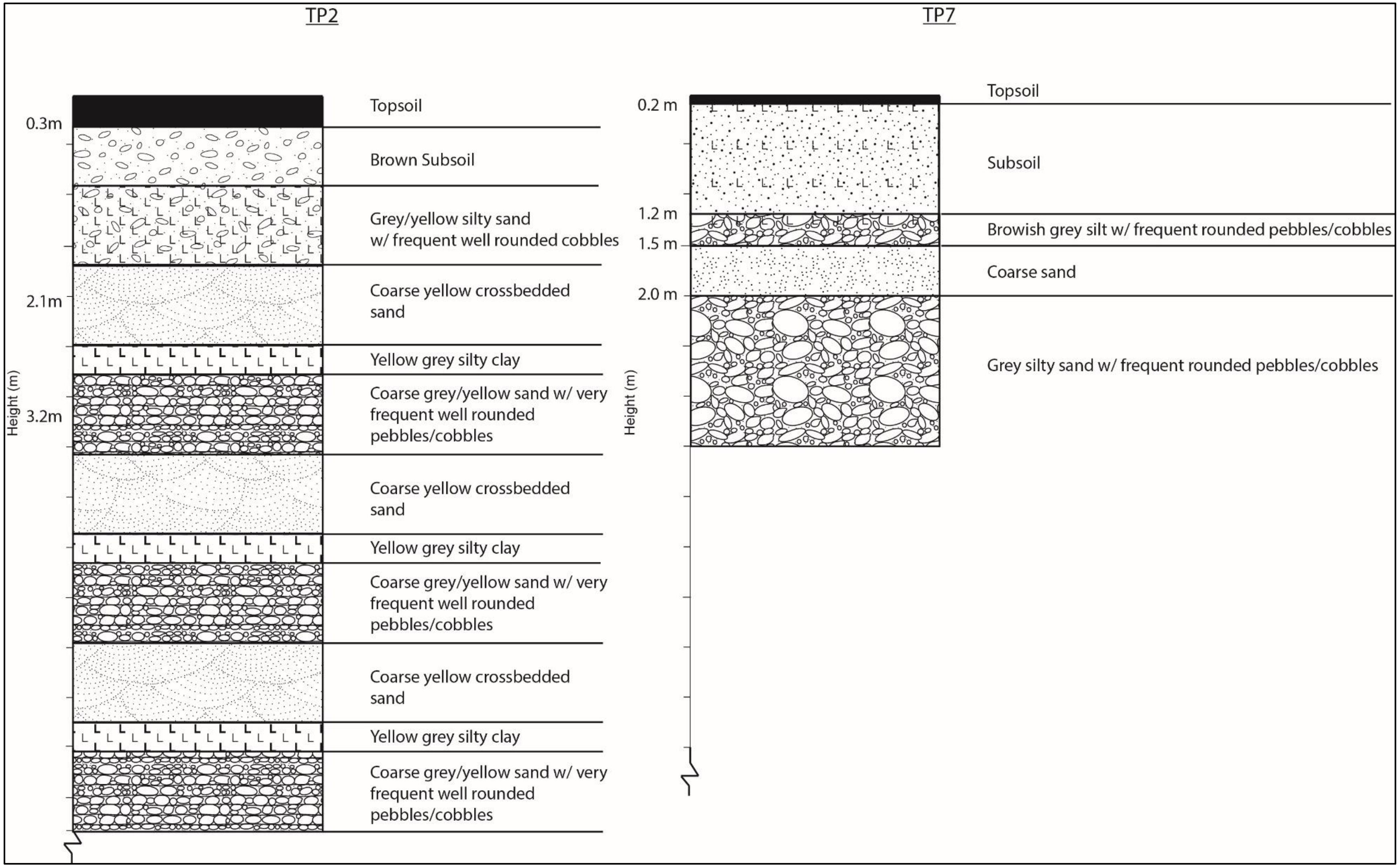

Figure 9. Sediment logs of TP2 and TP7.

4.4 Landform Unit 1d: Late Devensian/Holocene Lower Slopes and Enclosed Basins

4.4.1 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 (Figure 2). 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 glacio-fluvial 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 site and hosts two smaller (2c) kettle-type depressions that are described below. Slope units may extend up to *c*. 46 m OD, but locally they extend to low-relief surfaces as low as 39 m OD that fringe Late Devensian / Holocene low terraces (1e), valley floors (1f) and enclosed basin and kettle hole deposits (2c).

4.4.2 Landform element 1d units originated following isostatic uplift during the later stages of deglaciation which 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.

4.4.3 Sedimentary sequences associated with 1d landforms have been exposed in TP1, TP4, TP9, TP11 and TP13 (Figure 2 and 10). TP1 and TP4 are located on the lower slopes of upstanding river terrace (1d) deposits in the central part of the Extraction Area. Sequences in TP1 and TP4 are broadly similar in their upper 3 m (TP4 terminating at this depth), having relatively thin (0.50-0.70 m) and gravelly soil and subsoils overlying well-rounded gravels in a silty sand matrix (Figure 10). In TP1 these coarse sediments overlie 0.7 m of silty clay before passing abruptly to coarse sandy gravels with a maximum recorded depth of 7 m (Figure 10). TP9 is located 150 m south of the southern portion of the site but is associated with an extensive and continuous lower slope facet of relatively high elevation (48 m OD) till (1a) deposits forming the eastern margin of the site (Figure 10). Sediments exposed here show the uppermost 3.6 m to comprise coarse sands and gravel with a thin (0.7 m) subsoil and soil cap. Below 3.6 m these coarse sediments overlie 0.4 m of well-sorted, cross-bedded sand, 1.2 m of laminated grey clay and then 1.3 m of blue silty clay to the maximum recorded depth (Figure 10).

4.4.4 TP11 (Figure 10) is located in a small valley fill cut into glacio-fluvial sands and gravels (1b) in the western part of the site. The lower part of the fill between 1.7 m and 4 m shows a fining-upward sequence of silty rounded gravels, gravelly silt and a thin (0.3 m) bed of clayey silt. This sequence is buried by 0.9 m of clean, cross-bedded medium sand that in turn is overlain by 0.3 m of poorly-sorted gravelly sandy silt. The sequence is capped by 0.5 m of sandy soil and subsoil. At 42 m OD, TP13 is the lowest elevation pit on Landform Element 1d and exposes sediments forming the uppermost 2.7 m of a low, gently sloping terrace flanking the Late Devensian / Holocene valley floor (Landform Element 1f – see below) in the central part of the site (Figure 2). Sediments here form a fining-upward sequence of silty sandy clay, 0.5 m of laminated clay and 0.8 m of marl below thin (0.3 m) topsoil.

4.4.5 Generally coarse-grained sedimentary sequences in TP1, TP4, TP9 and the lower part of TP11 are consistent with deposition in till or glacial- and glacio-fluvial contexts and in none of these pits (with the possible exception of sediments above 0.8 m in TP11) are the uppermost sediments suggestive of thick accumulation of Holocene colluvium in their immediate localities. A glacio-lacustrine and/or glacio-fluvial origin may also be inferred for relatively well-sorted fine sediments below 3.6 m in TP9, between 0.8 m and 2.0 m in TP11 and the lower part of TP13.

4.4.6 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 Landform Element 1d surfaces (Waddington 2008).

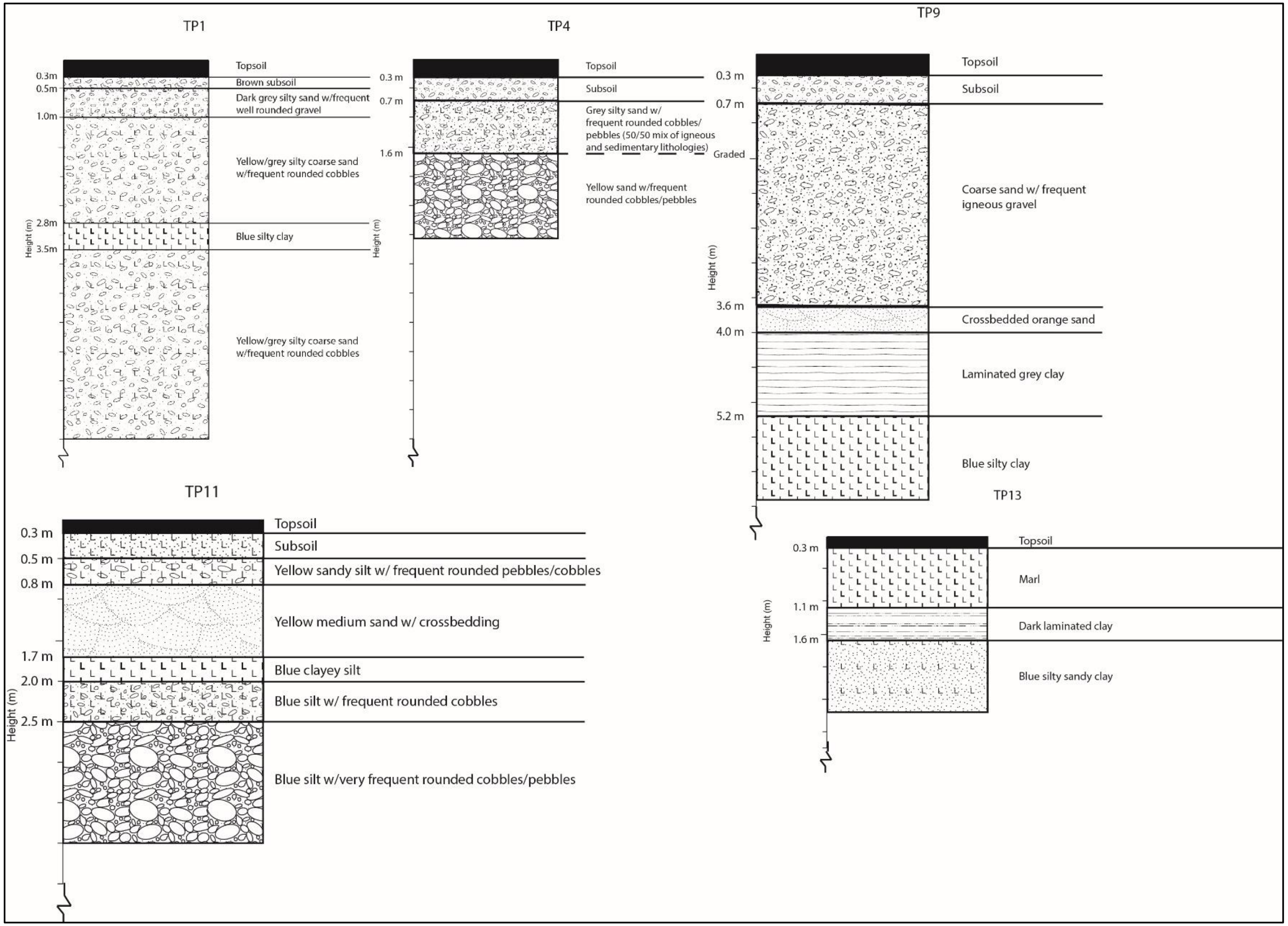

Figure 10. Sediment logs of TP1, TP4, TP9, TP11 and TP13.

4.5 Landform Element 1e: Late Devensian / Holocene Low Terraces

4.5.1 Late Devensian / Holocene low terraces have been mapped in the eastern part of the Phase 1 Extraction Area where they lie between 40-42 m OD and flank the low elevation (<40 m OD) Late Devensian / Holocene valley floors (Landform Element 1f; Figure 2). These are flat or gently sloping terraces that are interpreted as reflecting 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 glacio-fluvial landforms, and alluviation from local tributary streams and possibly also larger flood incursions from the Swale.

4.5.2 TP3 and TP5 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 up to 3.2 m (TP3) and 2.5 m thick (TP5), and dominated by silty sands (Figure 1, 2, and 12). TP5 was terminated at 2.5 m, but TP3 was excavated to 6.5 m in depth through grey silty sands with frequent well-rounded (fluvial) gravels. TP18, located on the rising southern margin of this terrace near Broad Close Farm (Figure 2), revealed a thinner (0.65 m) topsoil and silty clay marl subsoil overlying 1.25 m of gravelly silty clay (Figure 13). These relatively coarse and poorly-sorted sediments may reflect, at least in part, colluvial (or plough-zone) input from the adjacent (1d) slope unit. Below these coarse sediments is a thin (0.3 m) bed of silty clay that in turn overlies at least 1.3 m of sandy well-rounded (fluvial) gravels.

4.5.3 TP8, located in the southern part of Landform Element 1e, reveals coarse silty sand with pebbles and cobbles (Figure 1, 2, and 13). These coarse sediments overlie 1.55 m of finer silty clay, which becomes coarser at 1.9 m by moderately rounded pebbles. This unit is overlain by 0.30 m of marl sediments. Sediment core KB18, located at the northern edge of the southern portion of the site, has shown a 2.15 m deep sequence of clay and silt sediments, with fine sand laminations and organic materials in the bottom 0.75 m of the core (Figures 1, 2, and 13).

4.5.4 Outflow channels have been identified on the eastern margins of the high-elevation area (Landform Element 1a) which borders the southern edge of the Holocene alluvial valley floors and Holocene palaeochannels (Landform Element 1f and Landform Elements 2a/2b). This area forms the sole narrow outlet for the network of basins and valley floors. These are currently linked via drainage ditches to Fiddale Beck. A palaeochannel (KB23) (Figure 1 and 3) from this outlet was cored and displayed a combination of sand and silt deposits (Figure 11). This is indicative of water drainage from the Late Devensian/Early Holocene Valley Floors (Landform Element 1f) which would have drained into the Holocene alluvial valley floors (Landform Elements 2a/2b.

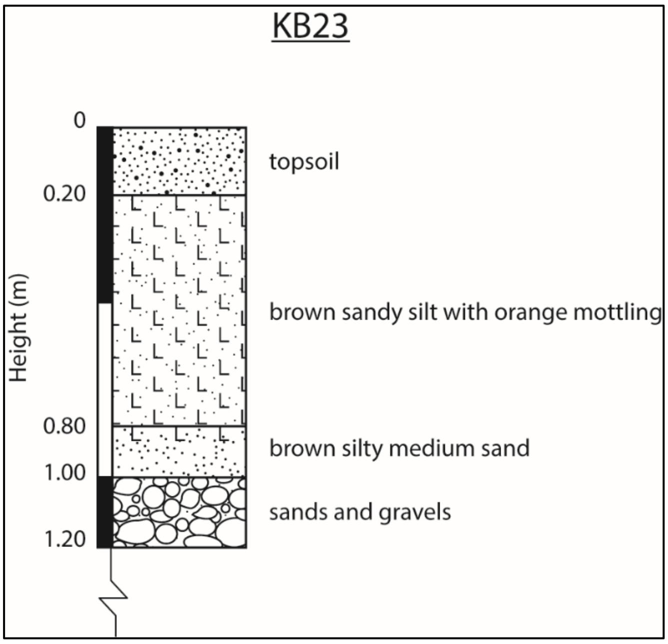

Figure 11. Sediment logs of KB23

4.5.5 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.

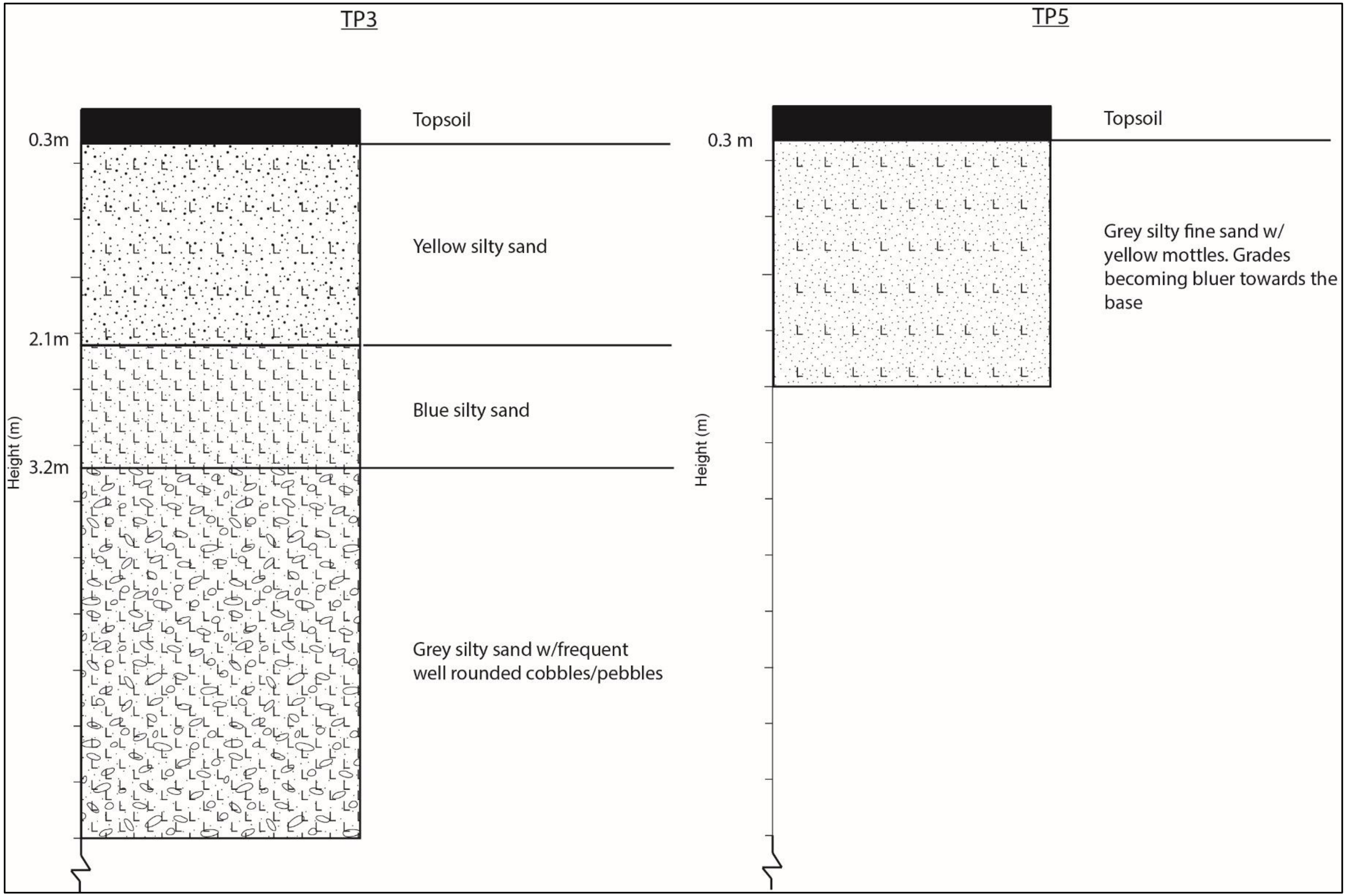

Figure 12. Sediment logs of TP3 and TP5.

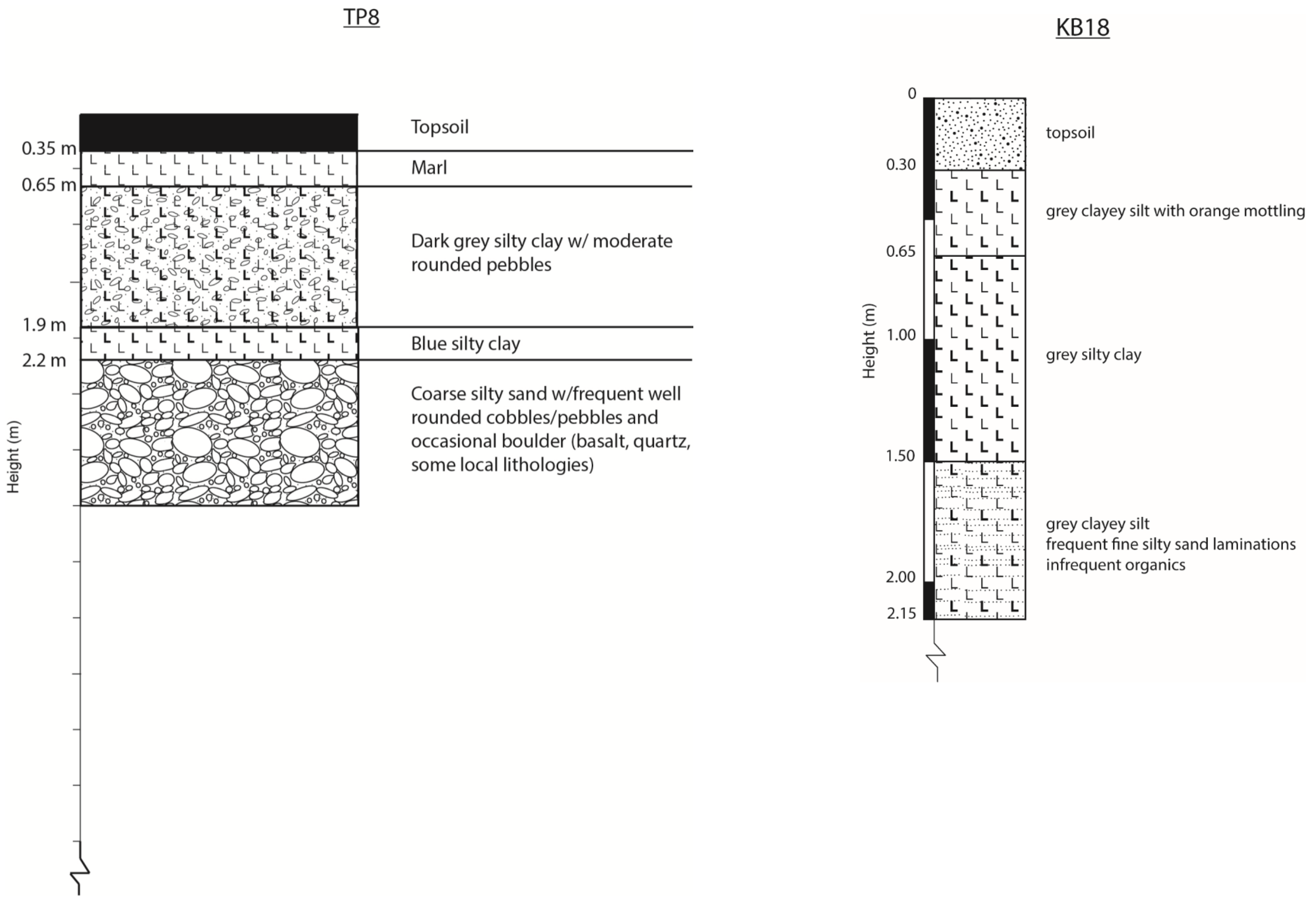

Figure 13. Sediment log of TP8 and KB18.

4.6 Landform Element 1f: Late Devensian / Holocene Valley Floors

4.6.1 Late Devensian / Holocene valley floors have been mapped as discrete low-relief surfaces in the western, central and eastern parts of the southern portion of the site (Figure 3). They lie at elevations of 46 m, 42 m and 39 m OD, respectively, and form part of a larger and partially connected low-lying valley network within this part of the Leeming Moraine complex centred on Killerby Hall. These low-relief surfaces are illustrated in the deposit model (Figure 5) as discrete, low-lying, peat and marl-filled basins. 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 (Figure 3). These low-lying landscapes are interpreted as reflecting the final phase of 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.

4.6.2 TP14 and TP15 assessed valley fill sediments in the central part of the site (Figures 1, 2 and 14). The latter sequence comprised a thin topsoil and 0.35 m of marl that overlay poorly-sorted gravelly silty clay to a depth of 2.2 m (Figure 14). A similar sequence was revealed by TP14 except here a bed of silty clay (0.65 m thick) separated the marl and coarser basal sediments (Figure 14). Core KB1 was located in a low-elevation depression and yielded 2 m of fine-grained inorganic sand, silt and clay that become clean, well-laminated and increasingly sandy below 1.20 m (Figure 15).

4.6.3 TP16 (Figure 15), located towards the northern portion of the western basin and at the northernmost extent of the planned quarry area (Figures 1 and 2) revealed a sequence of relatively coarse silty sand, overlain by mottled orange clayey silt, followed by a layer of marl. The orange mottling within the clayey silt reflects oxidised sediment associated with intrusion of plant roots. To the north of these sediment cores a BGS borehole (SE29NE23) has shown 0.60 m thick silt sediments rich in organics which overlie glacio-fluvial sand and gravel (Figures 1, 2 and 18). A coarser sandy silt unit containing shells and ostracods overlies the silt sediment. The sequence is capped by 1.40 m of silty peat rich in organics. These two cores are located within what would have been the northernmost extent of this topographic depression. The silty sands and clayey silts of TP16 and BGS SE29NE23 are interpreted as fluvial deposits associated with active drainage of the depression. The switch to marl formation within TP16 (as well as TP14 and TP15) is likely indicative of the depression becoming isolated from the outflow channel (described below) and forming a still body of water within which authigenic sedimentation could occur. The deeper part of the depression, classified here as part of Landform Element 2c (and therefore described below), also contained marl formation as a result of this process. Marl formation likely ceased within these sequences as the water depth within this depression became too shallow for authigenic calcium carbonate production to occur.

4.6.4 KB18, KB19, and KB20 are all located at the northernmost extent of the southern extraction area within what is interpreted as being a drainage channel which linked the two main basins together (Figures 1 and 2). Cores KB2, KB3, KB7, KB8, KB21, KB22, KB25, KB26, and KB27 were all located within the eastern basin which spans the north-easternmost section of the southern extraction area and which is planned to be used as a soil bund (Figures 1 and 2).

4.6.5 KB19 (Figures 1 and 2) has revealed glacio-fluvial sands and gravels, which are overlain by 1.26 m of clayey silt sediment, followed by a 0.34m thick sand unit with a silty component in the top 0.30m. Sediment core KB20 and KB21 (Figure 15) have shown a similar sequence of clay and silt (1.65m deep in KB20 and 1.85m deep in KB21) overlain by medium sands then topsoil. KB20 has also revealed a second clay silt unit of 0.20m, rich in organic materials, which is overlain by around 0.4m of peaty sediment (Figure 16).

4.6.6 KB22 revealed 3.60 m of organic-rich peat, which was interspersed with yellowish grey clay bands at 0.90m, 0.10m, and 0.15m and a clay unit at 0.25m (Figure 16). KB25 and KB26 show the same sedimentary sequence of organic-rich peat (with distinct bands of sphagnum moss in KB25) which underlies a clay silt unit (Figure 17)). A 0.40m grey sandy silt unit separates the peat and clay silt sediments in KB26. The peat layer can also be seen in KB27 (Figure 17), which is clay-rich and buries laminated sandy marl, where this sequence ends. These sediment cores illustrate that Holocene sediments have accumulated in variable thicknesses and show a good degree of preservation of organic materials, such as *Sphagnum* moss.

4.6.7 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 Landform Element 1f has been strongly conditioned by late Devensian geomorphological events, it is 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 the small basins and palaeochannels that have yet to be assessed for their local sedimentary sequences.

4.6.7 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 southern portion of the site, 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.

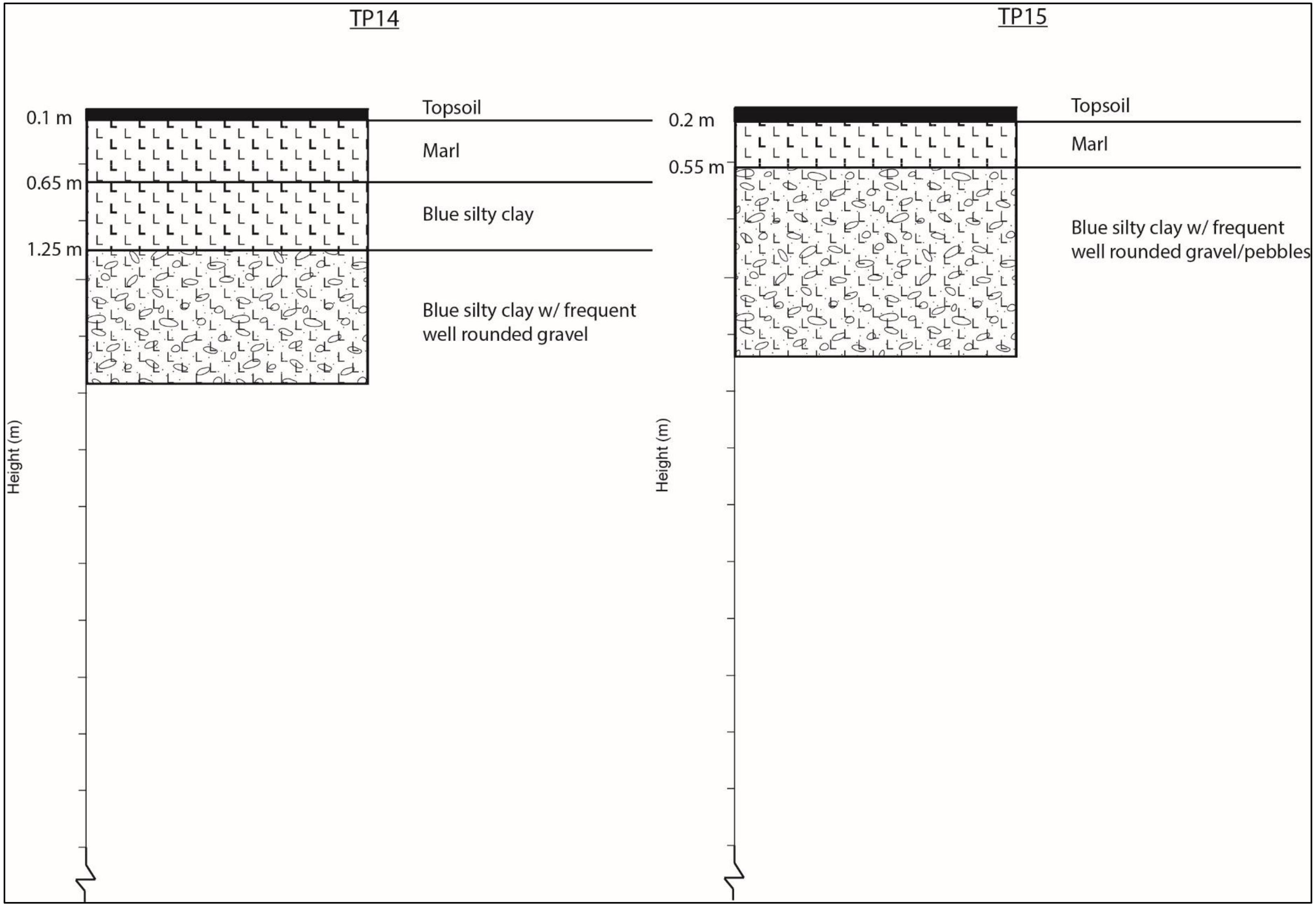

Figure 14. Sediment logs of TP14 and TP15.

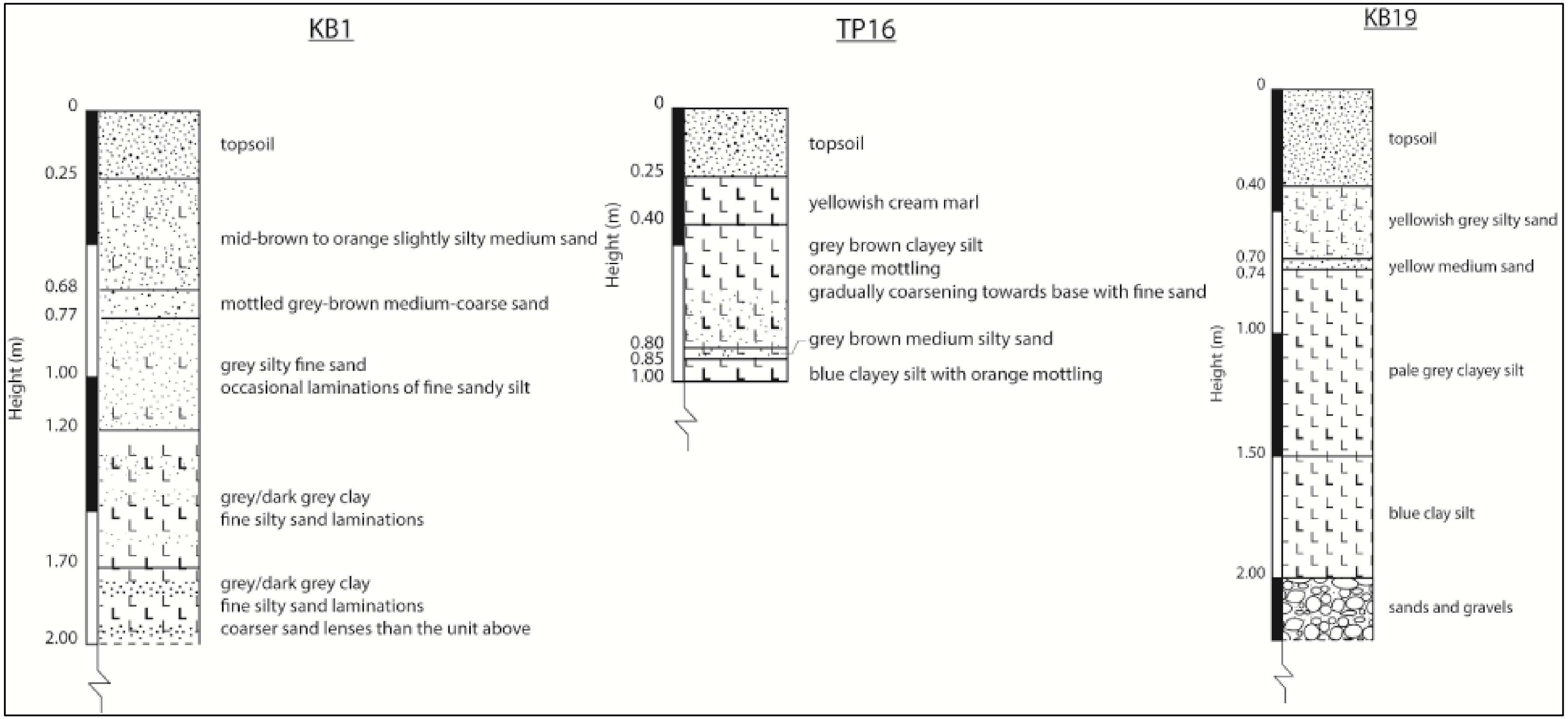

Figure 15. Sediment logs of KB1, TP16, and KB19

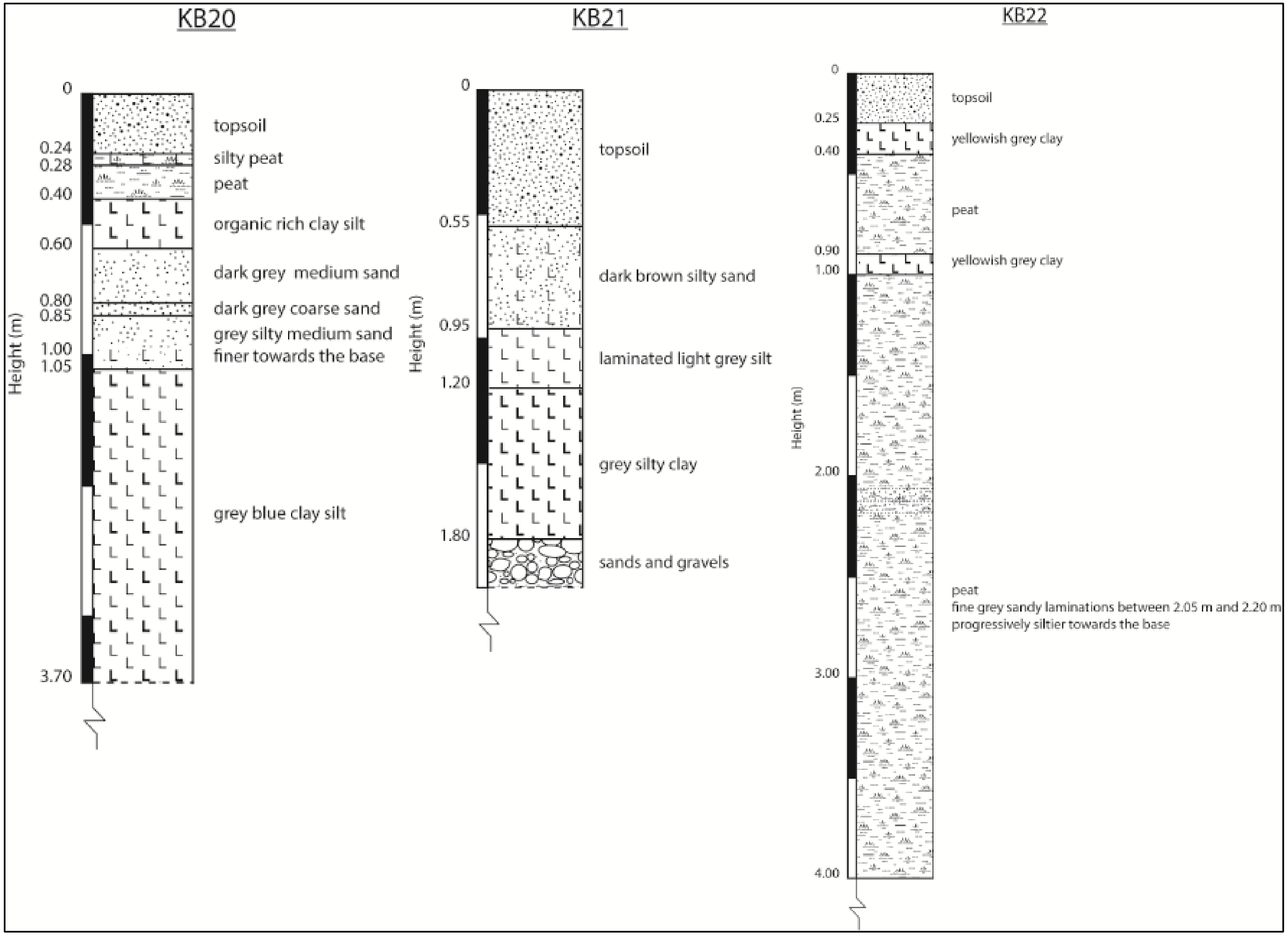

Figure 16. Sediment logs of KB20, KB21, and KB22

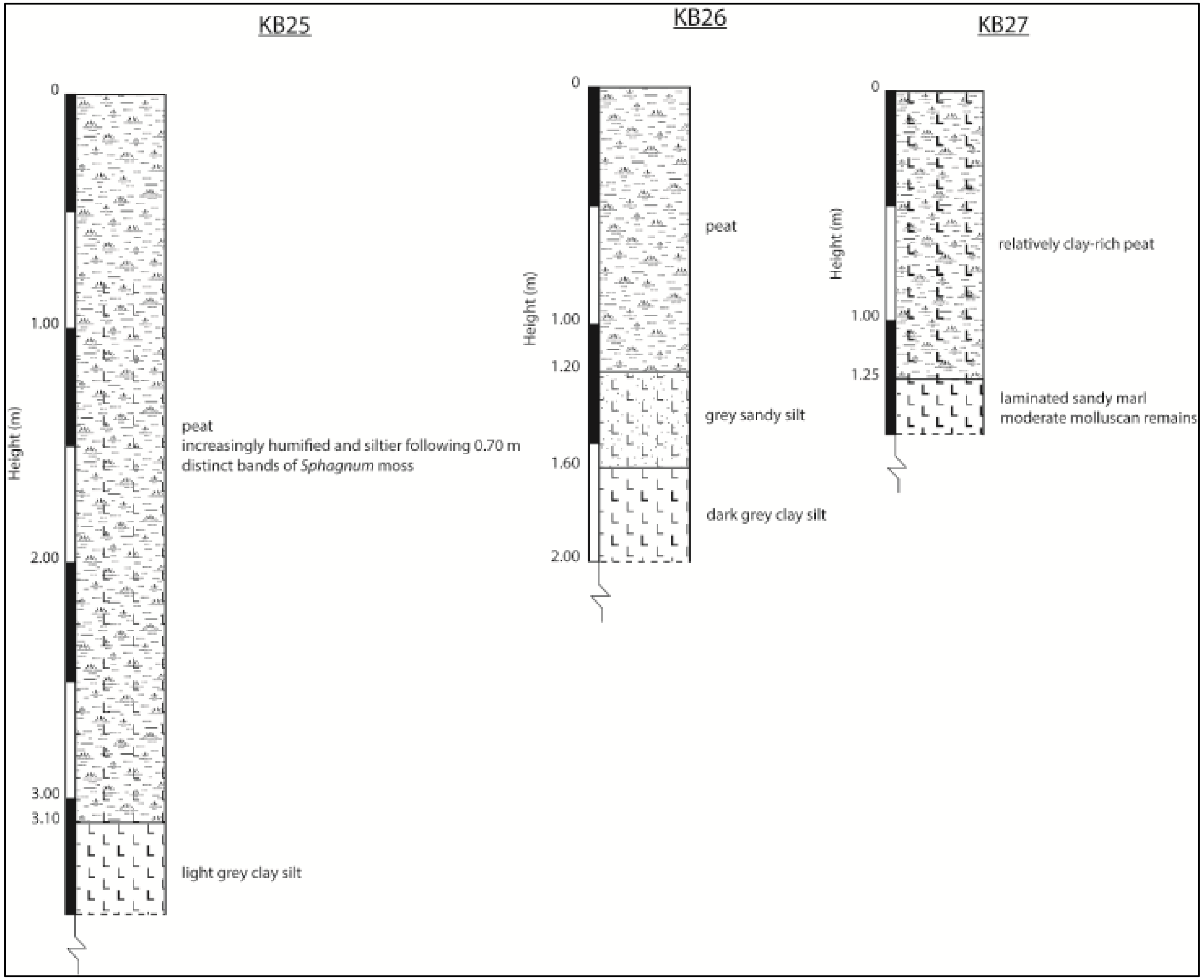

Figure 17. Sediment logs of KB25, KB26, and KB27

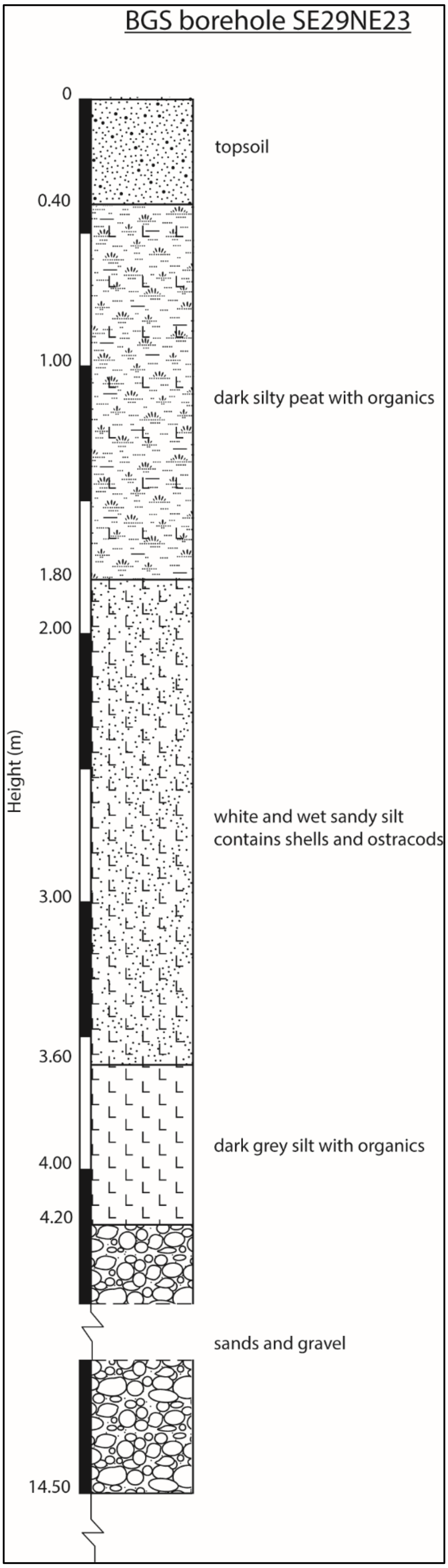

Figure 18. Sediment log of the BGS borehole SE29NE23.

4.7 Landform Units 2a and 2b: Holocene alluvial valley floors and Holocene palaeochannels

4.7.1 Holocene alluvium (2a) is extensively developed at lower elevations (*c.* 35-40 m OD) flanking the present River Swale and forms all bar the southerly extent of the northeastern portion of the site (Figure 3). These deposits feature a complex suite of cross-cutting meandering palaeochannels (2b) that are representative of shifting Holocene channel courses associated with lateral migration and(or) channel avulsion of the River Swale in this part of the valley floor (Figure 19). An area of Ellerton Quarry to the north of the Swale has also been mapped for palaeochannel identification purposes as part of this study on account of this area being traversed by the planned quarry conveyor belt and extraction also taking place here (Fig. 20). Ordnance Survey maps (1st edition, County Series and later) indicate that channel and bar development of the River Swale since the mid-nineteenth century has been focused in an area between c.100-200 m wide and confined within prominent flood embankments. Accordingly, palaeochannels evident on these alluvial surfaces pre-date the mid-nineteenth century (Figures 19 and 20).

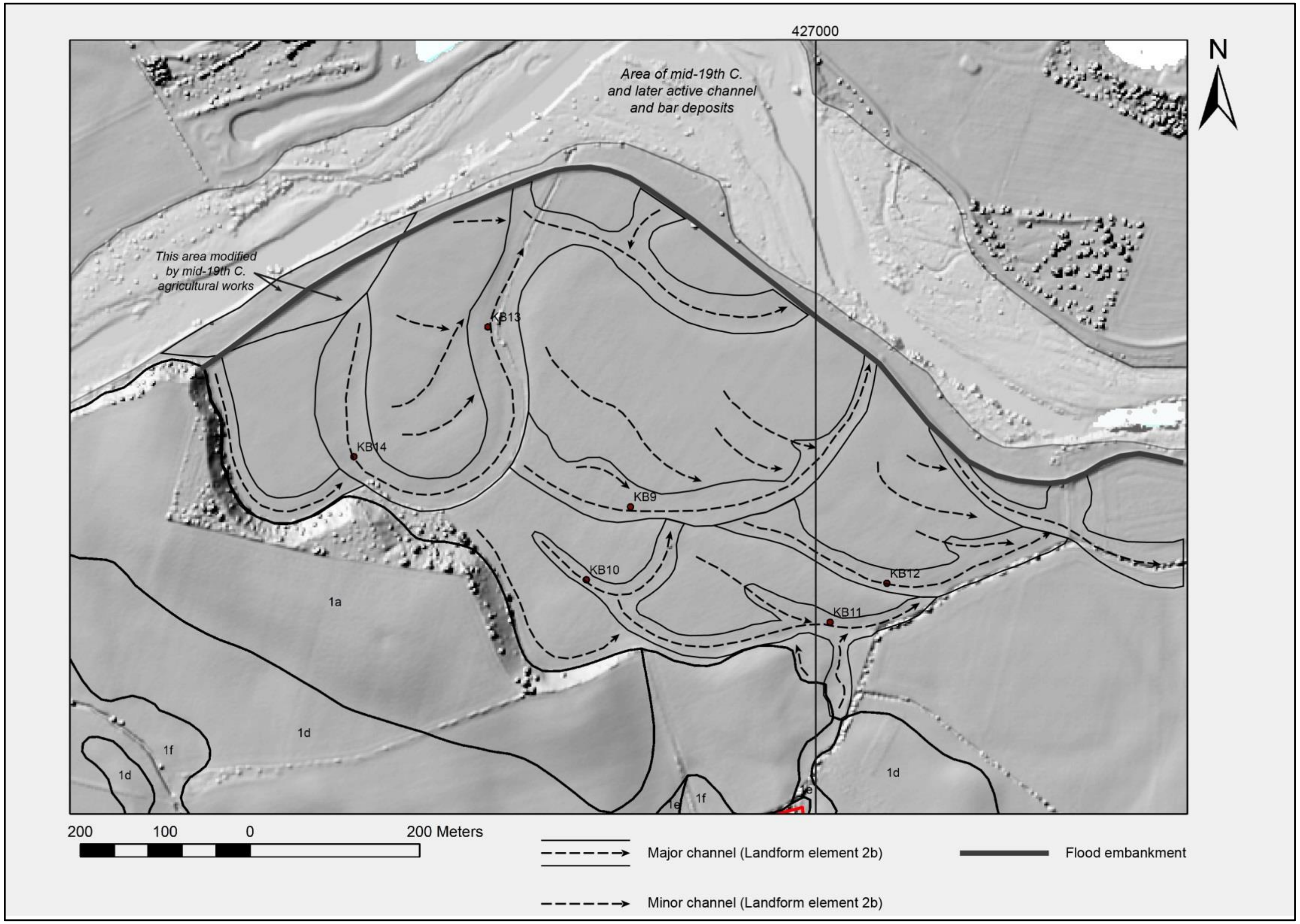

Figure 19. Holocene palaeochannels of the river Swale within the Holocene alluvial valley floor area (Landform Elements 2a and 2b) superimposed over hillshade LiDAR in the north-east area of the site.

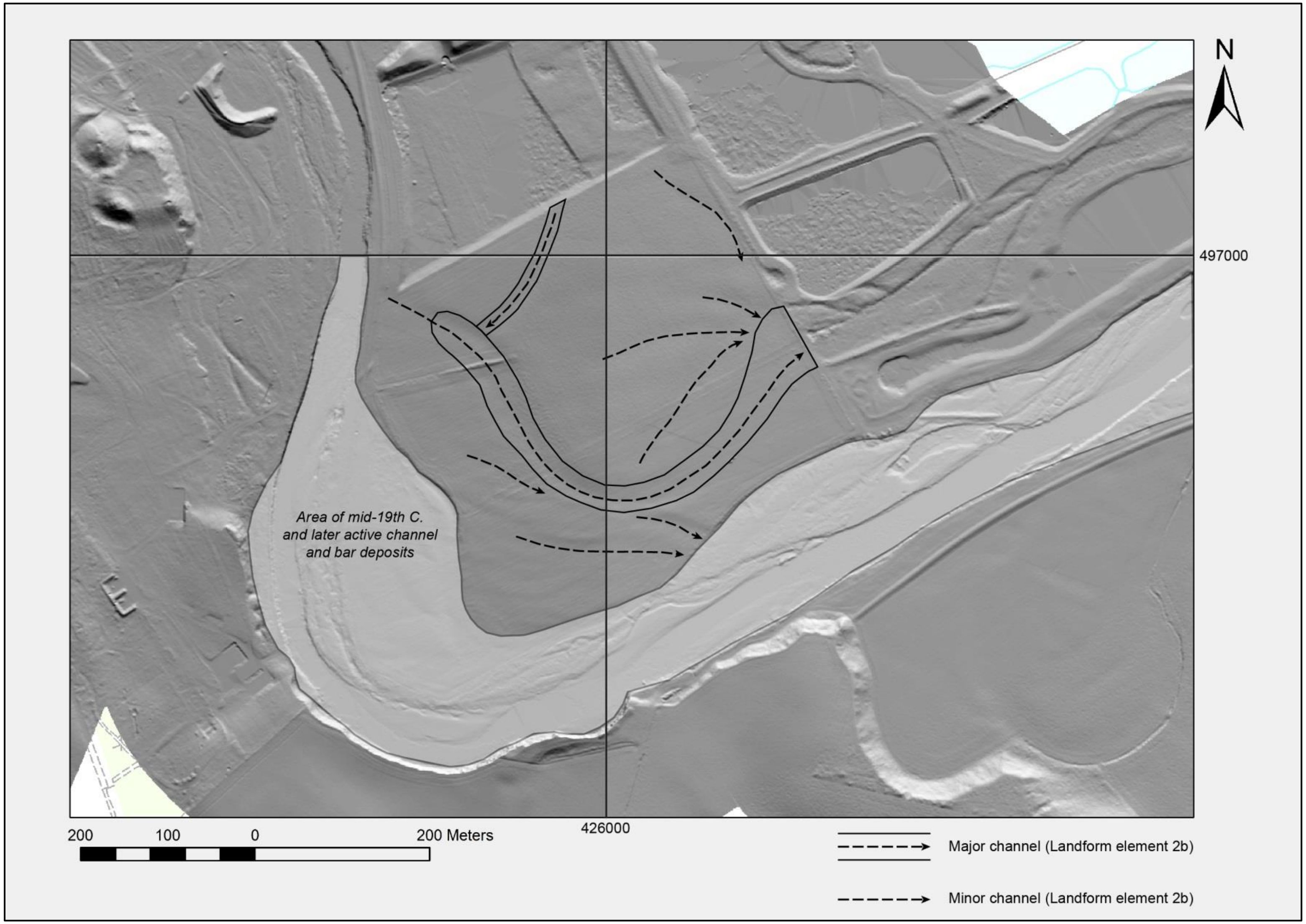

Figure 20. Holocene palaeochannels (Landform Elements 2a and 2b) on the opposite side of the river Swale in the area of Ellerton Quarry superimposed over hillshade LiDAR.

4.7.2 A total of six sediment cores (KB9, KB10, KB11, KB12, KB13 and KB14) were extracted from four of the most well-defined palaeochannels in the northeastern portion of the site (Figure 3). On morphostratigraphic grounds these become younger from south to north with the oldest channel fragment lying along on the southern margin of the valley floor (KB10, KB11). The downstream limit of this channel fragment is truncated by a channel of similar size and meander curvature to the northeast (KB12), and both are truncated to the north by a large palaeomeander cored at KB9. This meander is in turn cut by the most prominent and deepest meander bend to the northwest (KB13, KB14; Figures 3 and 19)

4.7.3 Fine-grained channel fill sediments in the most southerly channel at KB10 reached a thickness of 1.90 m above channel bed gravels and included a bed of silty macrofossil-rich peat between 1.50-1.75 m (Figure 21). This unit has been ^{14}C dated at 1.55 m to *c.* cal AD 560-770 (SUERC-26097) and has a pollen assemblage between 1.55-1.65 m that is characteristic of a sedge-alder fen carr (Hopla and Gearey 2009). KB11 sampled a palaeo-channel fragment on the northeastern margin of the site and here the fine-grained channel fill sequence reached a depth of 1.50m (Figure 21). The lower part of the sequence between 1-1.50 m was found to comprise humified peaty silt that has been ^{14}C dated at 1.12 m to *c.* cal AD 430-650 (SUERC-26098) and has a pollen assemblage between 1.10-1.20 m that is characteristic of largely treeless open grassland with areas of pasture and arable cultivation. Radiocarbon dates for the lower part of the KB10 and KB11 channel fills indicate these palaeochannel fragments were abandoned sometime before the late-Roman or early Anglo Saxon period and their overlapping age spans suggest they may have been part of a contemporary channel system.

4.7.4 Channel fills sampled by cores KB12 and KB9 were found to reach a thickness of 1 m and 0.60 m, respectively, above gravelly bed material and comprised fining-upward inorganic sands and silts (Figure 22). No radiocarbon dates were obtained from these sequences, although it is interesting to note that the downstream part of the younger of these channels (extending northeast from the site of KB9) is traced by part of the parish boundary and may therefore have been active or a prominent wetland during or shortly before the medieval period.

4.7.5 KB13 and KB14 were taken from the downstream and upstream parts, respectively, of a large palaeo-meander loop in the north-west part of the north-eastern portion of the site (Figure 22). On the basis of morphostratigraphic relationships this constitutes the youngest channel fragment investigated for its sedimentary fills. Here Sediment coring exposed fine-grained channel fill deposits to reach a thickness of respectively 1.33 m (KB13) and 2 m (KB14) above former channel bed gravels (Figure 22). Channel fill sediments in KB13 comprised progressively fining-upward sands and silts with little organic content, and similarly fine and inorganic sediments overlying gravels are also evident to a depth of 0.8 m in a BGS borehole (SE29NE18) located 140m to the south (Figure 23). The deeper channel fill sequence in KB14 (Figure 22), however, featured humified peat and organic-rich silty sediments between 1.38m-1.75m that have been ^{14}C dated at 1.64 m to *c.* 400-200 cal BC (SUERC-26102). Pollen analysis of KB14 sediments between 1.60-1.70 m indicates that the contemporary landscape in the vicinity of the palaeochannel featured a mixed woodland assemblage (dominated by hazel and alder) with areas of open grassland and heathland.

Radiocarbon dating of channel fill sediments at KB14 suggests this palaeochannel was abandoned sometime during the mid-Iron Age, but this date is inconsistent with the age-sequencing of palaeochannels to the east and south that are inferred by morphostratigraphic relationships to be older and yet have younger radiocarbon dates (KB10 and KB11; Figure 21). It is recognised, however, that these single radiocarbon assays give only a provisional age estimate for their associated fills and that the radiocarbon dates are derived from the upper levels of the respective organic-rich units; further dating assays of material closer to the basal contact with former channel bed materials will facilitate a more robust estimate of the chronology of channel abandonment, while assessment of additional channel deposits elsewhere across the valley floor can also be expected to help resolve the chronology and morphostratigraphic relationships of these palaeochannel remnants. Nevertheless, and notwithstanding these limitations of the data, the available dating controls for Holocene channel fill deposits constitute evidence of frequent and widespread lateral channel shifts over at least the past *c*.1500 years at Killerby, and possibly also from the later prehistoric period. Pollen analyses of these fills suggest that floodplain and nearby elevated terrace environments during the late prehistoric and early historic periods at Killerby supported a patchwork of sedge-alder car in wetter palaeochannel settings while drier parts of the valley floor were becoming increasingly cleared of woodland as pasture and, by the early medieval period, cereal cultivation became widespread.

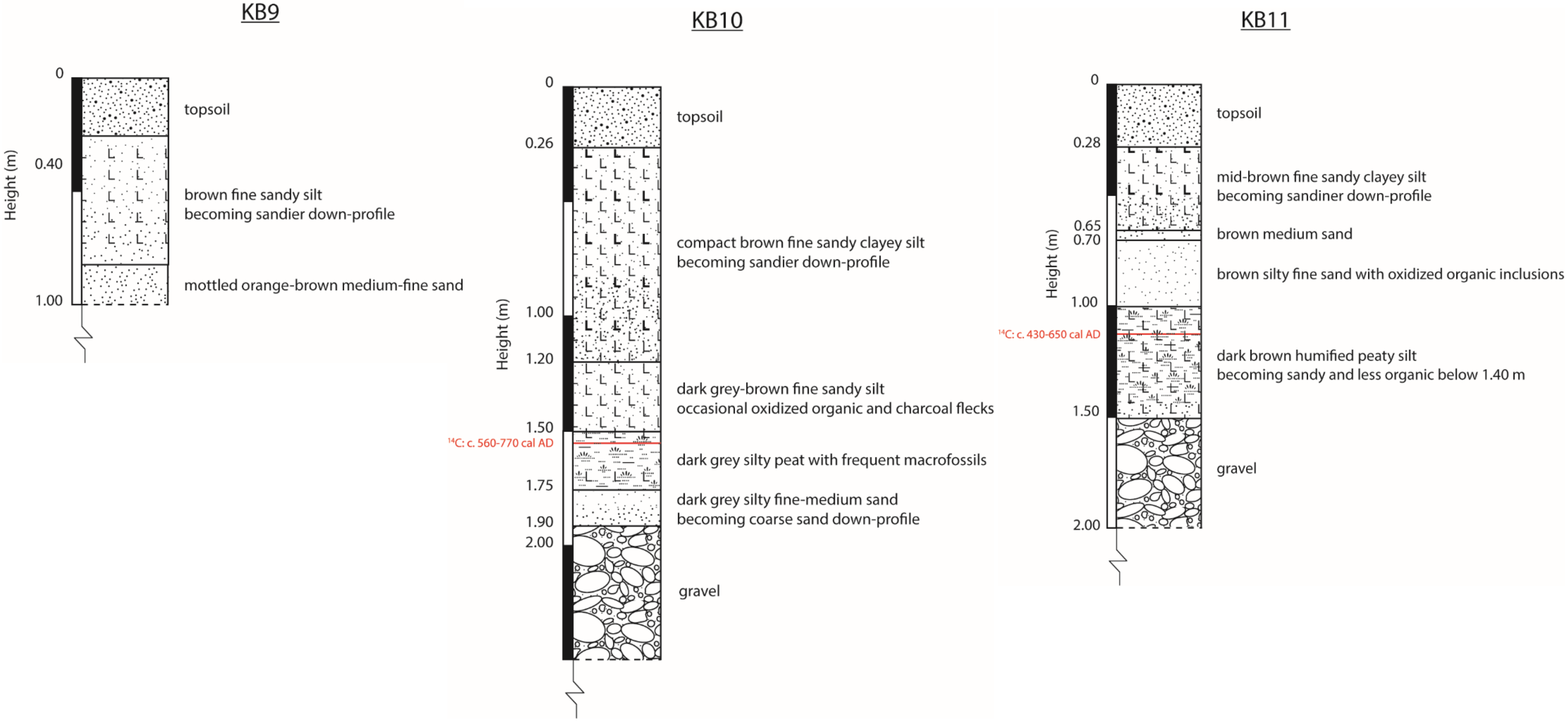

Figure 21. Sediment logs of KB9, KB10 and KB11.

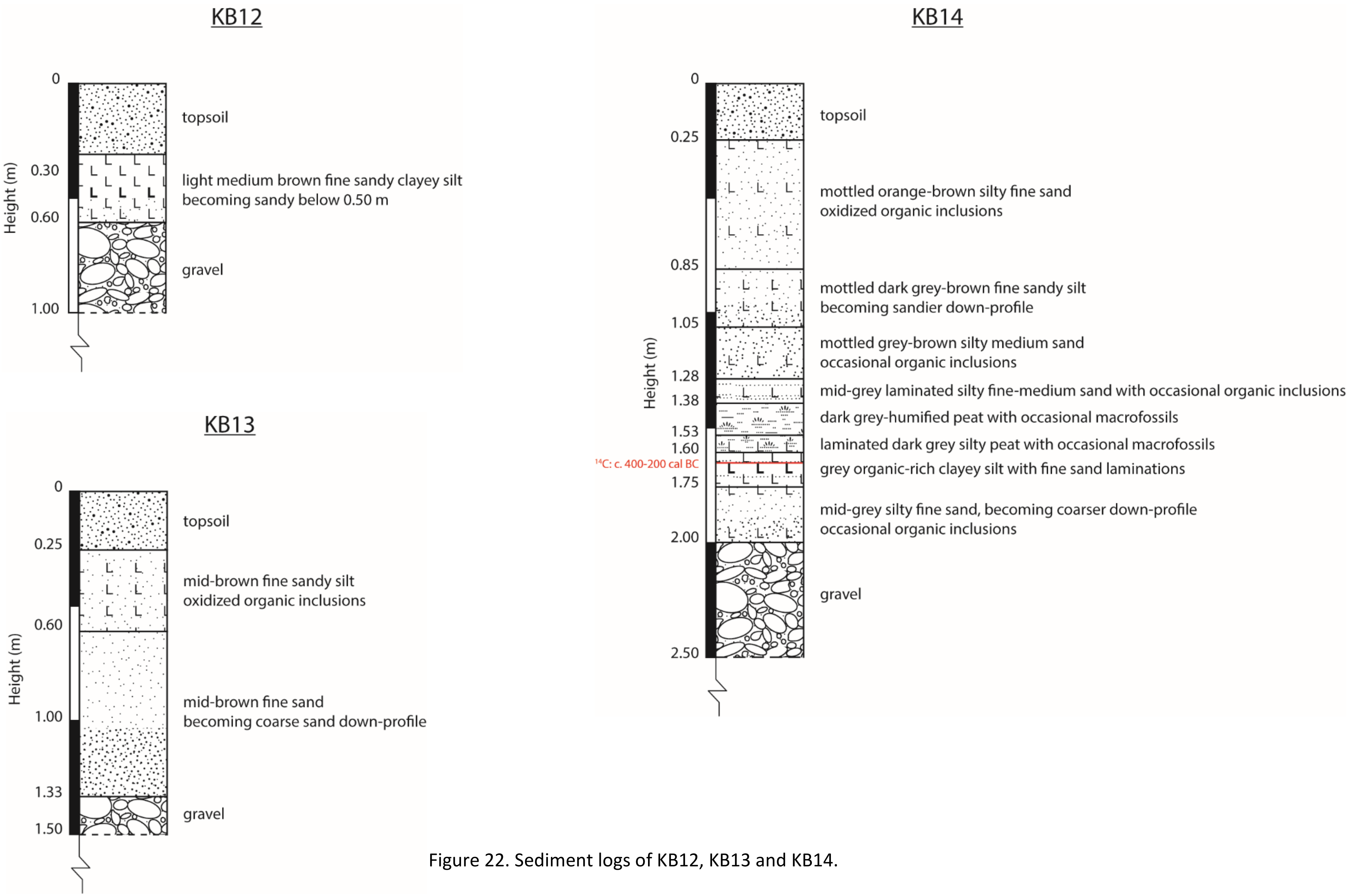

Figure 22. Sediment logs of KB12, KB13 and KB14.

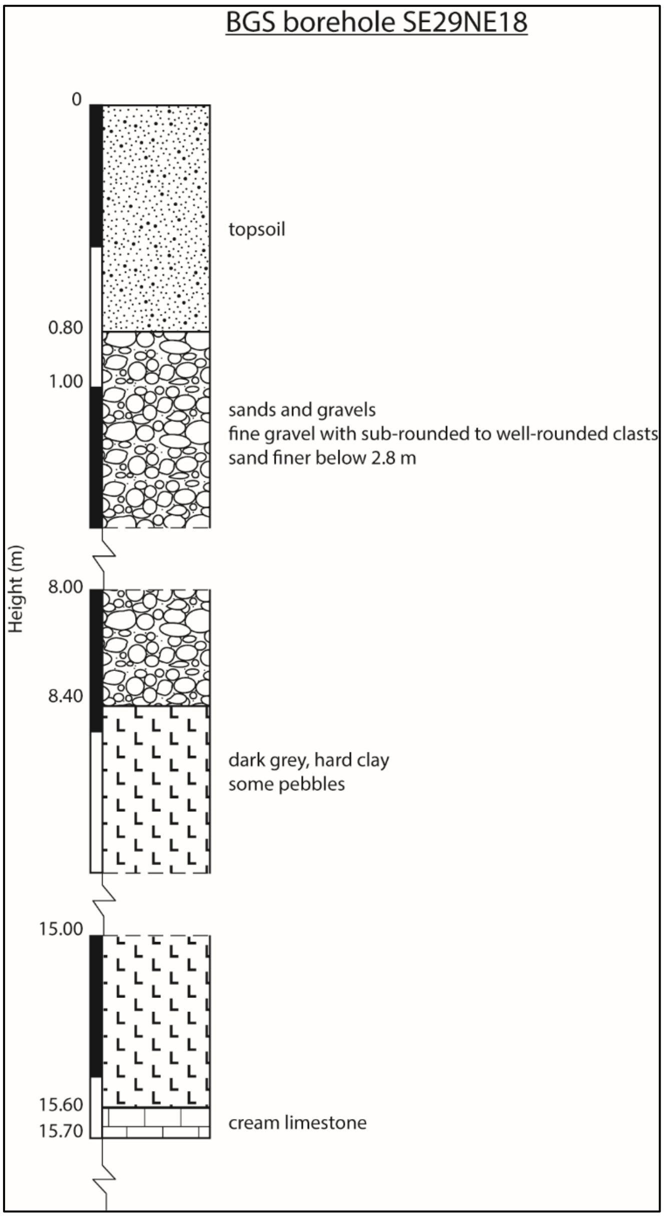

Figure 23. Sediment logs of BGS borehole SE29NE18.

4.8 *Landform Element 2c: Late Devensian and Holocene basin and kettle hole deposits (peat)*

4.8.1 Enclosed basins and smaller sub-circular depressions have been mapped in both low-lying (1f) and high-elevation (1a/d) parts of the southern portion of the site (Figure 2). They are interpreted as reflecting the melt-out of ice blocks (e.g. kettle holes) and associated subsidence during regional deglaciation 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.

Figure 24. Identified kettle-like depressions (2c) within the eastern depression of the quarry's plant site alongside minor cross-cutting palaeochannels (2b). Red dots indicate core sample locations.

4.8.2 Within the low-lying basin of Landform Element 1f in the western part of the southern portion of the site (Figure 2) KB6 revealed a sharply defined sediment sequence (pictured in Figure 25) containing a layer of organic-rich, peaty silt, which immediately overlay glacial clay. This organic-rich peaty silt was overlain by shell-rich marl, followed by more organic-rich silt which gradually became peatier towards the surface (Figure 26). This sequence reflects the organic-rich water body becoming isolated from the outflow channel, which resulted in marl formation, followed by deposition of dark brown peat as the water body became shallower as described in Landform Element 1f. This sequence was sampled for pollen analysis which is reported in detail elsewhere (Parker *et al.* 2018) and is briefly summarised below.

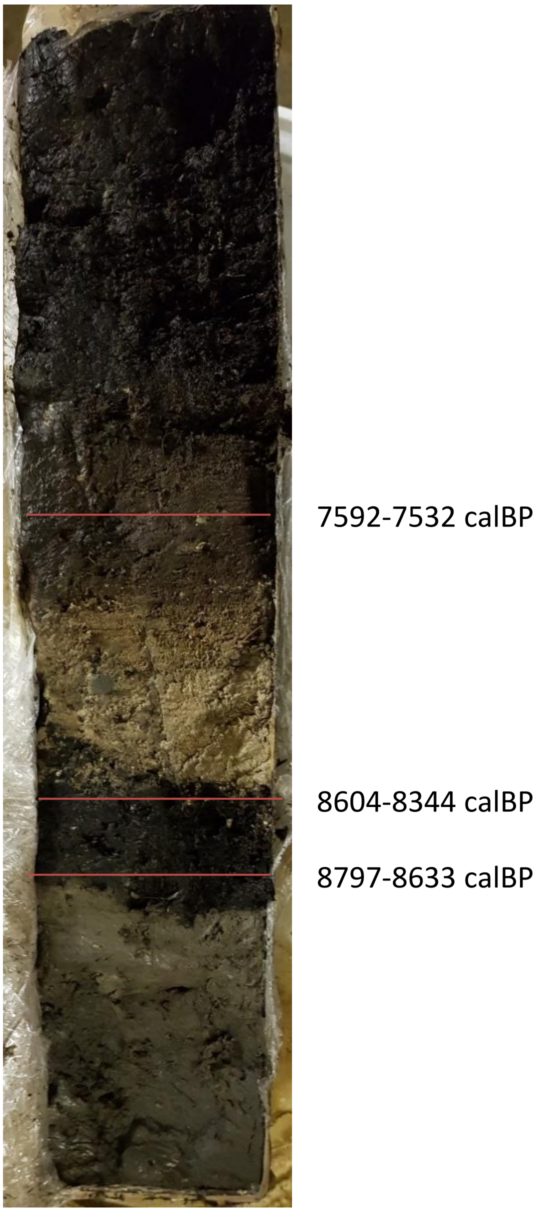

Figure 25. Monolith of the sediment sequence extracted from KB6 including the sample locations of radiocarbon dates.

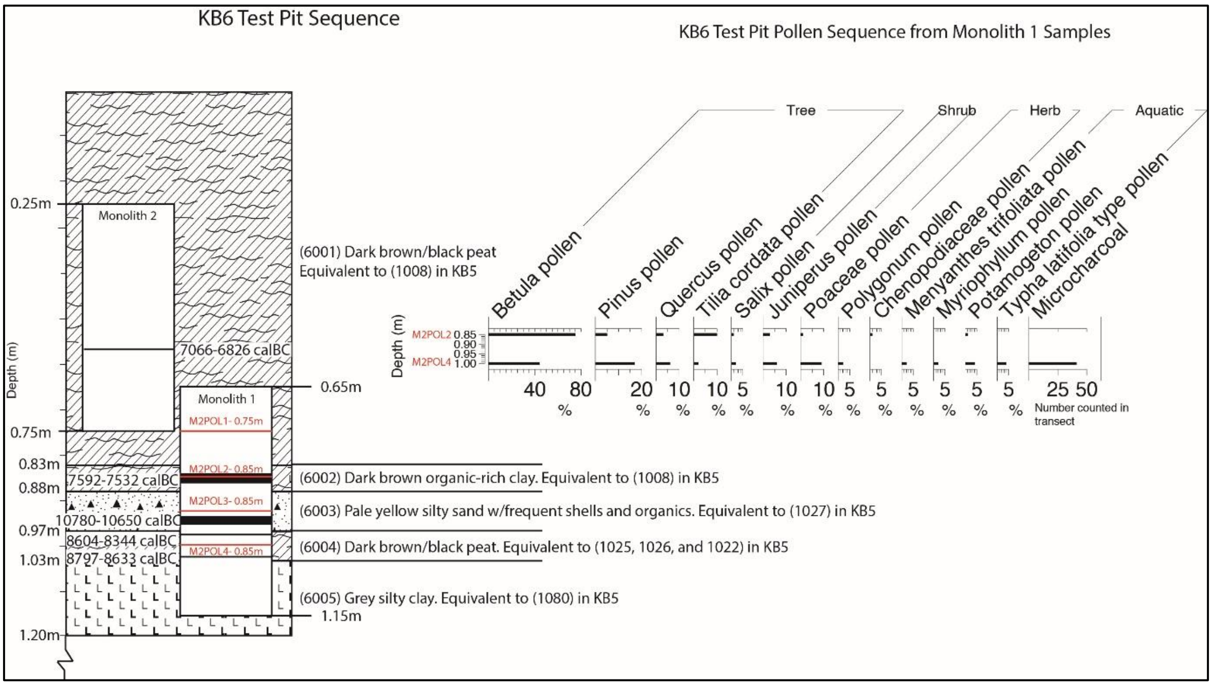

Figure 26. Stratigraphy of the KB6 sequence, alongside radiocarbon dates and pollen sub-sample depths. Pollen sequence also detailed, however only two of the four sub-samples yielded sufficient identifiable pollen.

4.8.3 The pollen sampled from the lowermost peat layer (6004) contained significant quantities of *Betula*, as well as the presence of *Quercus* and *Tilia* which is indicative of an early Holocene sequence (Figure 26). This dating inference is consistent with bulk-sample radiocarbon dates that indicate around half of the KB6 sediment sequence dates to 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 50cm of sediment between these two dates represents only c.1800 years of deposition. Accordingly the Early Holocene in this sediment sequence appears to be a period of relatively rapid accumulation, and is followed during the mid to late Holocene by a reduction in organic peat deposition. The lowermost radiocarbon date of 8797-8633 cal BC (9438±32 BP, SUERC- 79318 (GU47411)) 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.

4.8.4 The pollen sampled from the upper organic-rich sediment displayed a significant decrease in *Betula* population as well as an increase in *Tilia* pollen compared with the lowermost organic-rich sediment (Figure 26). 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 cover and particularly the increase in *Tilia* could indicate somewhat warmer conditions than the lower organic-rich sediment.

4.8.5 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 (KB2, KB3, KB7, KB8, and KB25; Waddington and Passmore, 2008; Figure 24) with basal dates as early as 8230-7750 cal BC (8845±60BP, SUERC-26092) (KB2), 9450-9140 cal BC (9800±65BP, SUERC-26093) (KB3) and 12850-12000 cal BC (12325±80BP, SUERC-26096) (KB8). The basal part of KB8 (Figure 28) has an age span that lies within the Windermere Interstadial and has produced a pollen assemblage dominated by grasses with some limited birch scrub, which is broadly consistent with the relatively mild but short-lived climatic conditions during this part of the Lateglacial period. Pollen from the upper part of the organic sequence in KB8, between 0.40-0.50 m, records the local presence of a sedge fen and surrounding mixed deciduous woodland with a high proportion of hazel and also alder, oak, pine and elm. The presence of alder in this sample may be indicative of sediment deposition sometime after the widely documented rise in alder woodland that occurred sometime shortly after *c.* 5000 cal BC.

4.8.6 The very early Holocene date of *c.*9450-9140 cal BC (9800±65BP, SUERC-26093) in basal organic sediments of core KB3 (Figure 27) is contemporary with a pollen assemblage representative of local open / slack water and a surrounding birch wood and scrubland with stands of pine, hazel and willow. A similar pollen assemblage is also characteristic of overlying peat between 1.10-1.18 m. Basal peats in core KB2, dated to *c.* 8230-7750 cal BC (8845±60BP, SUERC-26092), are associated with a sedge fen with surrounding hazel, pine and birch woodland. This assemblage is succeeded in overlying silty peat between 1.70-1.80 m and 1.10-1.20 m by pollen indicative of hazel-dominated woodland with some elm, oak and birch.

4.8.7 In combination, all three of these sediment cores have basal organic-rich sedimentary sequences with dating controls and pollen assemblages that provide a broad confirmation of the vegetation history and inferred chronology obtained by earlier work by Bridgland *et al.* (2011) with the additional evidence in KB8 of deposits that extend into the Lateglacial Windermere Interstadial. The absence of alder in the mixed deciduous woodland assemblages in upper levels of the organic-rich sequences in KB2 and KB3 would also point to deposition prior to the alder-rise of *c.*5000 cal BC. It is recognised, however, that further radiocarbon and palaeoenvironmental analyses are necessary in order to corroborate this provisional chronology, especially since the potential for hard-water errors in the radiocarbon chronologies are significant in these calcareous depositional environments (see, for example, Jones *et al.* 2000).

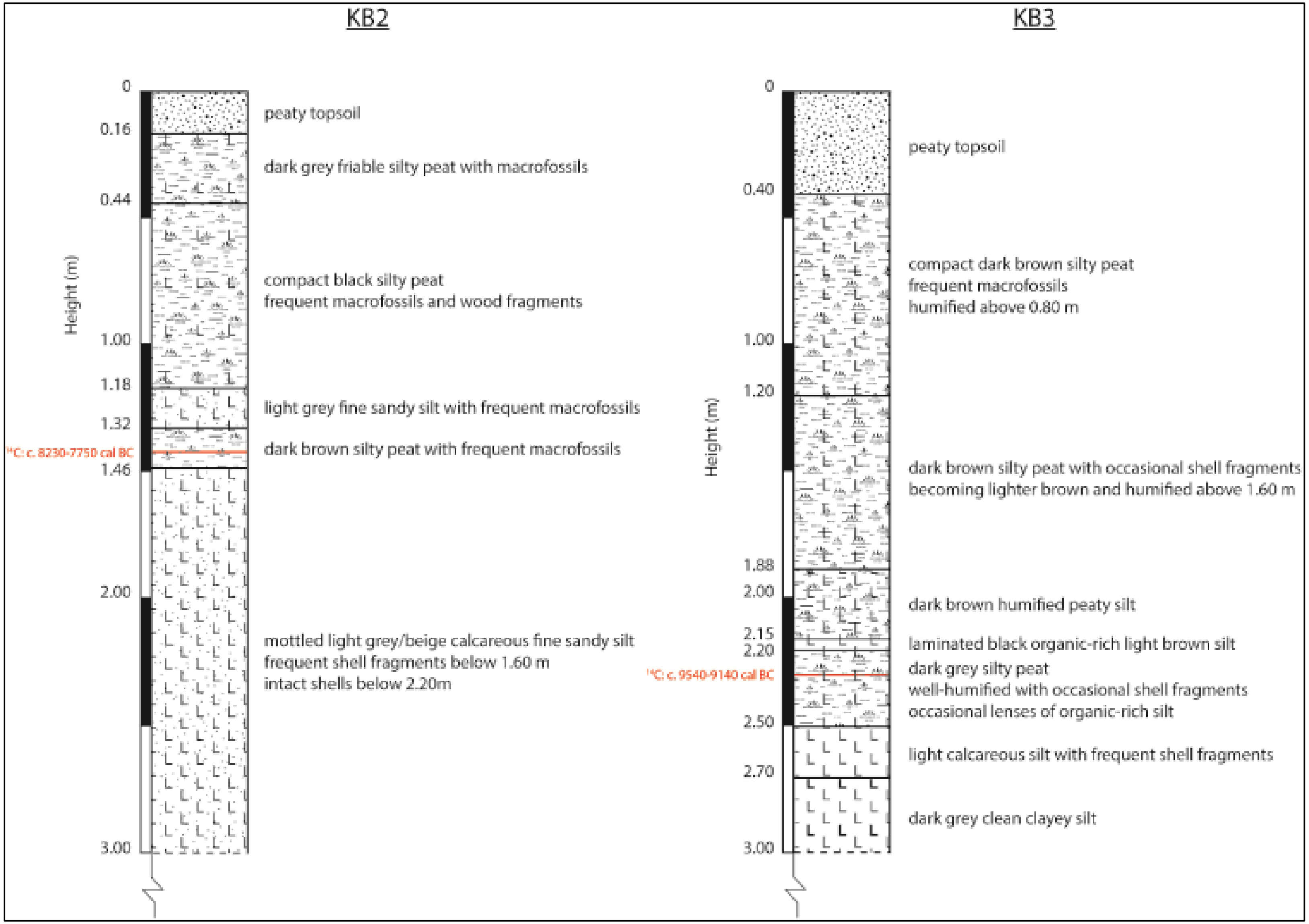

Figure 27. Sediment logs of KB2 and KB3. Red lines indicate radiocarbon dates.

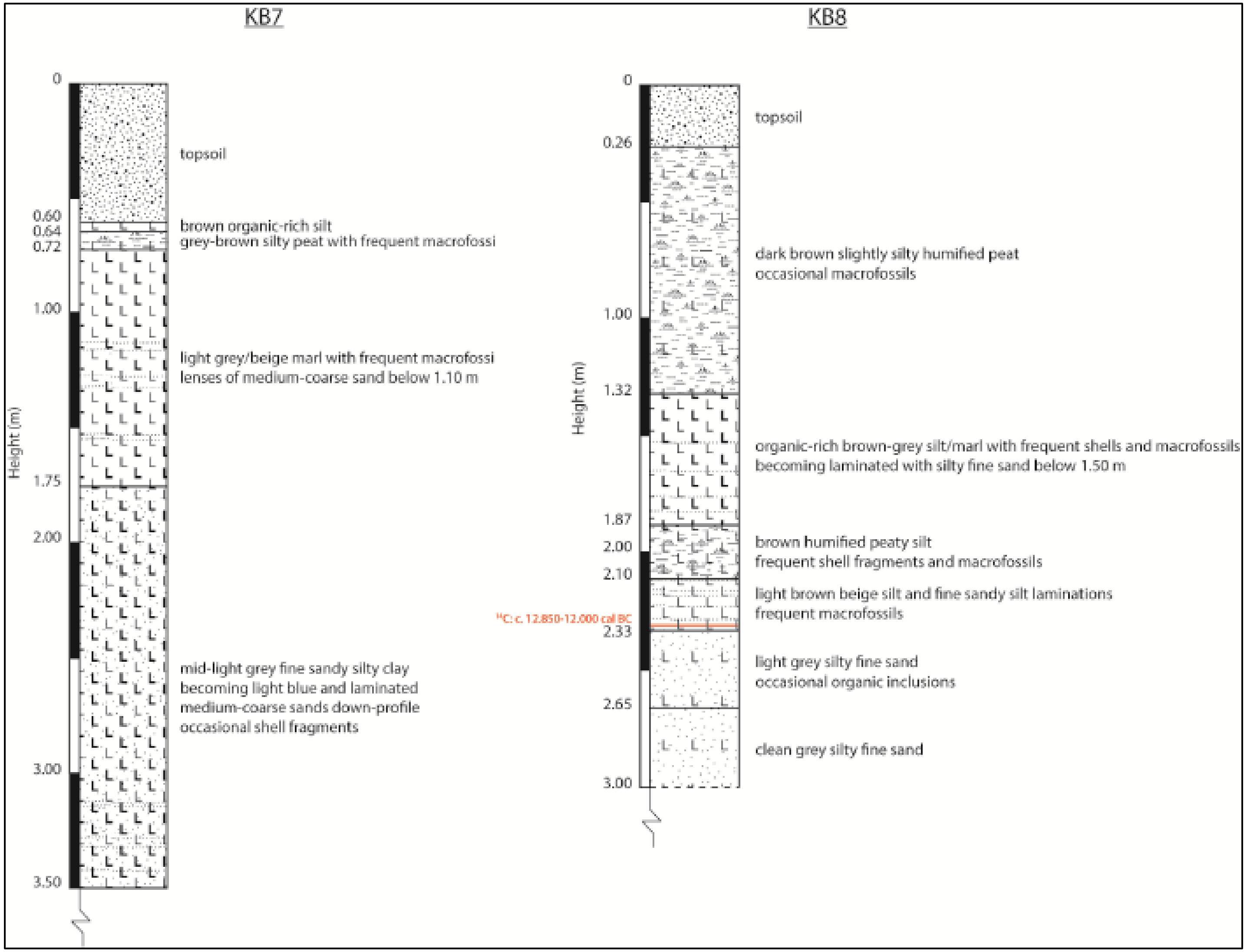

Figure 28. Sediment logs of KB7 and KB8. Red line indicates radiocarbon date

4.8.8 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.

4.8.9 On the relatively high-elevation 1a ridge in the western part of the Extraction Area a depression/kettle-hole (Figure 2) has been subjected to an extensive programme of excavation, and palaeoenvironmental sampling and assessment. Though reported in full elsewhere (Parker *et al.* 2018), the findings are summarised below.

4.8.10 Monoliths were extracted from the sedimentary sequence within the kettle hole KB5 which were then sub-sampled for palynological and palaeobotanical analysis. Samples were taken from both the centre (Figure 29) and the margins (Figure 30) of the kettle hole. A mid-Holocene peat layer within the kettle fill also featured waterlogged oak timber platform, some of which were worked, alongside worked flint scatters and animal teeth. The lowest timbers were dated from 5542-5472 cal BC (6540±25 BP, SUERC-80722 (GU48310)) which indicates construction in the later Mesolithic. Later additions and use of this platform occurred into the Neolithic period an uppermost timber piece dating to 2471-2310 cal BC (3910±20 BP, SUERC-80721 (GU48309)). This timber platform exhibits a long period of usage and likely multiple phases of occupation from the Late Mesolithic into the Neolithic and this is supported by the flint assemblage within the platform area that included diagnostic Mesolithic pieces as well as Neolithic pieces. The Neolithic pieces were conspicuous on account of not only being made from good quality flint but also being found in the uppermost layer of the platform, whereas the Mesolithic material was of poorer quality local flint and chert and found in the lower layers of the platform. Additionally, high microcharcoal concentrations observed from pollen analysis of the sediment sequence within the kettle hole indicates significant human activity in this area during the late-glacial period, as well as throughout the early and mid-Holocene. This is also highly significant as the microcharcoal provides a proxy for human activity in the late glacial and early Holocene in sediments that did not otherwise produce archaeological remains.

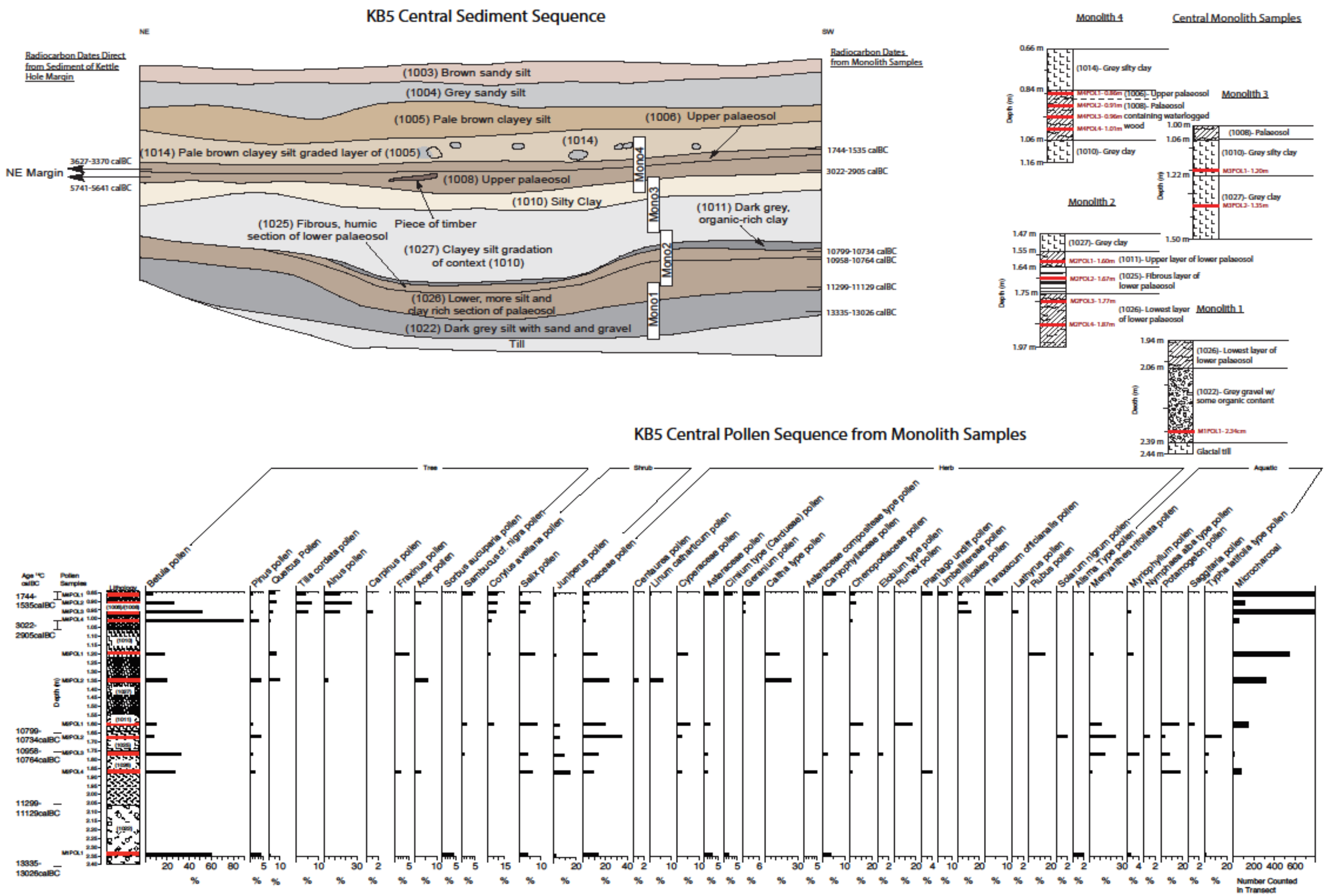

Figure 29. Stratigraphy and location of pollen samples from the central area of the kettle hole KB5 sequence.

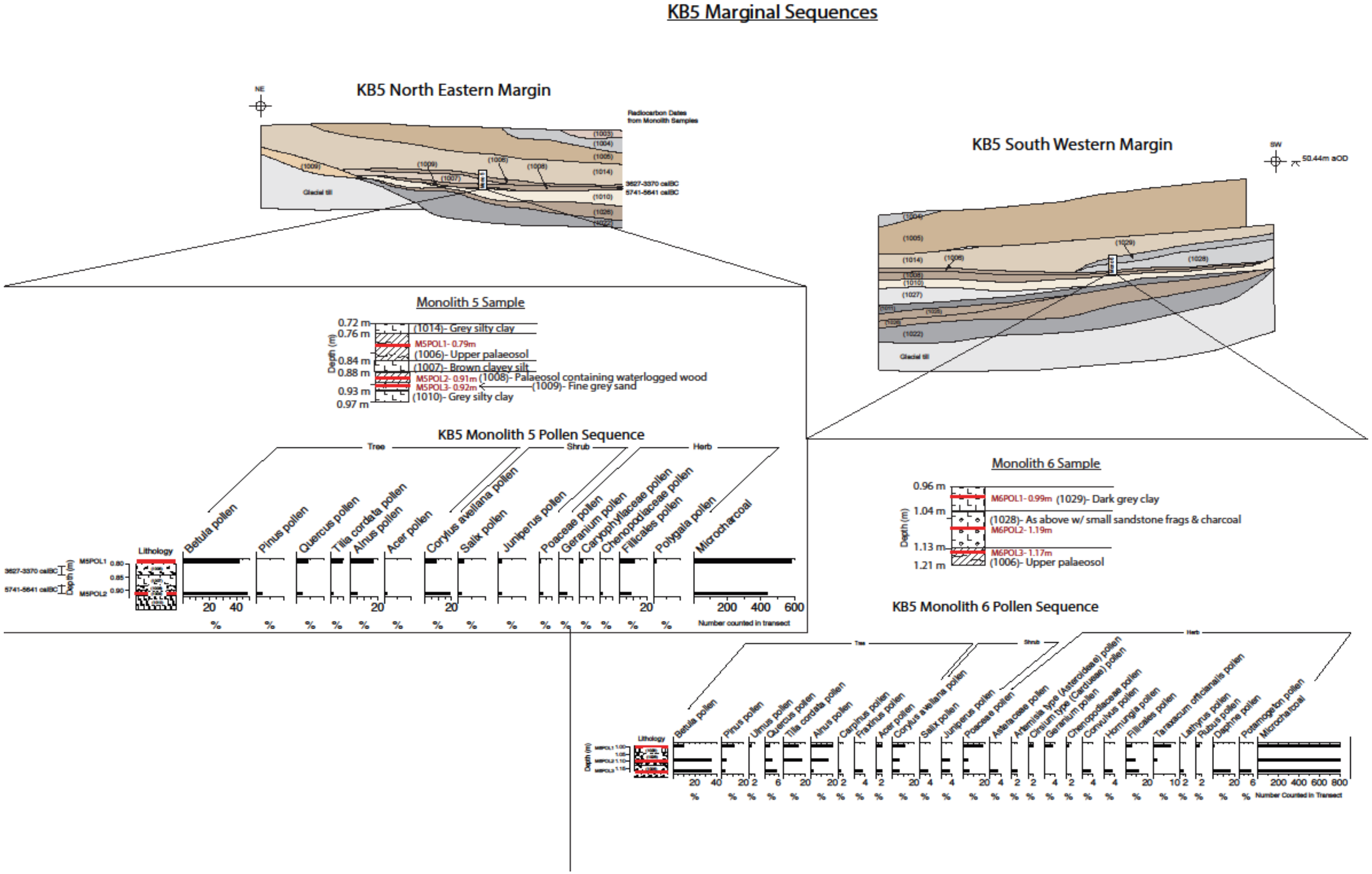

Figure 30. Stratigraphy and location of pollen samples from the margin of the kettle hole KB5 sequence.

4.8.11 The palaeoenvironmental analysis of the KB5 kettle hole revealed a continuous sedimentary sequence that spanned from the late Devensian period, through the Windermere Interstadial and Loch Lomond Stadial, and into the Holocene until the later Bronze Age. Seeds and pollen of rowan (*Sorbus aucuparia*), birch (*Betula sp.*), and other species which prefer cooler or high-altitude habitats were recovered from the lowermost sedimentary unit (1022) and reflect the early forests which gradually began to colonise the post glacial landscape during the last phase of the Devensian immediately following glacial retreat.

4.8.12 High concentrations of aquatic-type pollen and seeds characterised the overlying sediment (1026, 1025, and 1011) which was composed of a succession of organic strata. The lower boundary of this sediment was dated to 11299-11129 cal BC (11132±32 BP, SUERC-79305 (GU47400)), indicating a mid-late Windermere interstadial origin for this organic layer. The abundant aquatic pollen and botanical macrofossils illustrates the vibrant community of marsh/pond-side flora (especially flowering plants) which grew in the ameliorated climate of the Windermere interstadial. The fluctuation of the varieties of flora which grew within what would have been a small pond reflects fluctuating water levels which occurred through this period. Inorganic silts and clays (1010 and 1027) overlay the Windermere interstadial peat strata and indicated a termination of the vibrant aquatic and pond-side flora.

4.8.13 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, which is reflected by the herbaceous pollen types present which are very typical of the open tundra-type landscape of the Younger Dryas.

4.8.14 The transition from the silty clay unit (1010) into overlying organic sediment (1008) indicates a stabilisation of the environment that is interpreted as reflecting the Younger Dryas-Holocene transition. Pollen concentrations indicate an initial colonisation during the early Holocene by birch woodland followed by a steady replacement by more well-developed deciduous woodland. This woodland development is characterised by the rise of alder and lime, as well as oak. The rise of alder is a well-known phenomenon which generally occurs by around 7000-6500 BP (Tallantire 1992). This growth in alder is commonly observed as occurring alongside a rise in lime populations, with lime often being viewed as a warmth-demanding species which becomes an important component of primary woodland cover in the mid-Holocene (Grant *et al.* 2011). Towards the upper limit of these upper organic-rich strata there is a distinct drop in tree-type pollen and a growth in herbaceous-type pollen; however *poaceae* (grass) is not among these. It is possible that the 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 distinct reduction in tree pollen. This is supported by the presence of cattle teeth in these layers recovered during the archaeological excavation from within the kettle hole. It is within this sediment that the aforementioned oak wood platform was uncovered alongside associated archaeological residues (see Hunter and Waddington 2018).

4.8.15 It was noted that there was a lack of earlier Holocene dates recovered from the upper organic sediments. 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. It seems likely that organic formation did occur from the end of the Younger Dryas and through the early/mid Holocene, however the lower organic sediments have been highly compressed.

4.8.16 Archaeological associations of Landform 2c 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. In addition to those sequences from KB5 described above there is high potential for localised *in situ* and waterlogged archaeological remains of late glacial and early-mid Holocene date in equivalent contexts. Surface artefacts are absent from these environments in the central and eastern parts of the site, 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.

5 Discussion of Killerby in a Regional Context

5.1 Geoarchaeological investigations at Killerby have, and continue to, document an unusually long and detailed record of late-glacial and Holocene environmental change and human activity in the Leeming Moraine complex of the Swale-Ure valley. Many of the geomorphological elements of the Killerby landscape are characteristic of the glacial and early post-glacial development of the surrounding area. In particular, this includes the extensive and relatively high-elevation till and ice-contact meltwater deposits (Landform Element 1a) at Killerby which form the local manifestation of the well-documented regional re-advance of Wensleydale glacial ice and the formation of marginal kamiform features. The glacio-fluvial (1b) and fluvial (1c) gravel terraces which characterise the southern portion of the Killerby site are also well represented in the nearby Swale area and particularly around Catterick and Scorton (Bridgland *et al*. 2011).

5.2 Many areas of the Leeming Moraine complex have been shown to exhibit networks of low-lying, poorly drained basins and channels that formed during the early stages of de-glaciation, and which locally feature distinctive kettle-type depressions reflecting delayed melt-out of isolated ice blocks and masses (Bridgland *et al*. 2011). At Killerby these low-lying landscapes (1d-f; 2c) have been subject to detailed geoarchaeological analysis and this has revealed kettle-type depressions with good preservation of significant deposits of peat which locally have been shown to date to the Windermere Interstadial period and, in the case of the KB5 kettle hole, even as far as the Devensian/Windermere transition. The palaeoenvironmental potential of these long-term sediment sinks has been documented elsewhere in the region, most notably at Wykeham Quarry in the Vale of Pickering where Lincoln *et al.* (2017) have described one of the most extensive and comprehensive post-glacial palaeoenvironmental records in Northern England. Killerby is providing a similarly detailed sequence and, moreover, has yielded one of the most significant explorations of a kettle hole with archaeological and palaeoenvironmental records in north-west Europe.

5.3 In addition to kettle-type depressions, other low-lying and poorly-drained landform elements at Killerby, including enclosed Late Devensian / Holocene valley floors (1f) and basins (2c) and Holocene palaeochannels (2b) have promoted locally well-developed peat and organic-rich sedimentary sequences that are also yielding palaeoenvironmental records of varying length and geographical context. These are complementing comparable studies published elsewhere in the region, while again giving unusually long records extending back to the early Holocene.

5.4 A summary of the main palaeoenvironmental sequences and their chronologies at Killerby (pending further analyses as work at the quarry progresses) is presented alongside Bridgland *et al*.'s (2011) overview of palaeoenvironmental records in the wider Swale-Ure region in Figure 31. This includes the full sequences from the KB5 and KB6 kettle and basin deposits, as well as composite records from alluvial sequences KB3, KB6, KB8, and KB22.

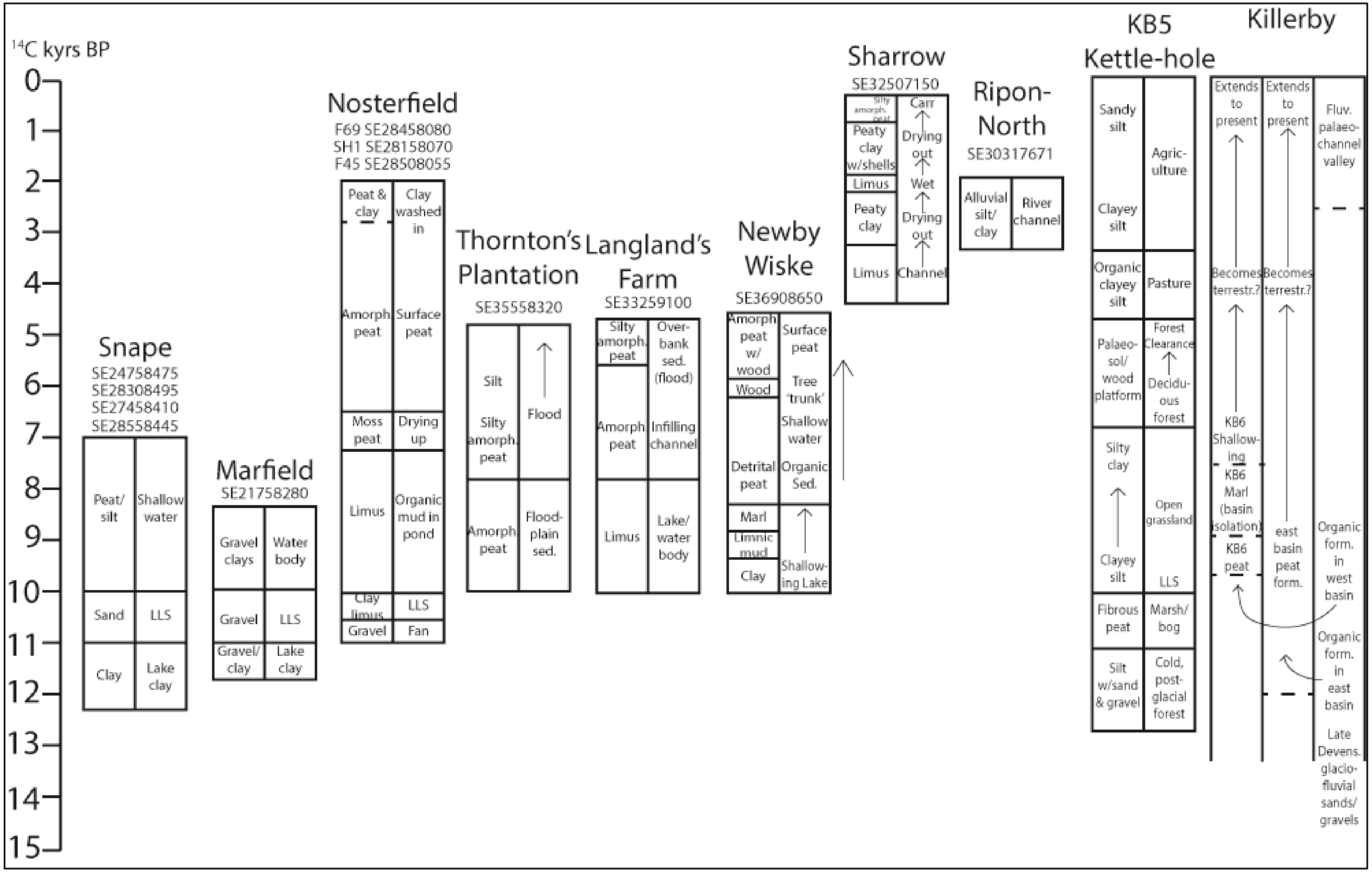

Figure 31. Regional palaeoenvironmental summary showing the Killerby data in relation to those from other regional sites (derived from Bridgland *et al*. (2011) with records from Killerby integrated

5.5 Figure 31 shows sedimentary records from Killerby extend from the Late Devensian, through the Late-Glacial and Holocene periods and up to the present day forming one of the most complete records for the Swale-Ure region. The lowermost silty gravel-rich sediment from the kettle-hole KB5 represents some of the earliest studied fossil-bearing sediment within the Swale-Ure region (Bridgland *et al.* 2011) and covers the Late Devensian/Early Windermere interstadial transition. The lowermost pollen sample from KB5 most resembles that of nearby Swale-Ure region sites at Snape Mires or Marfield (Bridgland *et al.* 2011) or, looking further afield, the Vale of Pickering at Palaeolake Flixton (Abrook 2017) and Wykeham (Lincoln *et al.* 2017), where birch woodland dominated the landscape. The KB5 sequence then reflects the development of extensive wetland vegetational communities around the kettle hole during the ameliorated climate of the Windermere Interstadial, which again resembles the Snape Mires and Marfield sequences. Sampled cores from the eastern basin yielded radiocarbon dates which were as old as 12850-12000 cal BC for KB8, providing further evidence for organic formation within the Windermere Interstadial at Killerby, however full palaeoenvironmental analysis of these possible further Windermere Interstadial sequences has not yet been undertaken. Microcharcoal concentrations within the Windermere Interstadial sediments of KB5 suggests the presence of human inhabitants during this early period and are comparable to values observed within the Snape Mires and Marfield sequences (Bridgland *et al.* 2011), and also the detailed records available from Star Carr (Day 1996).

5.6 The Holocene is particularly well represented within the organic-rich sediments at Killerby. Within the western basin the stratigraphy of the lacustrine sediments suggests an extensive Holocene sequence as described above in the landform element unit 1f and preliminary radiocarbon dates and pollen records from KB6 suggest a well-developed sedimentary archive spanning the early-Holocene period. Holocene peat deposits in the eastern basin at KB22 and KB25 reach depths over 4m and 3m respectively, and these have the potential to constitute some of the longest Holocene palaeoenvironmental records for the entire Swale-Ure region. Holocene pollen records currently available from the Killerby sediments display a similar vegetational pattern to those documented elsewhere in the Swale-Ure region. In particular, the extensive birch concentrations during the early Holocene at Killerby mirror records throughout the Swale-Ure region (Bridgland *et al.* 2011), as does the subsequent alder rise of *c*.5000 BC (Bennett and Birks 1990). Lime expansion within the KB5 sequence is similarly reflected throughout the Swale-Ure region during the extensive deciduous woodland growth of the Mid-Holocene. The early Holocene sequence of the KB5 sediment was relatively restricted, due to compression of the sequence and so the as-yet unstudied sediments from the two main depressions (KB1 and KB6) may represent the opportunity to more precisely characterise this period.

5.7 As the development of Killerby Quarry continues, our understanding of the archaeological, geoarchaeological and palaeoenvironmental picture of the site will further develop. This will necessitate continued updates of the current model and interpretation which is in place for the Late-Glacial and Holocene development of the site.

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