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French, Charles, Pears, Ben, Langdon, Catherine, Scaife, Rob, Payne, Neal, Toms, Phillip ORCID logo ORCID: <https://orcid.org/0000-0003-2149-046X>, Wood, Jamie ORCID logo ORCID: <https://orcid.org/0000-0003-0923-5511>, Taylor, Sean, Ferraby, Rose and Millett, Martin (2026) A multi-period riverine landscape narrative of the Ure Valley north of the Roman town of Aldborough (Isurium Brigantum). *Archaeological Journal*. doi:10.1080/00665983.2026.2614230 (In Press)

Official URL: <https://doi.org/10.1080/00665983.2026.2614230>
DOI: <http://dx.doi.org/10.1080/00665983.2026.2614230>
EPrint URI: <https://eprints.glos.ac.uk/id/eprint/16205>

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To cite this article: Charles French, Ben Pears, Catherine Langdon, Rob Scaife, Neal Payne, Phil Toms, Jamie Wood, Sean Taylor, Rose Ferraby & Martin Millett (15 Apr 2026): A multi-period riverine landscape narrative of the Ure Valley north of the Roman town of Aldborough (*Isurium Brigantum*), *Archaeological Journal*, DOI: [10.1080/00665983.2026.2614230](https://doi.org/10.1080/00665983.2026.2614230)

To link to this article: <https://doi.org/10.1080/00665983.2026.2614230>



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RESEARCH ARTICLE



A multi-period riverine landscape narrative of the Ure Valley north of the Roman town of Aldborough (*Isurium Brigantum*)

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ABSTRACT

Geoarchaeological survey and palaeoenvironmental analyses were conducted in the floodplain of the river Ure to the north of the Roman town of *Isurium Brigantum* (Aldborough, North Yorkshire) as part of a complementary campaign of geophysical survey and excavations (2018–2024). This involved an intensive coring survey to understand the development of the valley and the environmental context of the settlement. A large palaeochannel was discovered south of the present day canalized river which was sampled for palynological, physical and geochemical analyses, with portable OSL determinations, and radiocarbon and OSL dating. The sedimentological analysis revealed riverine activity from the Late Mesolithic period (ca. 4600–4300 BC) through Roman and Medieval times. A 6 metre deep, multi-process fluvial system was present with evidence of active and low/slow flow phases in earlier prehistoric times, followed by prolonged periods of overbank alluviation from the Iron Age onwards, and particularly coincident with the Roman occupation of *Isurium*. By the Roman period, there was a shallow channel in a wide floodplain, slowly filling with alluvium, necessitating the construction of a lengthy road-bridge structure, before shifting northwards. This was set against progressive woodland diminution and extensive human impact during the late prehistoric, Roman and early historic periods.

Introduction and background

This paper presents the results of the geoarchaeological survey and the sedimentary and palaeoenvironmental analyses of the floodplain of the River Ure immediately to the north of the Roman town of *Isurium Brigantum* (Aldborough) in North Yorkshire (Figure 1). This work forms one element of research initiated by the Aldborough Roman Town Project in 2009. The broader project is designed to provide a clearer understanding of the development and character of Roman

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 Supplemental data for this article can be accessed online at <https://doi.org/10.1080/00665983.2026.2614230>

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Figure 1. Location map of Aldborough and the main area of geoaerchaeological survey (R. Ferraby).

Aldborough, a town which played a pivotal role in Roman Britain, acting as the administrative centre of the *civitas* of the Brigantes (Ferraby and Millett 2020a, 94–100). As such, *Isurium* is central to any understanding of the development of the frontier region.

Research for the Aldborough Roman Town Project was initiated in two stages, with the initial phase combining a geophysical survey of the town and its immediate environs with the collation and assessment of all previous work at the site (Ferraby and Millett 2020a). This was followed from 2016 to 2023 by a complementary campaign of excavations (2016–2018) which have now been fully published (Ferraby and Millett 2021b, 2022, 2024b), with work in hand on the analysis of the complex sequence explored in the larger area excavated just inside the North Gate in 2019–2023 (Ferraby and Millett 2020b, 2021a, 2023, 2024a).

On the basis of the reassessment of all evidence from past excavations and our new research, it has been concluded that the Roman period settlement was established at Aldborough in the AD 70s, with the planned town laid out at the same time as the construction of the *forum* in the early Second Century AD (Ferraby and Millett 2020a, 94–100). In contrast with previous discussions, it is suggested that in its initial phase the settlement was not a military foundation, but was probably created as a trading settlement populated by those from outside the area, rapidly growing in size and likely taking the administrative role of *civitas* centre prior to the establishment of the planned town. Central to this argument was the lack of evidence for any major

pre-Roman focus beneath the Roman town, and the location of the earliest settlement at the point where the river Ure, navigable up to this point, met the Roman road leading northwest from York. As such, the conclusion is that the town was a new foundation.

Against this background, a third strand of research within the Aldborough Roman Town Project was initiated in 2018 to explore and address these issues with two main work-streams. The first involved the extension of the geophysical survey that had been completed across the town itself to map activity in its immediate hinterland. This work was inspired by the successful use of fluxgate gradiometry to map the landscape of the Vale of Pickering (Powlesland 2014), using the technique as a mode of prospection rather than for the mapping of already known sites. The second involved an intensive coring survey of the floodplain of the river Ure to the north of the Roman town in order to understand the development of the valley and establish the palaeovegetational record, the context of the settlement and the location of the Roman bridge across the river. It was also hoped that this new data would complement the evidence from the analysis of samples taken from the early phases of the town collected during the excavations of 2017 and 2018, which provided small-scale insights into the nature of exploitation of the landscape at the time of the town's foundation (Ferraby and Millett 2022, 2024b) and a little further to the north in 2024 (Ferraby and Millett 2025).

The discovery of a substantial waterlogged palaeochannel with a well preserved and lengthy pollen sequence during the geoarchaeological coring work provided evidence of vegetation history through the *longue durée* from the Mesolithic to the post-Medieval period. Although there are a few palynological studies from elsewhere in the Ure valley (e.g. Howard et al. 2000), Vale of Pickering (e.g. Cloutman 1988; Cloutman and Smith 1988), and the Vale of York (e.g. Geary and Lillie 1999), and many more from the North York Moors (e.g. I. G. Simmons and Innes 1996), there are no palaeovegetational and sedimentary studies that are directly relatable to Aldborough, especially before, during and after the occupation of the Roman town itself, making this palaeochannel a significant palaeostratigraphic and palaeoenvironmental data repository for the immediate region.

This geoarchaeological work also led to the development of a third, complementary strand of research. As excavations close to the North Gate in 2019–2023 (Figure 3, red square) had revealed evidence for large-scale iron-smithing and lead-working, it was therefore decided to undertake chemical analysis of close interval samples through the upper part of the same core (borehole BH14 - as used for the sedimentary and palynological studies here) (Figure 3) to trace the longer-term history of metal-working in the catchment. This aspect of the work, which focused on the late Roman and post-Roman periods, is the subject of a separate paper published elsewhere (Loveluck et al. 2025).

This paper presents the results of the geoarchaeological survey and the associated palynological, sedimentological and chronological analyses of a major buried palaeochannel of the river Ure, enabling a broader understanding of the palaeoenvironment, palaeovegetation and agricultural landscape of the immediate Aldborough area throughout most of the Holocene.

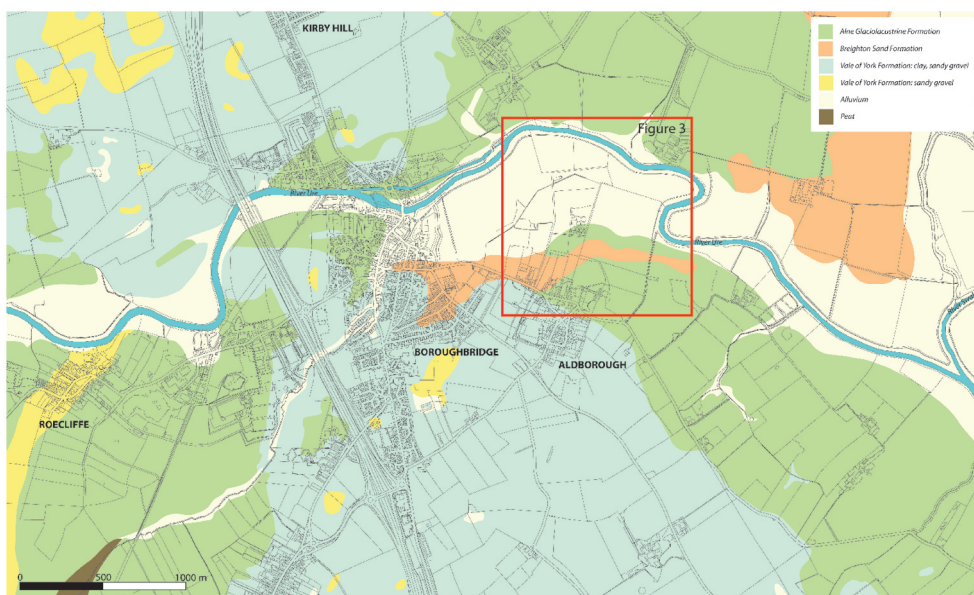


Figure 2. Geological map of the Aldborough environs and Ure river floodplain area (R. Ferraby).

Geographical setting

The Roman town of *Isurium Brigantum* is located near the centre of the Vale of York on the southwest side of the river Ure, about 2 km upstream from its confluence with the river Swale. Except for the areas occupied by housing around Boroughbridge to the west, the present landscape is largely occupied by open farmland with a little woodland. Much is now used for arable cultivation but there remains extensive grassland pasture.

The landscape of the Vale is the product of its complex geomorphological history during and after the Devensian glaciation (Figure 2). Drift deposits derived from the melt-water lake that occupied the area at the end of the glaciation mask the solid geology across most of the landscape (BGS Digimap n.d.). These comprise a series of lacustrine clays and silts as well as fluvio-glacial gravels and morainic deposits along its fringes. The deposits vary in character and depth, masking the underlying solid geology, although the red Sherwood Sandstone of the late Permian–mid-Triassic era does outcrop at places along the ridge that fringes the southwest side of the valley (BGS Digimap n.d.), and on which the southern part of the Roman town was built. The landscape is locally varied but much has a deep silty soft brown topsoil which is agriculturally fertile. The floodplain of the Ure, which is prone to seasonal inundation, is covered by fluvial clays derived from overbank flooding and aggradation.

The geoaerchaeological survey

Aims

Geoaerchaeological fieldwork was undertaken in 2018 and 2019 to reveal the fluvial history of the south floodplain side of the river Ure to the north of the Roman town.

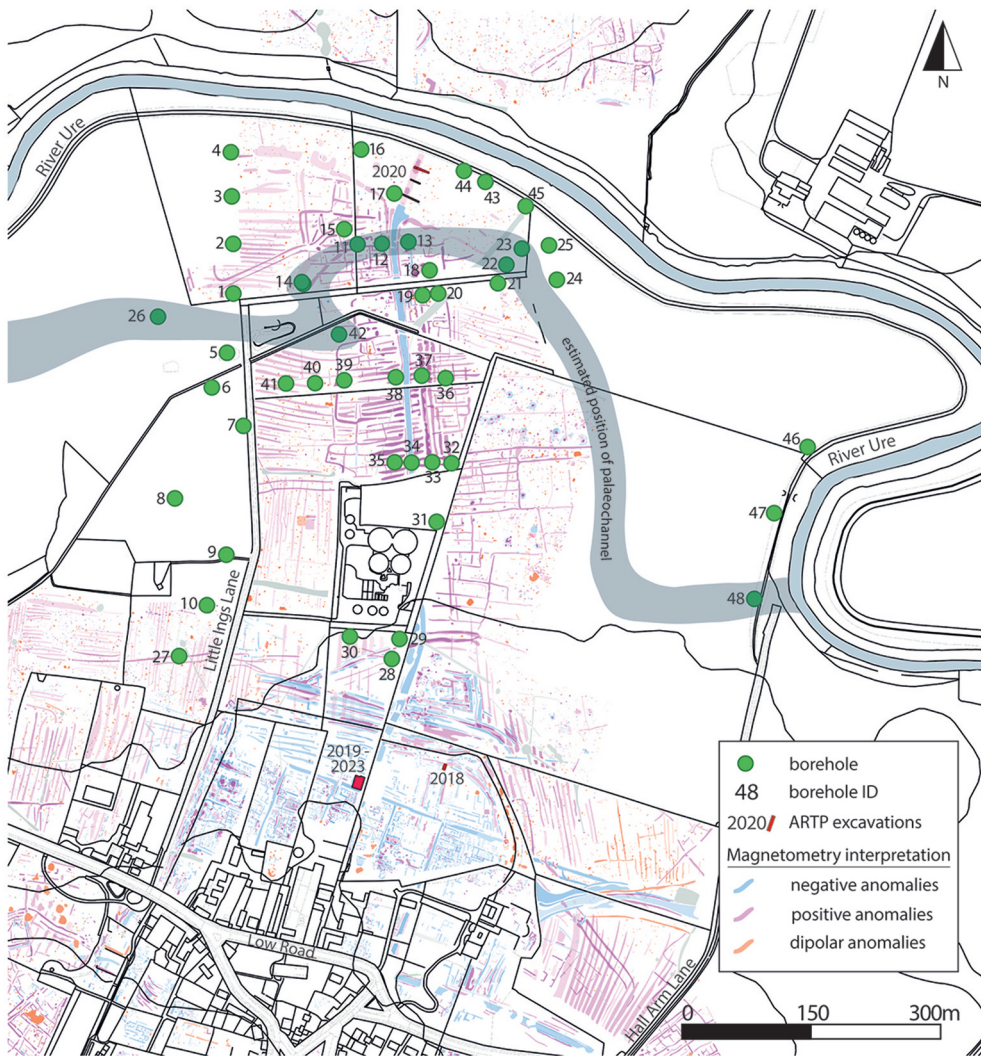


Figure 3. The location of the boreholes set against the geophysical results (R. Ferraby).

A series of 48 boreholes were made by hand using a combination of 3 cm diameter Dutch and gouge augers, backed up by a series of three machine cut trenches in 2020 (Figure 3).

The geoarchaeological investigation of the floodplain sediment deposits aimed to:

- locate and define palaeochannels with good sediment archives of the immediate watershed and alluviated valley-scape;
- obtain suitable cores for geoarchaeological and palynological analyses, and samples for radiometric and/or Optically Stimulated Luminescence (OSL) dating;

- define the extent and intensity of alluviation on the northern side of the Roman town and prospect for buried soils beneath the alluvium to gain information about prehistoric and historic land-use around the Roman town; and
- if possible locate the main Roman road/bridge river crossing of the river Ure.

Methods of sediment analysis

Each of the sediment analyses of borehole BH14 outlined below was conducted on 97 samples between 2–5 cm resolution across the 5.95 m core from 0.60 m to 5.95 m under laboratory conditions designed to draw out the key variations in depositional history of the sequence. These analyses included loss-on-ignition (LOI), magnetic susceptibility (MS) (Dearing and Oldfield 1999), particle size (Blott et al. 2004; Konert and Vandenberghe 1997), dry bulk density (DBD), portable Optically Stimulated Luminescence (pOSL) analyses (Sanderson and Murphy 2010) and multi-element determination of the sediment sequence calculated using a Niton XL3t GOLDD+ portable XRF (pXRF) analyser (Weindorf, Bakr, and Zhu 2014) (see Supplementary Information).

Additional laboratory work was undertaken by Dr. Ben Pears (University of Southampton) on the physical and geochemical characteristics of the borehole BH14 core, and by Prof. Rob Scaife and Dr. Catherine Langdon (University of Southampton) for the palynological analysis of the same core. This was accompanied by six radiometric dates of humic acids from sample depths of 1, 1.5, 2.63, 3.4, 4.9 and 5.65 m in BH14 which were processed by SUERC, University of Glasgow, accompanied by optically stimulated luminescence (OSL) sampling and dating of the upper ca. 1.2 m of the alluvial sequence by Prof. Philip Toms and Dr. Jamie Wood, University of Gloucestershire (Toms and Wood 2023) (Table 1; Supplementary Information), and age-depth modelling by Dr. Pears. In combination, these studies have provided an excellent palaeoenvironmental context of the Ure valley associated with Aldborough Roman town, which is described below.

Borehole deposit descriptions

The latest deposit over the whole floodplain zone, and the one that is currently under arable agricultural use, is a well structured, dark brown, fine sandy/silt loam. This

Table 1. AMS radiocarbon and OSL dates from borehole BH14 (note that date GU55511 is omitted from the age-depth model).

Sample depth (m)	OSL date	C-14 years BP date	x ^C -14 years cal. BC/cal.	
			AD date (95.4% probability)	Laboratory number
0.40	AD 1330–1420			GL22074
1.2	AD 1020–1140			GL22079
1.0		2761 ± 24	976–833 cal. BC	GU55511
1.5		2543 ± 24	799–553 cal. BC	GU55510
2.63		4604 ± 23	3499–3347 cal. BC	GU55509
3.4		5021 ± 26	3942–3711 cal. BC	GU50295
4.9		5714 ± 22	4617–4485 cal. BC	GU55508
5.65		5467 ± 27	4358–4261 cal. BC	GU50296

alluvium (or overbank flood deposits of eroded soils from the catchment upstream) was uniformly present over the whole floodplain zone, ranging in thickness from ca. 1–2.5 m. In places at the base of this upper alluvial deposit, especially on the visible west–east ridges in the modern floodplain in boreholes BH12 and BH15, there is also the strong possibility of a well established, former floodplain grassland surface being present at ca. 1.2–1.6 m beneath the modern ground surface that contains probable Roman artefact fragments.

This eroded soil material derived from the catchment valley and slopes upstream sealed a number of gleyed silty clay alluvial deposits, peaty muds and palaeochannel fills, often exhibiting alternating finer/coarser laminar deposits. To illustrate these sequences, three representative borehole sequences will be described – one in the present day floodplain (BH4), one in a palaeochannel (BH11), and one part-way up the southern slope of the valley (BH8). A transect of boreholes presented in [Figure 4](#) illustrates the valley fills.

Borehole 4 was located in the floodplain just to the south of the present day embanked river Ure ([Figure 3](#)). It exhibited ca. 1.1 m of brown silt loam alluvial material beneath the modern ploughsoil (a gleyic Fluvisol) (W. R. B. 2014), with another metre below of increasingly gleyed and greyish brown in colour, silt loam, all accumulating on a brown, fine-medium sand substrate. Essentially here there is at least 2.5 m of alluvial material deposited by low velocity overbank river flood action, developed on some kind of basal (late glacial) levee or earlier large channel fill deposit.

Borehole 11 was located within the southern third of the modern floodplain zone about 50 m to the north of Little Ings Lane ([Figure 3](#)). This profile exhibited ca. 0.6 m of dark greyish brown silt loam alluvial material beneath the modern ploughsoil, over ca. 0.4 m of a very dark brown to black humic silt with fragments of partly humified



Figure 4. Lidar image with the pale grey/tan areas mapping the approximate line of the prehistoric palaeochannel (B. Pears).

organic matter, probably acting as a former, stable floodplain topsoil. Beneath this (from ca. 1.4 m) were a series of horizons indicative of palaeochannel fill deposits to a depth of over 5 m, with the groundwater table reached at a depth of ca. 2.2 m. These comprised about 1.6 m of increasingly reduced grey fine sandy silt loam, overlying about 1.7 m of alternating horizons of variable thicknesses composed of fine-medium sand and grey fine sandy silt, overlying a basal zone (4.78–5.05+ m) of very thin laminae (<0.5 cm) of black humic material interleaved with thin (<2 cm) lenses of grey fine sandy silt. This lowermost horizon was not bottomed as the material was too waterlogged to remain in the gouge auger. Note that the nearby and similar borehole BH14 from the same palaeochannel (Figure 3), with better sample recovery over a total depth of 5.95 m, was chosen for all the subsequent analyses described below.

Borehole 8 was located just above and to the south of the break of slope (Figure 3). Here a Cambisol (or a weakly developed brown soil) (W. R. B. 2014) exhibited about 0.4 m of a reddish brown fine sandy loam ploughsoil over ca. 0.6 m of an orangey brown fine-medium sandy loam to loamy sand acting as a B horizon. This was developed on ca. 0.5 m of a partly gleyed/oxidation mottled orangey brown, fine sandy/silty clay or a weathered B/C horizon, over a medium-coarse sand C horizon (with the underlying sandstone bedrock not reached at a depth of 1.9 m). This is essentially typical of the soil profile present above the influence of the floodplain, but it has probably been in receipt of hillwash (eroded soil) material from upslope through arable use leading to its ca. 1 m thickness.

Palaeochannels

From the borehole and LiDAR surveys, it appears that there is one main palaeochannel present in the landscape with several discontinuous parts of other palaeochannels evident across the floodplain (Figures 3–5). The substantial main palaeochannel runs along the line of the present day sinuous west–east ditch to the right-angled corner of the north–south/west–east Little Ings Lane and then diverges in a northeasterly sweep through the floodplain fields to the north of the west–east green lane. It is probable that this palaeochannel bifurcates in several places, with sand levees in between, possibly creating more of a braid plain type of landscape. These channels are between ca. 5 m and 6.2 m deep and at least ca. 50–60 m in width. Importantly, stratigraphic indications are that this earlier main channel system is ostensibly infilled by the time of the upper phase of alluvial deposition and was no longer the main active channel by Roman to Early Medieval times.

The best expression of this principal Holocene palaeochannel identified is in borehole BH14 (Figures 3–5), bottomed at 6.2 m below the modern ground surface (see below). The same palaeochannel was also located in boreholes BH11–13, 22 and 23 ca. 50–175 m to the east, and borehole BH26 to the west, also with reed peat and varved/finely laminar deposits in its basal 2.5+ m. About 600 m further to the southeast, borehole BH48 probably also identified the same palaeochannel, with similar ‘varved’ alternating laminae of fine sand/medium sand/humic silt evident from ca. 3.7–5.95 + m below the modern ground surface.

The river system then probably moves north to a position more or less occupied by the modern canalized river Ure, with a main floodplain zone over 100 m in width to its

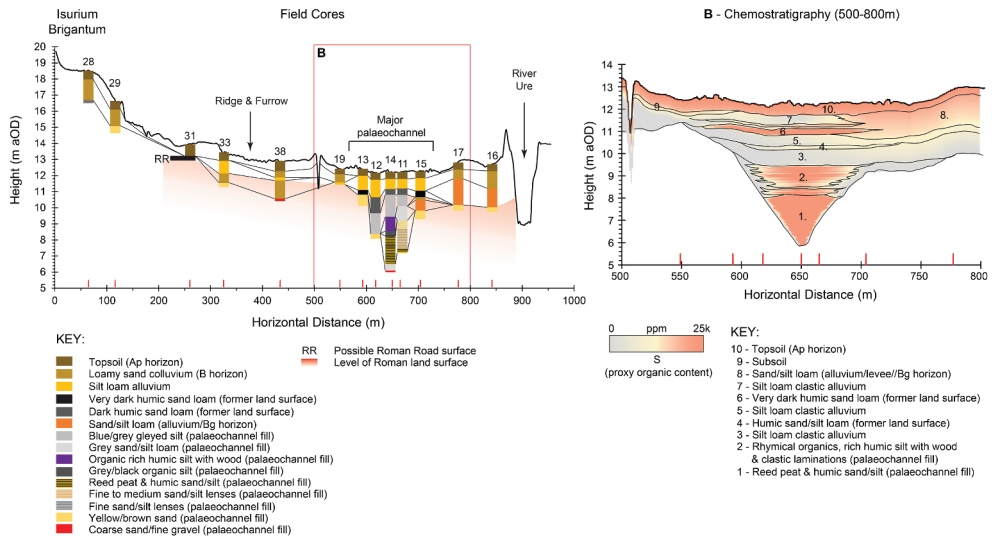


Figure 5. Schematic borehole transect from Aldborough Roman town northwards across the Ure valley illustrating the position, depth and stratigraphy of the floodplain and main palaeochannel (A), with the chemostratigraphy for sulphur (B) modelled as a for proxy organic material, which illustrates the rich organic basal deposits (with very high S concentrations), and then pseudo-laminated organics and clastic deposits, and organic free horizons above, and possible floodplain surface development for a small section of the floodplain between 500–800 m (B. Pears).

south (Figures 3 and 4) and a more constricted floodplain area to the north as the topography rises quickly up the geological contour (as seen by the gap in data in the geophysical data plots) (Ferraby and Millett 2020a, 76–77, fig. 3.38). In the periods of most intensive flooding, alluvial material from overbank flooding could have spread extensively over at least a ca. 200–250 m width of floodplain and up to about the 15 m contour.

Location of the Roman road and bridge footings

A previous magnetometry survey had identified the south–north route of the Roman road (Dere Street) from the North Gate of the town heading towards the river Ure as well as a feature interpreted as the stone base of the bridge crossing the river (Ferraby and Millett 2020a, 76–77, fig. 3.38) (Figure 3, in blue and purple). It was not possible to locate the exact position of this roadway and bridge of the Roman period in terms of solid features given the wide interval between boreholes in this evaluation. Nonetheless, the position of the buried main palaeochannel and sand levee system does suggest that the most likely location for a bridge is to the north of the present day, east–west stretch of Little Ings Lane and just to the south of the present day river (Figure 3). It is also possible that the road-line/bridges spanned the floodplain in a series of smaller bridges or causeways, ‘jumping’ from levee to levee, as suggested by the alignments observed in the geophysical survey (Figure 3).

A series of boreholes (BH28–32) were made south to north from just outside the North Gate of the Roman town downslope to and past the sewage works and then

east–west in two pasture fields (boreholes BH33–35 and 36–41) to confirm the location of the Roman road running north from the town across the Ure floodplain (Figure 3). Boreholes BH28–30 on the down-slope all exhibited about 1.5 m humic silt loam developed on yellowish brown very fine sand/silt deposits. These deposits are suggestive of a mixture of some hillwash, but mainly overbank alluvial deposits, accumulating on a shallow scarp face which is forming the southern side of the Ure valley. Today it is hard to initially envisage alluvial accumulations occurring ca. 2–3 m above the current level of the floodplain (at ca. 14 m OD), but, as floodwaters have been known to reach the modern Boroughbridge road, some 200 m to the south and upslope, this is very possible. The sandy substrate material is probably levee bank material ‘plastered’ up against the main geological contour, and may be a feature of later Quaternary times.

In the pasture fields immediately to the north of the sewage works (Figure 3), anthropogenic material of brick/tile, pottery, charcoal and cinders occurred as a wide spread of material defining between about 0.25 m and 1.0 m and 1.3–1.9 m below the modern ground surface over a ca. 30–40 m wide, low, linear mounded area (as visible in the field today). In each case, the spread of archaeological material and stone pebbles is defining at about the half-way depth zone of humic silt loam alluvial material. This suggests that the road was built on pre-existing alluvial deposits, and was subsequently buried by them as well, although this would repay further investigation by targeted trenching in the future.

An attempt was also made along the southern side of the modern river bank in boreholes BH17 and BH43–45 to pin-down the location of the curving line of the Roman road. This proved impossible with the whole field dominated by an impenetrable oilseed rape crop, and will have to receive further attention in the future. Nonetheless, boreholes BH43–45 (and 46) consistently exhibited over 5 m of sandy loam to loamy sand deposits. These become fully gleyed and waterlogged from a depth of ca. 2.8–3.5 m to 6.2 m. Although dominated by very fine to fine sands, these deposits are substantially coarser than most others encountered in the auger survey, and suggest greater flow and depositional energy in this part of the floodplain system. It is hypothesized that this thick fine sand dominated material represents the post-Roman, Medieval and later alluvial aggradation of the floodplain, prior to the canalization and embanking of the river at about the end of the Nineteenth Century (as shown on the 1908 OS map).

Radiocarbon and OSL dating of borehole BH14

An age–depth model was calculated using Bacon modelling software (Blaauw and Christen 2013) on six AMS radiocarbon and two OSL dates obtained from samples taken from borehole BH14 (Table 1; Figure 6). This enabled the identification of chronological outliers and provided a comparison with pollen zone data for closer chronological phasing (Table 2) (see Loveluck et al. 2025).

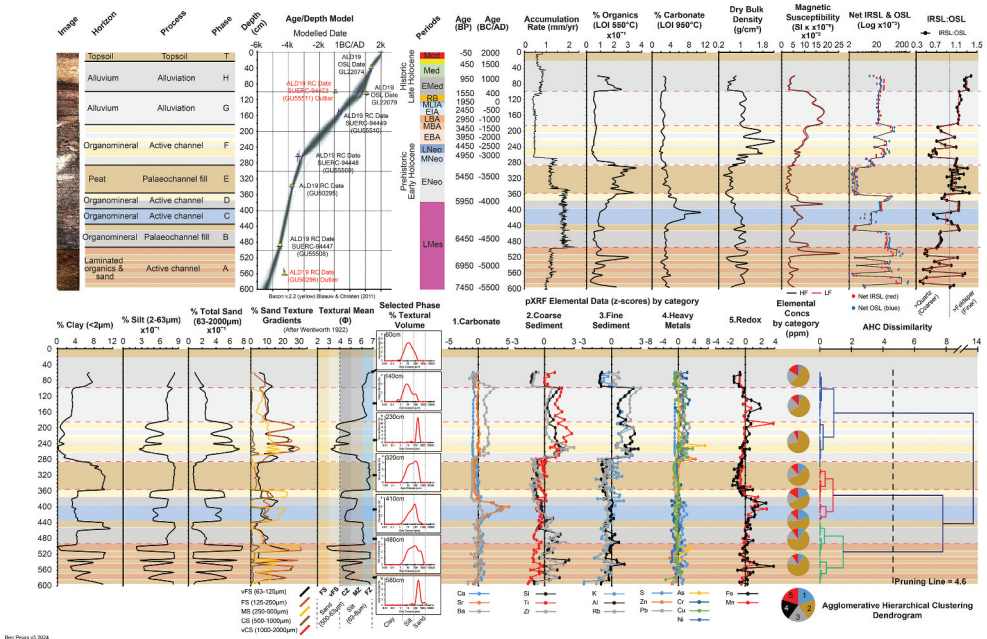


Figure 6. The chrono-stratigraphy, age-depth model, particle size, carbonate, organic and magnetic susceptibility results, and pOSL analysis (B. Pears).

Table 2. Dated sediment phase and palynological zonation correlation in the palaeochannel at borehole BH14 based on OSL and radiocarbon dates and age-depth modelling.

Depth (m)	Sediment phase	Pollen zone	Geomorphological process	Chronological range	Period
0.2–0	T	–	Ploughsoil	c. AD 1700–present	Post-Medieval to modern
1.1–0.2	H	B: 5	Alluviation	c. AD 400–1700	Early Medieval to post-Medieval
1.85–1.1	G	B: 4	Alluviation	c. 1200 cal. BC – cal. AD 400	Late Bronze Age to Roman
2.85–1.85	F	B: 3- B: 4	Active channel	c. 3300–1200 cal. BC	Middle Neolithic to Middle Bronze Age
3.6–2.85	E	B: 3	Palaeochannel fill	c. 3900–3300 cal. BC	Early Neolithic
3.6–4	D	B: 3	Active channel	c. 4100–3900 cal. BC	Late Mesolithic to Early Neolithic
4–4.5	C	B: 2	Active channel	c. 4300–4100 cal. BC	Late Mesolithic
4.5–4.9	B	B: 2	Palaeochannel fill	c. 4600–4300 cal. BC	Late Mesolithic
4.9–5.95	A	B: 1	Active channel	c. 5500–4600 cal. BC	Late Mesolithic

Sediment analyses results

Detailed sedimentological analysis of the core samples from borehole BH14 demonstrates a complex depositional history (Figures 5 and 6; Tables 2 and 3). The profile has been sub-divided into depositional zones and is discussed below in relation to chronological period as determined by the Bacon age-depth model of available radiocarbon and OSL dates with the results summarized in Tables 1–3 and Figure 6 (Loveluck et al. 2025, app. 2 OSM2a).

Table 3. Summary of average sedimentological information from the key units from the fluvial sedimentary sequence in borehole BH14 at Aldborough. Elemental results from pXRF analysis as average mg/kg (ppm) per sedimentological unit with categories as indicated in text. pOSL results as average number of intensity readings per sedimentological unit.

Analysis (average by unit)	Sedimentological Unit								
	T	H	G	F	E	D	C	B	A
	0–20 cm	20–110	110–185	185–285	285–360	360–400	400–440	440–490	490–595
% Organics	No	14.54	5.94	7.83	24.65	15.56	9.41	6.95	9.92
% Carbonate	Data	2.77	2.33	2.35	3.31	5.32	6.17	3.08	3.06
MS κ (SI $\times 10^{-6}$)		53.80	164.45	74.94	30.14	76.88	66.32	61.07	61.75
% Clay (<2 μm)		6.14	2.97	1.54	9.20	3.64	3.93	5.88	5.31
% Silt (2–63 μm)		77.66	71.69	51.47	80.56	61.16	49.81	75.65	55.97
% Sand (63–2000 μm)		16.20	25.34	46.99	10.24	35.20	42.02	18.47	38.72
Ti, Si, Zr (Coarse Clastic)		68,299	148,026	164,234	53,494	75,458	115,686	136,292	143,532
K, Al, Rb (Fine Clastic)		22,929	44,590	49,749	19,177	26,330	28,957	25,846	26,145
Ca, Sr (Carbonate)		3679	3654	3300	11,053	29,631	38,419	18,226	17,991
Fe, Mn (Redox)		10,942	23,563	17,459	11,091	24,227	24,454	20,087	20,244
S (Proxy Orgs)		543	475	872	2,535	7173	12,615	9271	11,006
Heavy Metals		219	322	340	206	234	227	206	186
Net IRSL (red) feldspar		2819	2269	2636	361	3396	1368	3315	3,940
Net OSL (blue) Quartz		2238	1994	3464	340	3478	1430	4277	7,834
pOSL Ratio		1.27	1.14	0.85	1.08	1.03	0.86	0.82	0.72

At the base of the sequence (5.95–4.9 m) (Phase A; ca. 5500–4600 cal. BC; Late Mesolithic) distinctive laminated sediments were determined comprising four couplets between ca. 2 cm and 10 cm in thickness of very dark greyish brown sand rich layers with high coarse grained particle size, pOSL readings and elemental indicators (Figures 5 and 6; Table 3). In contrast these were interbedded with very dark grey brown organic rich laminae with higher organics (up to 30%), clay (ca. 4–10%) and silt (ca. 20–80%) contents, and lower and more variable pOSL (ca. 200×10^{-1}) and coarse and fine elemental indicators (Figure 6; Table 3). The uppermost horizon in phase A (5.1–5 m) also showed a dramatic increase in magnetic susceptibility (from ca. 27–250 SI $\times 10^{-6}$).

Above the basal laminated deposits the sedimentology changed to a more uniform 0.5 m thick dark grey deposit (4.9–4.5 m) (Phase B; ca. 4600–4300 cal. BC; Late Mesolithic) with a graded boundary to the coarser sediments below (Figures 5 and 6). This horizon had reduced organic (ca. 4–12%) and carbonate contents (2.79–3.62%), as well as reduced magnetic susceptibility (ca. 34–115 SI $\times 10^{-6}$) and stable levels of textural variables dominated by fine to coarse silt (69.3–84.6%), although 5.3–26.4% of a very fine to medium sand presence was still evident with enhanced pOSL values (to 5449) and coarse and fine elemental indicators (Figure 6; Table 3). In the uppermost 10 cm of Phase B (4.5–4.4 m) the sediment record changed to an organic, rich dark brown coloured, clay silt deposit with a major decrease in pOSL (to ca. 5000 to $<3000 \log \times 10^{-3}$) and textural characteristics (Figure 6; Table 3).

Deposition from 4.5–4 m (Phase C; ca. 4300–4100 cal. BC; Late Mesolithic) demonstrated another clear change in depositional process (Figures 5 and 6). Although sediment colour remained typically dark greyish brown with reduced organic content (ca. 8–10%), as seen in the lower deposit of Phase B, there was a major increase in carbonate content (ca. 3–11%) and elemental indicators alongside variable pOSL intensity readings (ca. 502–1813) and magnetic susceptibility (ca. 60–91 SI $\times 10^{-6}$) (Figure 6; Table 3).

From 4–3.6 m (Phase D; ca. 4100–3900 cal. BC; Late Mesolithic–Early Neolithic) there is a return to more variable depositional conditions (Figures 5 and 6). Initially from 4–3.8 m, the carbonate levels decrease (to 5–7%) with a dominance in magnetic susceptibility (from ca. 42 rising to 178 SI $\times 10^{-6}$) and redox elemental indicators alongside finer grained clay (ca. 3%) and silt (ca. 61%) with increased organic content (to 12–16%) and very fine to fine sand (ca. 35%), and stable pOSL levels (at ca. $23\text{--}24 \times 10^{-3}$) (Figure 6; Table 3). Between 3.8 m and 3.6 m there is a return to much coarser silts to very fine sands (43–44%) with increased levels of pOSL (from ca. $38\text{--}64 \log \times 10^{-3}$) and total sand (51–52%) (Figure 6; Table 3).

From 3.6–2.85 m (Phase E; ca. 3900–3300 cal. BC; Early Neolithic) there is a major change in sedimentation within the sequence (Figures 5 and 6). The boundary to Phase D is sharp and sees the development of a very dark brown, organic rich peat deposit comprising low carbonate (2–44%), dry bulk density ($<0.7 \text{ g/cm}^3$), magnetic susceptibility (17–41 SI $\times 10^{-6}$), pOSL (ca. $2\text{--}9 \times 10^{-3}$), variable redox (ca. 5–25k ppm) and dominated by a clay (4–10% and silt (48–84%) texture with mixed sand content (6–46%) (Figure 6; Table 3). Phase E also demonstrates a clear increase in quantity and variability of other elements (Figure 6). Carbonate signatures generally remain variable (ca. 5–16k ppm) in line with the LOI result carbonate content (2.17–4.30%) (Figure 6; Table 3). Coarse (ca. 31–73k ppm) and fine (ca. 12–26k ppm) elemental signatures reduce but with marked variations between horizons, and there is also a subtle decrease in the proportions of heavy metals within this horizon (0.17–0.24k ppm) compared to the layers below (Figure 6; Table 3).

The shift from the organic dominated sediments of Phase E to the return of rhythmical clastic dominated horizons of Phase F (2.85–1.85 m; ca. 3300–1200 cal. BC; Middle Neolithic to Middle Bronze Age) is a sharp one and is marked by some significant changes in the sedimentological analyses, which share a number of similarities to the characteristics determined in Phase A at the base of the sequence (Figures 5 and 6). Phase F contains six rhythmical micro-horizons between 12–20 cm thick composed of alternating finer and coarser deposits typically grey to dark grey in colour with low organic, carbonate and clay content. Greater variability can be seen in other analyses. The finer horizons between 2.8–2.65 m, 2.46–2.34 m and 2.17–2.05 m contain lower dry bulk density ($<1 \text{ g/cm}^3$), pOSL intensities (ca. $15\text{--}20 \times 10^{-3}$), and a sand content (ca. 15–30%) with a dominance of fine to coarse silts (ca. 51%) (Figure 6; Table 3). In contrast, the coarser horizons between 2.65–2.46 m, 2.34–2.17 m and 2.05–1.85 m contained higher bulk density values (ca. $1.5\text{--}2 \text{ g/cm}^3$), pOSL intensities (ca. $30\text{--}100 \times 10^{-3}$) and are dominated by sand textures (56–73%) (Figure 6; Table 3).

Following the cessation of the final coarse horizon of Phase F there is then a prolonged phase of finer silt (ca. 71%) dominated sedimentation (Phase G, 1.85–1 m; ca. 1200 cal. BC to ca. AD 400; Late Bronze Age to Roman) (Figures 5 and 6). This is characterized by a grey coloured fine to medium silt with ca. 5–6% organics and ca. 2–3% carbonate contents, a decreased yet stable bulk density (ca. 1–1.2 g/cm⁻³) and pOSL intensity (ca. 18–26 ×10⁻³), but markedly raised magnetic susceptibility (from 135 to 185 SI × 10⁻⁶), redox (ca. 15–32k ppm) and fine clastic indicators (ca. 40–52k ppm), and a reduction in coarse indicators (ca. 132–171k ppm) (Figure 6; Table 3). As determined in Phase F, there is an overall continuation of higher barium (Ba) and heavy metals (Figure 6).

The uppermost horizon in the core sample Phase H (1–0.6 m; ca. AD 400–1700; Early Medieval to post-Medieval) demonstrates a further shift in depositional conditions at the sample location (Figures 5 and 6). This phase consists of a darker grey to dark grey brown coloured fine silt (ca. 72–84%) with a greater clay (ca. 3–7%), pOSL (ca. 10–34 ×10⁻³), and organic content ranging from ca. 5–25%, alongside reduced sand content (ca. 9–23%), bulk density (<1 g/cm⁻³) and magnetic susceptibility (<50 SI × 10⁻⁶). This textural change is echoed by similar ranges in elemental results, particularly coarse (ca. 24–210k ppm) and fine (ca. 10–65k ppm) sediment indicators and redox (0.66–17k ppm) levels (Figure 6; Table 3).

Interpretation and discussion

Geoarchaeological analysis of the sediment sequence from the river Ure floodplain at Aldborough has demonstrated a complex, progressive stratigraphy which reflects changing fluvial activity. The establishment of a sequence chronology using both radiocarbon and OSL methods (Tables 1 and 2), alongside the calculation of age-depth modelling (see Loveluck et al. 2025) (Figure 6), means that the stratigraphic history for the core can now be discussed in terms of fluvial processes through time.

The laminated coarse and fine sediment couplets identified within Phase A (5.95–5 m) represent a highly active phase of direct fluvial activity within a former channel of the river Ure active during the Late Mesolithic period (ca. 5500–4500 BC). The nature of the interbedded horizons suggests repeated phases of higher energy channel activity resulting in coarse sediment deposition alongside periods of lower energy sedimentation and increasing organic dominance as the palaeochannel progressively infilled. The major increase in magnetic susceptibility towards the top of the feature fill, probably driven by increasing oxidation of iron (Allen and Macphail 1987; Mees and Stoops 2010, 552–553), indicates a shift in depositional processes with a reduced fluvial influence and greater drying out of the former channel. Critically, the lack of an expected gravel terrace at the base of the sediment sequence suggests that this channel does not form part of a Late Glacial braided fluvial system, as determined elsewhere across the Ure and Swale catchment (Bridgland et al. 2011; Howard et al. 2000; Innes et al. 2021) and other river systems of northern England (Howard et al. 1998; Macklin 1997; Macklin, Passmore, and Rumsby 1992, 2000; Passmore et al. 1993; Taylor and Macklin 1997; Taylor, Macklin, and Hudson-Edwards 2000). Rather, it represents a multi-channel

anabranching form with multiple channels becoming activated and abandoned at regular intervals across the floodplain landscape.

Following the cessation of the active palaeochannel, the sediment sequence demonstrates a phase of more uniform fine-grained deposition followed by a period of organic development between approximately 4500–4300 BC (Late Mesolithic; Phase B; 5–4.4 m) (Figure 6). At this stage, the former channel may have become distanced from the active river channel and become filled with water during flooding events leaving a standing pond or pool allowing fine sediments to develop alongside the organic rich material present within the top of this channel fill unit.

Between 4300 and 4100 BC (Late Mesolithic; Phase C; 4.4–4 m) there appears to have been a shift in accretional conditions and a reactivation of semi-permanent fluvial activity within the palaeochannel. The presence of greater carbonate rich and coarser sedimentology suggests a period of prolonged higher energy yet shallow water flow possibly exacerbated by flooding events interspersed by prolonged phases of dry conditions (Figure 6).

More variable fluvial activity appears to have developed in Phase D between 4100–3900 BC (Early Neolithic; 4–3.6 m). This is indicated by the progressive deposition of low energy silts in a largely inactive channel followed by a rapid, higher energy reactivation of permanent fluvial activity, possibly as a single avulsion event.

From 3900–3300 BC (Early to Middle Neolithic; Phase E; 3.6–2.85 m) the sediment sequence demonstrates evidence of a prolonged period of fine, organic rich sediment accumulation indicative of very low energy conditions (Figure 6). During this period, the palaeochannel appears to have filled with water but with no influx from the active fluvial system. The overall reduction in magnetic susceptibility and redox elements throughout Phase E suggests a progressive increase in sediment drying up-profile associated with a readily mobile water table aligned with the rapid fluctuation in depositional conditions and possibly a variability in source material. Subtle variation in this horizon might be inferred from the increased variability in coarse and fine elemental indicator results, particularly titanium (Ti) and potassium (K) (Figure 6; Table 3), which suggest that the organic layer may have had greater clastic input between 3.2–2.85 m, either during its deposition or through post-depositional transfer from Phase F horizons.

These conditions change rapidly from 3100 BC, possibly as a result of an avulsion event which reactivates the palaeochannel to become part of the active fluvial system. Between 3300–1200 BC (Middle Neolithic to Middle Bronze Age; Phase F; 2.85–1.85 m), there is a return to the interbedded coarse and fine texture sedimentation. This is associated with cyclical higher and lower energy deposition alongside greater variability in active water table conditions. Variations in the thickness, texture and geochemistry of these laminated channel infills differ from those observed in Phase A. These features suggest that their input derives from a more active fluvial system, possibly dominated by a single or bifurcated channel system and one which perhaps demonstrates increased evidence of anthropogenic influence on the surrounding landscape in later prehistory. By about 1200 BC this

phase of active riverine conditions had ceased and lateral channel migration had abandoned this section of the river.

Despite direct channel influence, the sediment sequence for the uppermost 1.85 m was dominated by overbank alluviation (Figure 5). Initially, from 1200 BC to AD 400 (Late Bronze Age to Roman; Phase G; 1.85–1 m) this was dominated by lower energy, fine to medium silts. Then, from AD 400–1700 (Early to post-Medieval; Phase H; 1–0.6 m), the alluvial aggradation had become even finer with an increasing clay content (Figure 6; Table 3), presumably as a result of continued arable agriculture in the catchment and channel migration to its current location on the northern edge of the floodplain. In addition, in both these latter phases, the higher barium (Ba) and consistent heavy metals presence (Figure 6; Table 3) may relate to increasing anthropogenic influence in the watershed (cf. Entwistle, Abrahams, and Dodgshon 1998; Fleisher and Sulas 2015; Wilson, Cresser, and Davidson 2008), including pollution from increased metal production and smelting in the catchment and at Aldborough (see Loveluck et al. 2025).

The progressive development of overbank alluviation across the floodplain between the Middle Bronze Age to Early Medieval period demonstrates a considerable phase of reduced direct fluvial channel activity across the sample location for a considerable period. This may reflect increased open land cover conditions, slope instability and soil erosion in the upper headwaters from the end of the Roman period (Chiverrell et al. 2008), channel entrenchment driven by greater climatic stability (Long et al. 2004) alongside an intensification in land use activity within the fluvial and terrestrial landscape, increasing sediment erosion into the floodplain and influencing the fluvial conditions within the Ure. Similar accelerated alluviation across floodplains driven by increased anthropogenic/climatic processes has been demonstrated across many other major British fluvial systems (e.g. Brown 2000a; Brown et al. 2013, 2021; French 1990; 2003, 113–132; French, Scaife, and Allen 2012; French et al. 2024; Pears et al. 2020a, 2020b, 2023). In addition, the lack of distinctive variation during the Iron Age and Roman periods in the sediment sequence in conjunction with the concentrated occupation of the floodplain margin is further evidence that the palaeochannel identified during this sampling phase is not that which would have been present in the landscape in the later prehistoric and early historic periods.

Implications

From the radiocarbon assay of this prehistoric palaeochannel, now observed in boreholes BH11–14, 22, 23, 26, 42 and 48, it was active from at least 4617–4485 cal. BC (5714 ± 22 BP; GU55508) and 4358–4261 cal. BC (5467 ± 27 BP; GU50296) in the late Mesolithic period. But it was most probably out of use by the Roman period with the construction of a road/bridge across the floodplain. Nonetheless, it probably existed as a shallow contour dip in the ground surface of the day, and was still prone to becoming an occasional shallow channel feature in the landscape whilst slowly but surely filling up with humic silt loam alluvial material. In the post-Roman period and into Medieval times, the depositional dynamic of alluvial deposits becomes slightly coarser, much more sandy (rather than silty to very fine sand) material, and the main river floodplain shifts northwards. This new river alignment appears to more or less mirroring the route of the current embanked

river, but with its southern bank extending some 50–100 m south of the southern base of the modern flood bank (Figure 3).

The investigated sedimentological sequence from Aldborough provides important evidence for understanding the nature of the fluvial history of the river Ure. Despite not being an active channel during the period of maximum human occupancy in the Roman period, the analysis has determined a prolonged history of riverine activity across the local floodplain landscape from the Late Mesolithic period. The range of sedimentological analyses conducted has illustrated a complex multi-process fluvial system in place with evidence of active channel phases, shallow water carbonate rich periods, stages of stationary water dominated by organics and prolonged times of overbank alluviation which occurred in line with the significant occupation of the site in the Roman period.

The palynological analysis of borehole BH14

Borehole BH14 was selected for study as the most representative sediment archive of the main palaeochannel in proximity to the Roman town with good potential for pollen analysis and environmental reconstruction. Most regional pollen work has originated from upland peats, coming primarily from the North York Moors (e.g. I. G. Simmons 1969; I. G. Simmons and Innes 1988a, 1988b), the Tabular Hills (e.g. I. Simmons et al. 2021), the Yorkshire Wolds (e.g. Bush and Flenley 1987) or the Yorkshire Dales (e.g. Honeyman 1985; McCarroll et al. 2016). These upland areas will have been significantly vegetationally and environmentally different to the lowland zone of the Aldborough region. The analysis presented here is situated within an expanding corpus of lowland pollen research primarily deriving from palaeochannels of the Ure northwest of Isurium (Bridgland et al. 2011) and from Healam Beck near the Roman site at Healam Bridge (O'Brien et al. 2017). This analysis sets out to provide a long-term environmental record for the Aldborough region, and to provide a thorough examination of the environment and any change specifically associated with Aldborough's Roman occupation. Such factors as agriculture and riverine transport links are considered.

The pollen data

Sub-samples for pollen analysis were taken from the borehole BH14 core at 8 or 10 cm intervals. Standard techniques were used for the extraction of sub-fossil pollen, spores and other microfossils; largely pre-Quaternary palynomorphs (Moore and Webb 1978; Moore, Webb, and Collinson 1991). Details of palynological procedures and calculations used in the construction of the pollen diagram are given in the Supplementary Information.

Five local pollen assemblage zones (l.p.a.z.) have been recognized in this 5.95 m sequence which are detailed in Table 4 and Figure 7. Within these principal zones, local pollen assemblage sub-zones (l.p.a.s.z.) are also recognized. On-site changes in the wetland flora are given in Table 5. These pollen zones, in part, relate to the changes in stratigraphy which may have strongly influenced the taphonomy.

Table 4. Non-wetland pollen zonation of borehole BH14 data.

Pollen assemblage zone	Sediment phase	Palynological characteristics
I.p.a.z. ALD B: 5 1–0.24 m Ericaceae-Plantago lanceolata- Lactuicoideae-Poaceae	H	This upper zone is defined by increase of Ericaceae (Calluna to 20%; Erica <3%) and Sphagnum (rising to 20%). APF values remain low whilst levels of micro-charcoal increase. Arboreal and shrub pollen is at their lowest levels (15–16% tdlp). Quercus and Corylus avellana type (peak top 20% and declining) are most important. Herbs remain dominant with Poaceae (34%), Cereal type (10%), Lactuicoideae (to 26%), Plantago lanceolata (13%) (I.p.a.s.z. 5. vi) and Sinapis type (15%; I. p.a.s.z. 5: v). Cannabis sativa type (sporadic occurrences) is noted. Dryopteris type and pre-Quaternary palynomorphs remain important.
I.p.a.z. ALD B: 4 2.44–1 m Poaceae-Cereal type-Plantago lanceolata- Lactuicoideae-Dryopteris type-Pre- Quaternary	F-G	APF values decline sharply along with levels of tree and shrub pollen and expansion of herb diversity and percentage values. Micro-charcoal numbers increase. Quercus declines in the lowest zone to <5% with subsequent minor regeneration (ca. 10%). Tilia declines further to only sporadic occurrences and Corylus avellana type to an intermittent record of peaks and troughs (10–40%). Dwarf shrubs/Ericaceae start to become more abundant (Calluna). Herbs become dominant with Poaceae sharply attaining high values (to 55%) with Cereal type (increasing to ca. 30%) (Secale cereale occurs), Lactuicoideae (to 27%) and Plantago lanceolata (peak to 10%). There are other peaks in Apiaceae (22%), Brassicaceae (6%), Caryophyllaceae (5%), continuous records of Chenopodiaceae and Asteraceae types. Centaurea cyanus is noted in the top of the zone. Herbs are diverse with sporadic occurrences of other types including Plumbaginaceae (Armeria 'A' and 'B' line). Fern spores remain at high levels after expansion at the top of Zone 3. Sphagnum starts to become important (to 5%). Pre-Quaternary palynomorphs continue to expand from upper Zone 3.
I.p.a.z. ALD B: 3 3.56–2.44 m Quercus-Corylus avellana type-Plantago lanceolata-Poaceae C14: 5021 ± 26 BP (3.4 m)	E-F	APF values are generally high and along with upper levels of Zone 2 are the highest values in the sequence (silty peat and wood peat). This zone is defined by a very sharp reduction in Ulmus from high values (to 5–10%) and Tilia (to 5–7%). Quercus increases (peak to 40%) with Corylus avellana type attaining its highest percentages (to 76%). Hedera helix dies out. Betula and Pinus remain at low levels with a minor expansion of Pinus at the top of the zone. Herbs increase with an initial expansion of Plantago lanceolata (2–3%) with Poaceae (to 20%) and including Cereal type pollen with a single peak to 10% and present throughout the zone (I.p.a.s.z. 3: iv). Fern, monolete-Dryopteris type spores are at low levels (4–6%) but regain importance from the top of the zone, rising to 23% sum + ferns. Reworked palynomorphs are at their lowest levels in this zone; absent but expanding from the top of the zone.

(Continued)

Table 4. (Continued).

Pollen assemblage zone	Sediment phase	Palynological characteristics
l.p.a.z. ALD B: 2 4.92–3.56 m Ulmus-Quercus-Tilia-Corylus avellana type	B-C	APF numbers increase progressively through this zone. The base of zone is delimited by start of consistent decline in Tilia from high values at the top of Zone 1 to <10% at the top of Zone 2. Ulmus (to 35%), Quercus (20–25%), Tilia (noted) and Corylus avellana type (generally increasing from ca. 45–60%). There is a peak of Fraxinus (16%) at the top of the zone (l.p.a.s.z. 2.iii). Betula, Pinus and Hedera helix remain as in zone 1. Herbs remain as Zone 1 with peaks of Poaceae from Zone 1 (l.p.a.s.z. 1: ii); Ranunculus type and Artemisia are reduced. Dryopteris type (fern) peaks (28% sum + ferns) followed by consistent decline along with Polypodium. There are small numbers/peak of Sphagnum at the base of the zone (in l.p.a.s.z. ii; 4%). Pre-Quaternary palynomorphs (5–7%) die out in the upper zone. Moderate levels of micro-charcoal continue from Zone 1.
l.p.a.z. ALD B: 1 5.95–4.92 m Ulmus-Quercus-Tilia-Corylus avellana type C14: 5467 ± 27BP (5.65 m)	A	APF values are low. Trees and shrubs are dominant (to 95%) with few herbs (5%). Ulmus (to 27%), Quercus (to 39%), Tilia (50% at base) and Corylus avellana type (to 67%) are dominant. There are small numbers of Betula (5%), Pinus (3%) throughout and Fraxinus (at the top of the zone). Hedera helix is more abundant in this zone with sporadic peaks (to 6%). Herbs comprise largely Poaceae with an initial peak (to 7%) and increased values and sporadic at the top of the zone and subsequently (l.p.a.s.z. ALD B: 1-i and ALD B: 1-ii). Other herbs include sporadic occurrences of Ranunculus type, Apiaceae, Artemisia and a single record of Plantago lanceolata at 5.44 m associated with ALD B: 1-ii and a tentative Cereal pollen grain. Dryopteris type undiff., D. filix-mass and D. palustris type and undifferentiated, monoete fern spores are consistent (to 20%) with occasional Polypodium. High values of pre-Quaternary palynomorphs are present in basal levels and more consistently in the upper zone. APF values are low with moderate micro-charcoal.

The terrestrial pollen

Absolute pollen frequencies and preservation were, as might be expected, very variable and with differing levels of preservation. These factors relate largely to the variations in lithostratigraphy and changes in the environment of deposition.

The on-site (wetland) vegetation and the environment of deposition

The pollen assemblage zones recognized are largely the same as for the non-wetland habitats and further relate to the complicated taphonomy of changes in the sediment types and environment of deposition. The highest arboreal fen pollen values occur in those zones (ALD: 2–3) where Alnus (alder) was dominant as alder carr floodplain woodland on, or near the borehole site. The essential changes seen in the autochthonous vegetation are detailed in [Table 5](#).

Table 5. Details of the on-site wetland palynology and vegetation change in borehole BH14.

Pollen assemblage zone	Sediment phase	Palynological characteristics
l.p.a.z. ALD B: 5 1–0.24 m Cyperaceae- Sphagnum	H	This upper zone is a gleyed floodplain alluvium with low absolute pollen frequencies. The high values of fen/marginal aquatic pollen taxa of Zone ALD B: 4 are much reduced with only Cyperaceae remaining important; to 22% with increasing numbers at the top of the zone. Alnus values are low (7–8%). Salix is absent and the overall diversity of wetland taxa seen in Zone 4 is devoid in this upper zone. Of note is the increasingly important expansion of Sphagnum (to 19% Sum + Misc.). Pre-Quaternary taxa remain consistent (10–20%). Occasional Pedicularis.
l.p.a.z. ALD B: 4 2.44–1 m Typha angustifolia type-Cyperaceae	F-G	The stratigraphical change from peat to silty clay is accompanied by a substantial reduction in APF values for the terrestrial flora and by a marked change from Alnus and Salix of Zone 3 to one dominated by marginal aquatic, fen taxa. Typha angustifolia (two peaks to >50%) and Cyperaceae (increasing to 40% at the top of the zone) are dominant. Some aquatic macrophytes are present; Myriophyllum spp., Potamogeton type, and Lemna. Marginals comprise Alisma plantago-aquatica, Butomus umbellatus and Typha latifolia in addition to the high values of Typha angustifolia/Sparganium and Cyperaceae. Isoetes lacustris and Equisetum (wetland taxon?) are present at the base of the zone. Alnus of the preceding zone remains with low values; peak to 25% and declining. Pre-Quaternary palynomorphs become numerous (22% Sum + Misc.). Sporadic Pedicularis.
l.p.a.z. ALD B: 3 3.56–2.44 m Alnus glutinosa-Salix C14: 5021 ± 26 BP (3.4 m)	E-F	Peat with high APF values also showing a transition to silty-clay at the top of the zone (2.92–2.75 m). Alnus remains dominant with consistent and highest values in this sequence (to 45% Sum + Marsh). Salix is important with a basal peak of 20% reducing throughout the zone (to ca. 5%). Aquatic macrophytes remain as in the preceding zones with the addition of Nymphaea, possible Hottonia palustris, Lemna and Isoetes lacustris. Marginal aquatic taxa are more diverse than the preceding zone with Alisma plantago-aquatica, Lythrum salicaria, cf Oenanthe, Menyanthes trifoliata and Typha/Sparganium. Surrounding wet pasture taxa include Caltha cf palustris, Hydrocotyle vulgaris and Filipendula. There are few pre-Quaternary palynomorphs.
l.p.a.z. ALD B: 2 4.92–3.56 m Alnus glutinosa	B-C	Change to a silty/sand with peat lenses and wood peat in the upper levels. APF values are high but variable with a peak of 143 grains/ml at 4.4 m. These decline and become larger to peak at 3.84 m. Alnus remains dominant with high values (38% declining to ca. 15%). There are sporadic macrophytes with Nuphar, Myriophyllum alterniflorum, and Potamogeton type. There are also sporadic marginal-aquatic with Typha/Sparganium and marginally higher values of Cyperaceae than in Zone ALD B:1. Derived pre- palynomorphs are consistent in the lower zone but decline to absence. There is a minor peak of Sphagnum at the base of the zone. Occasional Pedicularis.
l.p.a.z. ALD B: 1 5.95–4.92 m Alnus glutinosa C14: 5467 ± 27 BP (5.65 m)	A	Fine, coarsely laminated silt/sand filling the base of palaeochannel. There are some humic/peaty lenses. Alnus glutinosa (45% Sum + Aquatic) is dominant. Small numbers of Salix are present, especially in the upper part of the zone (>5.3 m). There are sporadic occurrences of aquatic macrophytes; Stratiodes aloides, Myriophyllum spicatum, M. alterniflorum and Potamogeton type. Marginals comprise occasional Butomus umbellatus, Typha/Sparganium and Cyperaceae. Dryopteris palustris type is present and monolete Dryopteris type (incl. T. palustris?). There is a large spike of derived palynomorphs and a more continuous presence from the upper zone.

The inferred vegetation and environment

The pollen data can be considered in terms of the on and near site vegetation and the vegetation growing adjacent to the wetland, and the regional and extra regional pollen elements. Pollen numbers and importance of the latter are, as expected, subordinate to

that from the former autochthonous and near allochthonous vegetation communities present.

The development of the wetland. The development of the wetland Basal sand and gravel (>6.2 m) suggests that the earliest stages of sedimentation were fluvial. The channel itself may be of Devensian age formed in periglacial conditions and glacial outwash. Subsequently, during the early post-glacial through to the middle Holocene it is likely to have been colonized by woodland. The reasons for the initiation of sedimentation are not clear and only suggestions can be made. Possibilities are that climatic change occurred in tandem with increased wetness, regional eustatic change and changes in the local water table caused by anthropogenic activity. That is, with woodland clearance and agriculture causing reduced evapotranspiration, increased surface run-off and higher ground water table causing waterlogging at low elevations resulted in mire/wetland formation and causing fluvial systems to develop or be re-activated. Here, the basal fill of the channel comprises coarse sand and fine gravel suggesting an initial medium energy fluvial environment. This would clearly not provide suitable conditions for pollen preservation. It is not clear what caused this initial change in fluvial conditions.

With a reduction in energy, finer sediment was deposited (from ca. 6.2 m) which facilitated preservation of pollen which has been examined down to 5.95 m (or the base of l.p.a.z. ALD B: 1). This basal sediment contains pre-Quaternary pollen and spores (palynomorphs) which implies that the sediment source was from the erosion, transport and re-deposition of contained microfossils from earlier alluvial sediment and/or through bedrock erosion. More recent (Holocene) pollen in such sediment is taphonomically complex with possibility of transport from the upstream catchment. APF values are typically small and with degraded/abraded pollen present. The very fluctuating nature of the pollen 'curves' in Zone ALD B: 1 are typical/symptomatic of these factors. Initially, there are high values of alder (*Alnus glutinosa*) showing the colonization of alder as dominant floodplain carr woodland. Small numbers of aquatic macrophytes in this phase (e.g. water milfoil) attests to standing or slow flowing water, perhaps in the central channel. It is probable that this pollen comes from overbank flooding and deposition with the mineral sediment. Radiocarbon dating places the start of this phase at ca. 4600–4300 cal. BC (5714 ± 22 BP, GU55508; 5467 ± 27 BP, GU50296). Willow (*Salix*) became progressively more important as part of this carr woodland (in the top of Zone ALD B: 1). Contrasting with alder with its high pollen productivity and general over representation in pollen spectra, willow is usually poorly represented and here it was periodically important during this early phase, becoming more important as the habitat stabilized. The ground flora of the carr is poorly represented but probably consisted of grasses (Poaceae), occasional sedges (Cyperaceae) and especially typical marsh frond ferns of various types. These include identified *Dryopteris filix-mas* and *D. palustris*. These probably also form a larger part of the undifferentiated *Dryopteris* type, that is, those spores that have lost their diagnostic outer perinous layers.

Alder carr remained important throughout Zone ALD B: 2 in its upper levels and throughout zone ALD B: L3 where alder-willow carr was fully developed by ca.

3942–3711 cal. BC (GU50295). It appears that the sediment accumulation rate was high through this Early Neolithic period. This is also indicated by the rapidly fluctuating values of alder, fern spores and pre-Quaternary palynomorphs. Pollen Zone ALD: 3, as noted, shows increased stability with more consistent alder and marked dominance of willow (*Salix*), certainly growing on site. Facies of wood peat within the sequence attest to this on-site dominance. The continued presence of aquatic macrophytes and marginal aquatic/fen taxa represent standing water, perhaps in cut-offs and slow flowing water in the river channel with marginal plants and the ground flora of the carr.

Summary of the alder carr phase. This phase sees the development of topogeneous, rheophilous alder carr on the floodplain from ca. 4600 cal. BC which became progressively more stable by ca. 3700 cal. BC after a period of apparently rapid sedimentation accumulation, aided by overbank deposition. After this period, there was a phase of more stable floodplain carr woodland with dominance, on-site, of willow (*Salix*) along with nearby alder (*Alnus*). Aquatic macrophytes throughout this period indicate standing or slow flowing water either in the main channel or meander cut-offs.

At 2.4 m there is a significant change from stable alder-willow floodplain woodland (ALD B: 3) to an open herb rich fen (Zone ALD B: 4) which probably occurred in the Early Bronze Age. This phase shows dominance of grasses, sedges, and bulrush and/or bur reed (*Typha angustifolia*/*Sparganium*), aquatic macrophytes and marginal aquatic fen plants. Algal *Pediastrum*, albeit in small numbers, also attest to a freshwater habitat. The lithostratigraphy changes from peat to humic clay-silt with re-deposition of pre-Quaternary palynomorphs in reworked sediment.

This important transition, seen at the top of Zone ALD B: 3 (2.92–2.75 m), saw the removal of alder and willow from on-site due to increasing wetness. Alder will tolerate up to three (winter) months of flooding of the root boles in the carr (Iversen 1949; McVean 1956). This was apparently succeeded during this phase, resulting in open fen whilst alder will have moved (asynchronously) to more suitable fringing habitats. Alder does remain at much lower levels. The cause of this transgressional event may be due to regional eustatic change in the North Sea basin that caused the ponding back inland of freshwater systems (Long et al. 1998; Macklin 1997; Macklin et al. 2000). Whilst the distance inland from the sea is considerable, there is tentative evidence for even brackish water incursion with sporadic occurrences of thrift and/or sea lavender (*Armeria/Limonium*) in this zone. The only other possible halophytes are *Chenopodiaceae*, although many plants of this family may also be attributable to other (especially disturbed arable and waste ground) rather than taxa of salt marsh. As such, this may have implications for transport access to Aldborough during the early historic period and also relates to the Roman sea-level high stand (Macklin et al. 2000; Taylor, Macklin, and Hudson-Edwards 2000).

During this phase in the later Neolithic, there is a marked increase in the taxonomic diversity. This is in part a function of increasing human impact with woodland clearance, agriculture and animal husbandry (cf. Neil et al. 2016; Oswald and Pollington 2012) also causing changes in pollen taphonomy. The preceding carr woodland phase (ALD B: 1–3) is represented primarily by airborne pollen whilst the fen has reworked sediment and pollen (cf. pre-Quaternary palynomorphs become important). There is, therefore, a strong possibility that a significant portion of both the terrestrial/

dry-land pollen and the aquatic/fen taxa pollen may be fluviially derived from a wider catchment. It is noted in this zone that records of Ericaceae (ling) and Sphagnum (bog moss) become evident. These are taxa of acid, dry heath (*Calluna*) and bog (Sphagnum). It is considered unlikely that these were growing in the floodplain habitat which was predominantly a eutrophicated fen. As such, it is probable that these acidophilous elements derive from inland, drier areas of the catchment and were fluviially transported. This becomes more apparent in the upper levels of the profile (Zone ALD B: 5).

Summary of the aquatic/fen stage. There was a change from alder-willow carr (ALD B: 3) to one of open herb, eutrophic fen (ALD B: 4) which represents a significant change in the fluvial regime in the later Neolithic. Alder-willow carr may be regarded as a semi-terrestrial habitat (Kulczynski 1949). Conditions on site became markedly wetter, supporting a floristically rich flora including aquatic macrophytes and dominant reed-swamp. Lithologically, there was a change from autochthonous organic accretion to allochthonous sediment from the fluves.

Whilst the eutrophic fen habitat seen in Zone ALD B: 4 became more stable as indicated by reductions of pre-Quaternary microfossils in upper Zone ALD B: 4, stratigraphical changes at ca. 1.05 to 0.4 m indicate a change to a floodplain environment with deposition of a gleyed silt-loam alluvium (see above). The typically gleyed and partly oxidized nature of the alluvium resulted in the markedly reduced pollen diversity of this zone (ALD B: 5) and the APF values are typically very low. This is also accompanied by poor pollen preservation and the possibility of reworked Holocene pollen as well as the pre-Quaternary elements noted. The former may include Lactucoideae (dandelion types; *Taraxacum*, *Leontodon*, *Hieracium*, etc.) which have a robust (fenestrate) pollen form. A consequence of this is their possible over-representation, although in this case, they are also a clear indication of a pastoral phase. Thus, pollen evidence for the nature of the floodplain habitat is, perhaps, restricted due to the above factors. The pollen data do, however, show a continued grass-sedge fen but also a typical pollen assemblage of less species rich floodplain vegetation character. Alder pollen remains at relatively low levels, but, as described for Zone ALD B: 5, alder was probably of more importance on the fringes of the floodplain away from the immediate sample site. The acidophilous heath community noted in the preceding zone ALD B: 5 became more important in this upper floodplain alluvium with significantly increased pollen numbers/percentages. This heath/bog habitat was similarly unlikely to have been growing on the actual floodplain and, as described, is represented through fluvial transport extending the pollen catchment and changing taphonomy.

The dating of this final stage of alluviation and subsequent period of drainage/land reclamation for agriculture (currently arable cropping) is of the Early to post-Medieval periods. Indeed, the presence of *Cannabis sativa* (hemp) type is diagnostic of the Saxon/Early Medieval to Medieval periods (see below). Such changes from wet fen to floodplain with alluvium is diagnostic of other river systems, and has been interpreted as changing patterns/styles of cultivation and resulting hydrological changes and sediment transport. This was initially identified for the middle Thames at Farmoor, Oxfordshire (Lambrick and Robinson 1979).

The top of the pollen profile at 0.24 m lies immediately below the present day agricultural topsoil. The absence of an expansion of pine pollen in these upper levels suggests that this most recent phase pre-dates ca. AD 1700. This relates to the introduction of exotic conifers (after the publication of John Evelyn's treatise *Sylva, or A Discourse of Forest-Trees and the Propagation of Timber in His Majesty's Dominions* in 1664) and later plantations on private estates, and from 1919 by the Forestry Commission (Long, Scaife, and Edwards 1999; Scaife and Long 2001), and is thus a useful biomarker.

Summary of the floodplain phase. The rich fen habitat of Zone (ALD B: 4) saw a transition to an alluvial floodplain in Early Medieval to Medieval times. Whilst remaining open, the floristic diversity of the preceding phase (ALD B: 4) was reduced with grasses and sedges remaining the dominant community and fringed by alder. Sphagnum (? bog) with dry heathland flora is shown, but is regarded as a taphonomic factor rather than on-site bog vegetation. This was an acid heath community at some distance in the catchment with fluvially transported pollen.

The dry-land vegetation. Borehole BH14 spans the period from ca. 4600 cal. BC (5714 ± 22 ; GU55508) to the post-Medieval period (AD 1330–1420; GL22074) (Table 1; Figure 7). As noted above, the taphonomy of the pollen is complicated by the changing lithostratigraphy reflecting the changing depositional environment.

Continuous accretion or hiatus? The inherent changes in the pollen spectra are described by local pollen zonation; that is relating solely to the individual sequence with no recourse to other pollen sequences. This has been carried out here also with no recourse to the stratigraphy. It is, however, clear that the pollen assemblage zones relate closely to changes in the lithostratigraphy. Whilst the depositional habitat will affect the taphonomy of the pollen (airborne versus fluvial), this poses the question as to whether there were hiatus at these pollen zones and lithostratigraphical boundaries or whether there was continuous accretion. Where pollen changes progressively (not-stepped), the likelihood of the latter is greater (e.g. ALD B: 1–2). It is thought that the somewhat fluctuating pollen values in l.p.a.z. ALD B: 1 represents an initial period of instability which settled down (ALD B: 2), and with clear on-site stabilization in ALDB: 3 under alder-willow carr woodland. Where there are marked stratigraphical and pollen changes (ALD B: 2–3 and 3–4), there is the possibility of temporal hiatus. This becomes a circular argument in that the substantial environmental changes which have taken place, influencing the vegetation, will also have affected the fluvial regime and consequent lithostratigraphy; that is, with little hiatus. This is considered to be the case in this profile. From the available radiocarbon and OSL dates (Table 1), it appears that sediment accumulation was rapid during the first 500 or 600 years of sediment accretion (in zones A–D, or later Mesolithic into the Early Neolithic), then more gradual in zones E and F (in the Neolithic to Early Bronze Age) and finally much slower in zones G and H (from the Middle–Late Bronze Age to Roman and Medieval times) (Table 2; Figure 6).

Bearing in mind the arguments/discussion on hiatus versus continuous sediment accretion, it appears that this almost six metre sequence dates back to at least ca. 4600–4300 cal. BC (5714 ± 22 BP, GU55508; 5467 ± 27 BP, GU50296) and extended

into the Early to Late Medieval periods (GL22079 and GL22074) (Tables 1 and 2). This, therefore, embraces the Late Mesolithic to post-Medieval periods within which significant changes in the degree of woodland cover changed due to human activity. Of note here are significant changes with declines in primary elm (*Ulmus*) and lime/linden (*Tilia*) woodland. These classic palynological phenomena are often related to human activity as the 'Neolithic Elm Decline' and the 'Lime Decline'. Of specific interest, in view of the nearby Roman town of Aldborough, is the early historic period and evidence of agriculture and overall environment and environmental change associated with its occupation.

The native woodland. The establishment of climax/dominant woodland in the region will have occurred during the Middle Holocene (Flandrian Chronozone II) from ca. 7000–5000 BP (Mangerud et al. 1974). The upper boundary/date for this period (the Atlantic/Sub-Boreal transition) in Britain is not well defined because of the incoming Neolithic economy and the associated Elm Decline caused by insect pathogens from ca. 5500–5000 BP (Girling and Greig 1985; A. G. Smith and Pilcher 1973) (see below). Here, the base of the pollen sequence at just below 5.95 m falls around ca. 4600–4300 cal. BC (5714 ± 22 BP, GU55508; 5467 ± 27 BP, GU50296). In common with a number of other English sites, especially from the lower Thames, peat/sediment accumulation was initiated at about this date and thus often not making any Neolithic Elm Decline evident (see below).

Although there is tentative evidence for human activity in l.p.a.z ALD B: 1–2, the pollen data demonstrates the background character of the climax woodland of the middle Holocene; after which there is a progressive diminution due to increasing human impact/interference. The characteristic importance of alder growing in valley wetland situations has been noted (e.g. Birks 1989; Brown 1988; McVean 1956). The vegetation of the drier soils on the interfluves is seen in ALD B: 1 and into ALD B: 2 and comprised woodland of elm (*Ulmus*), oak (*Quercus*), hazel (*Corylus avellana*) and especially lime/linden (*Tilia cf cordata*). Ivy (*Hedera helix*), as might be expected, was important in this woodland phase (as it is normally very poorly represented in pollen spectra). The concept of climax, mixed deciduous woodland of many earlier writers (e.g. Godwin 1956) has been replaced by the more realistic concept of polyclimax with dominance of different taxa on edaphically more suited locations (Godwin 1975). Thus, it is possible here for example that the oak and elm were more suited to lower and heavier valley side soils whereas lime (*Tilia*) may have been more suited to the better drained soil of the adjacent (sandy) floodplain levees, islands and the broader interfluve.

One of the principal features characterizing the woodland during the middle and early part of the late Holocene (Flandrian chronozones II and III) of southern and eastern England was the importance of *Tilia* (lime) (Greig and Limbrey 1982; Moore 1977; Scaife 1980). The pollen data from Aldborough adds to the past distribution record with its clear importance in the north of England, that is, beyond the assumed dominance in southern and southeastern England and East Anglia (Birks 1989; Birks, Deacon, and Peglar 1975; Godwin 1975; Waller 1994a). Lime/linden is renowned for its under-representation in pollen spectra (Andersen 1970, 1973) due to its entomophily and flowering during mid-summer; that is, when other trees are in full leaf, notably inhibiting pollen dispersion. Thus, the pollen values seen in pollen zones ALD B1 and

ALD B demonstrate the importance of this tree as a dominant in edaphically suited areas.

Human impact. It is clear that the period from ca. 4600–3700 cal. BC at this site was one of dominant, closed oak, elm, lime and hazel woodland (see above), after which very significant changes in woodland structure and diversity occurred. This was the local environment of the Late Mesolithic and Early Neolithic, and, if present, there is little evidence of any significant woodland modification here at this time. This contrasts with other regions of the country, especially southern England and Ireland for this period (e.g. Godwin 1975; Kearney et al. 2022; Scaife 1988; Waller 1994a). Typical pollen indicators including cereal pollen with the introduction of cropping and ribwort plantain (*Plantago lanceolata*) from grassland habitats. This plant and grasses have also been typically associated with ephemeral clearances; the ‘Landnam’ of Iversen (1941, 1949) and later writers (Scaife 1988; A. G. Smith and Pilcher 1973). Here, the first record of *Plantago lanceolata* occurs at the top of Zone ALD B: 1 and a possible cereal type also occurs in this zone. The latter is not, however, conclusive compared with the increasing occurrences from the base of zone ALD B: 3 and above. Small peaks of grasses (Poaceae) occur in zone ALD B: 1 (l.p.a.s.z. ALDB: 1.i) and into ALD B: 2 (l.p.a.s.z. ALD B:1.ii). It is possible that these ephemeral phases represent such localized Neolithic ‘Landnam’ clearances.

The Neolithic Elm decline. Changes in woodland structure occur at the top of zone ALD B: 2 with a minor peak of ash (*Fraxinus excelsior*) (l.p.a.s.z. ALD B: 2.iii). Ash is under-represented in pollen spectra and, thus, even small values may be significant, implying near and on-site growth. It has been noted by various researchers that ash became important, regenerating in areas from which elm died out (Iversen 1941, 1949; Scaife 1988). Here, this appears to be the case with an initial reduction of elm in this sub-zone and immediately prior to major reduction at the ALD B: 2/3 boundary.

Elm shows a dramatic decrease from high values (>30%) to <10% at the boundary between ALD B: 2 and ALD B: 3 at 3942–3711 cal. BC (5021 ± 26 BP; GU50295). This is typically coupled with an expansion of cereal, wild grass and ribwort plantain (l.p.a.s.z. ALD B: 3.iv.) and appears to be the primary Neolithic Elm Decline. The date also corresponds with the suggested date range of A. G. Smith and Pilcher (1973) for the Elm Decline from ca. 5500 to ca. 5000 BP and falls in its upper age range. A ‘late’ decline has also been dated at 4720 ± 90 BP at Glaisdale Moor (Jones, Cundill, and Simmons 1979) and Newtondale (Atherden 1976). More recent studies by Batchelor et al. (2014) have shown much earlier impact back to 7320–7240 cal. BP in the lower Thames valley and a much wider spectrum of possible dates in Ireland (Kearney and Geary 2024), contrasting with the data from Aldborough. The majority of dates from this broadly synchronous phenomenon do, however, fall within the Late Mesolithic–Early Neolithic range initially observed by A. G. Smith and Pilcher (1973).

There has been much discussion in the past and many theories which have dealt with this important palynological phenomenon (e.g. Scaife 1988; A. G. Smith 1970, 1981) and are not discussed here. However, the eloquent work of the late Dr Maureen Girling (1988) suggested that an insect pathogen was the likely cause of the elm disease of the

late Twentieth Century. Moreover the elm bark beetle (*Scolytus scolytus*) carrying the pathogen (*Ceratocystis ulmi*) resulting in elm disease was present prior to the Neolithic opening of the forest (Batchelor et al. 2014; Girling and Greig 1985; Parker et al. 2002; Peglar 1993; Rackham 2006). With the opening of woodland through increased human (Neolithic) activity, the insect vector became more important in spreading elm bark disease. Hence, the Neolithic Elm Decline is frequently closely associated with the first evidence of agriculture (Godwin 1944; Rackham 2006, 88; Scaife 1988).

It should, however, be noted that there is a marked change in the lithostratigraphy at this depth (ca. 3.4 m) and, as discussed above, there is the possibility of a hiatus and/or an erosional phase in the sediment accumulation. Such stratigraphical changes associated with the Elm Decline have been noted in other studies and have been attributed to external and more regional factors such as eustatic and climatic change. With regard to the latter, this is also the transition period from Flandrian II (Atlantic) to Flandrian III (Sub-Boreal). Clear evidence for climatic change at this time has never been clear from the lowland zone because of the interaction of humans and vegetation. It can only be said that here, the 'pollen curves' of oak (*Quercus*) and hazel (*Corylus avellana*) are 'smooth' across this transition. If a break in sedimentation and/or a phase was present, a more stepped record might be expected. *Tilia* (lime), however, also shows a significant decline along with elm at this time (l.p.a.s.z. ALD B: 2.iii.). Such an early lime decline is unusual but has been noted for some sites followed by a Late Neolithic and more usually the Middle Bronze Age decline (see below). The cause of this may be purely taphonomic. *Tilia* pollen, as noted above, is poorly represented in pollen assemblages at distance from its growth. Here, the change to a dominant alder-willow carr in Zone (ALD B: 3) at ca. 3700 cal. BC will have had a filtering effect on pollen entering the wetland zone (Tauber 1967a, 1967b), especially entomophilous *Tilia* flowering when other trees are in full (summer) leaf.

Above this significant transition (Elm Decline), there is evidence of cereal cultivation and pastoral agriculture (grass and ribwort plantain pollen), initially in l.p.a.s.z. ALD B: 3. iv. This may be attributed to the Early-Middle Neolithic. Typically, this activity declined in what is suspected as a phase of Late Neolithic woodland regeneration and possible period of change to woodland based pastoralism with a more open woodland structure with possibly foraging pigs (Geary and Lillie 1999, 115; Grigson 1982; Howard et al. 2000; Long et al. 2004). During this phase, there was an expansion of oak, some elm and especially hazel (? as scrub). These aspects have been discussed for southern English sites where a secondary elm peak and secondary elm decline and changing woodland structure have been described (Scaife 1988), and with evidence for some woodland regeneration in the Middle and Late Neolithic (e.g. Allen 2000; Allen et al. 2009; Brown 2000b). This, however, contrasts with other regions such as the upland areas of the Yorkshire Wolds which were probably almost cleared of woodland during the Neolithic (Bush and Flenley 1987) and the East Anglian Fens and Breckland areas where there is little evidence of Middle or Late Neolithic woodland regeneration (Godwin 1944; Waller 1994a).

The Lime decline. Along with the Elm Decline, the Lime Decline is frequently discussed and is an important palynological phenomenon (Geary and Lillie 1999; Grant, Waller, and Groves 2011; Turner 1962, 1970). Contrasting with the Elm Decline,

however, this phenomenon was not broadly synchronous with published dates ranging from the Neolithic to as late as the Medieval period (Baker, Moxey, and Oxford 1978). Most dates, however, occur for the Late Neolithic and Middle Bronze Age (e.g. Geary and Lillie 1999, 115; Grant, Waller, and Groves 2011; Greig and Limbrey 1982; Scaife 1980; Waller 1993, 1994a). Reasons for the reduction in *Tilia* are varied, but essentially relate to the clearance and opening-up of woodland on well-drained soil for agriculture due to increasing subsistence needs and changing agricultural practices. As such, the event is often associated with increasing pollen evidence of human activity changing the taphonomy by expansion of wetland (Geary and Lillie 1999, 120; I. G. Simmons and Innes 1996; Turner 1962, 1970); that is, pushing areas of lime growth away from sample sites (usually already wetland areas) through paludification (cf. Waller 1994b).

At Aldborough, the major decline has been described above and is associated with the Elm Decline. A second *Tilia* decline at 2.4 m shows a further pollen reduction from 7–8% to only sporadic occurrences. This is clearly associated with an expansion of herb pollen associated with human activity. This decline is above the transition from on-site alder-willow carr (ALD B: 3) to open grass-sedge fen (ALD B: 4). Thus, the former will have had a restricted pollen input to the site through filtration whilst the pollen catchment would have been much greater under the latter with evidence of agriculture from farther afield both by fluvial and airborne transport. Consequently, it is suggested that both increased human activity as well as marked changes in pollen taphonomy occurred. There is an increase in the diversity of herb pollen taxa with arable activity evidenced by cereal pollen and weeds/segetals, the latter including, for example, Brassicaceae (charlocks/mustards), Polygonaceae (bistorts), possibly Chenopodiaceae (goosefoots and oraches) and some Asteraceae (dandelion/daisy family) types. Grassland, probably pasture, is seen with a very substantial increase in *Plantago lanceolata* as well as Poaceae and Lactucoideae. Other taxa are not definable to a lower taxonomic and therefore, plant community level.

During the intervening period between the Elm Decline and the first Lime Decline and further lime reduction in zone ALD B: 3, woodland remained important but with changes in the dominant trees and shrubs. Oak (*Quercus*) remained important in the landscape along with hazel (*Corylus avellana*), both having an increased importance. The latter, hazel, was perhaps growing as scrub and flowering aided by more open conditions. This phase probably represents the Late Neolithic into the Middle Bronze Age (sediment Phase F) when sum percentage changes are considered. With the high values of elm and lime not being present, other taxa within the pollen sum may show increased percentages even though there may not have been changes in real growth. However, it is thought that, here, hazel may have been a scrub colonizer and more important 'on the ground'. The increased openness is also manifested by a small increase of wind dispersed pine from long distance/extra regional sources. Birch is similarly from wider regional sources.

It is within Zone ALD B: 4 that there is the change from late prehistoric (or Bronze Age) agriculture into the Iron Age, Roman and Early Medieval periods. Although there is a progressive increase in cereal pollen throughout this zone (ALD B: 4), it is thought that a peak of cereal pollen from ca. 1.6–1.5 m (l.p.a.s.z. ALD B: 4.v.) may represent increased cultivation associated with the Iron Age and Roman periods. Wheat-barley type cereal pollen is most important in this phase with occasional *Secale cereale* (rye)

which is typical of this and later periods (also present during the Iron Age). Excavations at Aldborough have produced substantial cereal microfossil evidence at ca. 500 m from borehole BH14 (Giorgi 2024; Payne 2024), and it seems likely that these data are related.

It is possible that changes in arable practices and intensification introduced during the Iron Age remained unchanged throughout the Roman occupation. As noted, cereal pollen records peak and the phase of maximum arable activity within the pollen catchment occurs at the top of Zone ALD B: 4 (l.p.a.s.z. ALD B: 4.v.). Arable records remain into the latest period represented (in ALD B: 5), which is thought to be of Early Medieval to Medieval in date. However, there also appear to have been fluctuating phases of pastoral activity. As noted, ribwort plantain (*Plantago lanceolata*), dandelion types (Lactucoideae), grasses (Poaceae) and other possible types become increasingly taxonomically diverse and important in Zone ALD B: 4. It is not clear whether the maximum of Lactucoideae in ALD B: 4 represents an intensified pastoral phase or, as more likely, increased numbers of robust Lactucoideae as reworked pollen from earlier sediment. This may be evidenced by the corresponding maxima of derived pre-Quaternary palynomorphs. A peak of *Plantago lanceolata* with Lactucoideae in ALD B: 5 (ca. 0.50 m) is interpreted as a pastoral phase subsequent to the arable phase noted.

During the time-span represented in zone ALD B: 4, there are sporadic and increasing numbers of acidophilous Ericaceae (*Calluna*) and Sphagnum bog moss. These become increasingly important and especially in the upper levels of the profile (zone ALD B: 5), that is, in the upper floodplain alluvium. It is tempting to attribute these acidophilous plants to wet and dry heath within the catchment, due to soil deterioration and acidification, and possible heathland development as a consequence of agricultural intensification. This will have been on more sandy interfluvies, with the pollen and Sphagnum spores being fluviially transported and redeposited overbank in the alluvial floodplain.

With the age-depth model (Figure 6), it is suggested that the maxima of cereal pollen and Brassicaceae in ALD B: 4 (l.p.a.s.z. ALD B 4: v) is possibly associated with Roman activity. If this is the case, the subsequent zone ALD B: 5 post-dates this and is of Early Medieval age. Although speculative, *Cannabis sativa* type is present. This taxon comprises both hemp (*Cannabis sativa*) and hop (*Humulus lupulus*). The latter is also identified in earlier and wooded phases. Differentiation of these two genetically similar taxa is not possible in the fossil state and recourse to ecological preference must be used. The latter (hop) is a native plant of alder-willow carr woodland, as seen here in ALD B: 1–3. However, the presence of *Cannabis sativa* (hemp) in the upper levels suggests hemp cultivation for fibre within the agricultural environment described. This was commonplace and often seen in pollen records spanning the Early Medieval–Medieval periods, and especially the latter when cultivation of hemp was forced by act of parliament (Bradshaw et al. 1981; Godwin 1967; Seare, Scaife, and Langdon 2015).

Wider regional palaeoenvironmental perspectives

The pollen data from borehole BH14 supports a substantial habitat change occurring in Late Bronze Age and Iron Age times. In contrast, the record of excavated Late Bronze

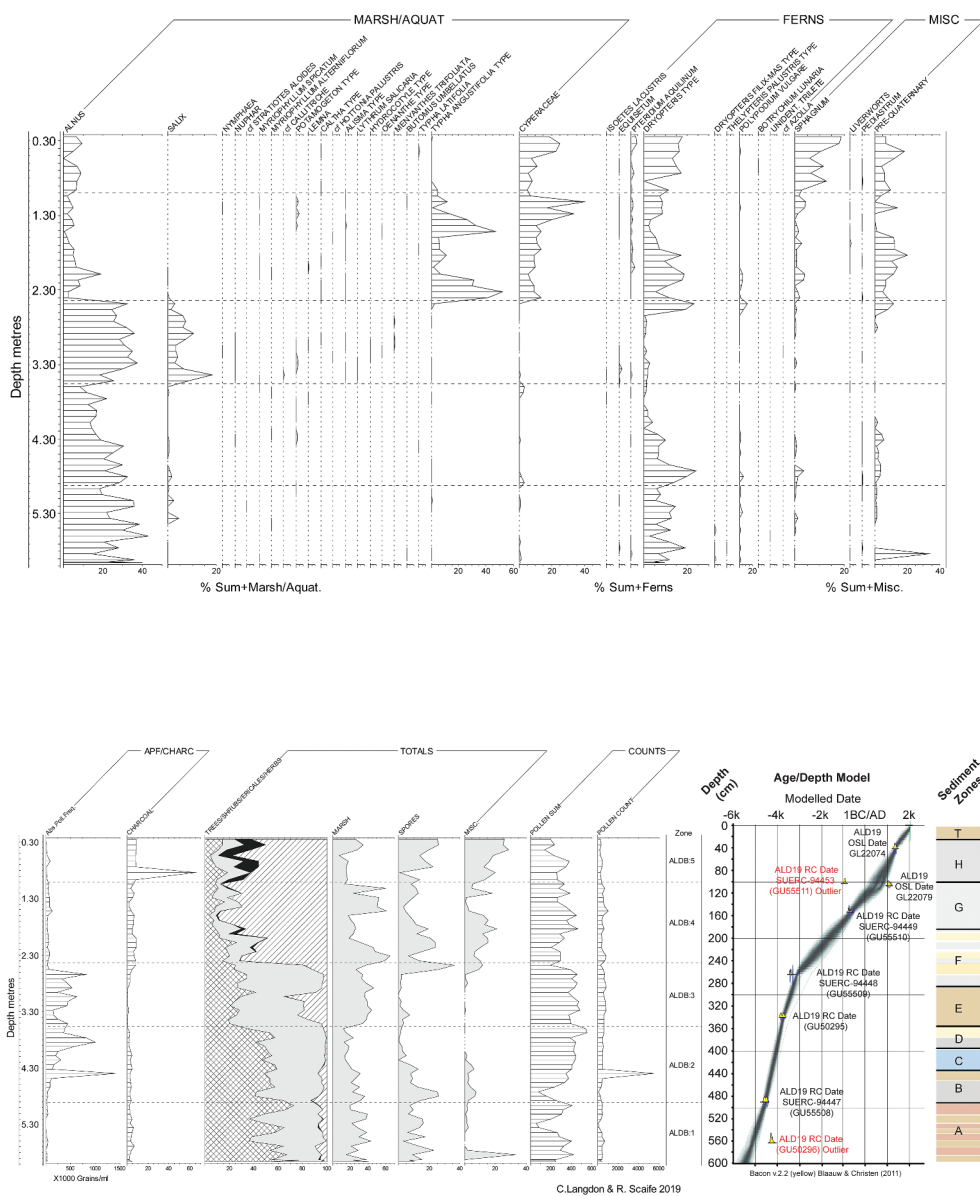


Figure 7. Pollen diagram for borehole BH14 (C. Langdon and R. Scaife).

Metcalf et al. 2000) and riverine flooding throughout the Ouse catchment (Macklin et al. 2000) and northern Britain more broadly (Charman et al. 2006). These hydrological changes accord with the formation of fen habitat in pollen zone ALD B: 4 (Figure 7). Similarly, pollen data from Nosterfield (SH1) demonstrates a major hydrological transition after 977–800 cal. BC (2715 ± 45 BP; GrA-24566), with wetter conditions characterized by an increasing abundance of sedge (Cyperaceae) pollen (Innes et al. 2021). At Sharow Mires an increase in aquatic macrofossils and pollen, notably of bulrush (*Typha* sp.), indicates wet conditions by 749–403 cal. BC (2426 ± 30 BP; OxA-12930) (Bridgland et al. 2011).

Increased wetness is also evident in the pollen data from near Healam Bridge (O'Brien et al. 2017), where monolith HB09/2 demonstrates a rise in Cyperaceae and Typha pollen at ca. 781–485 cal. BC (2500 ± 35 BP; SUERC-40913). A second monolith from Healam Bridge demonstrates similar trends at a slightly later date, 539–265 cal. BC (2341 ± 33 BP; WK-19437). This fen habitat persisted locally into the Roman period and is well represented in the macrobotanical evidence from Isurium, where sedges (*Carex* spp.) are frequent in samples (Figures 7 and 8), and other taxa, including blinks (*Montia fontana* agg.), bristle club rush (*Isolepis setacea* (L.) R.Br.), spike-rushes (*Eleocharis* sp.), rushes and pondweeds (*Potamogeton* sp(p).) demonstrate this wetland habitat's persistence and exploitation during the Roman town's occupation (Giorgi 2024; Payne 2024).

The fen habitat emerging in zone ALD B: 4 is complemented by more consistent *Calluna* pollen (Figure 6) which suggests heath development in the local landscape. The 2024 excavations from outside Isurium's city walls have produced abundant charred heather (*Calluna vulgaris* (L.) Hull) leaves, flowers (Figure 8), and stems along with other taxa, indicating turf exploitation by the peoples at *Isurium* (Payne 2024). The composition of heathland and wetland taxa in Isurium's macrobotanical record supports the exploitation of acid heaths, likely both dry and wet, and the fen habitats illustrated in the pollen data. Finds of *Danthonia* (heath-grass) and *Montia* from the nearby Roman fort at Roecliffe have been interpreted as evidence of cereal processing, though both taxa are strongly associated with turf assemblages and may provide further evidence of heathlands being exploited (cf. Huntley 2005).

The pollen data from borehole BH14 further evidences the expansion of arable agriculture during the Iron Age, with an expansion of cereal cultivation at most excavated sites in the region then engaged in the production of barley and spelt wheat (Payne 2024, 2025). This is regionally supported by similar arable indicators in the pollen data of nearby cores from Sharow Mires and Ripon North

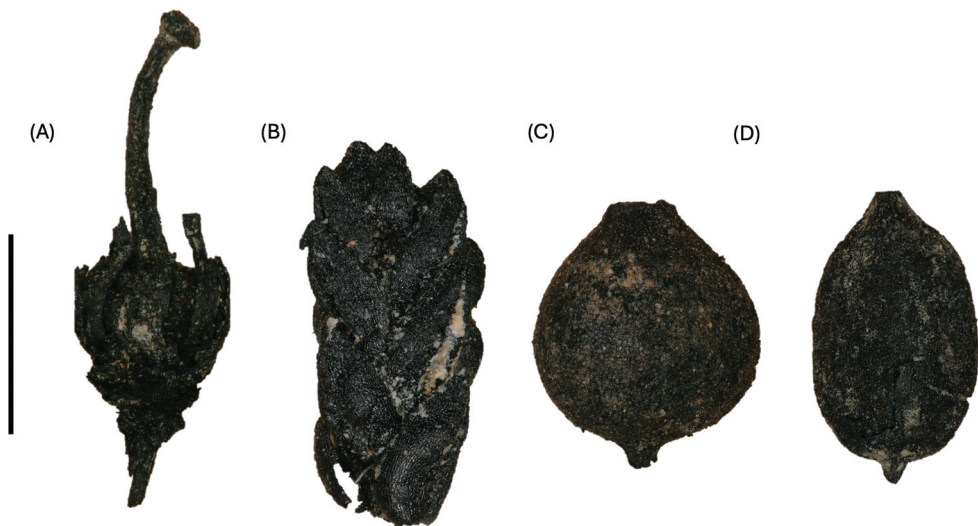


Figure 8. Images of charred heather (*Calluna vulgaris* (L.) Hull) (a) flower and (b) leaves, and (c and d) sedges (*Carex* spp.) from the Aldborough 2024 excavations, scale bar is 1 mm (N. Payne; images taken at the Pitt Rivers Laboratory, McDonald Institute for Archaeological Research, University of Cambridge).

(Bridgland et al. 2011), the Healam Beck at Healam Bridge (O'Brien et al. 2017) and at Askham Moor in the Vale of York (Geary and Lillie 1999). Further south in the Humberhead levels, pollen data from cores taken at Goole Moor (GLM1) and Rawcliffe Moors (RWM1) also evidence arable expansion throughout the Iron Age with a mixed farming regime occurring by the Late Iron Age (B. M. Smith, Buckland, and Limbert 2002). These lowland cores situate the onset of arable cultivation at a significantly earlier point than seen in upland cores, where pastoralism can persist as the dominant agricultural system well into the Late Iron Age or Roman periods (e.g. Yondhead Rigg; I. Simmons et al. 2021). These data align with the Middle Iron Age evidence for the proliferation of spelt agriculture seen in the macrobotanical records (Payne 2025). These arable developments correlate with the emergence of stock enclosures, trackways and boundary ditches in the archaeological record of the region (Griffiths et al. 2022). These developments suggest different manifestations of changing arable practices in the Vale of York (Geary and Lillie 1999), and it was within this arable context that the Roman town of *Isurium* emerged.

There is no apparent evidence for a Roman period reorientation of arable practices in either the pollen record presented here or in the region's macrobotanical data (Payne 2025). The arable strategies of *Isurium* are situated within the cultivation regimes established in the Iron Age, with the pollen data providing evidence for continuity in the landscape surrounding this major Roman town. There was an expansion of oat (*Avena* sp.) and rye (*Secale cereale*) macrofossils, the latter supported by its occurrence in the BH14 pollen record. Charred macrofossils of rye rachises were first recorded in Yorkshire during the Early Roman period, with only grains identified in earlier periods (Payne 2024, 2025). Both taxa have been recovered from recent excavations at *Isurium* (Giorgi 2024; Payne 2024).

In the borehole BH14 pollen data, arable agriculture appears to have persisted across the Late to post-Roman transition in the vicinity of *Isurium*, although with fluctuations in the pollen data indicating changes in the relative importance of pastoralism and crop cultivation. This variability highlights adaptability in the local mixed farming regime. In the Vale of York this transition is marked by a stark decline in macrobotanical evidence for spelt wheat (*Triticum aestivum* spp. *spelta*) with a continuation of barley (*Hordeum vulgare*) cultivation (Payne 2024, 2025); spelt's decline is near universal across Britain (van der Veen 2022). The lack of a clear agricultural reduction in the pollen data suggests that this crop change did not correlate with a significant shift away from extensive cereal cultivation practices in the Vale of York. The botanical data is supported by excavated evidence of Fourth to Fifth Century timber structures and the accumulation of substantial midden deposits rich in animal bone dated to after AD 360 (Ferraby and Millett 2021a, 2024a; Rajkovača 2024).

In contrast to the continuity seen in the borehole BH14 data, Sharow Mires evidences a return to wet conditions in the post-Roman period, potentially leading to a localized arable reduction, as cereal cultivation retreated from the increasingly wet landscape adjacent to the palaeochannel (Bridgland et al. 2011). The molluscan assemblage in the Sharow Mires core likewise supports increasing wet conditions at about cal. AD 544–640 (1494 ± 28 BP; OxA-13105) and this aligns with other regional palaeoclimatic data for increased wetness during this period (e.g. Charman et al.

2006). These differences between BH14 and Sharow Mires highlight the localized impacts of changes in this period. While further north in the Tees Valley, continued arable agriculture is supported by *Triticum/Avena*-type pollen from the Scots Dyke Ditch was dated to between cal. AD 332–773 using modelled OSL dates (Zant and Howard-Davis 2013) which suggested that Late/post-Roman cultivation continued in the vicinity of the ditch during its infilling. Also from the lowland Tees, Thorpe Bulmer likewise supports continued cultivation with low levels of arboreal pollen, *Centaurea cyanus* (cornflower type) pollen and the presence of *Cannabis*-type pollen in a pollen zone spanning the Late Iron Age through the Early Medieval period (Bartley, Chambers, and Hart-Jones 1976).

These examples of continuity are at odds with many of the upland cores, which frequently demonstrate arboreal arable decline such as at Yonthead Rigg and Seavy Slack (I. Simmons et al. 2021). Similarly sites in the Humber valley show localized reductions, though not necessarily cessations, in arable practices (B. M. Smith, Buckland, and Limbert 2002). In contrast, Thwaite Tarn in the Dales shows a possible decline in arable agriculture but continuation in arboreal decline and heath formation (Swindles et al. 2021). When considered as a whole, the lowland areas of the Vale of York and Tees Valley have stronger evidence for at least localized arable continuity into the post-Roman period, whereas the upland evidence suggests these regions were more likely to have undergone arable declines, probably having already been on the periphery of arable regimes during the peak of cultivation in the Roman period. Thus, these pollen records for the post-Roman period demonstrate a mosaic of change and continuity in arable practices at this cultural transition.

Conclusions

This study has produced a long-term sedimentological and palynological record of vegetation and environment in proximity to a major Roman town of *Isurium Brigantum*. Geoarchaeological analyses of a well preserved palaeochannel of the river Ure associated with the Roman river crossing at Aldborough revealed a prolonged history of riverine activity across the local floodplain landscape from the Late Mesolithic period (ca. 4600–4300 BC) through prehistoric, Roman and Medieval times. A ca. 6 m deep, complex multi-process fluvial system was in place with evidence of active channel phases, shallow water carbonate rich periods, stages of stationary standing water dominated by organics and prolonged periods of overbank alluviation which occurred in line with the significant occupation of the site in the Iron Age and Roman periods. By the Roman period, it was no longer the active channel but was still prone to becoming an occasional shallow channel feature in the landscape whilst slowly filling up with humic silt loam alluvial material, hence the necessity for a lengthy road/bridge structure built across this floodplain. Subsequently into Medieval times, the deposition dynamic of alluvial deposits becomes slightly coarser, and the main river floodplain shifts northwards with the new river alignment appearing to more or less follow the route of the current embanked river.

Pollen analysis of the fills of this same palaeochannel recovered from borehole BH14 has provided information on the vegetation and environment of Aldborough spanning the period from at least ca. 4600 BC until the later historic period, showing

progressive woodland diminution and expansion of human impact. There is evidence of the Neolithic Elm Decline, the Lime Decline and agricultural expansion during the late prehistoric period and especially the early historic period. In particular, the pollen data indicates an expansion of arable agriculture during the Iron Age, but with no apparent evidence for a Roman period reorientation of arable practices in either the pollen record or in the region's macrobotanical data. Arable agriculture appears to have persisted across the Late to post-Roman transition in the vicinity of *Isurium*, though with pastoral/cultivation variability highlighting a mosaic of adaptability in the local mixed farming regime. This continuity in arable cultivation through the late prehistoric and historic periods is the catalyst behind the aggradation of clastic dominated alluviation across the floodplain and subsequent canalization of the river channel.

Taken together with evidence from our recent geophysical surveys, this research significantly alters our understanding of the Iron Age, Roman and Early Medieval contexts within which *Isurium Brigantum* was founded and developed. It confirms that this part of the Vale of York was a heavily exploited agricultural landscape prior to Roman annexation, with an unusually high density of farmstead sites (an aggregate density of 4.4 sites per km²) in the vicinity of the later Roman town (Millett, Ferraby, and Maw 2025). In contrast to some other parts of the region, the absence of any central focus in the late Iron Age perhaps indicates that society was heterarchical.

The settlement and environmental evidence indicate that there was only limited change in the rural landscape following the establishment of the settlement of *Isurium* sometime in the period between AD 70 and AD 80, and the development of the planned town from about AD 120. The excavated evidence shows that the town became a major centre of consumption and industrial production (including iron smithing and lead working) (Loveluck et al. 2025), and continued in occupation into the Fifth Century AD (Ferraby and Millett 2020b, 2021a, 2022, 2024a). In contrast to other Roman towns, there is no evidence for the development of a cluster of villas in the surrounding area, perhaps because of the character of local social organization.

The results of the research presented in this paper are also particularly significant for our understanding of the Early Medieval transition, indicating that there was a broad continuation of farming patterns. Taken together with the evidence that shows that iron and metal working continued until the middle of the Sixth Century AD (Loveluck et al. 2025), this provides strong evidence that *Isurium* remained an important focus long after the end of Roman administrative control in the early Fifth Century AD. This confirms the tentative conclusions based on survey and topographic analysis (Dobinson et al. 2018; Ferraby and Millett 2020a, 120–124; Millett et al. 2018) and has significant historical implications for understanding the wider region at this period.

Acknowledgments

We are very grateful to the landowners and farmers who kindly gave us access to their land for our project: Andrew Lawson Tancred, Neil Bailes, Robert Bailes, Edward Craggs, Chris and Gillian Peacock and Tom Sanderson. We also thank the SUERC Radiocarbon Laboratory at the University of Glasgow.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was funded by a Cambridge Humanities Research Fund Grant (University of Cambridge, 2019), the Society of Antiquaries Jones Fund Grant (2020) and the McBurney Laboratory for Geoarchaeology, Department of Archaeology, University of Cambridge.

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