Lower Thames Crossing

6.3 Environmental Statement Appendices
Appendix 6.13 – Holocene Geoarchaeological Desk-based Assessment of the Route of the Lower Thames Crossing

APFP Regulation 5(2)(a)

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

Volume 6

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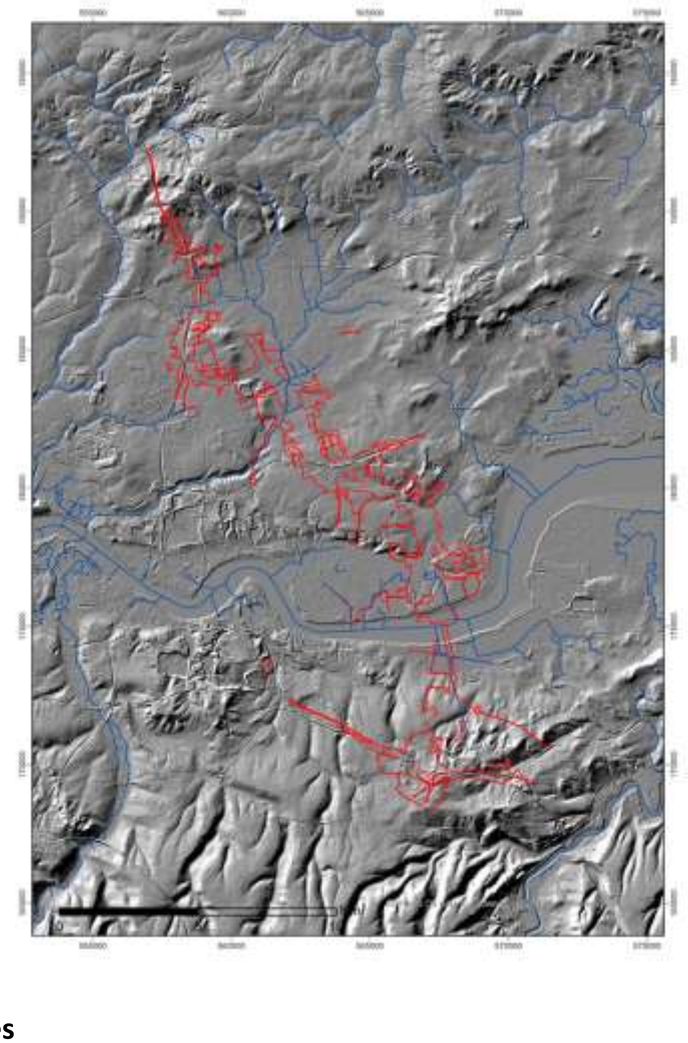
VERSION: 1.0

A HOLOCENE GEOARCHAEOLOGICAL DESK BASED ASSESSMENT OF THE ROUTE OF THE LOWER THAMES CROSSING

MARTIN R BATES

MARCH 2020



Martin Bates
University of Wales Trinity Saint David
[redacted]

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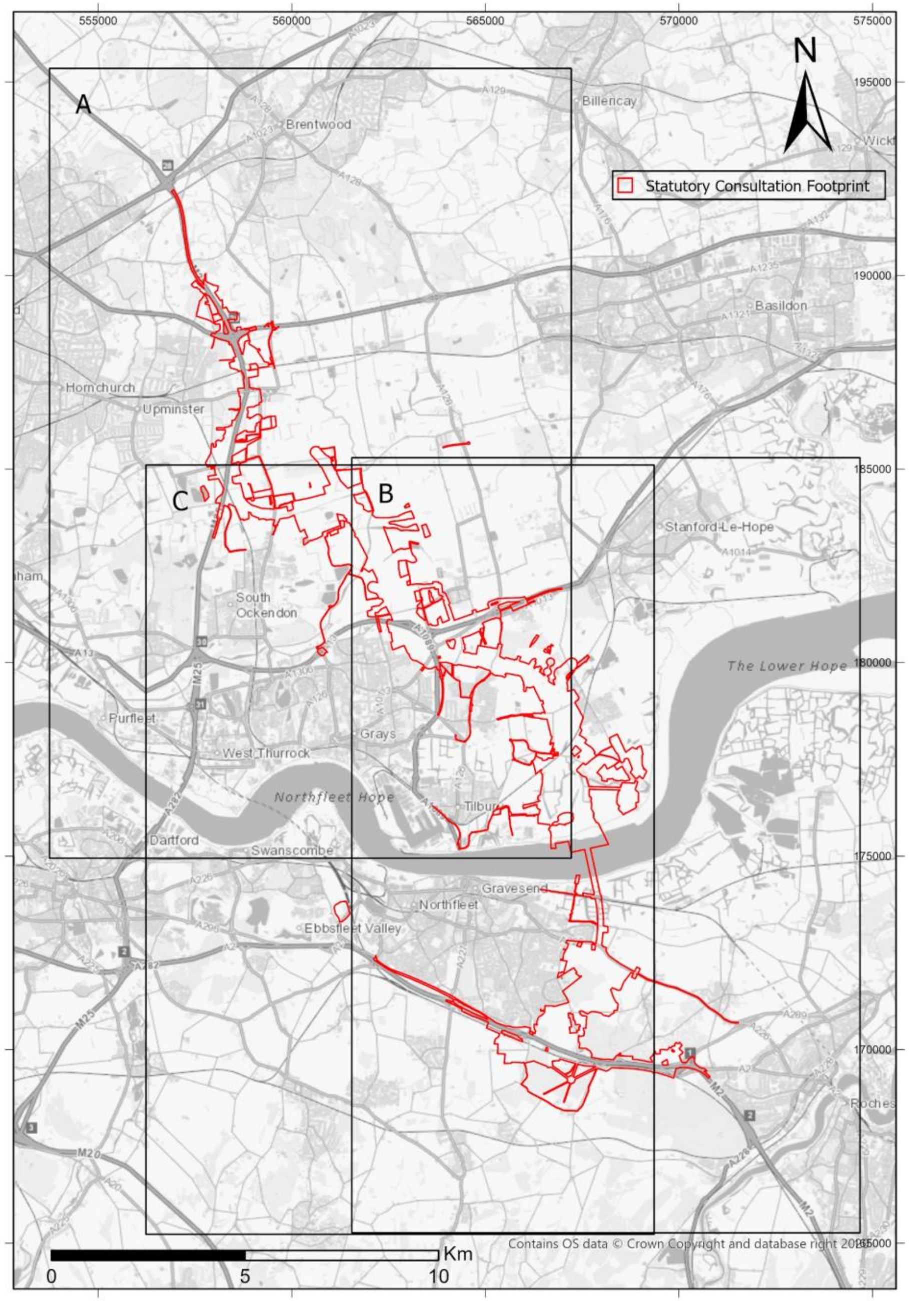


Figure 1. The study area and Statutory Consultation Footprint.

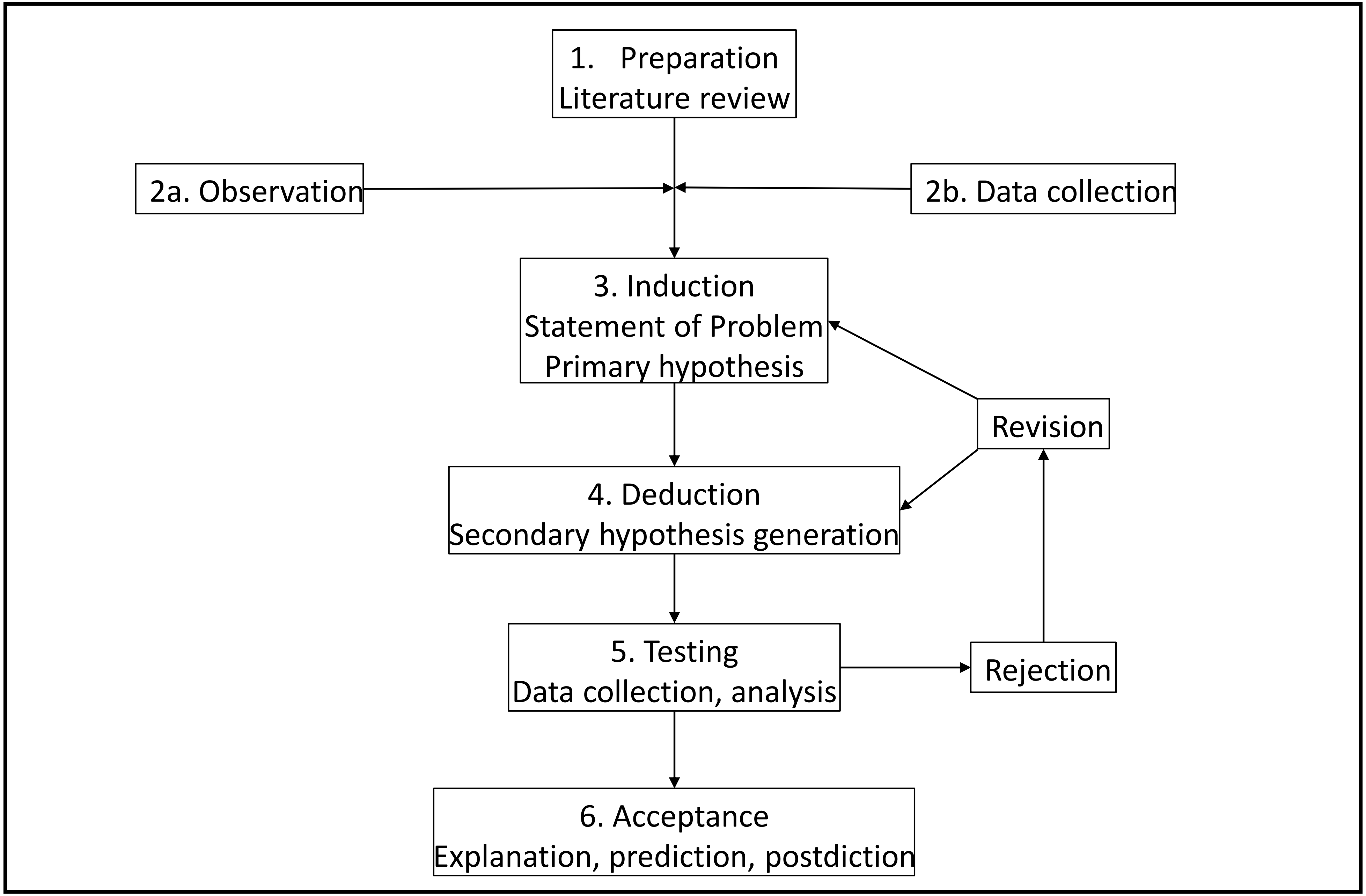


Figure 2. An outline of a scientific method (Schumm, 1991).

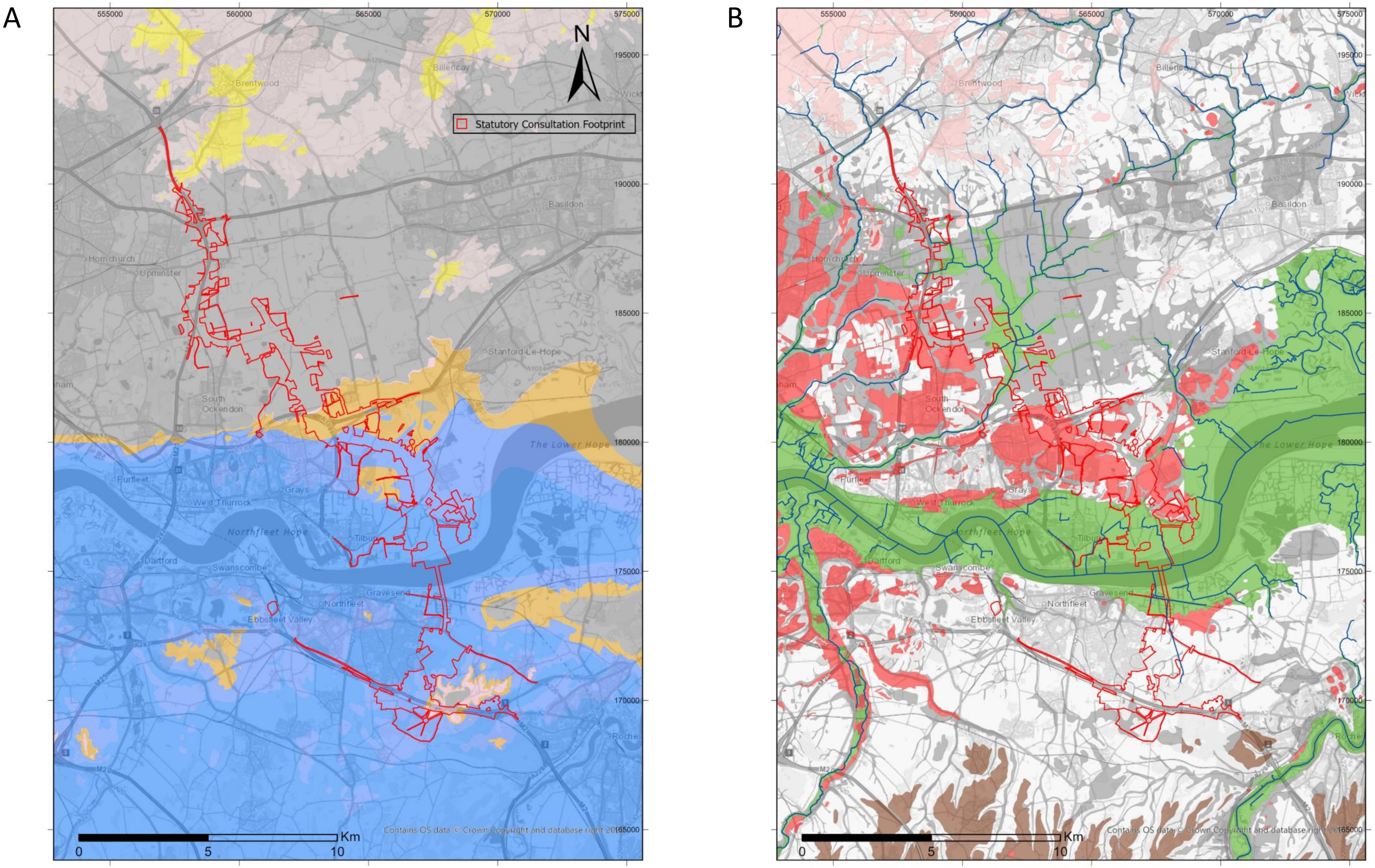


Figure 3. A: Bedrock geology of the route corridor. **B:** Superficial geology of the route corridor.

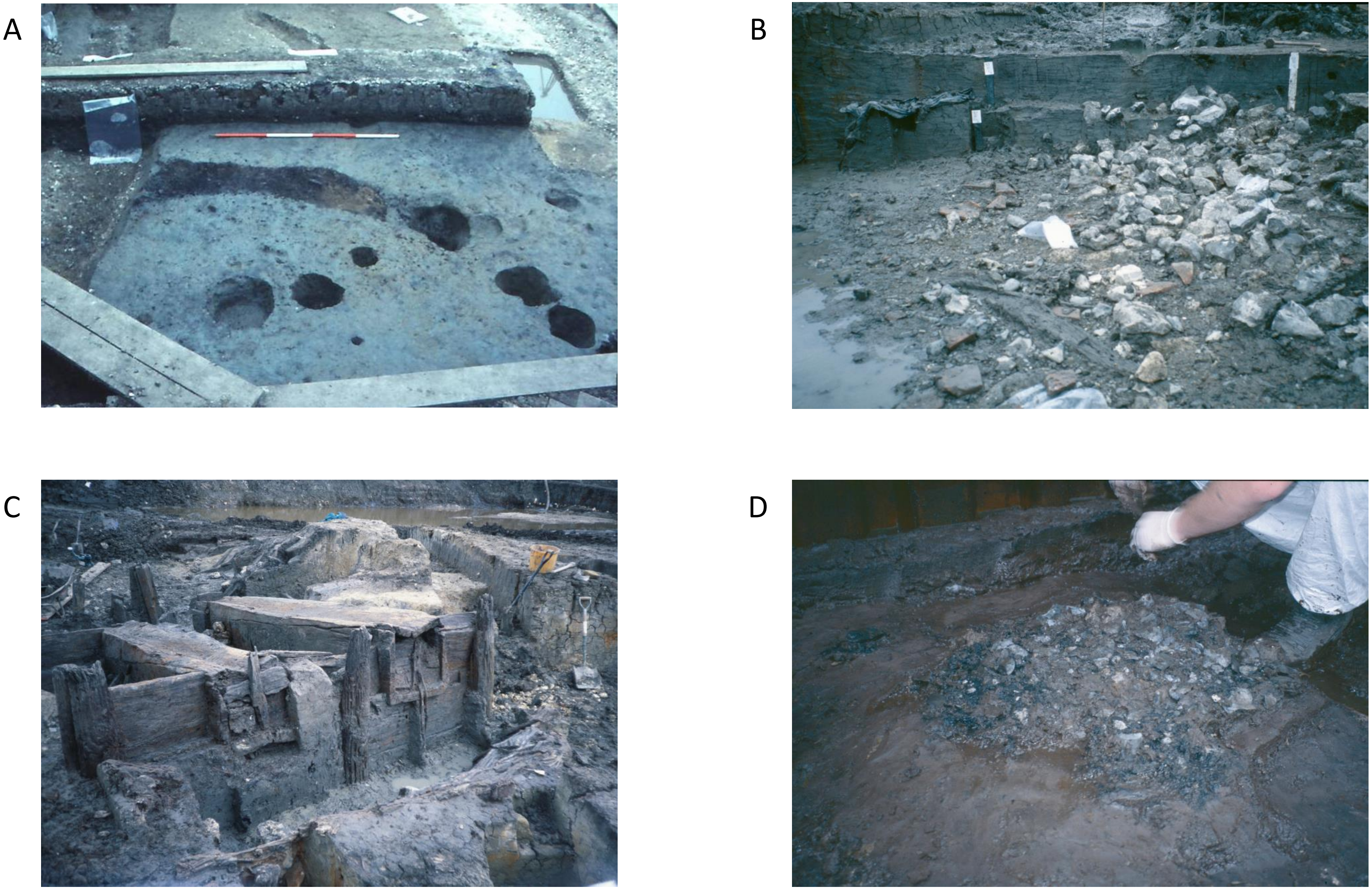


Figure 4. A: Iron Age ring ditch within alluvium, Medway Tunnel site. **B:** Saxon mill, Ebbsfleet buried in alluvium; **C:** pottery and wood on Roman foreshore at Ebbsfleet: **D:** Scatter of early Neolithic flints at Ebbsfleet near base of alluvium.

E

F

Figure 4 (cont.). E: Scatter of Mesolithic flints at Three Ways Wharf, Uxbridge buried by alluvium; **F:** wooden trackway in channel at Belmarsh.

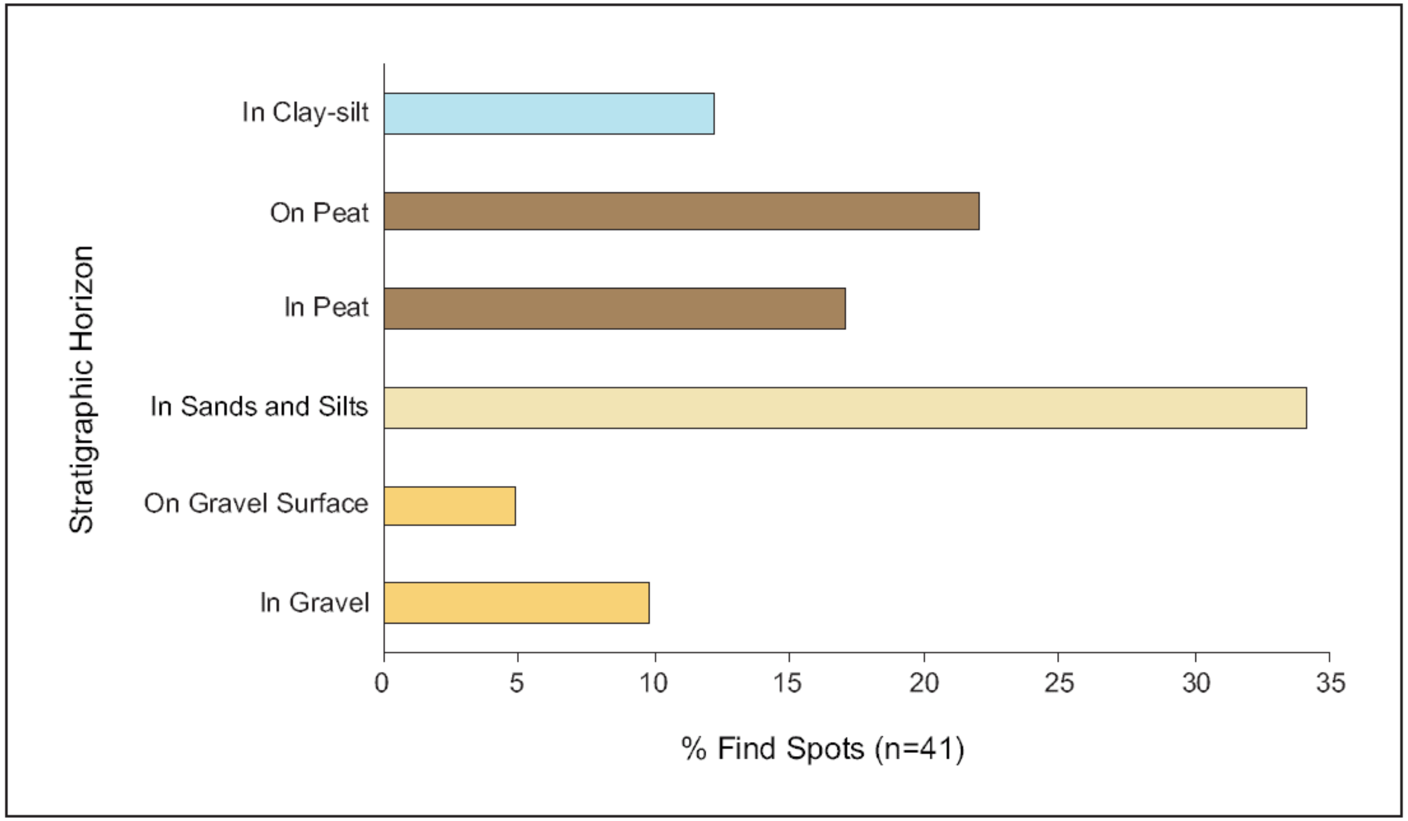
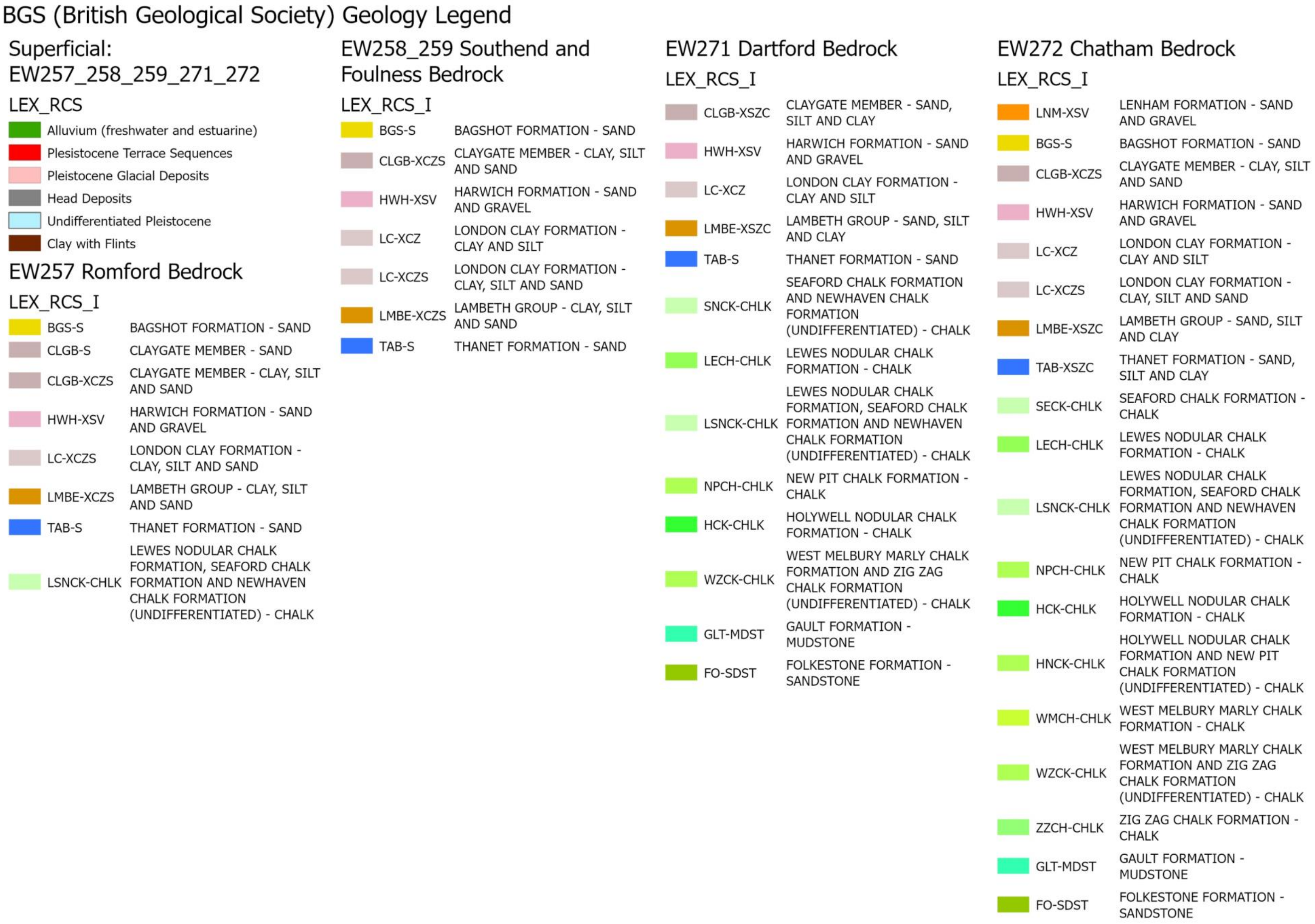


Figure 5. Distribution of find spots by stratigraphic context in the Lower Thames area (from Bates and Stafford, 2013)



BGS (British Geological Society) Geology Legend
Superficial: EW257_258_259_271_272
LEX_RCS
Alluvium (freshwater and estuarine)
Plesistocene Terrace Sequences
Pleistocene Glacial Deposits
Head Deposits
Undifferentiated Pleistocene
Clay with Flints
EW257 Romford Bedrock
LEX_RCS_I
BGS-S BAGSHOT FORMATION - SAND
CLGB-S CLAYGATE MEMBER - SAND
CLGB-XCZS CLAYGATE MEMBER - CLAY, SILT AND SAND
HWH-XSV HARWICH FORMATION - SAND AND GRAVEL
LC-XCZS LONDON CLAY FORMATION - CLAY, SILT AND SAND
LMBE-XCZS LAMBETH GROUP - CLAY, SILT AND SAND
TAB-S THANET FORMATION - SAND
LSNCK-CHLK LEWES NODULAR CHALK FORMATION, SEAFORD CHALK FORMATION AND NEWHAVEN CHALK FORMATION (UNDIFFERENTIATED) - CHALK
EW258_259 Southend and Foulness Bedrock
LEX_RCS_I
BGS-S BAGSHOT FORMATION - SAND
CLGB-XCZS CLAYGATE MEMBER - CLAY, SILT AND SAND
HWH-XSV HARWICH FORMATION - SAND AND GRAVEL
LC-XCZ LONDON CLAY FORMATION - CLAY AND SILT
LC-XCZS LONDON CLAY FORMATION - CLAY, SILT AND SAND
LMBE-XCZS LAMBETH GROUP - CLAY, SILT AND SAND
TAB-S THANET FORMATION - SAND
EW271 Dartford Bedrock
LEX_RCS_I
CLGB-XSZC CLAYGATE MEMBER - SAND, SILT AND CLAY
HWH-XSV HARWICH FORMATION - SAND AND GRAVEL
LC-XCZ LONDON CLAY FORMATION - CLAY AND SILT
LMBE-XSZC LAMBETH GROUP - SAND, SILT AND CLAY
TAB-S THANET FORMATION - SAND
SNCK-CHLK SEAFORD CHALK FORMATION AND NEWHAVEN CHALK FORMATION (UNDIFFERENTIATED) - CHALK
LECH-CHLK LEWES NODULAR CHALK FORMATION - CHALK
LSNCK-CHLK LEWES NODULAR CHALK FORMATION, SEAFORD CHALK FORMATION AND NEWHAVEN CHALK FORMATION (UNDIFFERENTIATED) - CHALK
NPCH-CHLK NEW PIT CHALK FORMATION - CHALK
HCK-CHLK HOLYWELL NODULAR CHALK FORMATION - CHALK
WZCK-CHLK WEST MELBURY MARLY CHALK FORMATION AND ZIG ZAG CHALK FORMATION (UNDIFFERENTIATED) - CHALK
GLT-MDST GAULT FORMATION - MUDSTONE
FO-SDST FOLKESTONE FORMATION - SANDSTONE
EW272 Chatham Bedrock
LEX_RCS_I
LNM-XSV LENHAM FORMATION - SAND AND GRAVEL
BGS-S BAGSHOT FORMATION - SAND
CLGB-XCZS CLAYGATE MEMBER - CLAY, SILT AND SAND
HWH-XSV HARWICH FORMATION - SAND AND GRAVEL
LC-XCZ LONDON CLAY FORMATION - CLAY AND SILT
LC-XCZS LONDON CLAY FORMATION - CLAY, SILT AND SAND
LMBE-XSZC LAMBETH GROUP - SAND, SILT AND CLAY
TAB-XSZC THANET FORMATION - SAND, SILT AND CLAY
SECK-CHLK SEAFORD CHALK FORMATION - CHALK
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NPCH-CHLK NEW PIT CHALK FORMATION - CHALK
HCK-CHLK HOLYWELL NODULAR CHALK FORMATION - CHALK
HNCK-CHLK HOLYWELL NODULAR CHALK FORMATION AND NEW PIT CHALK FORMATION (UNDIFFERENTIATED) - CHALK
WMCH-CHLK WEST MELBURY MARLY CHALK FORMATION - CHALK
WZCK-CHLK WEST MELBURY MARLY CHALK FORMATION AND ZIG ZAG CHALK FORMATION (UNDIFFERENTIATED) - CHALK
ZZCH-CHLK ZIG ZAG CHALK FORMATION - CHALK
GLT-MDST GAULT FORMATION - MUDSTONE
FO-SDST FOLKESTONE FORMATION - SANDSTONE

Figure 6.

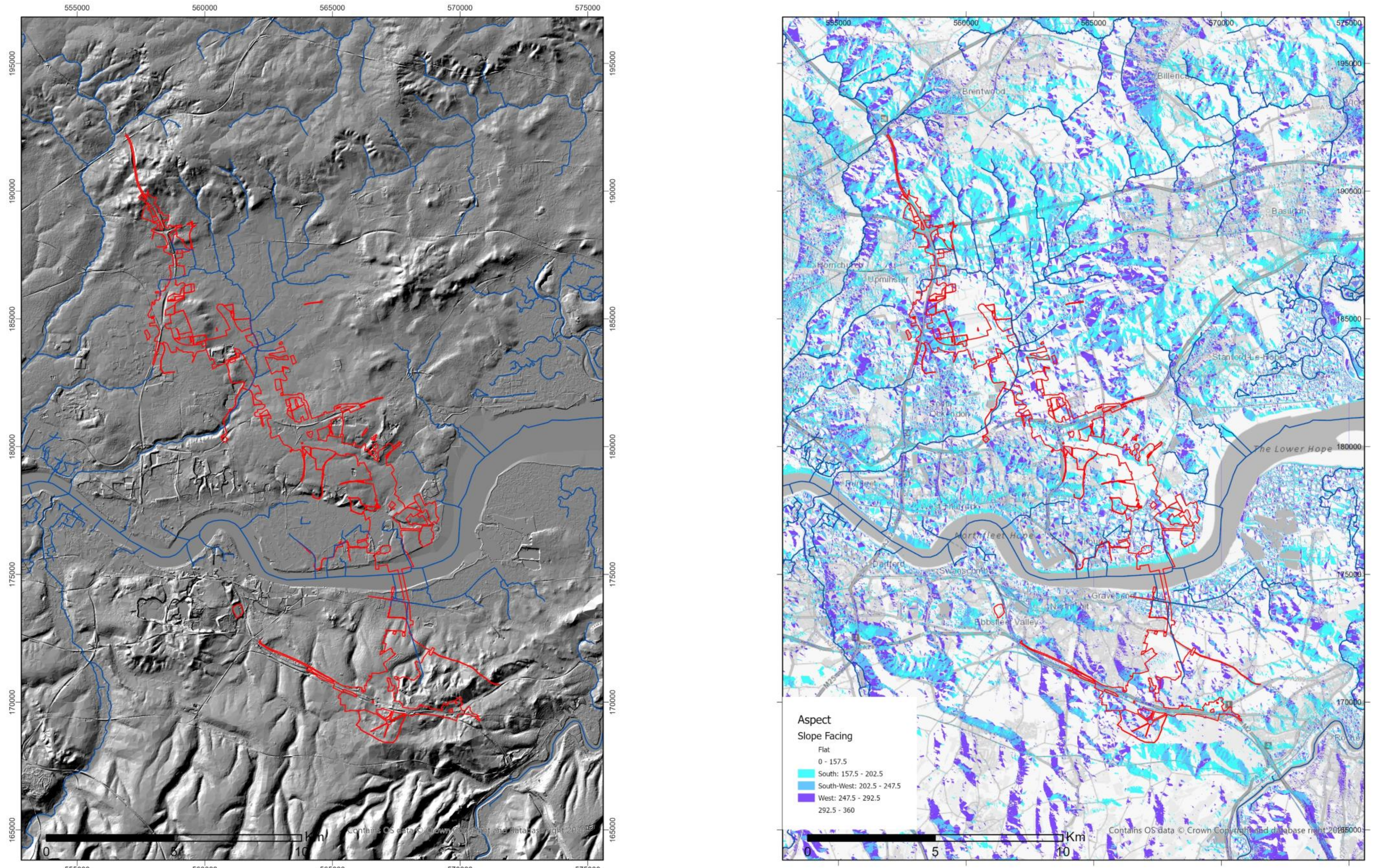

Figure 7. A: Topography and river network distribution of the route corridor. **B:** Slope aspect of the route corridor.

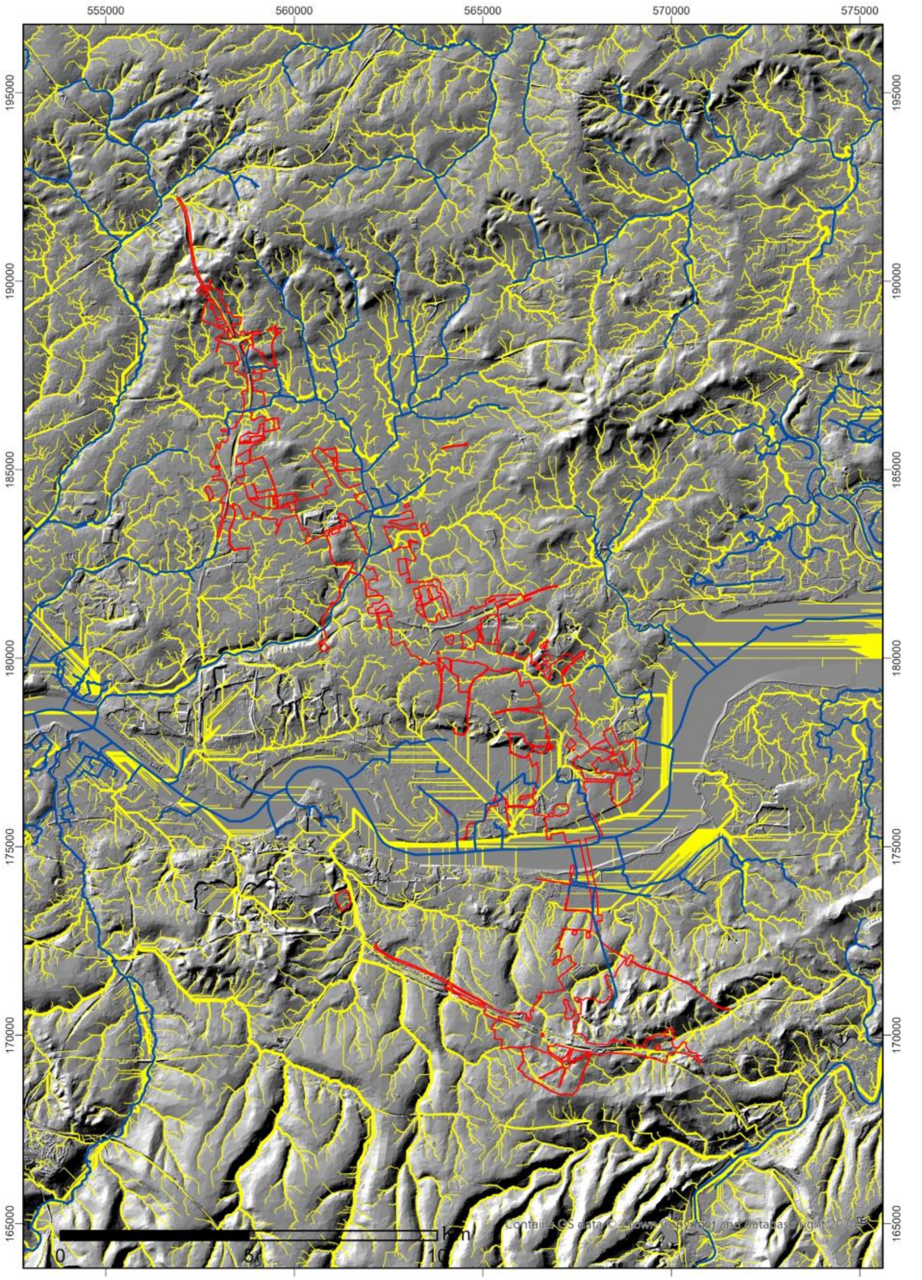

Figure 7. C: Stream networks (blue: actual; yellow: fitted).

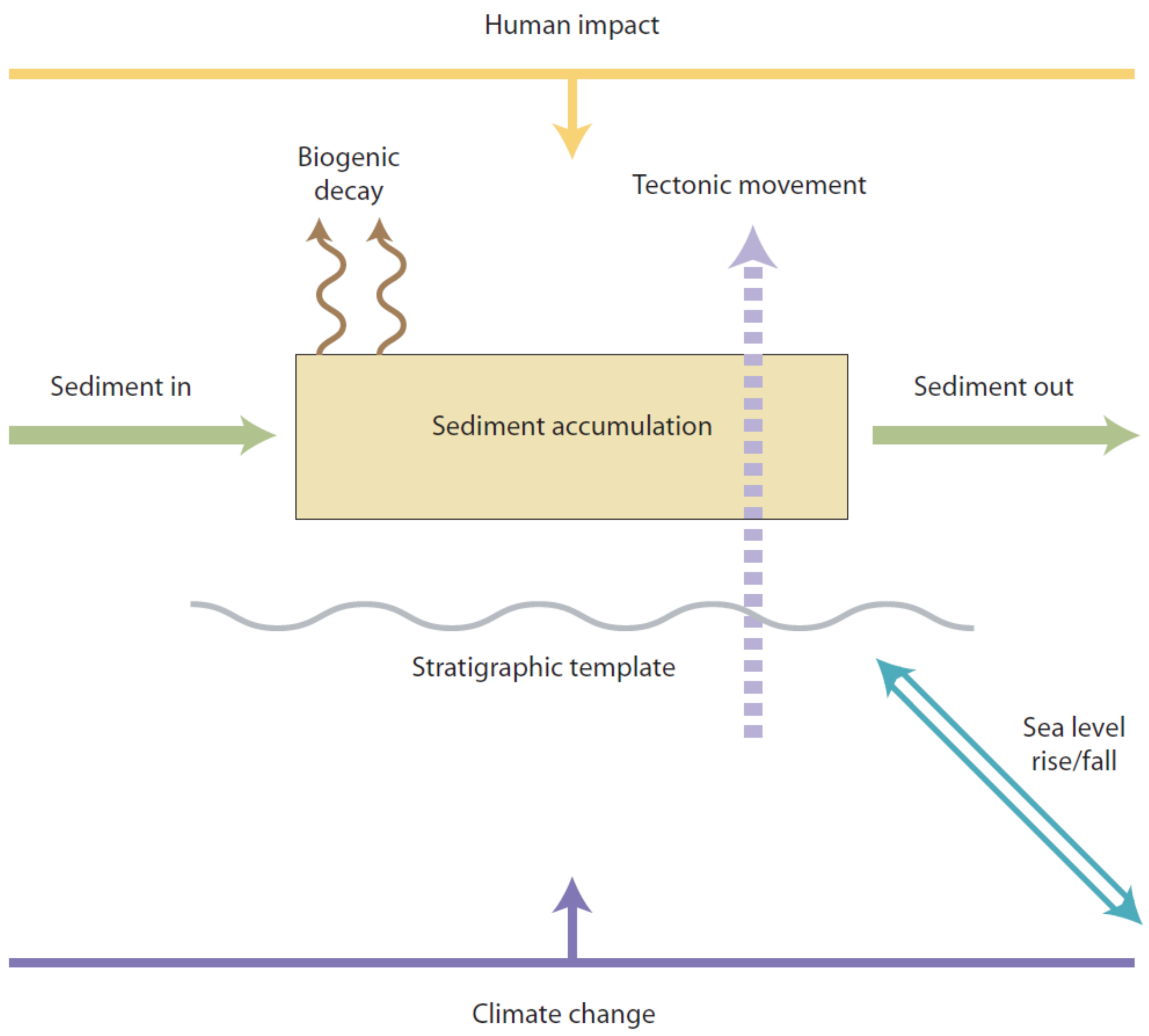

Figure 8. Factors controlling sedimentation in the study area (Bates and Stafford, 2013).

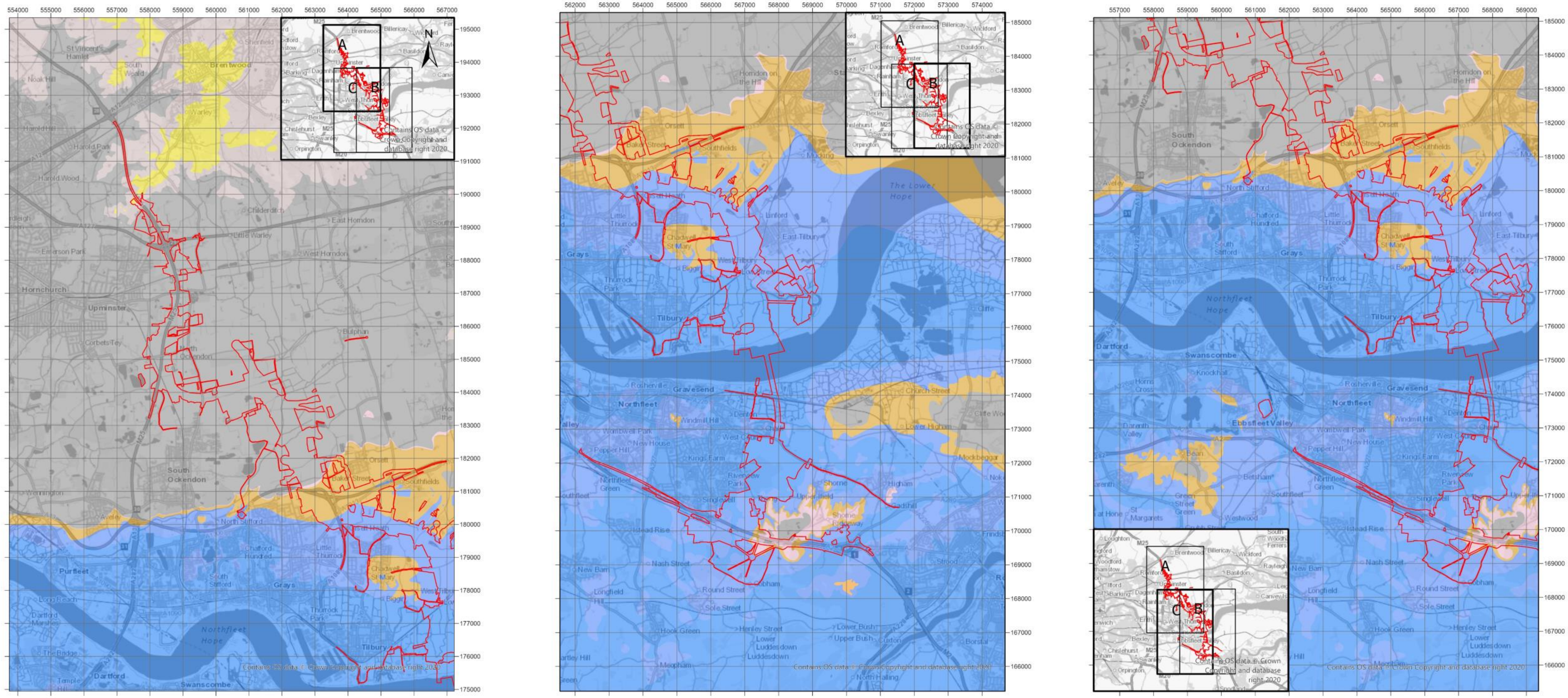

Figure 9. Bedrock geology for the route corridor.

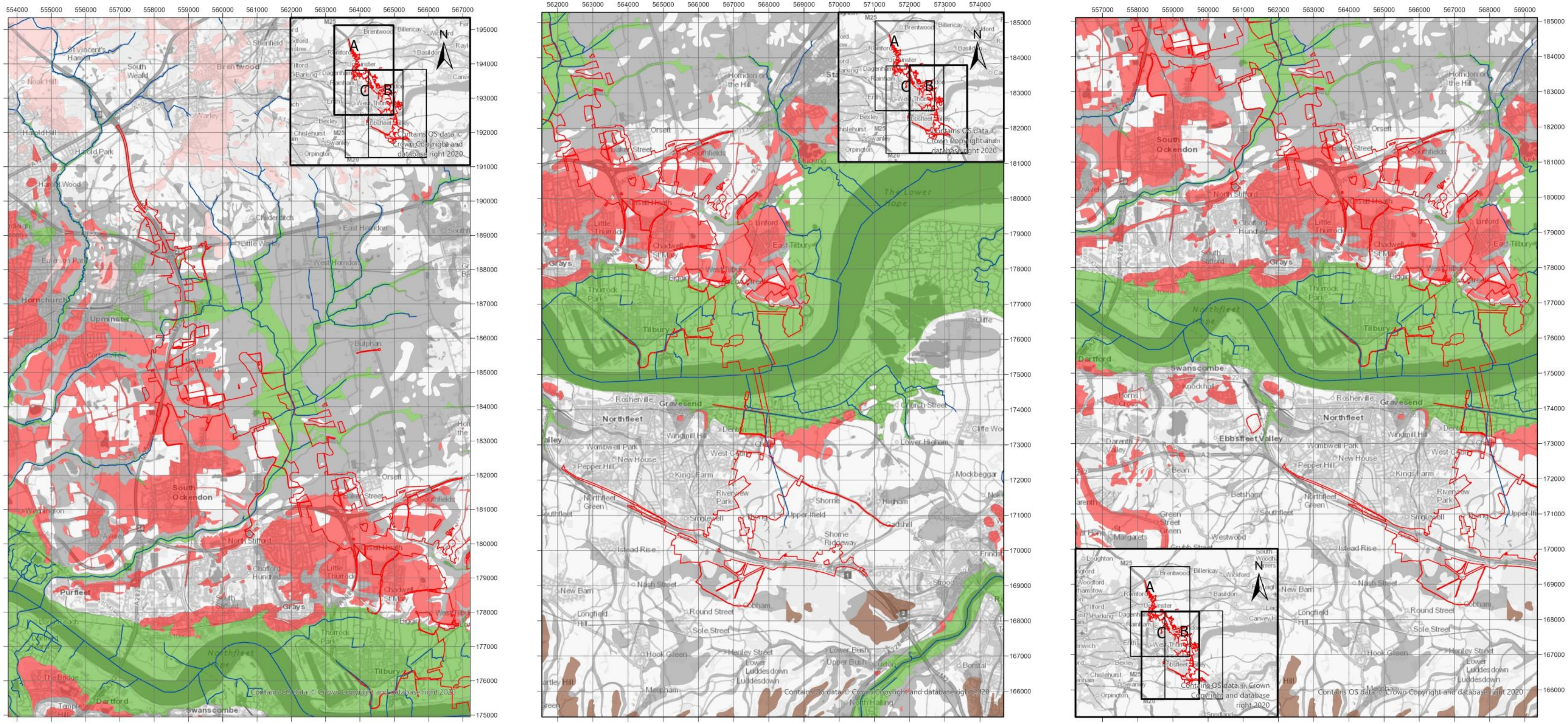

Figure 10. Simplified superficial geology for the route corridor.

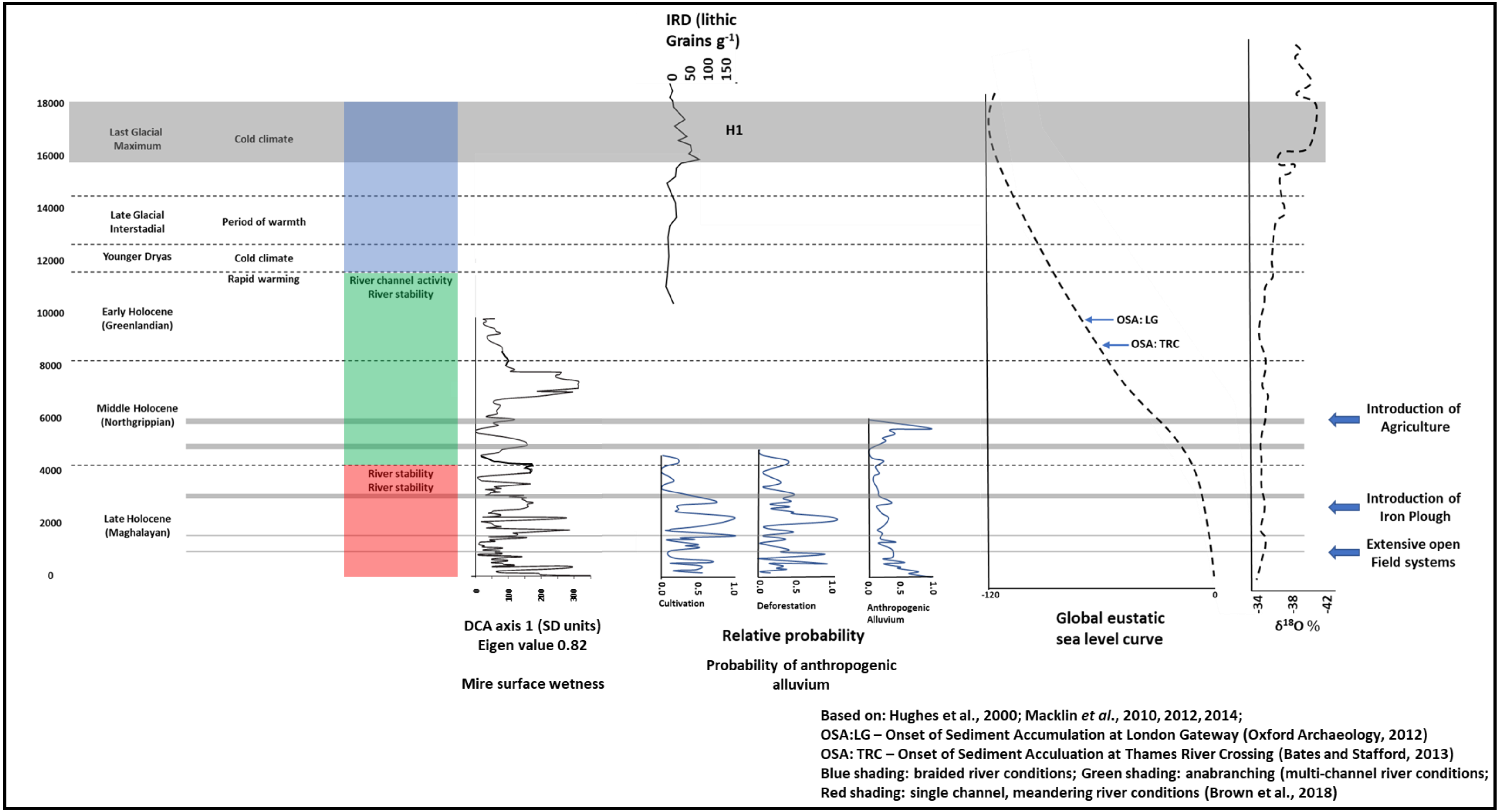

Figure 11. Study time scales and major events.

Figure 12. Thanet Sand and Chalk beneath Holocene colluvium at Northfleet, Kent.

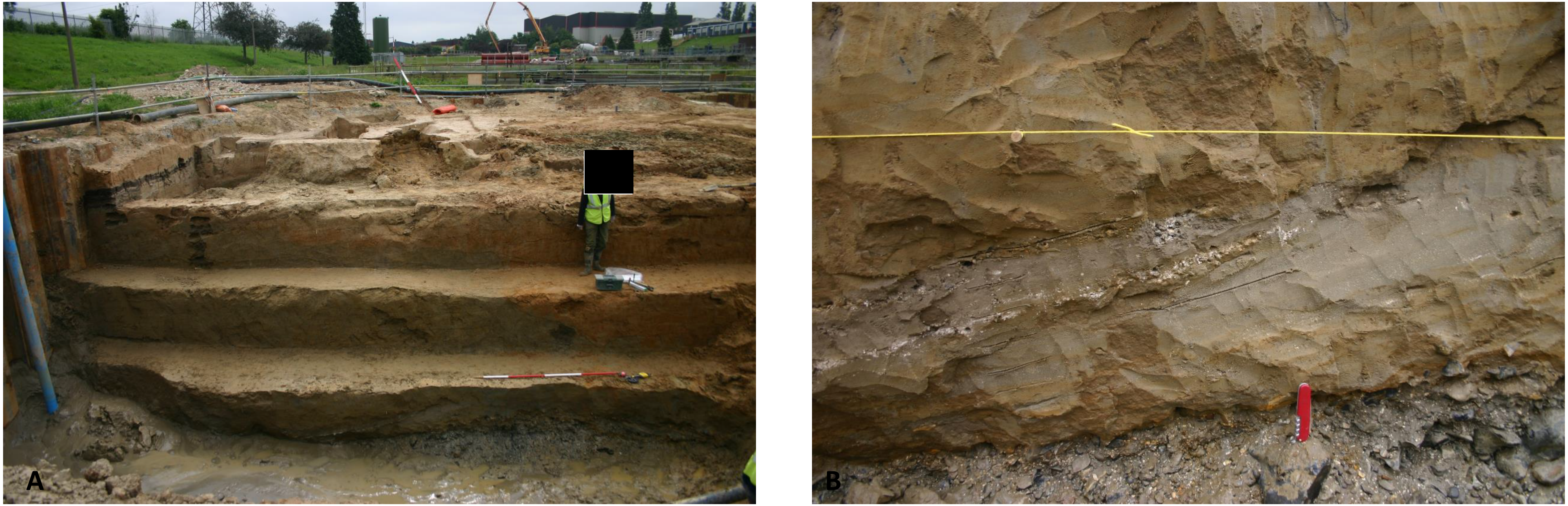

Figure 13. A: Holocene colluvium overlying Pleistocene colluvium at Northfleet WWTP. **B:** Base of Pleistocene colluvium showing bedded nature of the sediments at the base of the Pleistocene colluvium.

Figure 14. Colluvial sediments overlying Head and bedrock at Abermawr, Pembrokeshire showing lateral changes away from rock su
reflecting variability in colluvium grain size.

Figure 15. A: Late glacial palaeosol exposed in a Bronze Age ditch at Holywell Coombe, overlain by chalky head deposits. **B:** Buried soil in chalky slopewash sediments at Watcombe Bottom on Isle of Wight.

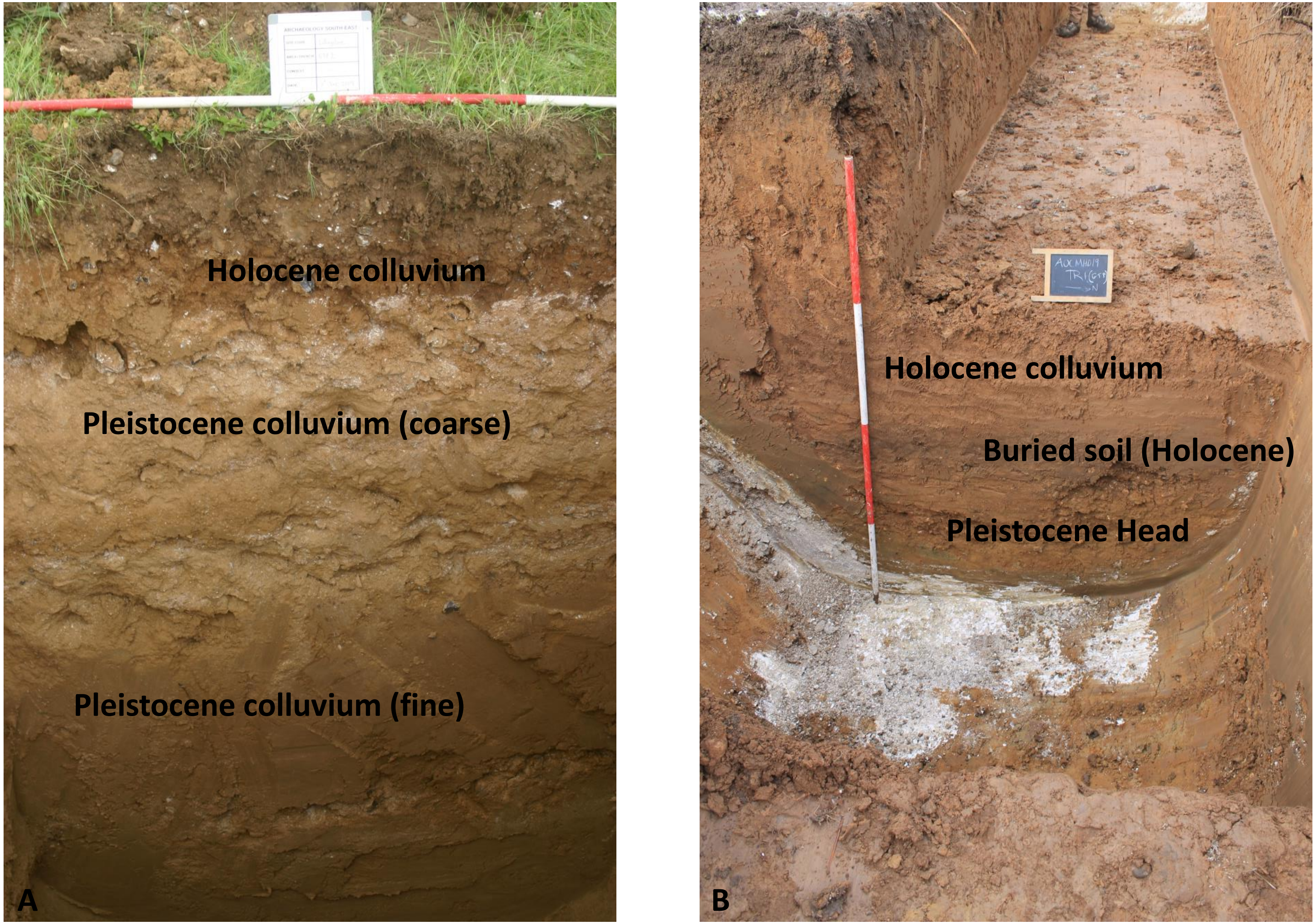

Figure 16. A: Holocene colluvium over coarse and fine Pleistocene colluvium at Lullingstone, Kent. **B:** Holocene colluvium overlying a buried soil and decalcified Pleistocene Head deposits at Marbledown Hospital site, Dartford.

Figure 17. A: Chalky head deposits below dark brown Holocene colluvium at Otty Bottom, Deal. **B:** close up rooting in calcareous head deposits at Otty Bottom, Deal.

A

B

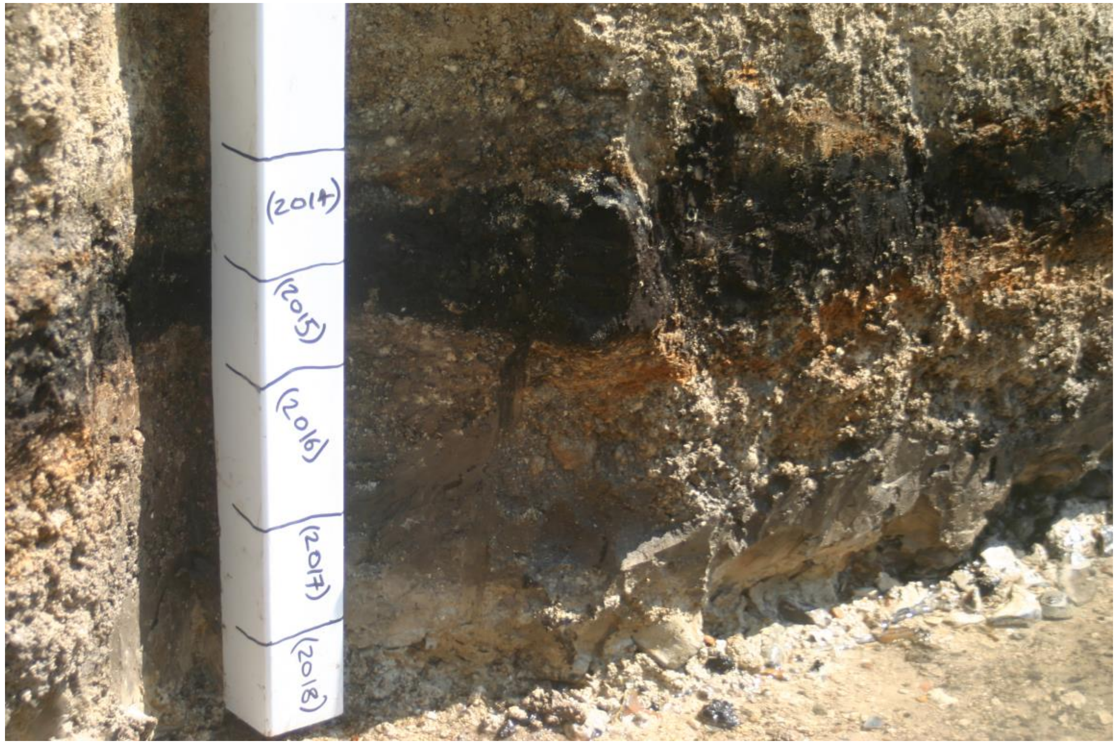

Figure 18. A: Freshwater alluvium and intercalated peats at Mint Yard, Canterbury. **B:** Tufa and peat sequences in channel at Dover, B and Q Site.

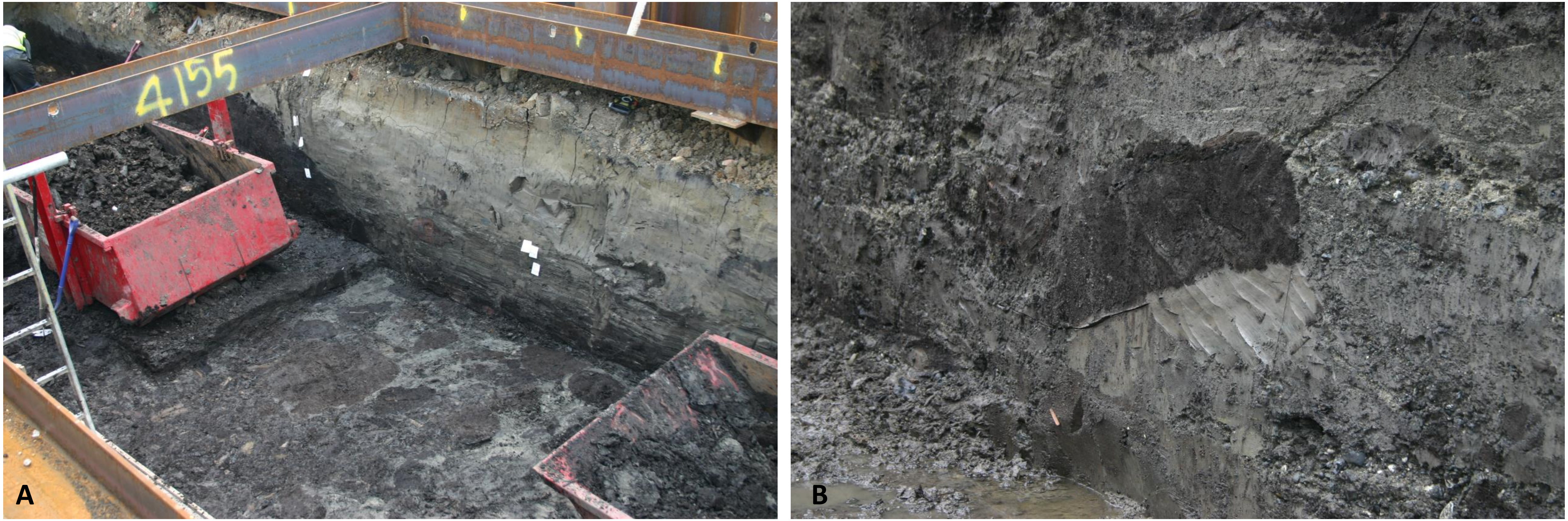

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Figure 21. Submerged forest deposits at Erith, S E London.

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Figure 23. A: Tufa barrage and pools at Caerws, North Wales. **B:** Close up of tufa barrage at Caerws. **C:** oncoidal tufa clasts in bed of stream at Caerws.

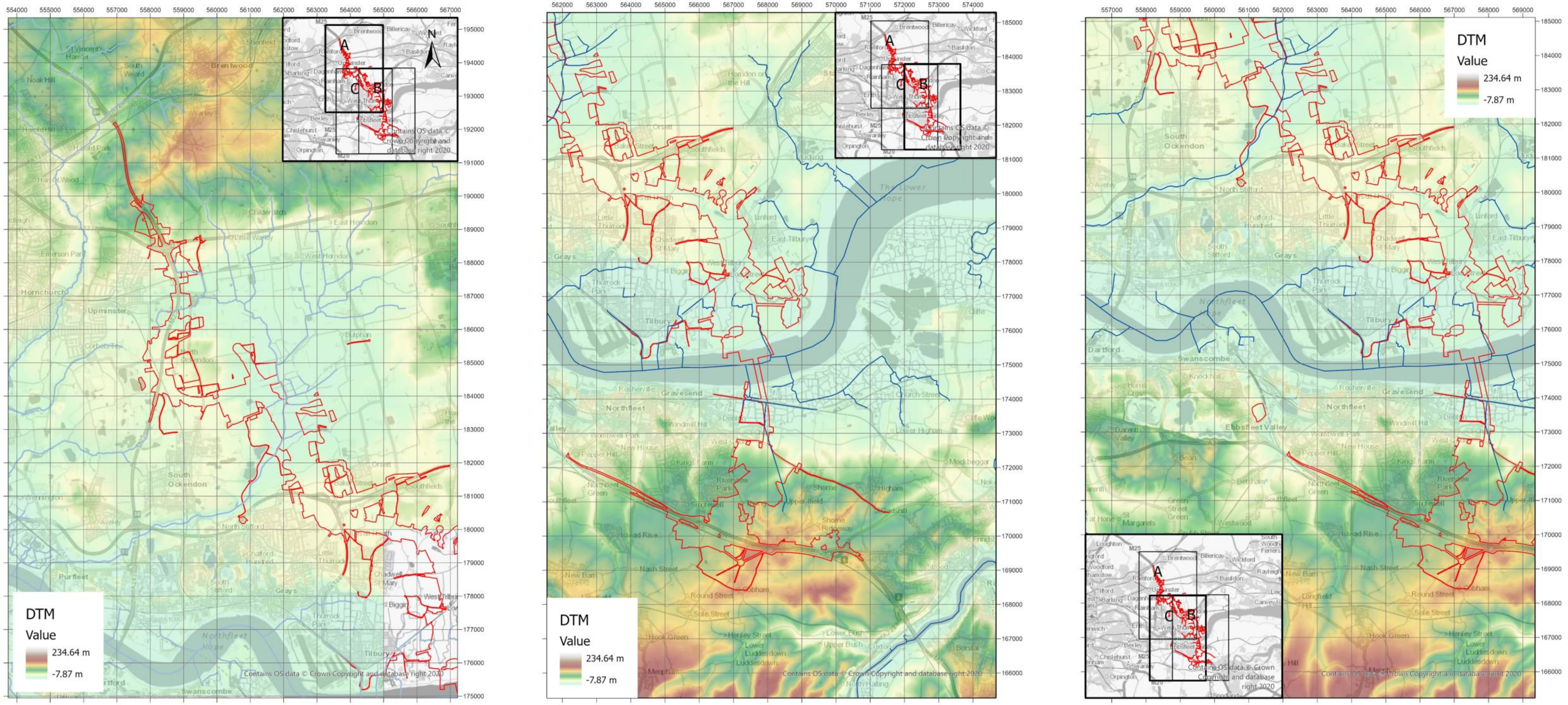

Figure 24.DTM for the route corridor.

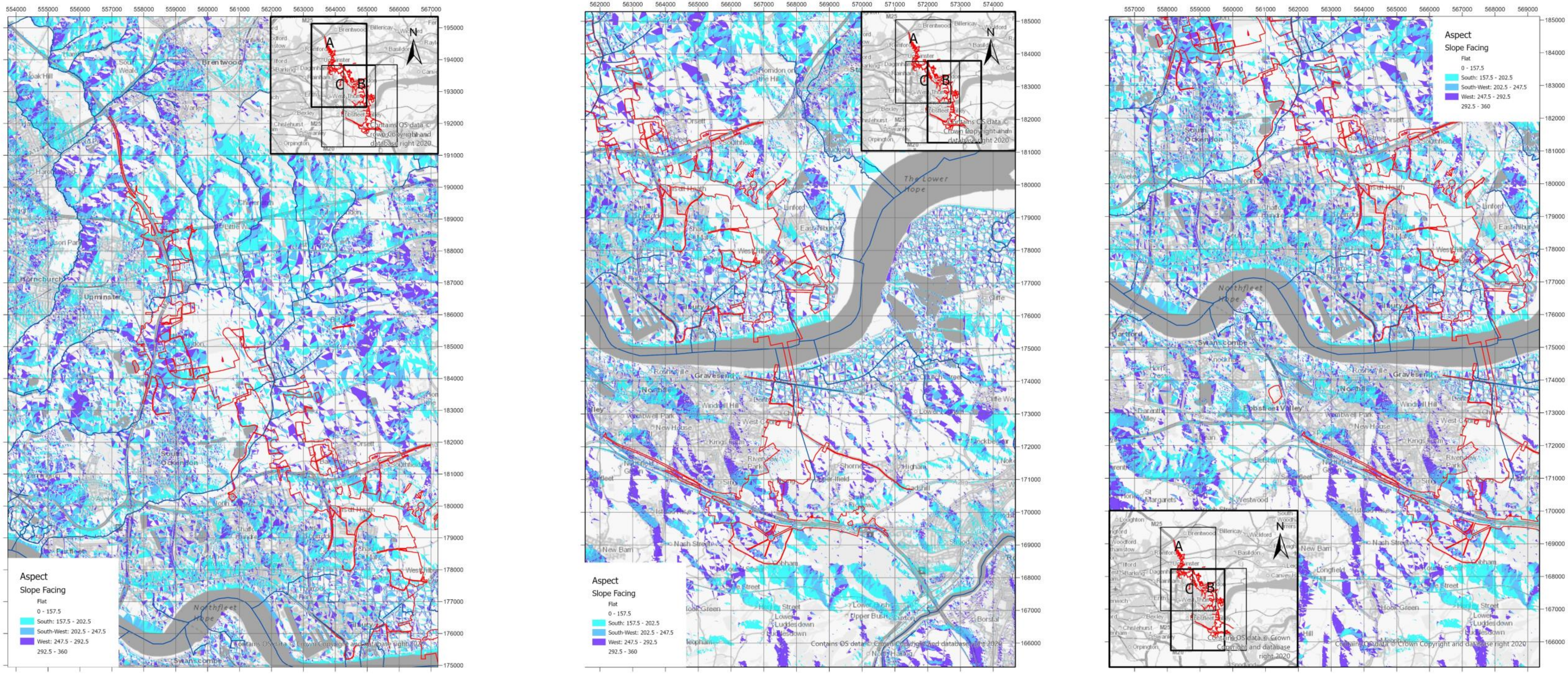

Figure 25. Slope aspect for the route corridor.

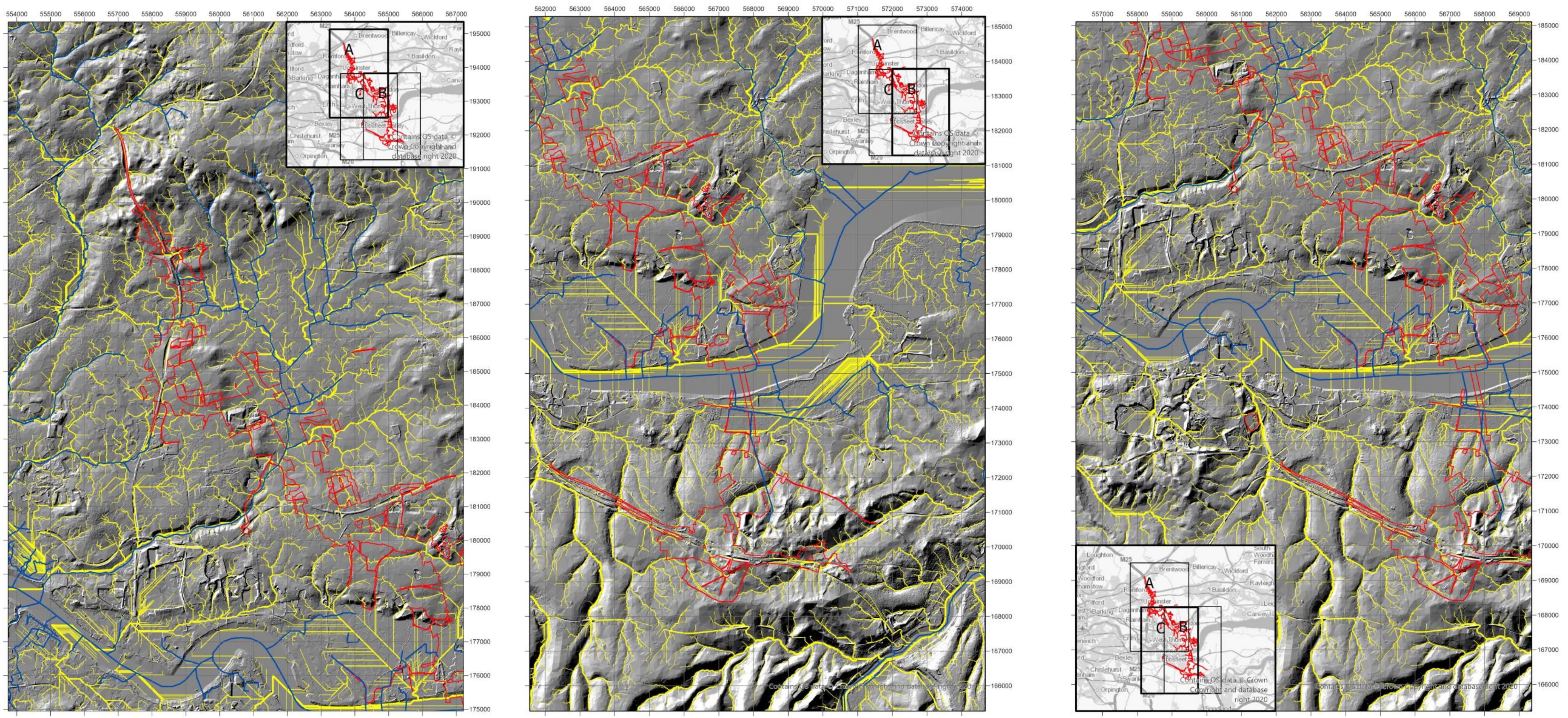

Figure 26. Terrain and actual (blue) and fitted (yellow) drainage networks.

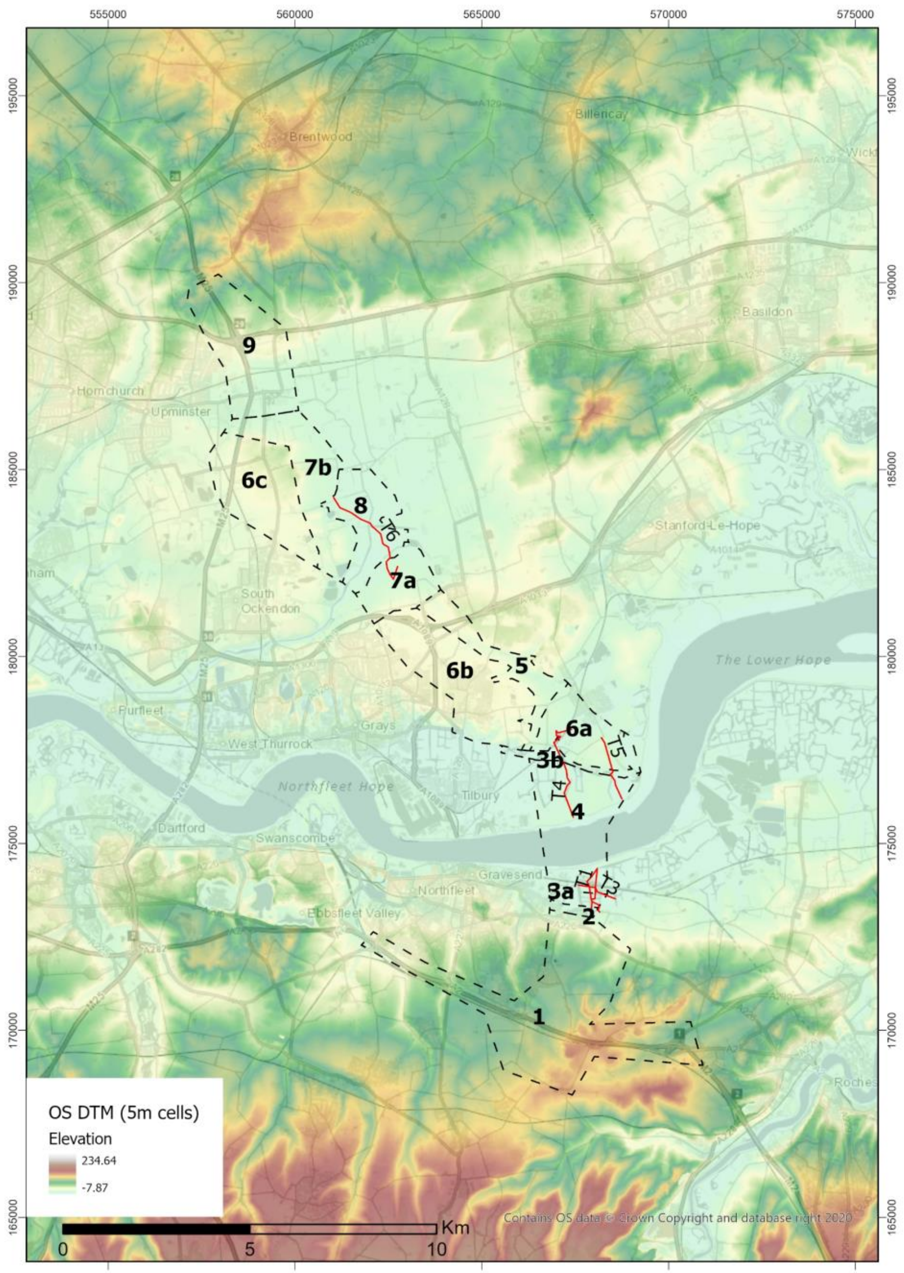

Figure 27. Distribution of zones across route corridor.

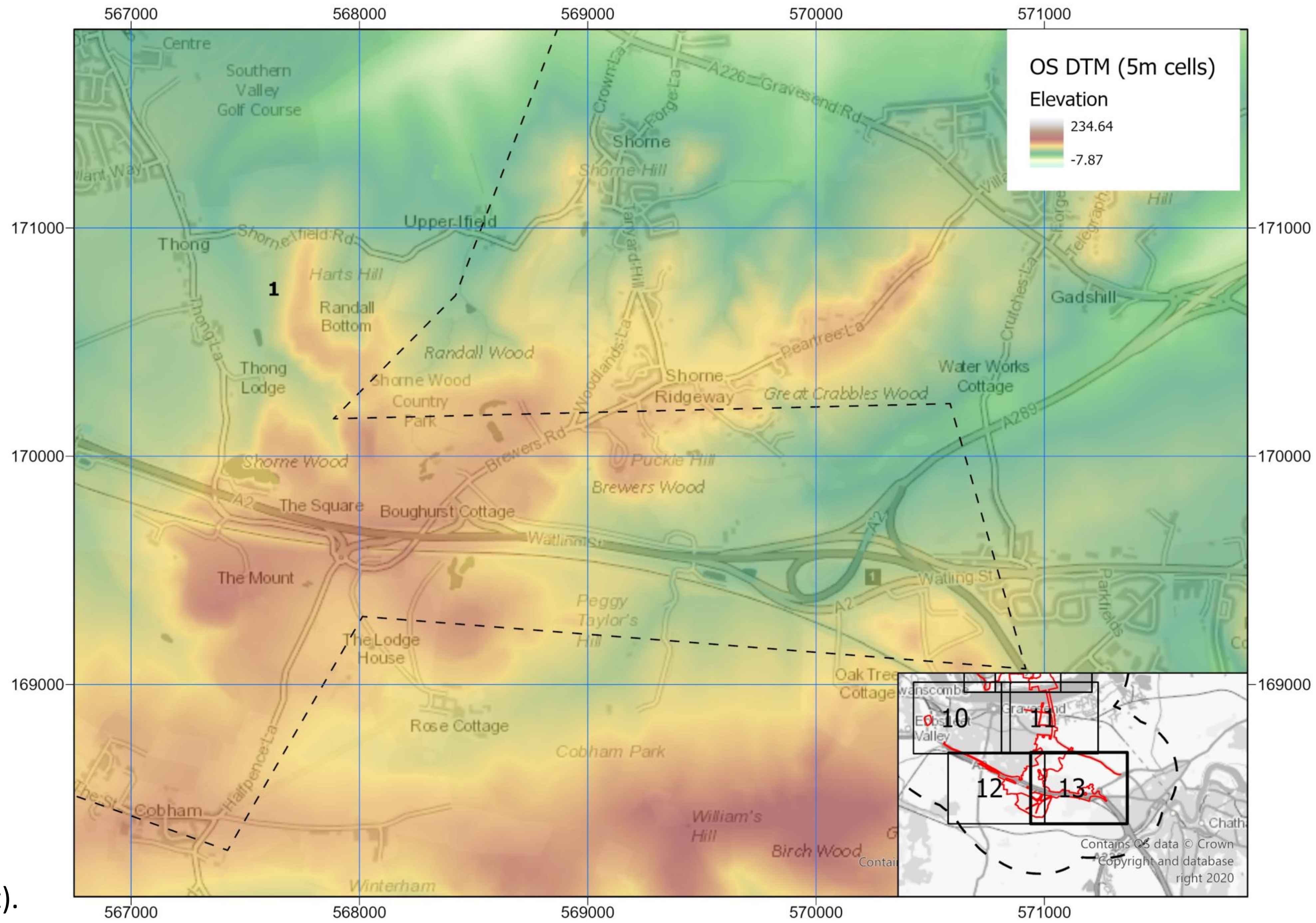

Figure 28. Zone 1 (east).

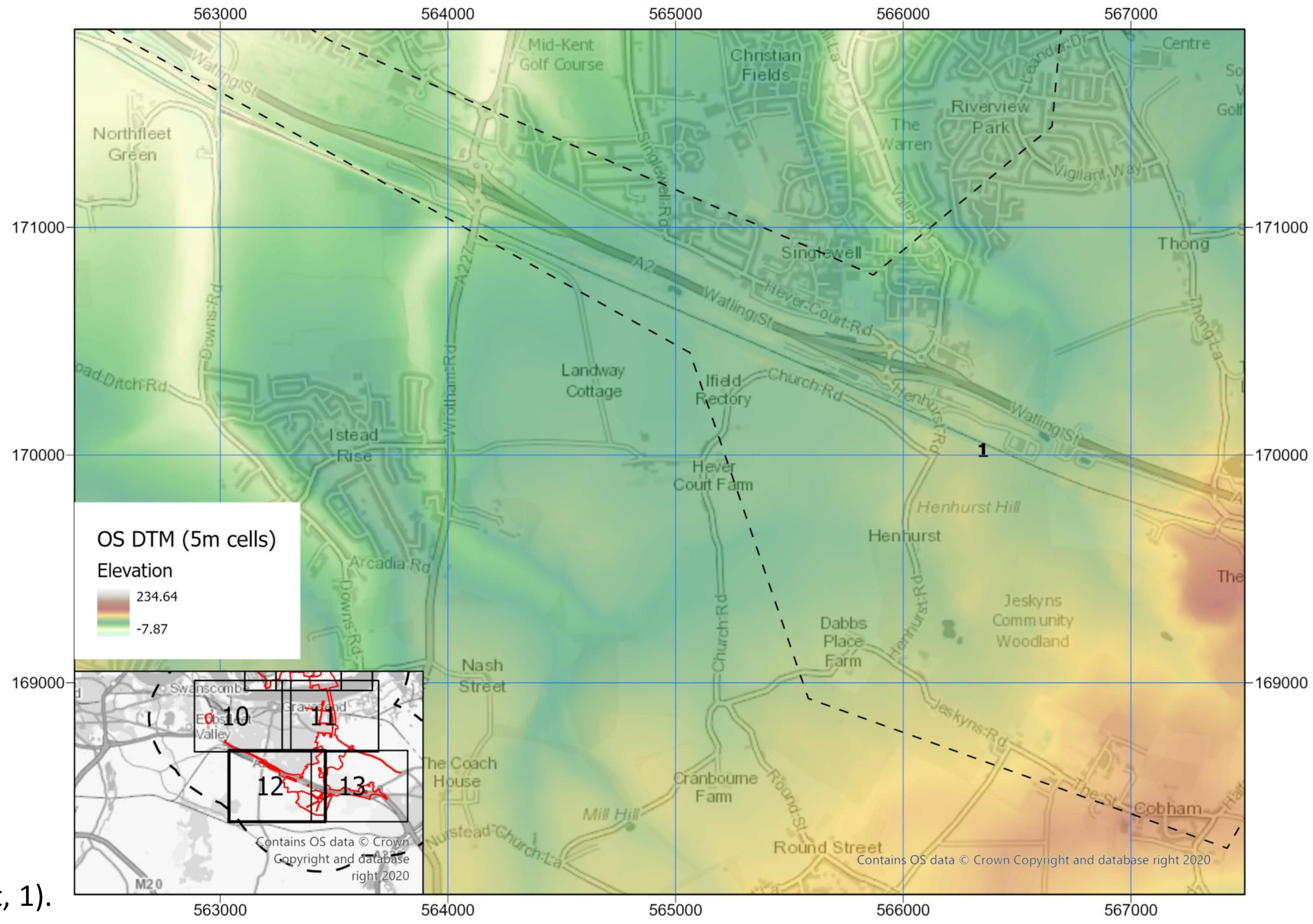

Figure 29. Zone 1 (west, 1).

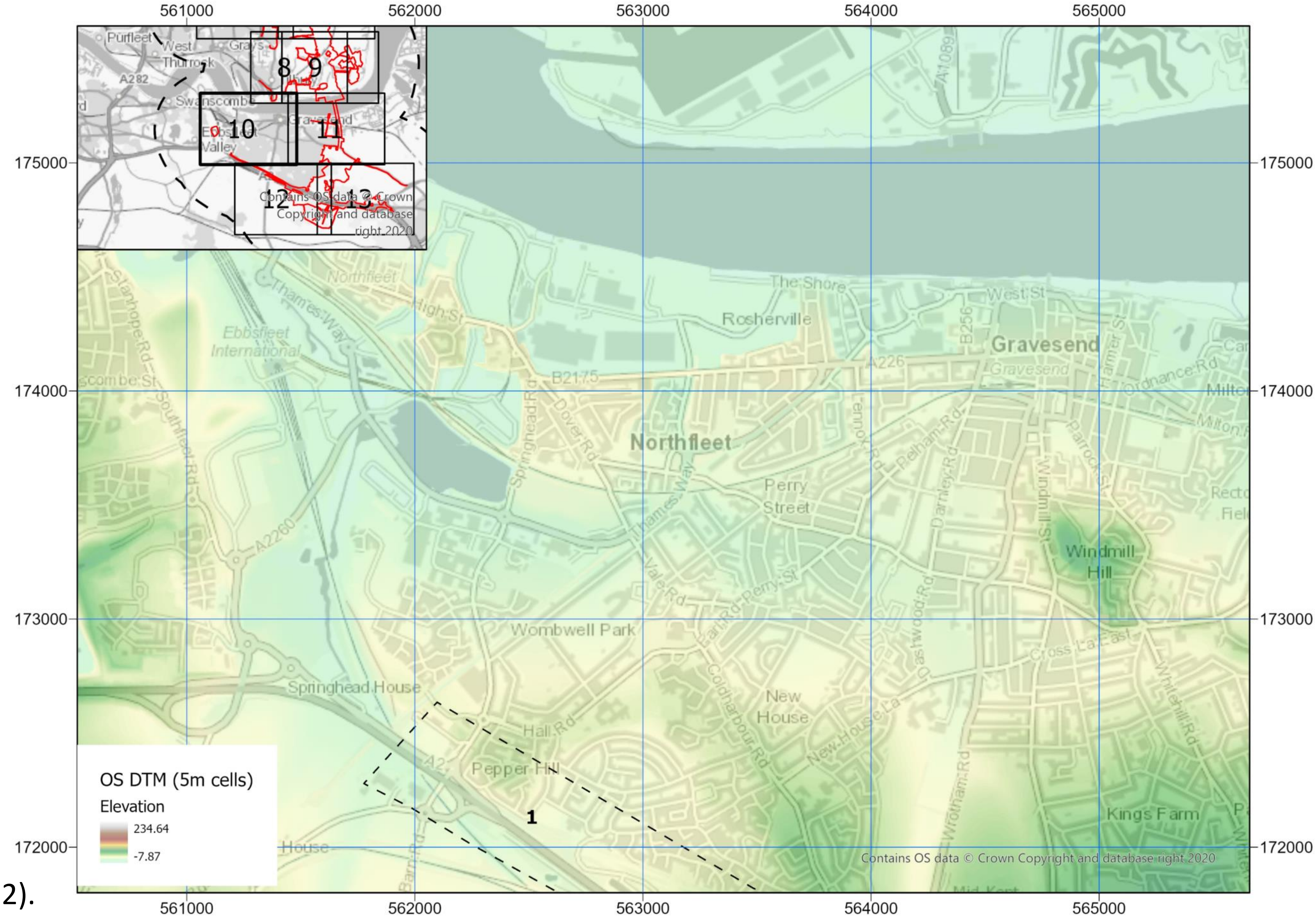

Figure 30. Zone 1 (west, 2).

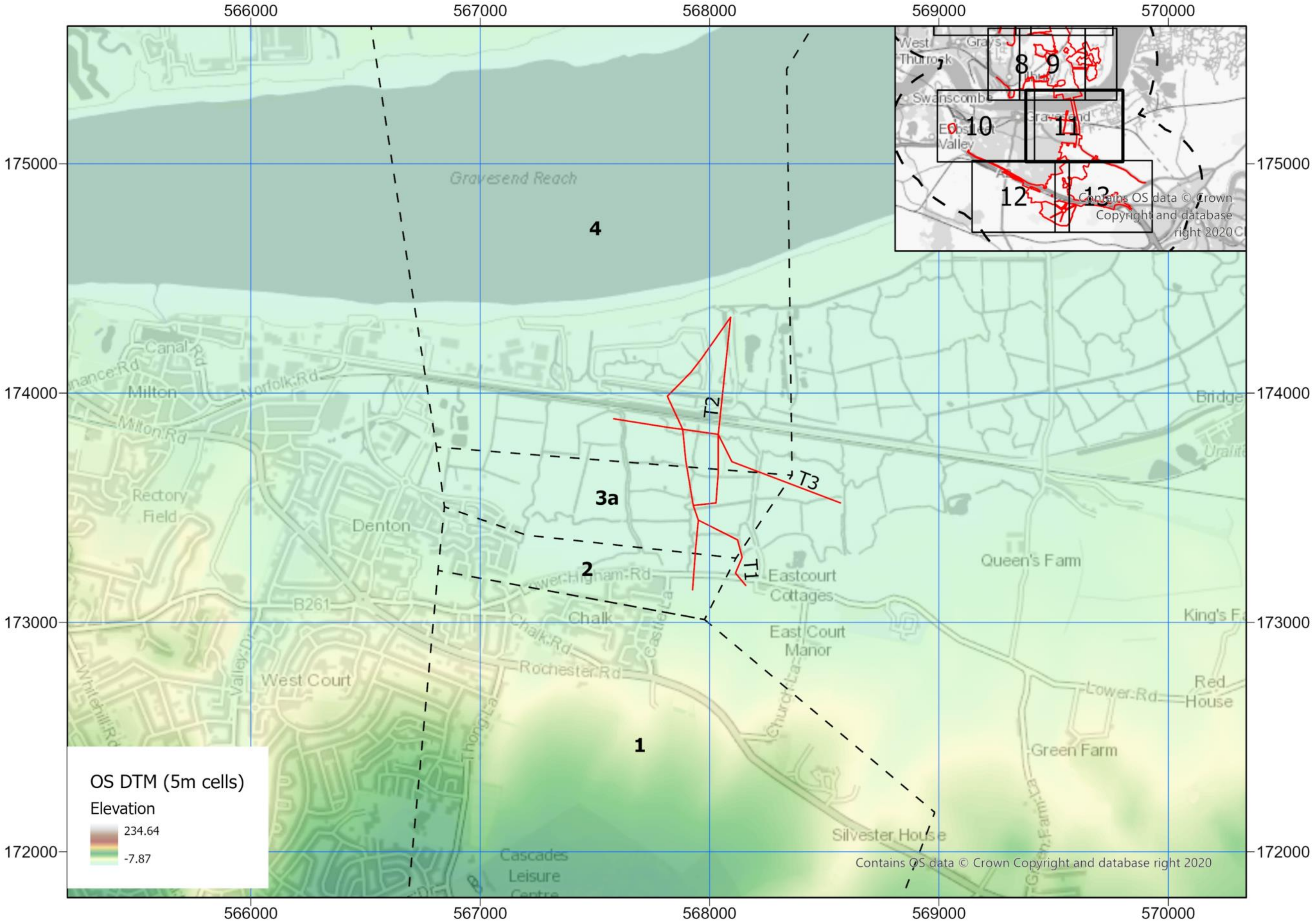

Figure 31. Zones 1-4.

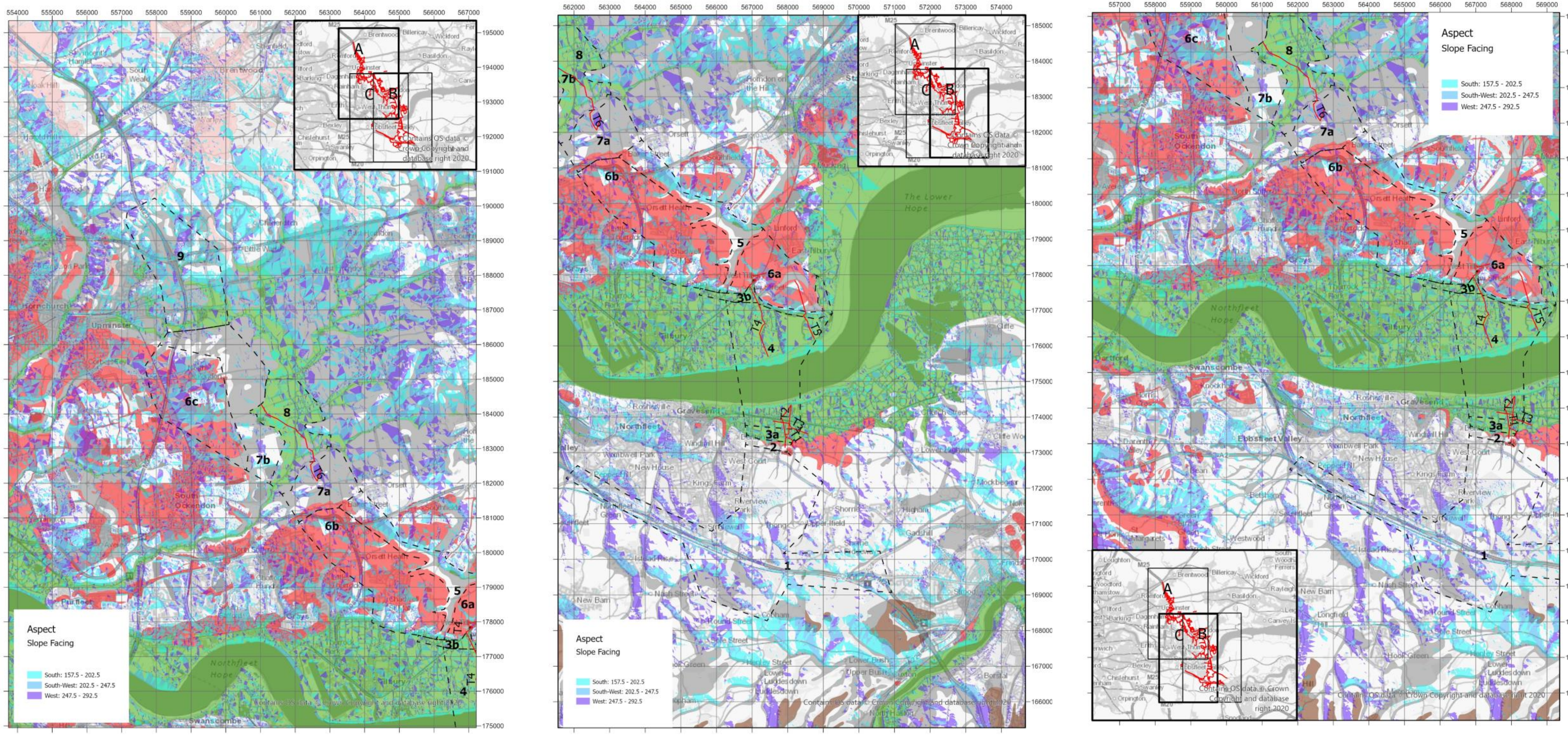

Figure 32. Superficial sediments and slope aspect (S/S-W/W facing).

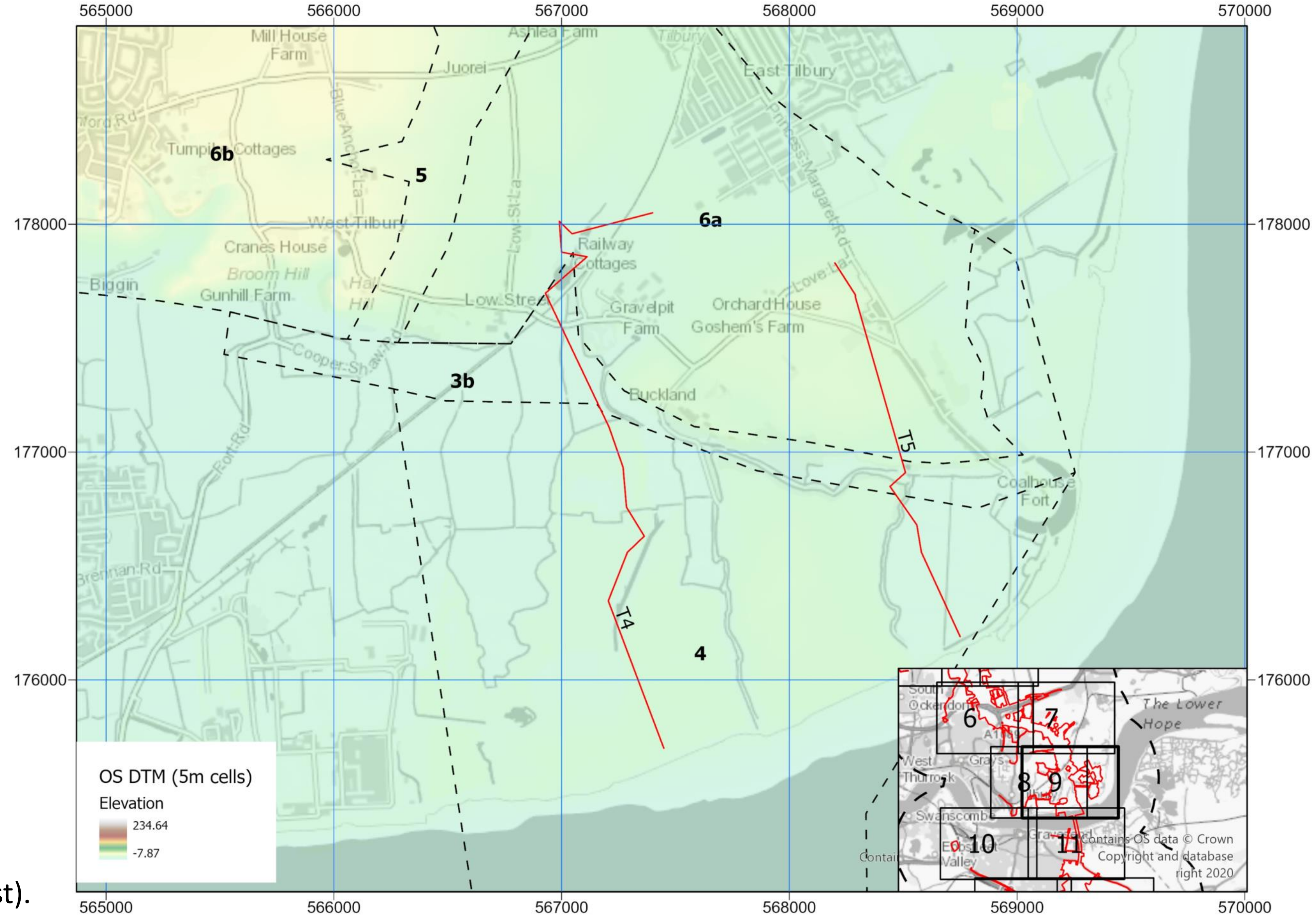

Figure 33. Zones 4-6 (east).

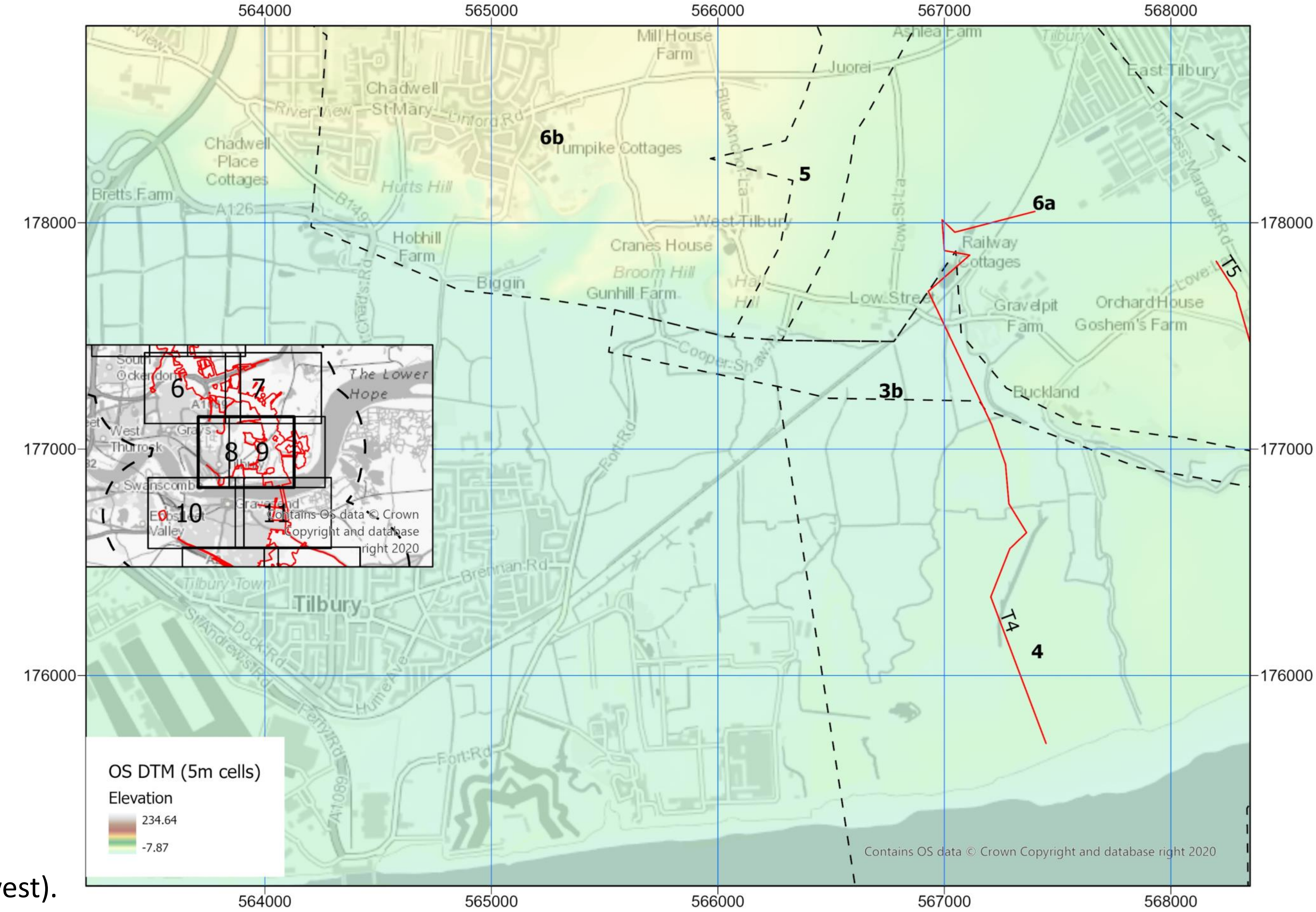

Figure 34. Zones 4-6 (west).

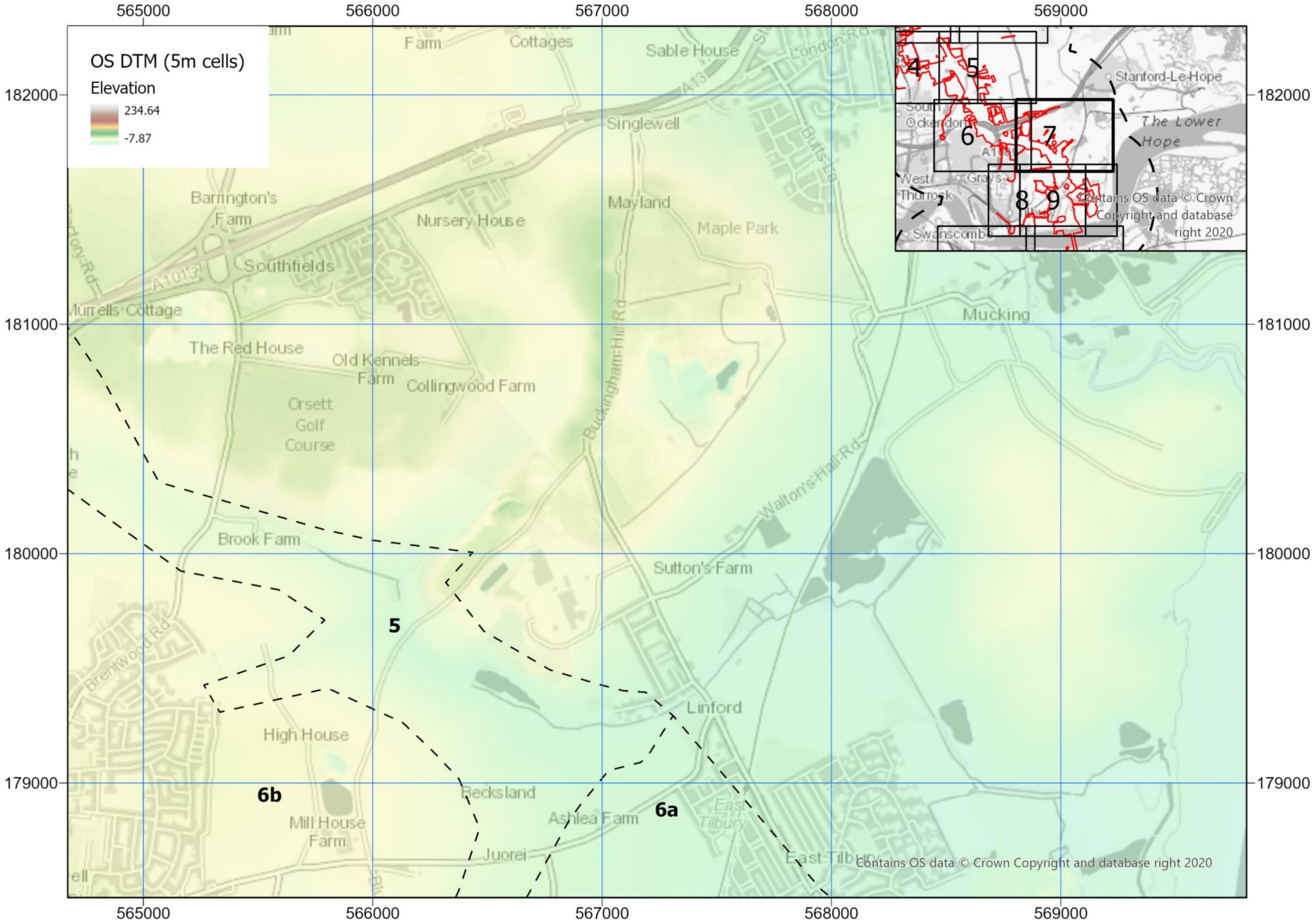

Figure 35. Zones 5 and 6.

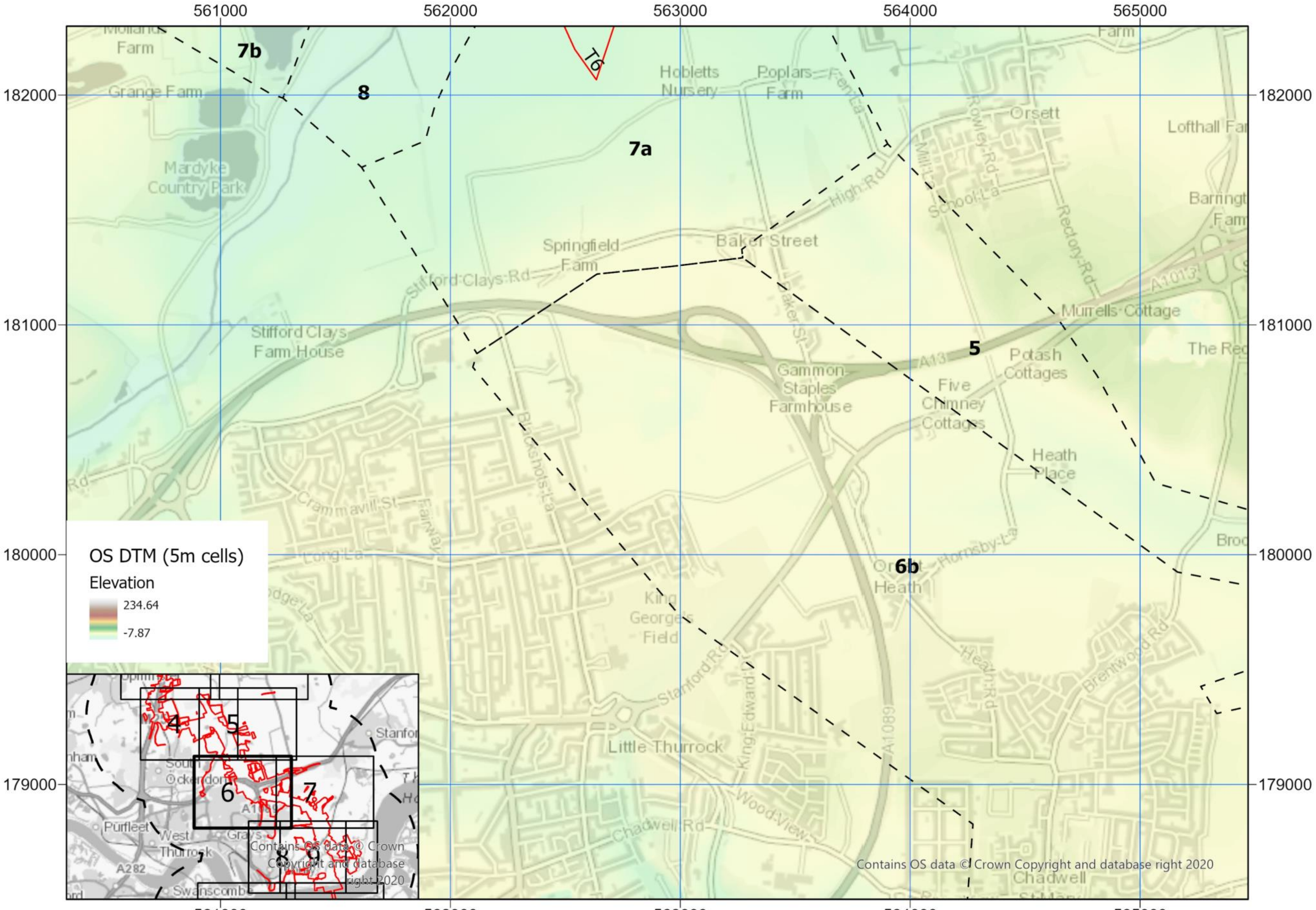

Figure 36. Zones 5-8.

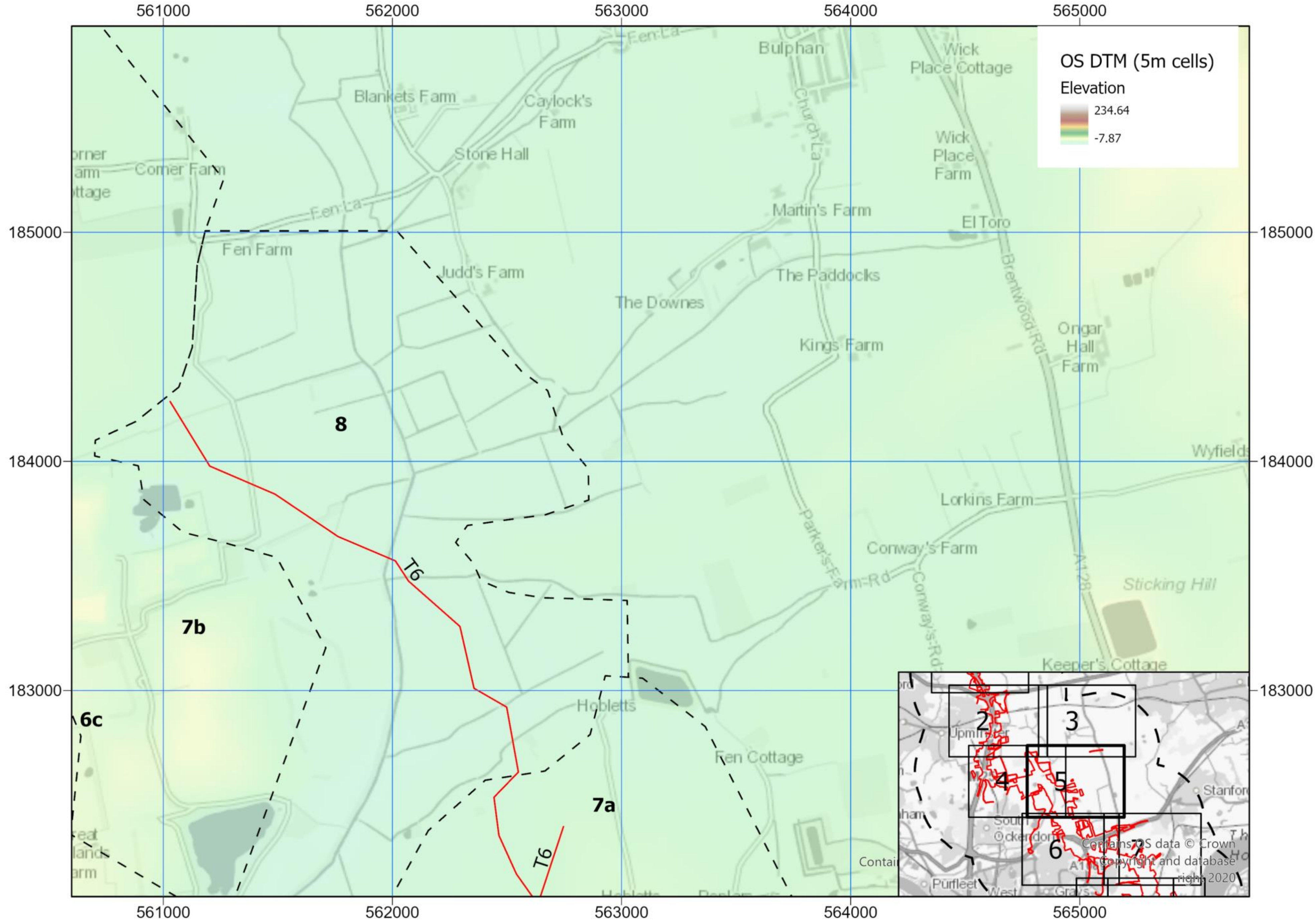

Figure 37. Zones 6-8.

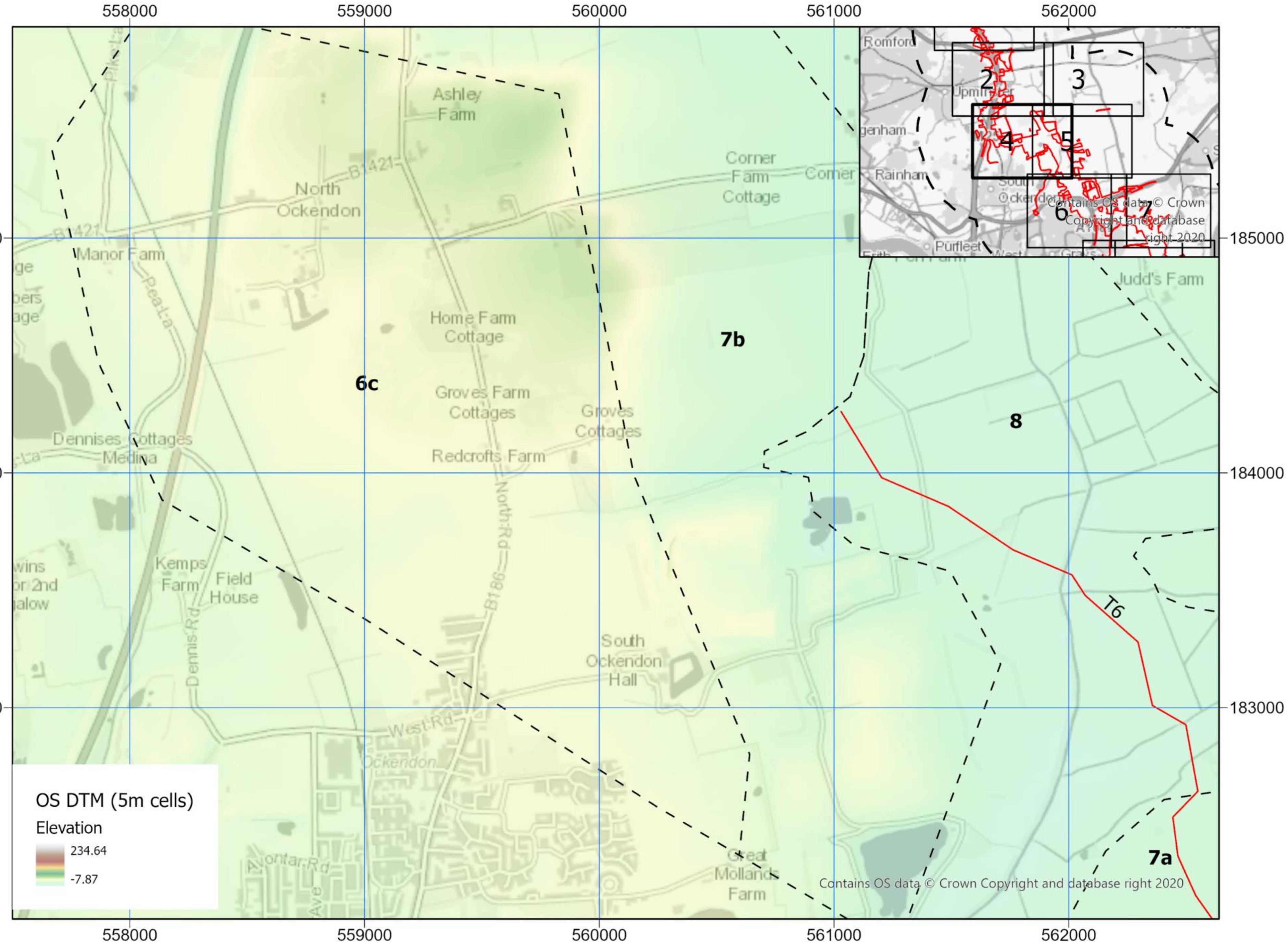

Figure 38. Zones 6-8.

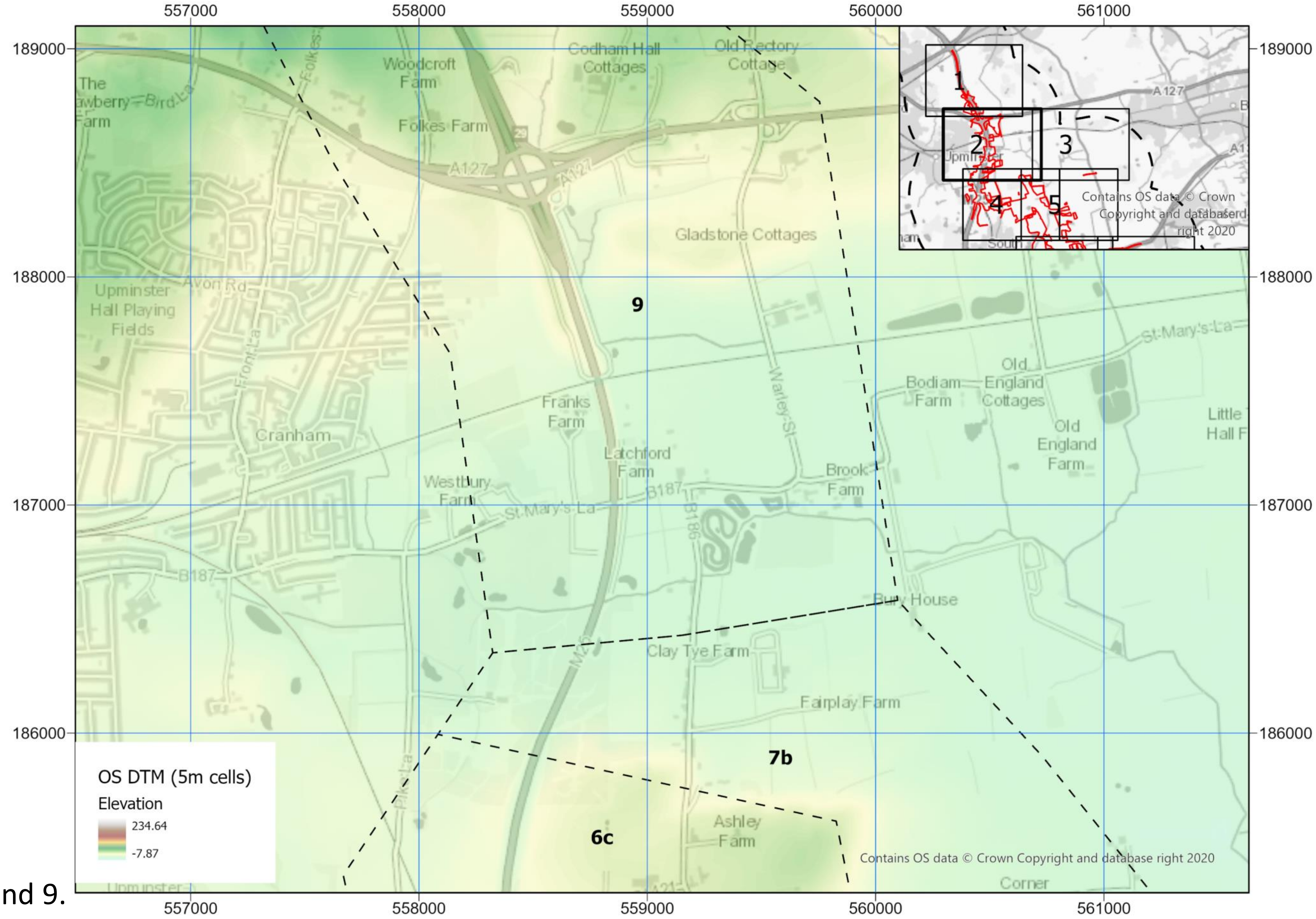

Figure 39. Zones 6, 7 and 9.

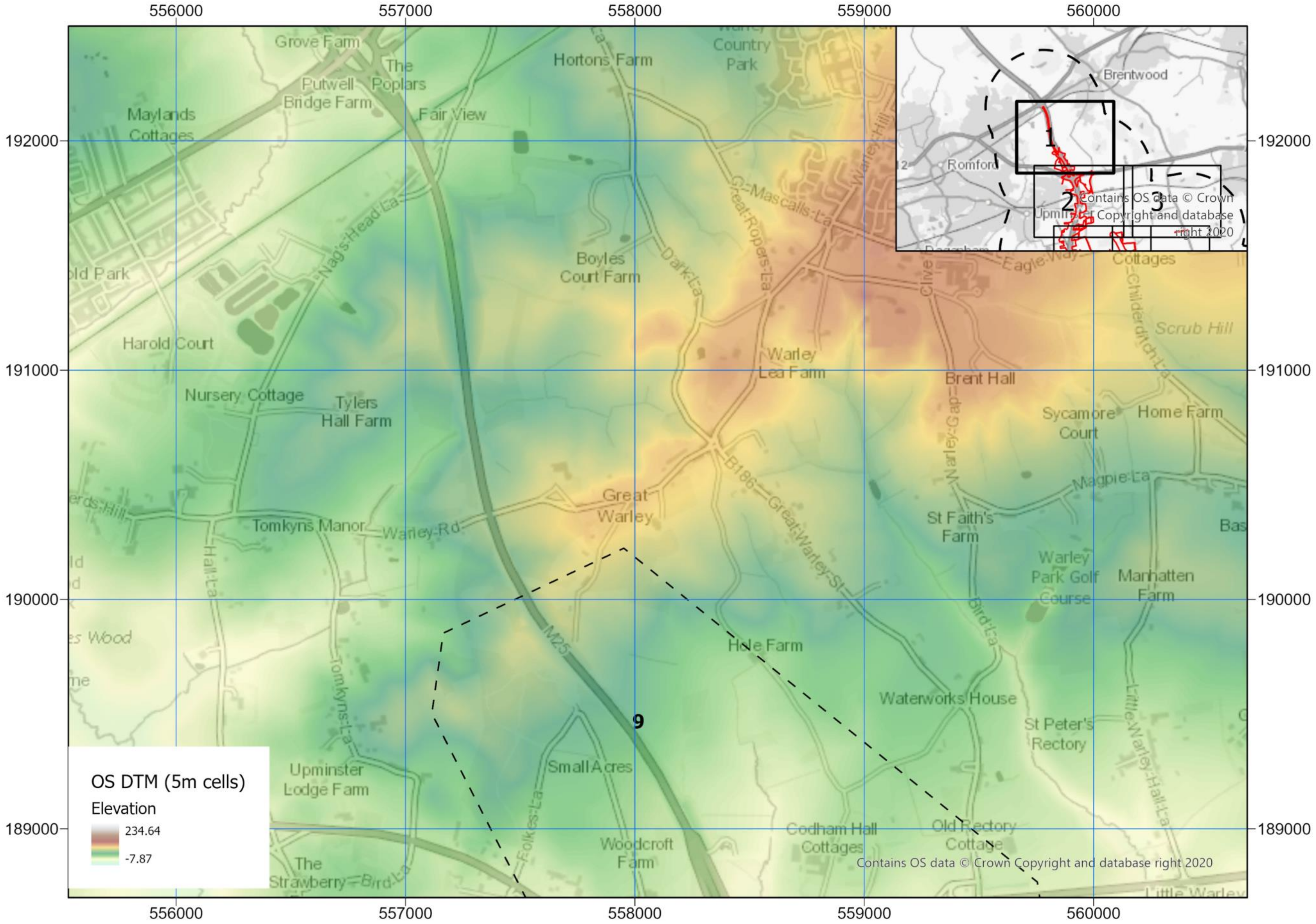

Figure 40. Zone 9.

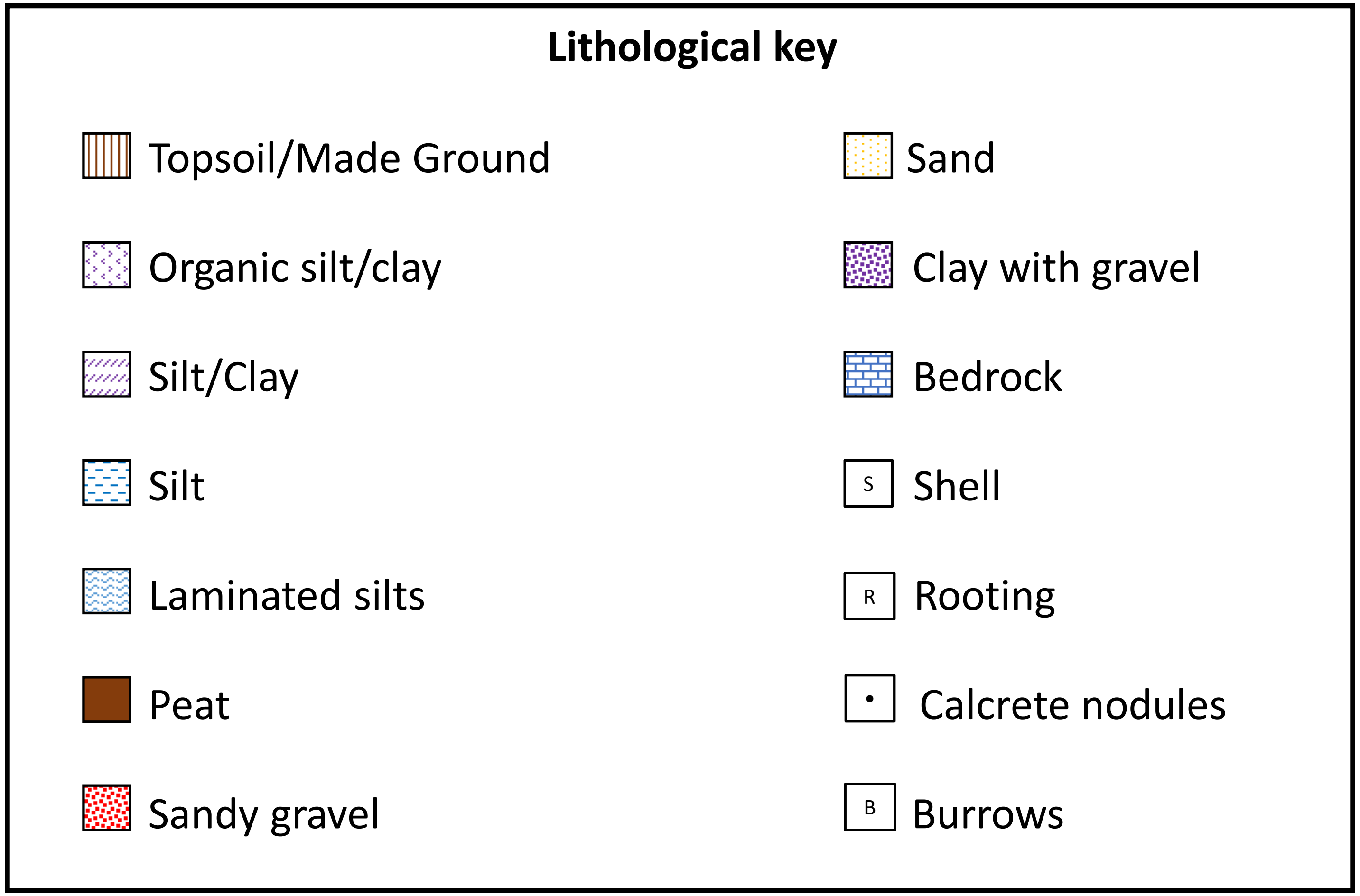

Figure 41. Key for geological profiles.

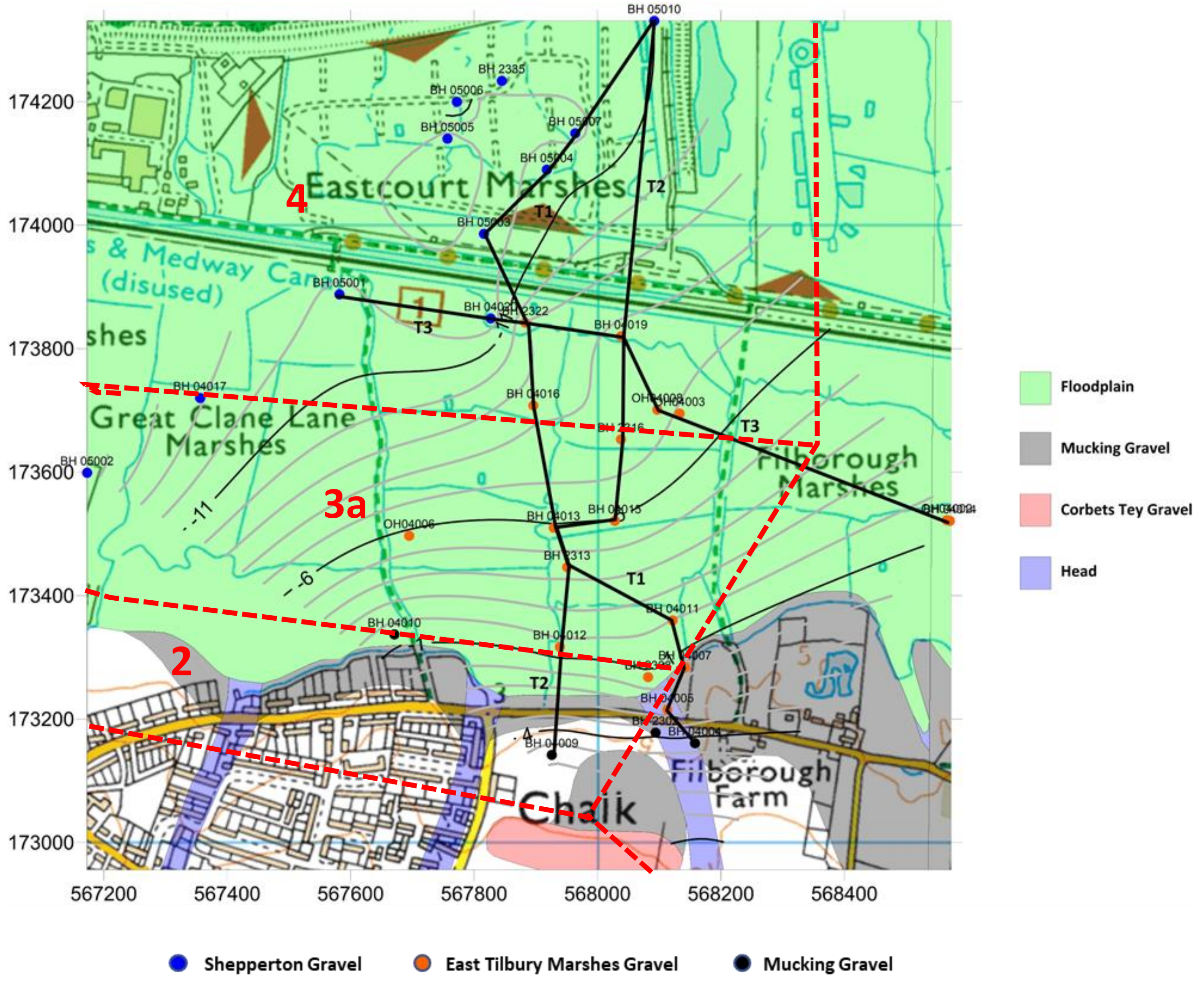

Figure 42. Map of geological transects in Zones 1-4 (south Thameside, Kent) and zones.

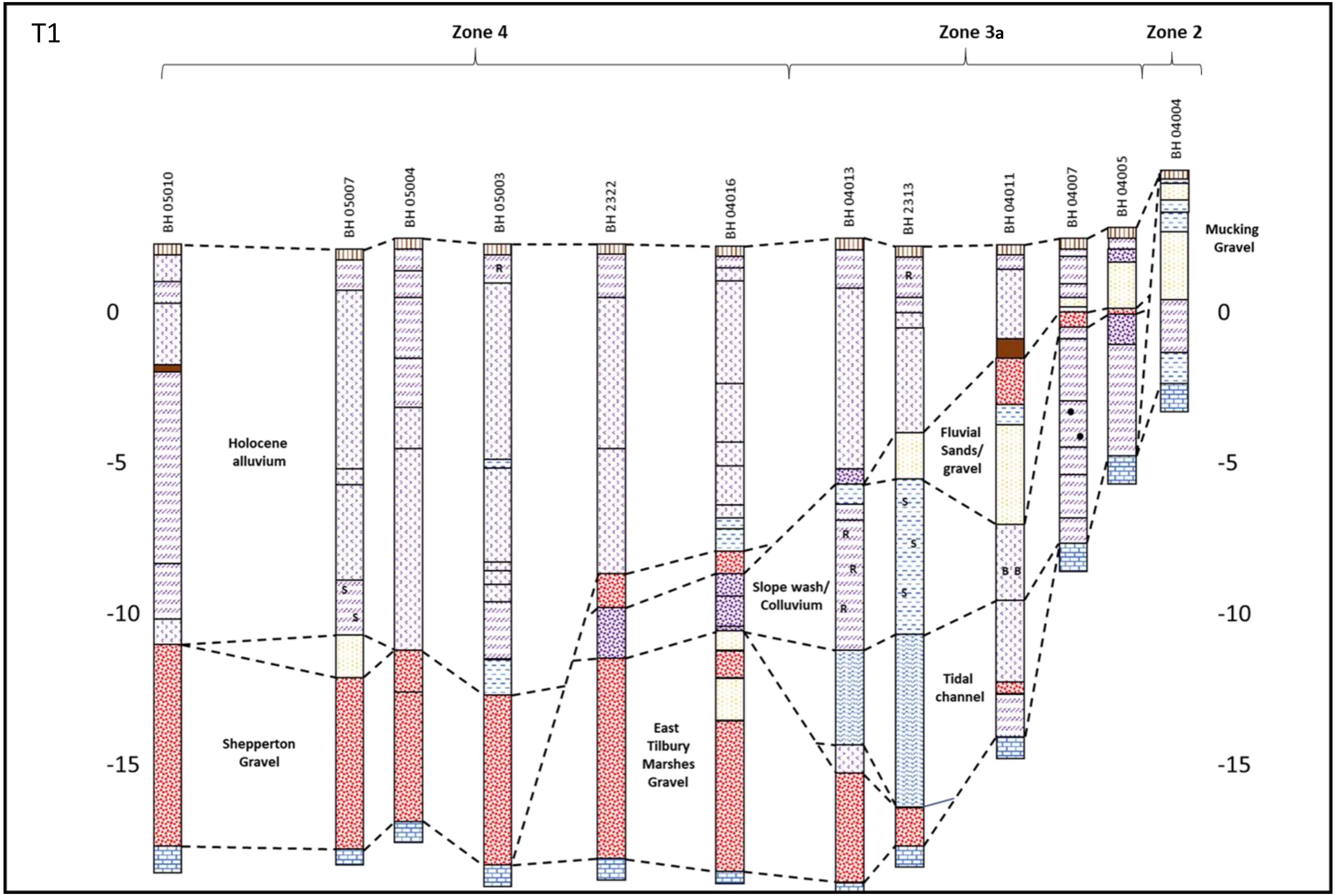

Figure 43. Transect 1.

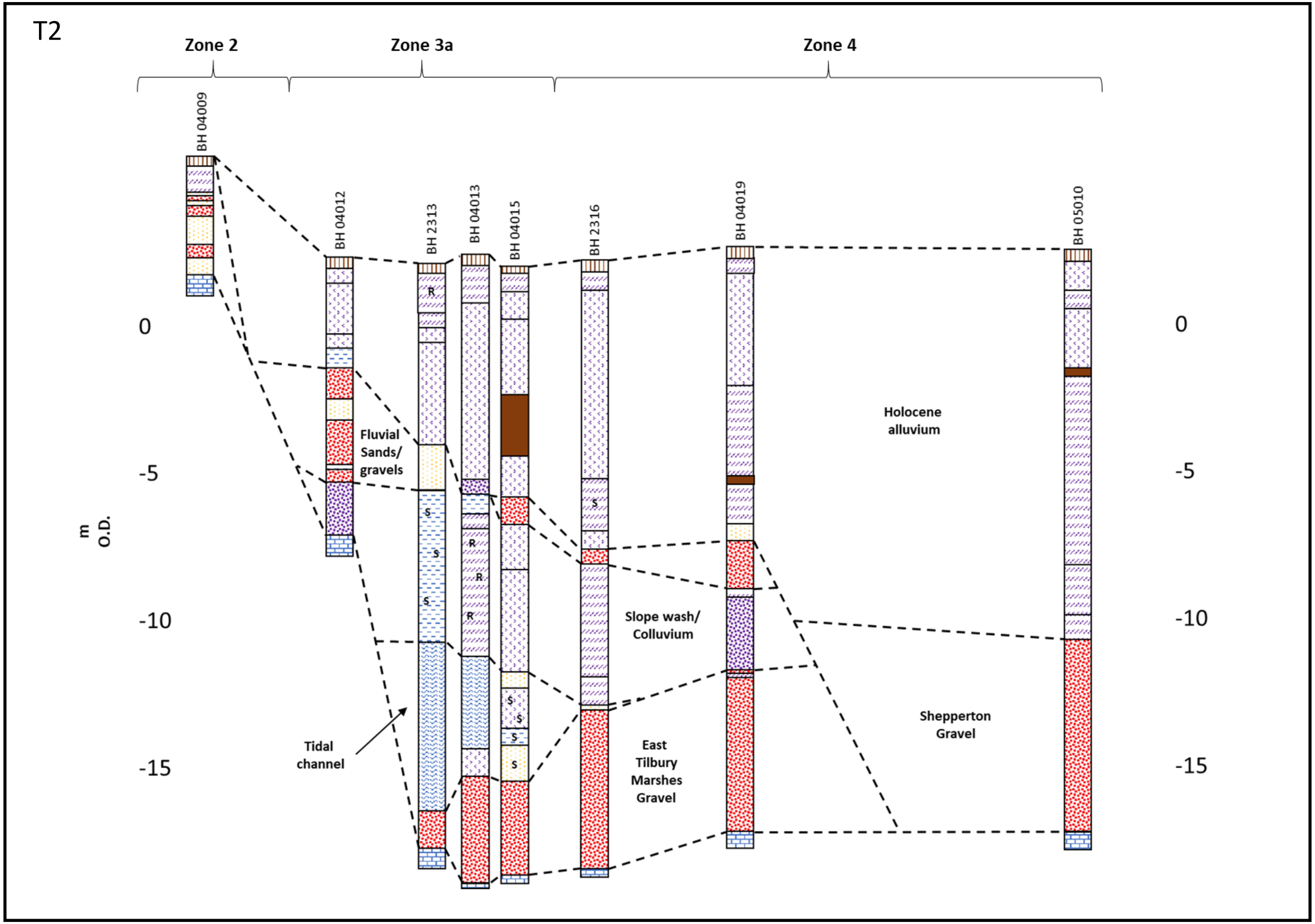

Figure 44. Transect 2.

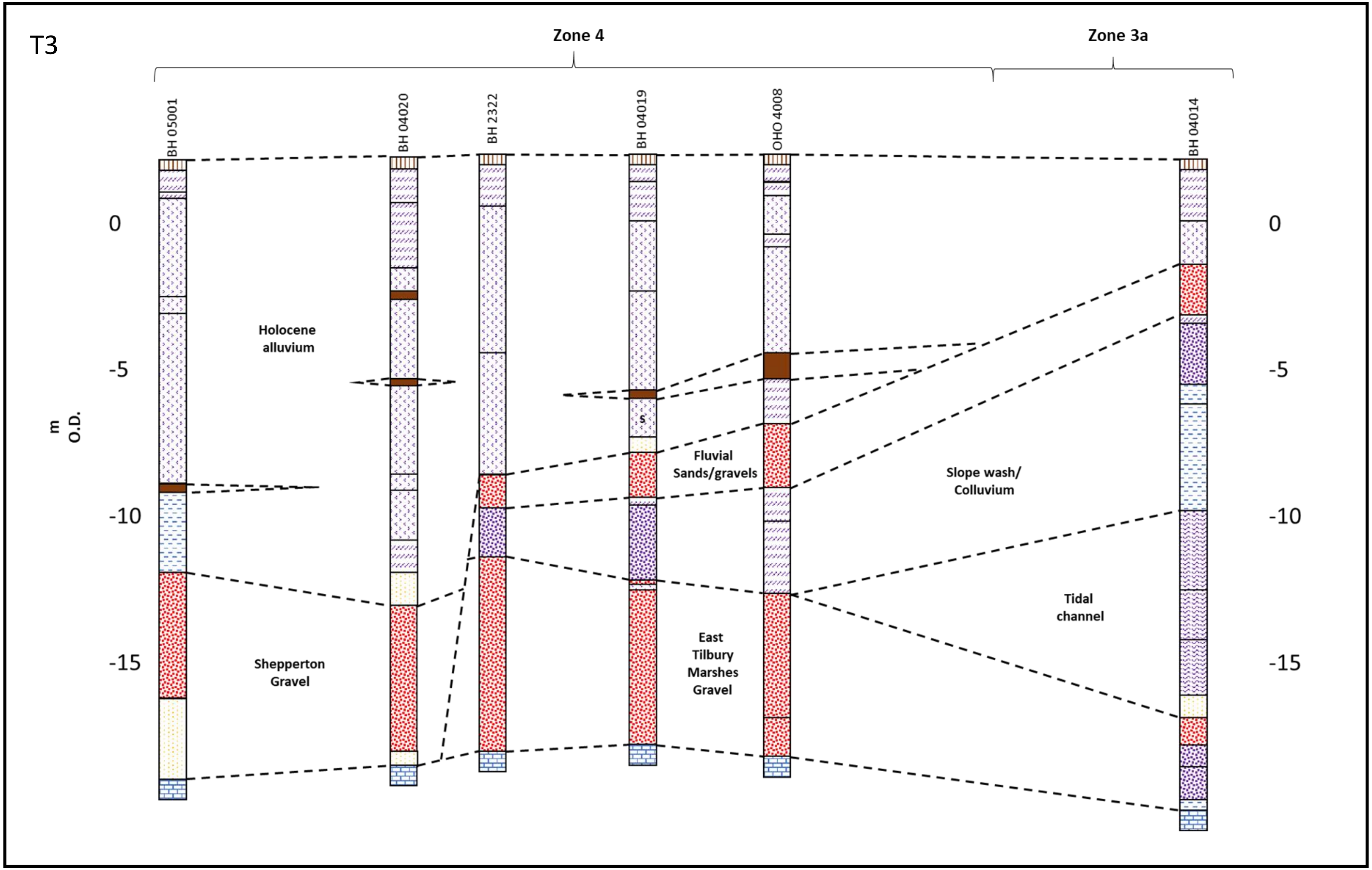

Figure 45. Transect 3.

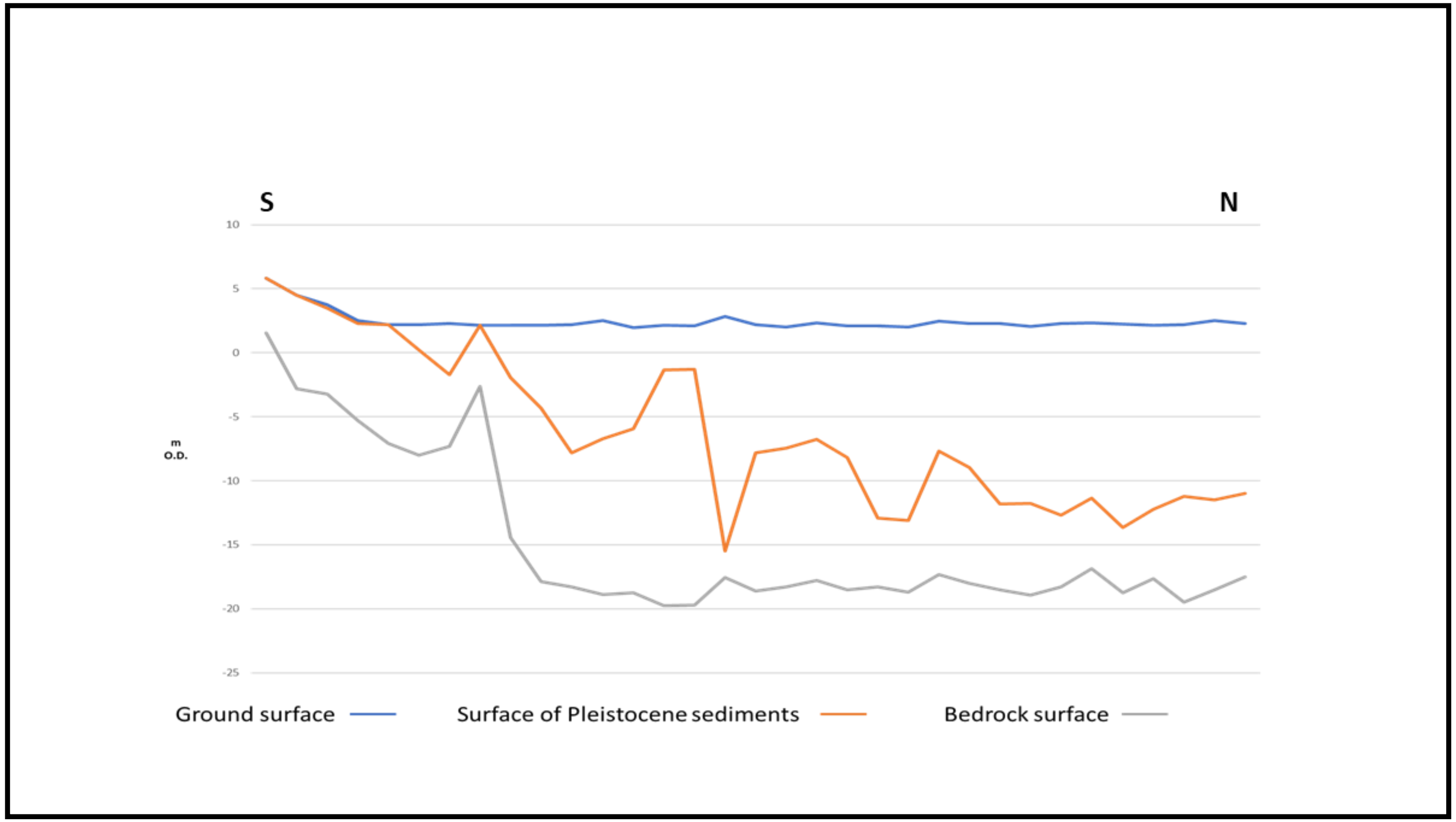

Figure 46. Ground surface, surface of Pleistocene/base of Holocene and bedrock surface in zones 1-4 (south Thames side, Kent).

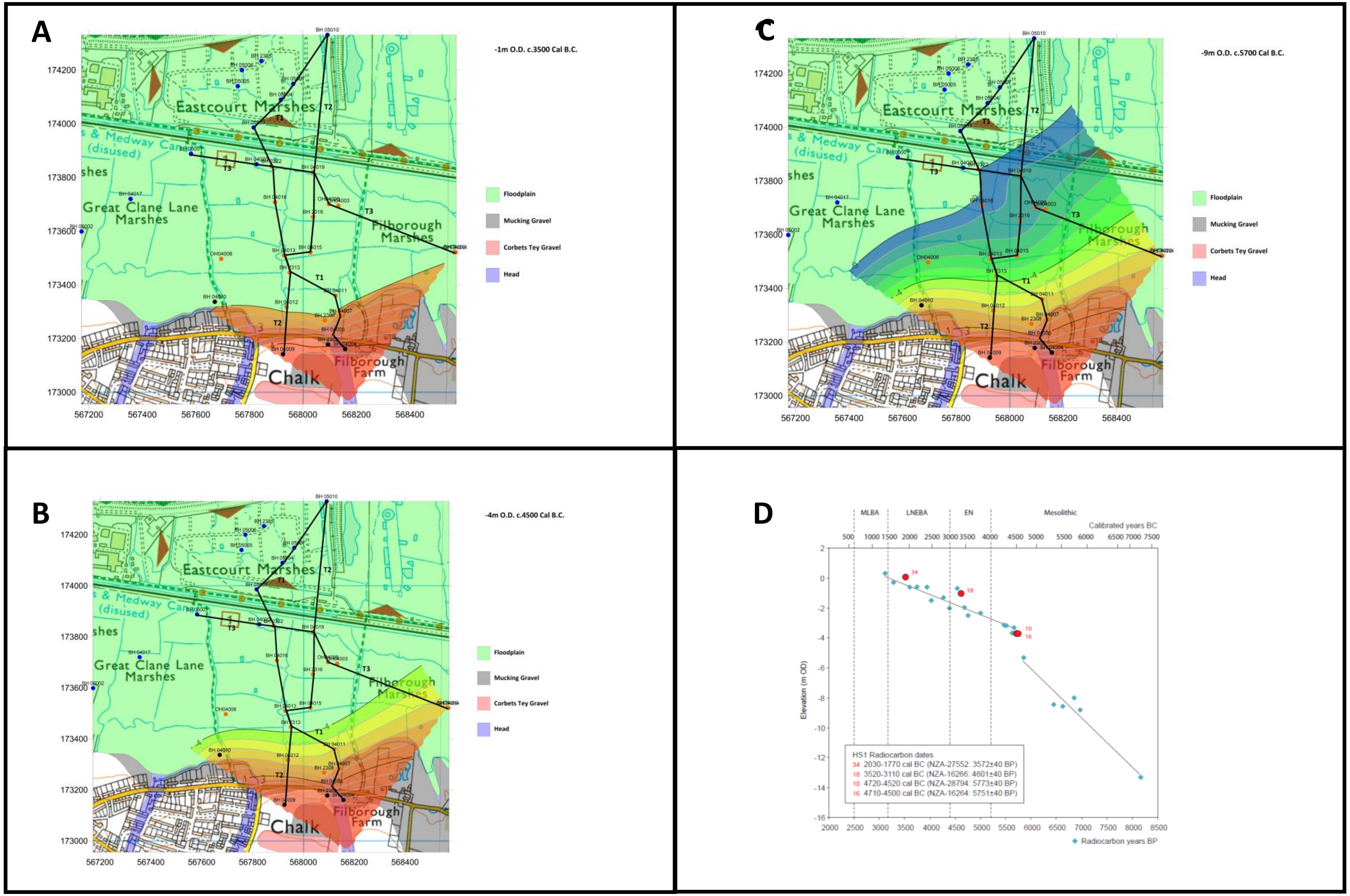

Figure 47. Flooding patterns across surface of Pleistocene in zones 1-4 (south Thames side, Kent).

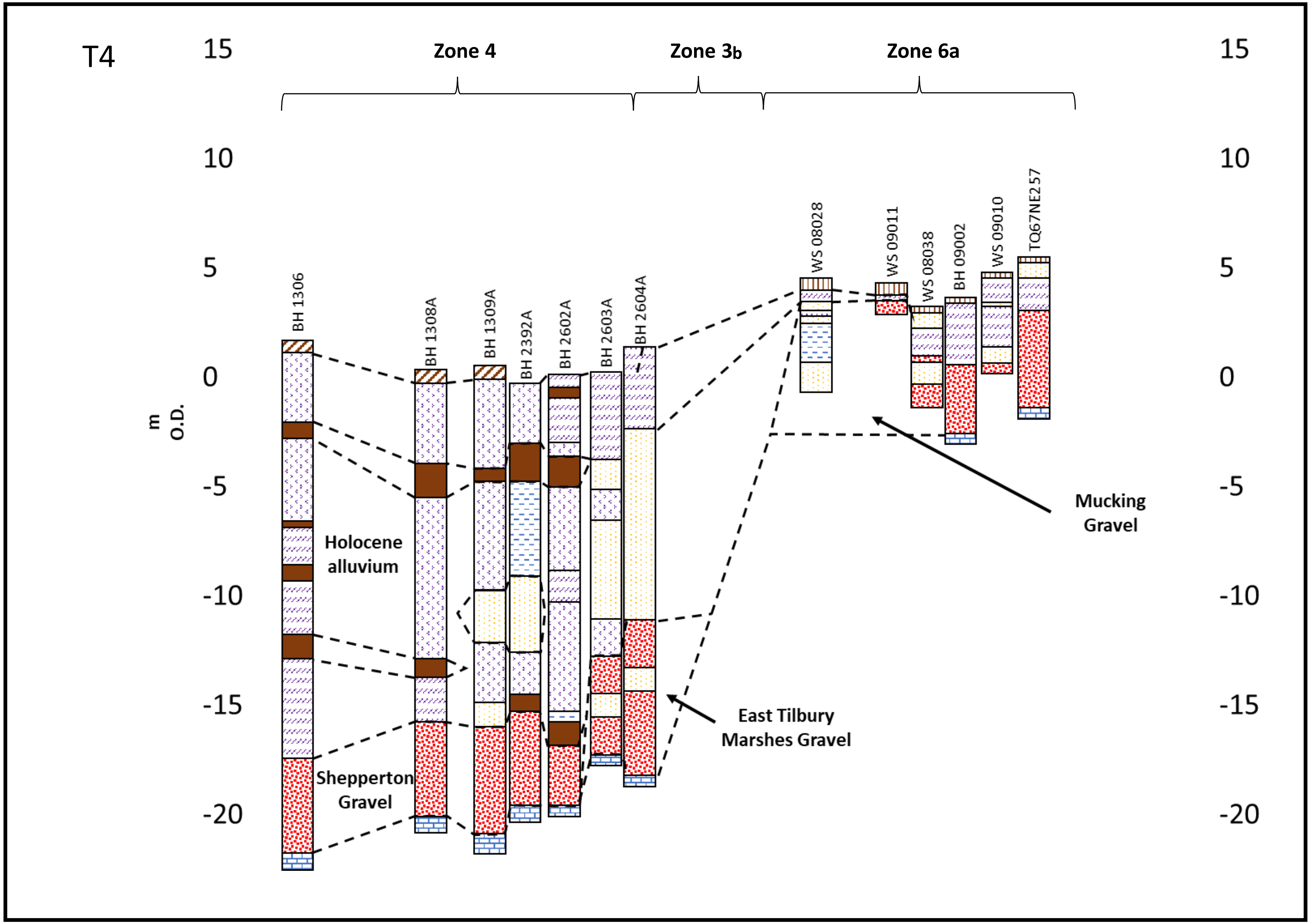

Figure 48. Transect 4.

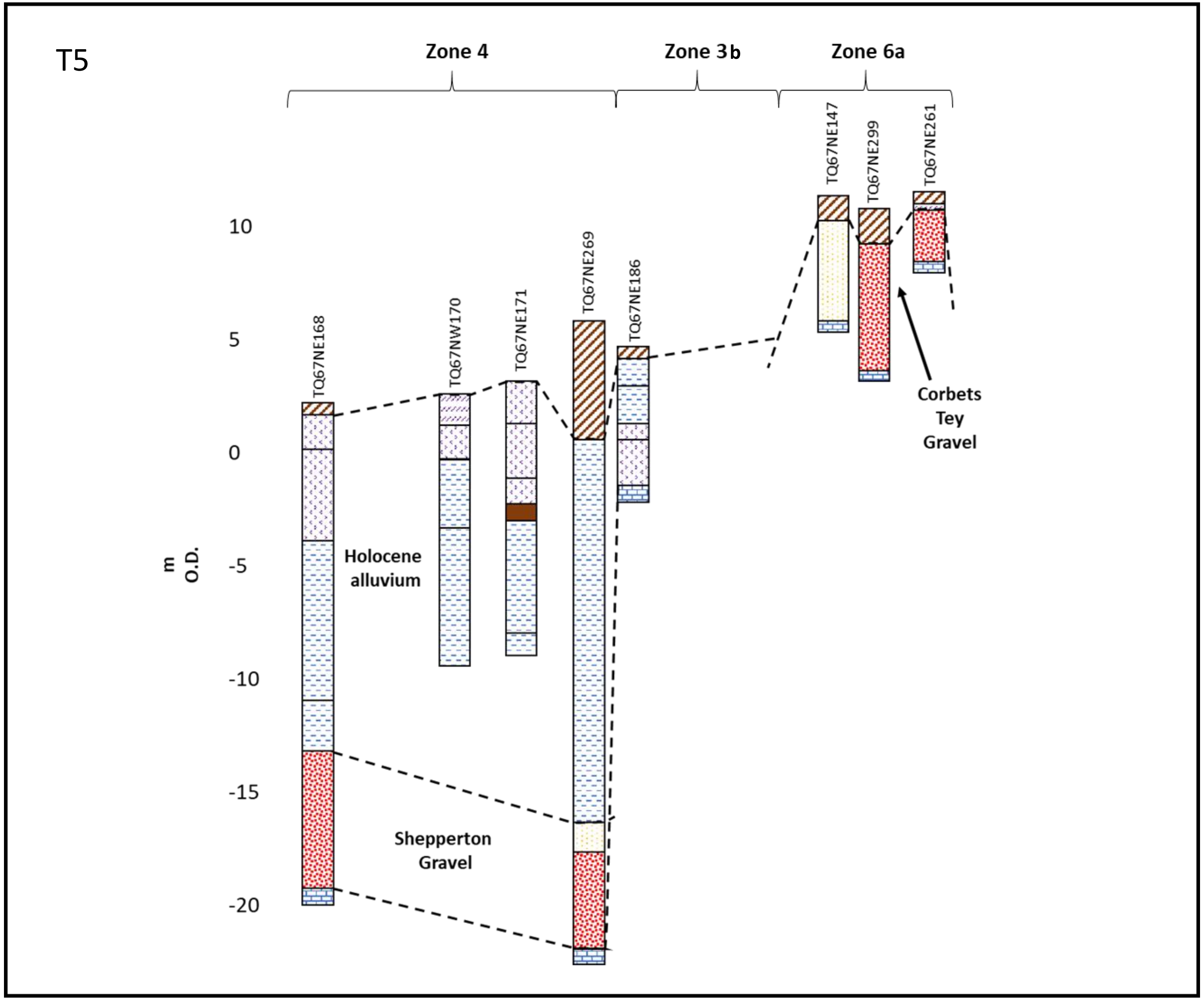

Figure 49. Transect 5.

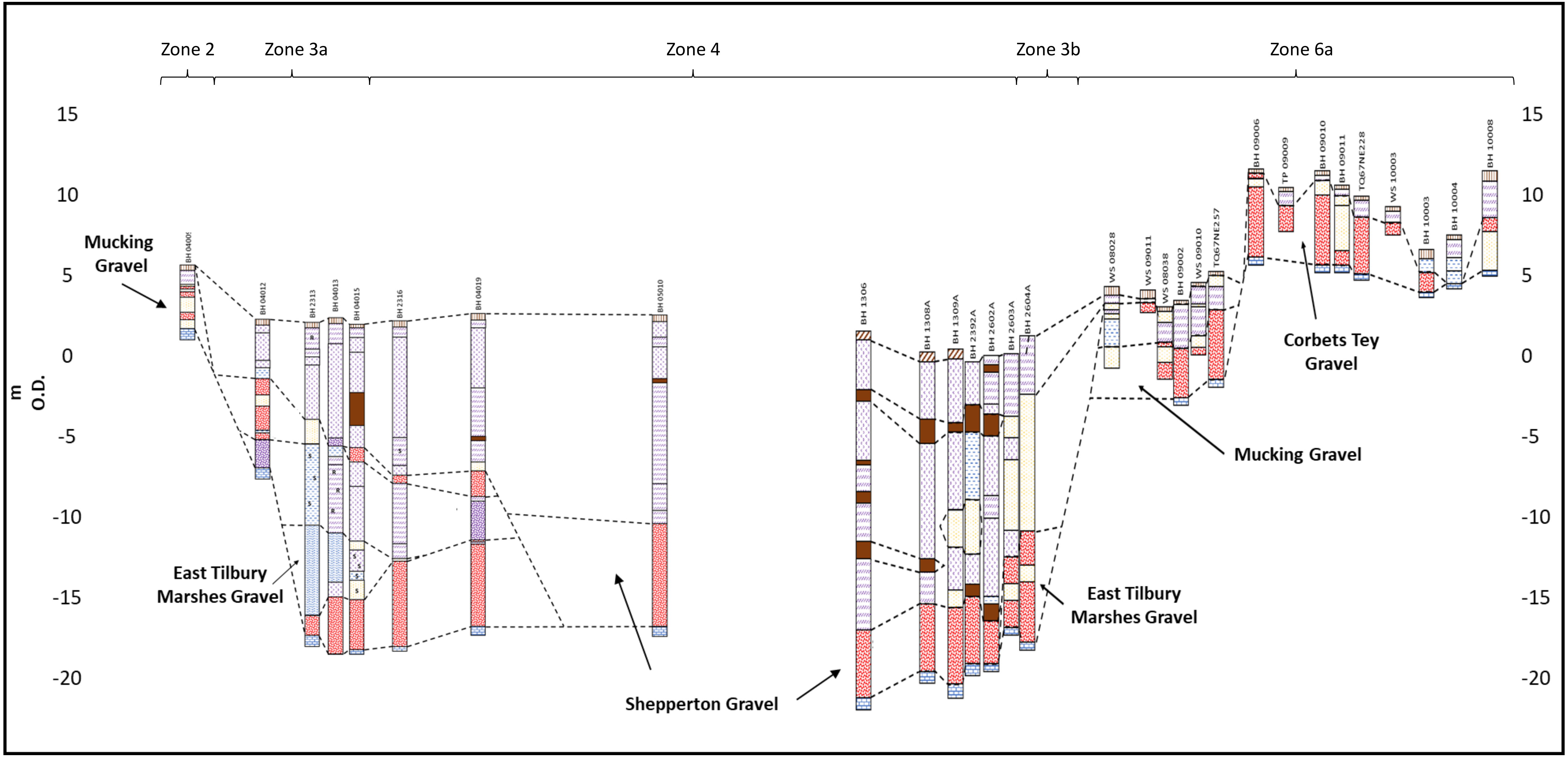

Figure 50. Cross Thames transects.

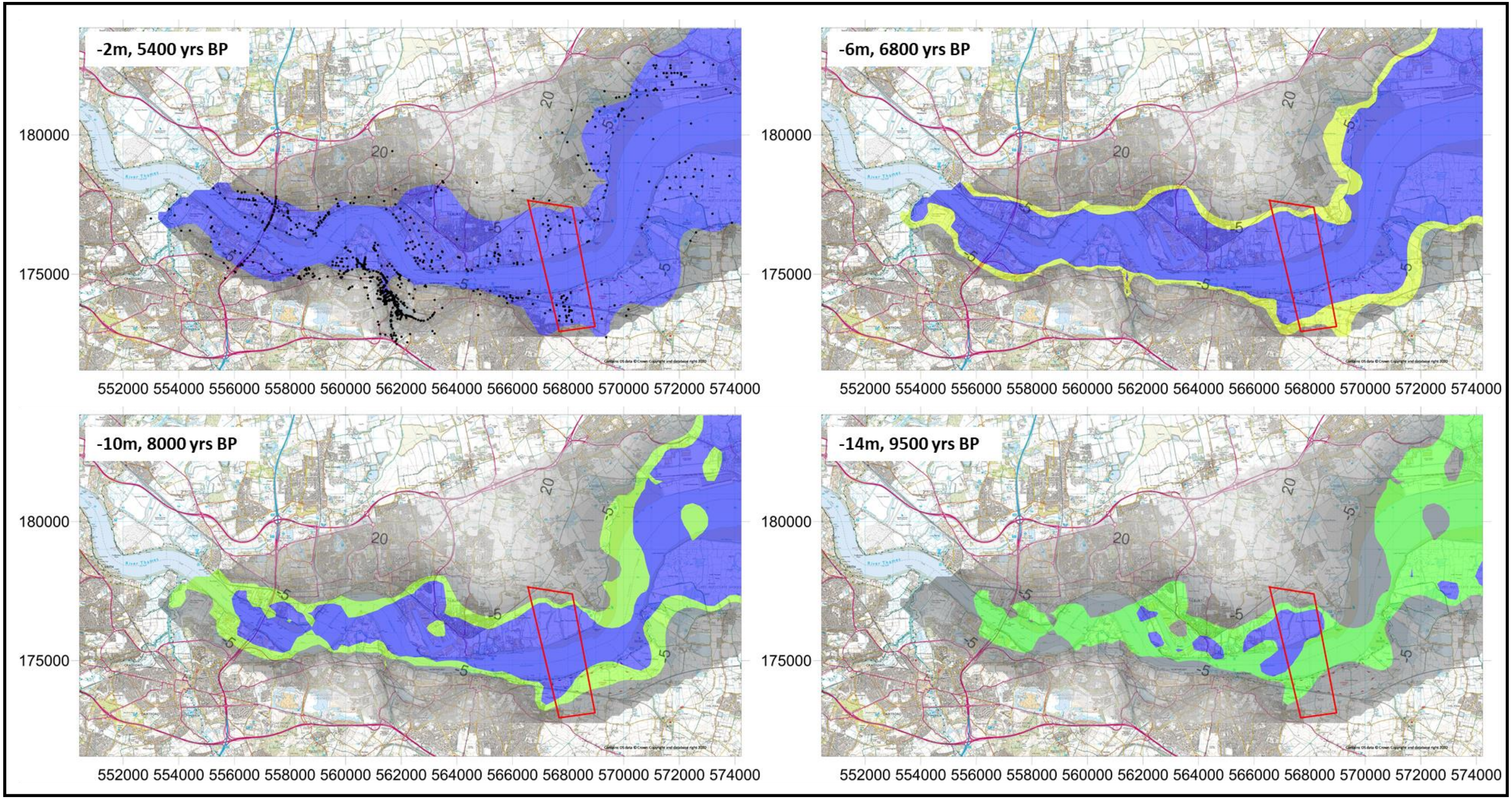

Figure 51. Modelled gravel surface topography showing effect of flooding at intervals through the Early and Middle Holocene (blue: fully flooded area; green intertidal zone with 3m tidal envelope; red box area of Lower Thames Crossing; all boreholes used shown in -2m image).

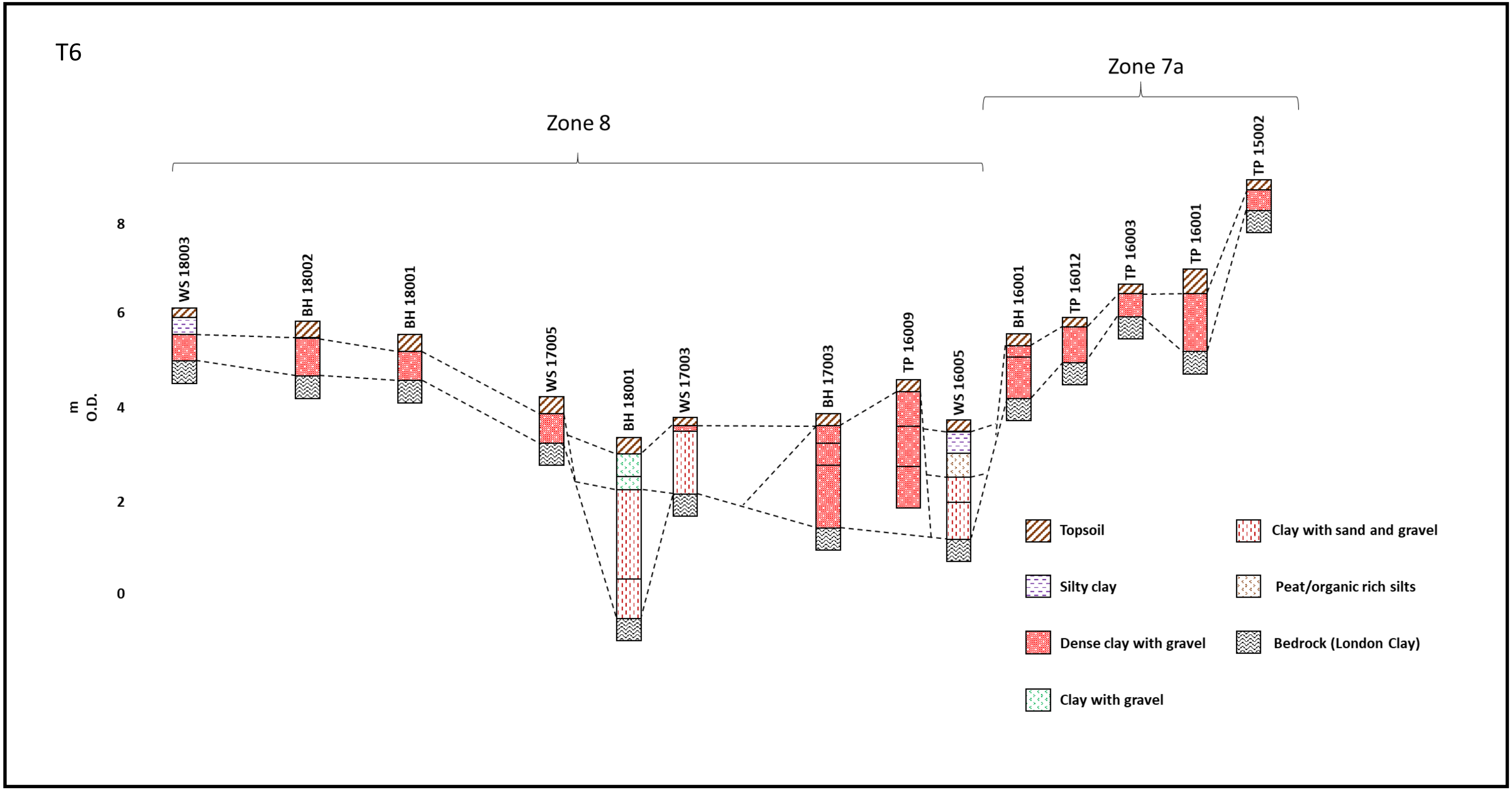

Figure 52. Transect through Mar Dyke.

a	b	c	d
Preparation	-	-	-
Observation	-	-	-
Recognition of problem	-	-	-
Statement of hypothesis	Statement of hypothesis	-	-
Data collection	Data collection	Data collection	Data collection
Data analysis	Data analysis	Data analysis	Data analysis
Evaluate hypothesis	Evaluate hypothesis	Evaluate hypothesis	-

Table 1. Outline of four different levels of research (from Schumm, 1991).

Groups	Sub-division	Associated sediment types	Age range	Location	Taphonomy of associated archaeology
Colluvium	Late Pleistocene	Fine grained sands/clay-silts with occasional gravel clasts/lenses	c. 20-11.7a b2k	Chalk Downs, edge of valleys, Essex Plateau surface	Reworked
	Holocene	Fine grained sands/clay-silts with occasional gravel clasts/lenses	11.7 a b2k to present	Chalk Downs, edge of valleys, Essex Plateau surface	Reworked
Palaeosols	Late Pleistocene	-	c. 20-11.7a b2k	Chalk Downs, edge of valleys, Essex Plateau surface, valley floors (Thames/Mar Dyke)	*In situ*
	Holocene	-	11.7 a b2k to present	Chalk Downs, edge of valleys, Essex Plateau surface valley floors (Thames/Mar Dyke)	*In situ*
Head	Late Pleistocene	Poorly sorted clay/silt with gravel clasts	c. 20-11.7a b2k	Chalk Downs, edge of valleys, Essex Plateau surface	Reworked
Alluvium	Freshwater	Clay-silts with peats/organic silts	11.7 a b2k to present	Mar Dyke	Reworked *In situ*
	Estuarine	Clay-silts and sand	?10 a b2k to present	Thames/Mar Dyke	Reworked *In situ*
Alluvial Fan	-	Gravels, often bedded	?	Mar Dyke?	Reworked
Springs	-	Tufa	11.7-3a b2k	*?*	*In situ*
Lakes, ponds and mires	-	Peats, organic silts, clay/silts, sands	15-present	*?*	*In situ*

Table 2. Sediment types in route corridor.

Zone	Geomorphological description	Bedrock geology	Superficial geology	Archaeological implications	Key questions
1	Dip slope of North Downs consisting of a series of dry valleys	Chalk with isolated outcrops of Thanet Formation, Lambeth Group, Harwich Formation and London Clay Formation	Clay-with-flints, Head and Dry Valley deposits	Late Pleistocene Head deposits may bury, and preserve, Late Upper Palaeolithic material while such material may also be incorporated in the final depositional event associated with Head accumulation during the Younger Dryas. The relative stability of the landscape during the Early and earlier part of the Middle Holocene would suggest Mesolithic archaeological material is unlikely to be commonly buried in this zone and may occur at the surface on the higher parts of the zone but buried and incorporated into the later Holocene colluvium on the lower slopes. Isolate patches of Mesolithic archaeological material may be buried by colluvium locally. From around 6000 yrs. BP increased erosion caused by woodland clearance and downslope transport of colluvium would have resulted in the reworking of Neolithic and Bronze Age material.	Are the predictions based on the slope analysis correct? Do certain locations along a slope provide better conditions for sequence preservation? Can we obtain high resolution isotopic records from the preserved mollusc faunas to better model Late Glacial climates?
2	Foot of dip slope of North Downs immediately above the main Thames Floodplain	Chalk	Outcrops of Pleistocene terrace gravels and Head	Thin sequences of Late Pleistocene Head deposits may bury, and preserve, Late Upper Palaeolithic material while such material may also be incorporated in the final depositional event associated with Head accumulation during the Younger Dryas. The relative stability of the landscape during the Early and earlier part of the Middle Holocene would suggest Mesolithic	Is there Mesolithic archaeology preserved along the margins of the zone?

				archaeological material is unlikely to be commonly buried in this zone and may occur at the surface on the higher parts of the zone but buried and incorporated into the later Holocene colluvium on the lower slopes. Isolate patches of Mesolithic archaeological material may be buried by colluvium locally. From around 6000 yrs. BP increased erosion caused by woodland clearance and downslope transport of colluvium would have resulted in the reworking of Neolithic and Bronze Age material.	
3a	Edge of Thames Floodplain	Chalk	Thin spreads of alluvium overlying thick sequences of Pleistocene sediments	The Holocene sedimentary wedge overlying and abutting the rising surface of the buried Pleistocene sediments may contain important, and well preserved, archaeological material. Modelling of the flooding of this surface indicates that preserved dryland Mesolithic archaeology may be present throughout this zone, while later Prehistoric dryland material will be preserved successively towards the margins of the modern floodplain.	Do we find archaeological material associated with the dry ground surface prior to flooding in the Holocene? What is the precise timing of flooding of this surface? Is there activity in the wetlands following flooding? Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?
3b	Edge of Thames Floodplain	Chalk	Thin spreads of alluvium overlying thick sequences of Pleistocene sediments	The Holocene sedimentary wedge overlying and abutting the rising surface of the buried Pleistocene sediments may contain important, and well preserved, archaeological material. Preserved dryland Mesolithic archaeology may be present throughout this zone, while later Prehistoric dryland material will be preserved successively	Do we find archaeological material associated with the dry ground surface prior to flooding in the Holocene? What is the precise timing of flooding of this surface? Is there activity in the wetlands following flooding? Is there a geochemical record preserved in the sedimentary sequence

				towards the margins of the modern floodplain.	of human activity on the dry ground adjacent to the floodplain?
4	Main Thames floodplain behind sea wall	Chalk	Thick sequences of Holocene alluvium over thin spreads of Late Pleistocene gravel	Previous experience at the Thames River Crossing suggest that archaeological material in this part of the floodplain is likely to be scare. Material may exist on the surface of the Pleistocene sediments and scattered intermittently through both the peats and the minerogenic sediments.	What is the age and environments of deposition of both the organic and minerogenic sediments? What is the precise timing of flooding of this surface? Is there activity in the wetlands following flooding? Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?
5	Dry valley systems connecting Thames Floodplain and Mar Dyke	Thanet Formation and Lambeth Group	Head deposits	The nature of the archaeological signature in these sequences remains opaque. It is possible Late Palaeolithic and Mesolithic archaeology is present within and buried below/sealed by the slope deposits.	Did this system for a fluvial network draining the Mar Dyke into the Thames in a southerly direction? Are there fluvial sediments preserved beneath the Head, or erroneously mapped as Head? Are Late Glacial sequences preserved in places in the zone?
6a	Thames Terrace plateau surface	Thanet Formation, Lambeth Group and Harwich Formation	Pleistocene fluvial sediments overlain by fine grained brickearths and/or Head deposits	The plateau like topography of this zone suggests little in the way of stratified sedimentary sequences are likely to have accumulated in the Holocene across much of this zone. However, the stream network fitting indicates localised pockets of alluvium/colluvium containing Holocene archaeological material may be present in places in these zones.	Do any of the putative stream systems contain Holocene sediments with associated archaeology?
6b	Thames Terrace plateau surface	Thanet Formation, Lambeth Group	Pleistocene fluvial sediments overlain by fine grained	The plateau like topography of this zone suggests little in the way of stratified sedimentary sequences are likely to	Do any of the putative stream systems contain Holocene sediments with associated archaeology?

		and Harwich Formation	brickearths and/or Head deposits	have accumulated in the Holocene across much of this zone. However, the stream network fitting indicates localised pockets of alluvium/colluvium containing Holocene archaeological material may be present in places in these zones.	
6c	Thames Terrace plateau surface	London Clay Formation	Pleistocene fluvial sediments overlain by fine grained brickearths and/or Head deposits	The plateau like topography of this zone suggests little in the way of stratified sedimentary sequences are likely to have accumulated in the Holocene across much of this zone. However, the stream network fitting indicates localised pockets of alluvium/colluvium containing Holocene archaeological material may be present in places in these zones.	Do any of the putative stream systems contain Holocene sediments with associated archaeology?
7a	Valley side gently sloping northwards into Mar Dyke	Lambeth Group, Harwich Formation and London Clay Formation	Head deposits	Archaeological material in this zone is likely to have been moved and transported in the Head or colluvium.	Is there any stratified sediments in this zone that contain archaeological material?
7b	Valley side gently sloping eastwards into Mar Dyke	London Clay Formation	Head deposits	Archaeological material in this zone is likely to have been moved and transported in the Head or colluvium.	Is there any stratified sediments in this zone that contain archaeological material?
8	Mar Dyke wetland basin	London Clay Formation	Alluvium and possibly mobile Pleistocene colluvial sheets/fan deposits	Archaeological material may be present in those parts of the sequences that are associated with the alluvium or in the Head deposits present along the margins of the Mar Dyke and within the inner part of the basin.	What are the different environments of deposition of sediments in the Mar Dyke? When were these sediments deposited? What is the age of the Mar Dyke basin? Is there any evidence of human activity in these deposits?

					Do the sediments contain a geochemical record for landscape history?
9	Sloping topography rising to the West Essex highlands	London Clay Formation	Head deposits and glacial sediments at northern end	Archaeological material of Late Palaeolithic and Mesolithic age may be present within the Head deposits.	What are the nature of the Head deposits in this area, are they Pleistocene or Holocene in age? What age are the sediments in the upper reaches of the Mar Dyke system?

Table 3. Zones and associated attributes.

Zone	Geomorphological description	Key questions	Investigation methods	Techniques
1	Dip slope of North Downs consisting of a series of dry valleys	Are the predictions based on the slope analysis correct? Do certain locations along a slope provide better conditions for sequence preservation? Can we obtain high resolution isotopic records from the preserved mollusc faunas to better model Late Glacial climates?	Trenching	OSL profiling and dating Tl dating of earthworm granules Mollusc shell geochemistry investigation
2	Foot of dip slope of North Downs immediately above the main Thames Floodplain	Is there Mesolithic archaeology preserved along the margins of the zone?	Trenching	OSL profiling and dating Tl dating of earthworm granules Mollusc shell geochemistry investigation
3a	Edge of Thames Floodplain	Do we find archaeological material associated with the dry ground surface prior to flooding in the Holocene? What is the precise timing of flooding of this surface? Is there activity in the wetlands following flooding? Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?	Trenching EM geophysical survey ERT 2D/3D Boreholes	OSL profiling and dating Mollusc shell geochemistry investigation Sedimentary DNA investigation Sediment geochemistry
3b	Edge of Thames Floodplain	Do we find archaeological material associated with the dry ground surface prior to flooding in the Holocene? What is the precise timing of flooding of this surface?	Trenching EM geophysical survey ERT 2D/3D Boreholes	OSL profiling and dating Mollusc shell geochemistry investigation Sedimentary DNA investigation Sediment geochemistry

		Is there activity in the wetlands following flooding? Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?		
4	Main Thames floodplain behind sea wall	What is the age and environments of deposition of both the organic and minerogenic sediments? What is the precise timing of flooding of this surface? Is there activity in the wetlands following flooding? Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?	ERT 2D/3D Boreholes	OSL profiling and dating Mollusc shell geochemistry investigation Sedimentary DNA investigation Sediment geochemistry
5	Dry valley systems connecting Thames Floodplain and Mar Dyke	Did this system for a fluvial network draining the Mar Dyke into the Thames in a southerly direction? Are there fluvial sediments preserved beneath the Head, or erroneously mapped as Head? Are Late Glacial sequences preserved in places in the zone?	Trenching EM EM geophysical survey ERT 2D/3D	OSL profiling and dating Tl dating of earthworm granules Mollusc shell geochemistry investigation
6a	Thames Terrace plateau surface	Do any of the putative stream systems contain Holocene sediments with associated archaeology?	Trenching	OSL profiling and dating Tl dating of earthworm granules
6b	Thames Terrace plateau surface	Do any of the putative stream systems contain Holocene sediments with associated archaeology?	Trenching	OSL profiling and dating Tl dating of earthworm granules

6c	Thames Terrace plateau surface	Do any of the putative stream systems contain Holocene sediments with associated archaeology?	Trenching	OSL profiling and dating Tl dating of earthworm granules
7a	Valley side gently sloping northwards into Mar Dyke	Is there any stratified sediments in this zone that contain archaeological material?	Trenching	OSL profiling and dating Tl dating of earthworm granules
7b	Valley side gently sloping eastwards into Mar Dyke	Is there any stratified sediments in this zone that contain archaeological material?	Trenching	OSL profiling and dating Tl dating of earthworm granules
8	Mar Dyke wetland basin	What are the different environments of deposition of sediments in the Mar Dyke? When were these sediments deposited? What is the age of the Mar Dyke basin? Is there any evidence of human activity in these deposits? Do the sediments contain a geochemical record for landscape history?	Trenching EM geophysical survey ERT 2D/3D Boreholes	OSL profiling and dating Tl dating of earthworm granules Mollusc shell geochemistry investigation Sedimentary DNA investigation Sediment geochemistry
9	Sloping topography rising to the West Essex highlands	What are the nature of the Head deposits in this area, are they Pleistocene or Holocene in age? What age are the sediments in the upper reaches of the Mar Dyke system?	Trenching	OSL profiling and dating Tl dating of earthworm granules

Table 4. Zones and associated approaches to investigation.

EXECUTIVE SUMMARY

University of Wales Trinity Saint David was commissioned to carry out a report into the Holocene geoarchaeology as part of the wider cultural heritage mitigation work. The project was desk-based and involved consideration of extant geotechnical data and published information on the area of the route corridor.

Nine discrete geoarchaeological zones were identified along the route corridor. The investigation indicates that these zones contain substantially different sedimentary sequences of Latest Pleistocene and Holocene age, they range in thickness from less than 1m to greater than 20m in places and are likely to both bury and contain archaeological material and associated palaeoenvironmental remains. The differing bedrock and superficial geologies suggest that the preservation potential for the survival of palaeoenvironmental material will vary along the route corridor. A number of key issues have also been encountered during this study which provide a focus for investigation during the lifespan of this project:

- **Little is known in detail about the precise timings and nature of minerogenic sedimentation in the main Thames floodplain.**

- **Traditionally developer funded projects have relied on tried and test approaches to investigating these sequences. New fields of study (e.g. sedimentary DNA and sediment geochemistry) may provide additional insights into both plant and animal species and human impact on the environment in past times.**

- **New methods in Optically Stimulated Luminescence dating allow rapid profiling of minerogenic sequences to enable suitable horizons to be identified.**

It is argued that the approach to Late Glacial/Holocene sequences in the Lower Thames Crossing project, while building on previous work, should seek to apply these new approaches and thinking to address key human and landscape issues in this part of the Thames Basin. This forms a strategy of "Enhance not Replicate" in order to drive the field and analysis phases of the project in new and novel directions. In order to implement the "Enhance not Replicate" strategy a scheme-wide approach to investigating sequences for the novel elements (e.g. sedimentary DNA/geochemistry) will be required that sits alongside the traditional developer-led approach to tender packages.

1. Introduction

1.1. Project background

A major new road crossing is proposed across the Lower Thames (Highways England project 540039). The new crossing will involve a double-bore motorway tunnel under the Thames between Gravesend and Thurrock (passing *c.* 10km to the east of the existing Dartford crossing), as well as overland link roads between the south and north tunnel portals, and the A2 and M25 respectively (**Figure 1**). This route was chosen in April 2017 as the preferred option (Option C) following several years of consultation. The overall length of the route is *c.* 27km and the impact footprint of the road and associated development is a little over 2630ha, as defined in the current Statutory Consultation footprint (revised version issued in January 2020).

In accordance with the requirements of the *National Planning Policy Framework* (initially issued in 2012, but updated in 2018) and those specifically for large national infrastructure projects such as this (*National Policy Statement for National Networks* 2014), various processes are being followed to ensure that the development takes place in a sustainable manner and with due consideration to avoid (and if necessary mitigate) impact upon cultural heritage. In summary, as a Nationally Significant Infrastructure Project (NSIP), authority to proceed with the project will be granted as a Development Consent Order (DCO) by the Secretary of State. The application for the DCO must be supported by various documentation, including an Environmental Statement (ES). The contents and scope of this latter document are to a large extent statutorily defined, and follow from various stages of preliminary work and reports.

Following from initial identification of the preferred route, an *Environmental Impact Assessment* (EIA) *Scoping Report* was issued in October 2017 (Highways England, 2017). This outlined (in Chapter 7, Cultural Heritage) the general approach that would be taken to assessing the environmental impact of the proposed new crossing. It identified:

- national and regional bodies for consultation, such as Historic England and Local Authority planning archaeologists

- relevant heritage datasets, such as nationally important heritage lists and, for non-designated heritage assets, local Historic Environment Records

- work that would be undertaken to contribute to an Environmental Statement (ES) to be submitted as part of the process for gaining formal government planning consent to proceed with the scheme, such as a desk-based assessment of cultural affects and field evaluation of areas with insufficient desk-based information for the impact of the scheme to be adequately predicted

- parameters and criteria for assessing the significance of heritage assets, and the magnitude of impact relating to the proposed new crossing.

The initial scoping report was followed by a more-detailed *Preliminary Environmental Information Report* (PEIR) in September 2018 (Highways England 2018). This reviewed the legislative framework applicable to cultural heritage in relation to the new crossing, and reiterated the requirements of the Environmental Statement (ES) that will accompany the DCO application, and the proposed approach to addressing these requirements. In relation to cultural heritage (Chapter 7 of the PEIR), these include:

- a detailed and up-to-date Desk-based Assessment (DBA) of heritage assets (designated and undesignated) affected by the proposed new crossing, with an assessment of their significance, will be included as an appendix to the ES

- for assets of uncertain significance, methodologies for field evaluation will be agreed with heritage stakeholders and presented as appendices to the ES

- where suitable, and for key areas of greatest uncertainty, suitable preliminary (stage 1) field evaluation will be carried out to try and identify the nature and significance of any unrecognised or poorly-known heritage assets, and the results included as an appendix to the ES, and taken account of in the ES chapter itself

- the assessment of heritage assets will include a consideration of the level of impact on them from the proposed development, and in particular whether there is a risk of substantial harm or total loss of significance

- an outline of mitigation measures to record and advance understanding of any heritage assets that will have their significance diminished by the project, proportionate to their significance and the impact

- to identify areas with the greatest potential for new discoveries of heritage assets during the project, and specification of measures to identify and suitably investigate any such new discoveries.

Both the EIA Scoping Report and the PEIR specified that the principles of the "Rochdale envelope" should be followed (PEIR para 2.1.14-2.1.16, pp6-7). This specifies that the parameters of a project design may not be fixed at the stage of ES production. Therefore worst-case variations should be considered in the ES and accompanying technical documents, to ensure that likely significant environmental effects of a project are properly assessed. From the perspective of the Holocene geo-archaeology, this means that (a) worst-case impacts of project design will be considered, and (b) worst-case possibilities for harm to the historic environment will be considered, where there is uncertainty over the nature/importance of remains.

Thus the scope and content of the ES should be sufficient for the Secretary of State to make an informed decision for the project to proceed with confidence that the impact upon any cultural heritage assets is well-understood and will be suitably mitigated. Limited pre-DCO field investigations (stage 1 evaluation) may take place and inform the ES, but the bulk of archaeological investigation, including further (stage 2) evaluation and subsequent targeted mitigation will follow granting of the DCO. At the time of writing (March 2021) the proposed programme is for the DCO and accompanying appendices (including the DBA of heritage assets, and other related cultural heritage appendices) to be submitted in xxxxx. And then the bulk of any archaeological evaluation and mitigation required for the culturally sustainable delivery of the project will be carried out as part of the first phases of works (pre-enabling and early works) between xxxx and xxxx, following from granting of the DCO.

The CASCADE joint venture - incorporating Arcadis UK, Cowi and Jacobs - have been contracted by Highways England to support the sustainable delivery of the new crossing, and in particular to deliver the Environmental Statement and carry out necessary work in relation to cultural heritage for the project. University of Wales Trinity Saint David (Martin Bates) has in turn been commissioned by Lower Thames Crossing CASCADE - henceforth LTC - to carry out specialist work in relation to the Holocene geo-archaeology as part of the wider cultural heritage mitigation work. A glossary of acronyms and technical terms is included as an appendix (**Appendix 1**).

1.2. Holocene Deposit Model (HDM): rationale and scope

The purpose behind the preparation of this document was to provide a basis for the investigation of the Holocene sedimentary sequences along the route corridor where important archaeological material may be buried below or within bodies of sediment laid down by natural processes associated with the river, estuary, slopes or any other geomorphological context. The context of any Holocene archaeological remains cut into or resting on these deposits is not considered in this report.

The rational behind the development of the model provided by the report is based on the recognition that scientific data collected for archaeological purposes needs to be collected and interrogated within a framework of scientific thinking (Schumm, 1991) (**Figure 2**). This rationale can be seen to operate at different levels (**Table 1**) whereby the investigation process may commence at different stages in the process of deduction; in many commercial archaeological investigations this is represented by process b or c (**Table 1**) whereby relatively opaque statements of hypothesis, perhaps driven by regional research agendas, are the start of the investigative process (b) or simply at the stage of data collection (c). Here we attempt to follow path a towards the evaluation of the route corridor, beginning with this document (steps Preparation, Observation, Recognition of the problems).

1.3. Scope of this document

This document comprises the *Holocene Deposit Model* (HDM). It provides an overview of varying deposits likely to be encountered in the Holocene and Late Glacial[1], their character and archaeological potential along the route of the project as specified above, it:

[1] The Late Glacial is included here because of the difficulties in many cases of separating Late Glacial from Early Holocene sequences and the recognition that they are part of a geomorphological continuum of processes operating across these time periods.

- takes a deposit-led approach and divides the project footprint into zones of varying deposit character and Holocene archaeological potential;

- highlights zones of greatest uncertainty, where further information is required to reach a reasonably confident understanding of the likely significance of any archaeological and palaeo-environmental remains and their vulnerability to impact by the project;

- presents an outline of suitable approaches to field investigation to (a) evaluate the significance of any Holocene heritage assets buried within Holocene sediments affected by the scheme, and (b) have sufficient information to identify mitigation needs;

- presents these results as figures and tables with suitable accompanying text, to contribute to the Environmental Statement (ES) for the DCO.

The HDM matches anticipated Holocene and Late Glacial sediments with primary geological logs held by the British Geological Survey and new Ground Investigation data. These are considered on a group by group basis and their anticipated location along the route corridor is highlighted.

2. Background

2.1. Geology and landscape context

As outlined above (Section 1.2), the LTC scheme is in an area in which extensive spreads of Quaternary sediments are preserved. The Thames valley contains an internationally important archive of deposits spanning the last 1,000,000 years (the later Lower Pleistocene, the Middle Pleistocene and the Late Pleistocene) (Bridgland 1994; Gibbard 1994) onto which Holocene deposits are intermittently spread.

The Late Glacial and Holocene geological development of the Lower Thames area and the establishment of the modern topography, including the Thames estuary, has been one in which a number of major factors have been at play:

- climate change from the Last Glacial Maximum (LGM) around 30,000 a b2k reflected in warming temperatures, shifts in vegetation and fauna;

- sea level change and the concomitant flooding of the lower Thames and its tributaries by freshwater and then estuarine conditions from c. 10,000a b2k;

- human activity, particularly followed the beginning of the Neolithic when land clearance and farming have resulted in major episodes of soil erosion.

In particular these processes have resulted in the accumulation of significant thicknesses of Holocene sediments associated with the modern river and its tributaries while the areas away from the river valleys will have seen the accumulation of substantial thickness of colluvium during the period from 6000 a b2k. Works associated with High Speed 1 (Bates and Stafford 2013) and infrastructure works in the Medway estuary (Bates *et al.* 2017) have documented their potential. Sequences in the Thames may be up to 35m in thickness and are likely to thicken both in a downstream direction and from the edge of the floodplain towards the river channel. They bury substantial Pleistocene sediments (see Wenban-Smith and Bates, 2020) and palaeosols will be anticipated on the surface of many of these buried sedimentary units.

Although many well-known sites containing both archaeological and palaeoenvironmental remains (Biddulph *et al*., 2012; Bates and Stafford, 2013; Wenban-Smith *et al*., 2020) are documented in the lower Thames, many questions remain concerning the nature and archaeological context of the Holocene deposits (Table 2) in the area of scheme impact. However, it is to be anticipated that:

- fluvial/estuarine sequences are known to be present in both the Thames and Mar Dyke systems.

- thick, potentially in excess of 35m deep, Holocene sequences are likely to be present adjacent to the Thames. These sequences may contain interbedded clay-silts and peats

- Little is known of the Mar Dyke sequences

- margins of the valleys are likely to be buried by colluvium, Head and Late Glacial solifluction (cold climate mass movement deposits) sequences with intercalated palaeosols

- Sequences in some areas such as the surface of Pleistocene terraces are less well understood.

2.2. Holocene archaeology of the sedimentary units

It is beyond the scope of this document to review the Holocene archaeological record for the region however it is important to document the types, contexts and taphonomic status of key archaeological remains that may be buried within the stratigraphy considered in this report.

Holocene (and Late Pleistocene) archaeological remains present within or beneath Holocene/Late Pleistocene sediments may be variably preserved (depending on the environment of deposition) and vary from *in situ* to reworked. Typical examples of the nature of such material is shown in **Figure 4 (A-F)** and can be summarised:

- Material buried by alluvium (freshwater or estuarine) resting on bedrock or Pleistocene sedimentary sequences

- Material buried within alluvium (freshwater or estuarine)

- Material incorporated within Head or colluvial sediments

- Material associated with buried soils within Head or colluvial sediments

- Material present within fluvial sediments

The distribution of archaeological material by stratigraphic horizon for selected finds in the Lower Thames area is shown in **Figure 5** (Bates and Stafford, 2013). Because of the nature of the sedimentary sequence enclosing the material as well as the nature of the material itself, flint scatters/wood etc, there is only a low probability of being able to detect the archaeology through standard archaeological survey methods (geophysics, fieldwalking and even trial trenching without consideration of the nature of the 'natural sediments') and consequently other approaches to the location of the archaeology are necessary.

2.3 Research frameworks

Research frameworks for both S E England and East Anglia have been produced and revised on a number of occasions in the last 15 years.

In Essex (Medlycott, 2011) a number of themes have been identified for future research including i) chronologies and processes of change (issues relating to chronologies and the processes of change have been identified as having particular significance in establishing a better understanding of the development of the region's historic environment)t ii) human interaction with landscape and environment and iii) wetland environments. In Kent key issues include environmental studies (including a better understanding the onset of flooding in the lower reaches of our river valleys and the nature of the landscape transformation resulting from this transgression (Bates and Corcoran, 2019)), issues with site location and lacunae as well as taphonomic issues linking geological process to archaeological site preservation and visibility (Pope *et al*., 2919).

Among the specific issues that require further work (as highlighted in these regional frameworks) are:

> "Early Upper Palaeolithic and particularly late Upper Palaeolithic (long blade) issues need further study — (*to*) characterise and model the EUP/LUP evidence for human activity within the region …... A fuller understanding of the Holocene environment is still required for the region" (Medlycott, 2011, p.7)

> "There is a need to create a lithostratigraphic framework for the area combined with a controlled dating programme and palaeoenvironmental studies, to enable a chronostratigraphic model of the Holocene development of the estuary to be formulated" (Medlycott, 2011, p. 7)

It is also noted that there has been a lack of progress in research into the Mesolithic period in Essex. Other factors such as the recognition and definition of sites and site types are identified as important issues within these regional frameworks.

3. Aims and objectives

3.1. General aims

The general aims of the initial HDM are:

- to provide an overview of varying character of the sediments and their geoarchaeological potential along the route of the project (including Late Glacial, as well as evidence associated with sediments deposited by natural processes during this period).

- to highlight areas of uncertainty, where further information is required to reach a reasonably confident understanding of the likely significance of any archaeological and palaeo-environmental remains and their vulnerability to impact by the project.

- to present an outline of suitable approaches to investigation of any areas of uncertainty, to improve understanding of their nature and significance.

- to present these results as a report supported by suitable figures and tables, to contribute to the ES for the DCO application.

3.2. Specific objectives

Specific objectives of the initial HDM are:

- to construct a model of the nature, distribution and depth of sub-surface natural Late Glacial and Holocene deposits along the route of the project.

- to interpret the information in terms of likely ages and environments of deposition of the different sequences.

- to relate the data to other litho-stratigraphic and interpretive models in use for the Lower Thames region.

- to assess archaeological potential and importance along the project route, with reference to relevant national and regional research frameworks, and taking account of artefactual and palaeo-environmental remains, and sedimentological sequences, as contributors to our understanding of the historic environment.

- to identify areas of uncertainty with insufficient data to reach a confident assessment of potential, and to provide recommendations for suitable investigations to resolve any uncertainty.

4. Methods

4.1. Desk-based study

The initial HDM has been produced mostly on the basis of a desk-based synthesis of all available relevant information on the Late Glacial/Holocene sediments within the project footprint and its surrounding area. Sources with information on these sequences have been reviewed, and the data collated to inform development of a site-wide deposit model, in conjunction with an understanding of the archaeological remains known (or likely) to be associated with the various deposits recognised in the model.

The results of this study have been collated into this initial HDM report, and include:

- maps showing the bedrock and superficial geology of the route corridor (**Figure 3A/B**).
- maps showing topographic aspect of the route corridor (**Figure 7A**).
- maps showing the slope aspect along the route corridor (**Figure 7B**).
- maps showing the real and fitted drainage network for the route corridor (**Figure 7C**).

Mapping was based on data downloaded from Digimap (https://digimap.edina.ac.uk/), including the Ordnance Survey DTM with a resolution of 5 metres. The Ordnance Survey DTM was used to create an Aspect raster (https://pro.arcgis.com/en/pro-app/latest/help/analysis/raster-functions/aspect-function.htm), which shows the *facing* of any particular cell of the raster. In this instance we only display south (157.5 – 202.5°), south-west (202.5 – 247.5°) and west (247.5 – 292.5°) facing cells.

For the generation of a stream network the Ordnance Survey DTM was used and the ArcGIS Pro Hydrology tools (https://pro.arcgis.com/en/pro-app/latest/tool-reference/raster-analysis/an-overview-of-the-hydrology-toolset.htm) were used to create stream networks. For the generation of the final stream network a conditional number of 1,000 was used. The final stream network was plotted on a hillshade (created using default values), which was derived from the Ordnance Survey DTM and can be compared with the existing stream/river network.

4.2. Sources

Construction of the ground model was undertaken on the basis of extant information only. Modification of the model during the lifespan of the project may be undertaken on the basis of newly collected data (from geotechnical investigations) as well as purposive geoarchaeological and archaeological field programs.

Primary sources for the construction of a model were:

- published academic papers, grey literature reports and any existing published works.

- borehole data from the British Geological Survey archive.
- mapped geological data from the British Geological Survey.
- archive data from extant phase of ground investigation for the project (Phase 1 and 2 GI).
- information from archives held by organisations and individuals.
- other forms of ground investigation data including results of geological geophysical surveys, Lidar, and remote sensing.

5. Geoarchaeological frameworks

5.1. A geoarchaeological framework for the sequences

An important consideration in a study of this kind is to consider the geoarchaeological status of expected/recovered finds. In order to best appreciate this and to better achieve our understanding of the past (including the present distribution of material from that past) the approach adopted is essentially the creation of a Prehistoric geography for the study area. Butzer (1971, p.3) states

> "Prehistoric geography" is chosen as a convenient designation that serves to emphasize both environment and man"

hence the geoarchaeological approach adopted. Should further justification for such an approach be needed Crawford provided this in 1922 when he stated that

> "the goal of the whole undertaking, and its explanation in terms of geographical influence is one of the finest intellectual pleasures that exist" (Crawford, 1922, p. 257).

Thus this study is based on the links that exist between landscape, sedimentary characteristics of geomorphological units in the landscape (i.e. sedimentary facies) and their contained archaeology. Defining the relationships between sedimentary facies and the nature of contained archaeological record can therefore:

- Provide predictive information on the likely types/focus of occupation/activity within a stratigraphic stack and

- Provide predictive information on the likely taphonomic status (and history) of any material present within that stack.

The factors defining the facies within the sedimentary stack are a function of the location of the space occupied by the sediments in the environment and the interaction of a range of factors within that space (**Figure 8**). These characteristics related to the nature of the environment of deposition can therefore be linked to site types known to habitually occur in such environments. Additionally, the nature of the environments of deposition will influence the preservational status of those deposits, i.e. whether or not artefacts etc. remain *in situ* after loss/discard.

For example, locations associated with animal capture/discovery and subsequent butchery are often in water edge situations, on meander inside bend slip off slopes or on floodplain flats. Many archaeological examples of such sites are known, e.g. the tool production and butchery areas at the Uxbridge late-glacial site (Lewis and Rackham, 2011). Sediments within such areas exhibit grain sizes from gravels to fine silts that can be used to identify facies types associated with these situations in field sections or drill core data. This information can be used to indicate the presence of contexts within which evidence of past human activity may be found. Consideration of the grain size relative to the size/status of any contained artefacts will provide information on any potential for reworking within the deposit. For example gravel substrates, deposited under high-energy conditions, indicate a high likelihood that any contained artefacts will be reworked. Artefacts such as axes, contained within finer grained sediments, are less likely to have been reworked (Brown, 1997).

Another factor to consider is the recognition of buried surfaces (used here to refer to presently buried former landsurfaces). This is of critical importance not only within archaeology but also within geology and geomorphology. The identification of buried surfaces within stratigraphic sequences has been used to divide up stratigraphies into packages of sediments (contexts) considered to display genetically and temporally related features. The surfaces identified may be the result of changes in the nature of sedimentation, breaks or hiatuses in sedimentation or represent phases of erosion. The identification of buried surfaces within the stratigraphic stack can be considered as an element of a greater set of attributes within the stack that can be used to reconstruct the palaeolandscape (Widdowson, 1997). Typically, integration of a range of geological and geomorphological data within a conceptual model containing palaeosurface information is often the objective of geoarchaeologists tasked within placing the archaeological site/area of investigation within a (pre)historical context.

Within the stratigraphic stacks key zones of considerable archaeological importance are those indicating the presence of former landsurfaces (Macphail and Goldberg, 2018). The inundation or burial of landsurfaces on which human activity has taken place can result in the sudden, *in situ* burial of human and animal remains. Within the Thames examples can be cited at London Gateway (Biddulph *et al*., 2012) and the Thames River Crossing in HS1 (Bates and Stafford, 2013).

Understanding of the geology of the route corridor is based on the understanding of the background data, coupled with extant boreholes and excavation data from the area of the route corridor articulated within the context of the geology of the wider Lower Thames region. Additionally information on bedrock geology and local geomorphology is utilised. Consequently, a number of considerations are made:

- What is the nature of the bedrock geology and how is that likely to have an impact on the nature and content of the overlying sequences?
- What is the nature of the superficial geology and how is that likely to have an impact on the nature and content of the overlying Late Glacial/Holocene sequences?
- What evidence do we have for the nature of sequences in the study area?
- Where are we missing data for the study area?
- What types of sequences do we anticipate finding in the area?
- What does the local geomorphology and sedimentary sequences imply for the any archaeology or palaeoenvironmental finds in the area?

- Where do we need additional data in order to begin to create a robust narrative for the route corridor?

5.2 Sediment sources and controls

As previously noted the nature of the sedimentary record of Late Pleistocene and Holocene sequences is dependent on a number of factors that control the nature of the sediments produced and deposited, where sedimentation takes place and post-depositional factors relating to preservation of material. Consequently a number of factors need to be considered when outlining likely nature of distribution of these sediments. Namely:

- Nature of the bedrock.
- Nature of the Pleistocene superficial sediments.
- Local geomorphology.
- Changing climatic conditions.
- Human activity.

5.2.1 Bedrock sources

Bedrock sequences within the red line boundary are shown in **Figures 3A** and in greater detail in **Figure 9**. These are dominated south of the river by the Cretaceous Chalk with an intermittent capping of Tertiary sediments and to the north of the river by the Tertiary sediments of the London Basin.

Chalk in Kent and beneath the Thames floodplain consists of the Lewes Nodular Chalk, Seaford Chalk and Newhaven Chalk Formations. The Chalk forms the major control on geomorphology south of the river where the Tertiary sediments exist as outliers of a more extensive suite of Tertiary sediments north of the river. On the Chalk a sequence of remaining Tertiary sediments outcrops in the vicinity of Shorne consisting of sands of the Thanet Formation, sand/silt/clays of the Lambeth Group, sand and gravel of the Harwich Formation and clays and silts of the London Clay Formation (Ellison, 2004).

The contact between the Chalk and the overlying Thanet Formation is marked by the glauconitic coasted flint gravel of the Bullhead Bed, while the main body of the Thanet Formation consists of clayey and glauconitic sands with rare calcareous beds. The Lambeth Group unconformably overlies the Thanet Formation and consists of clays with some sands and gravels and minor limestone beds. The Harwich Formation marks a return to glauconitic silty or sandy clays and sand with occasional flint gravel and shell beds in places. The sequences south of the river are capped by the London Clay Formation which is a weakly calcareous deposit that contains carbonate concretions as well as thin bands of shell in places (Ellison, 2004).

North of the river the Chalk is buried by the overlying Tertiary sediments and the surface of the Chalk dips downwards to the north east through the study area. Thanet Sand Formation is the bedrock immediately north of the Thames floodplain but this is replaced quickly to the north by the Lambeth Group by the time the A13 is reached. North of the A13 London Clay Formation dominates the remainder of the route corridor with the exception of a small patch of Bagshot Formation on the high ground at the northern end of the route corridor. These sediments are sands of variable colours that are generally decalcified.

In summary then the likely contribution of the bedrock to Late Glacial/Holocene sedimentary sequences would be dominated by sands and clays in the areas north of the river with localised inputs of sands south of the river where sequences will mainly derive from the breakup of Chalk and associated flints. The preservation of carbonate based palaeoenvironmental material will be enhanced on the Chalk, preservation on the Tertiary sediments will be highly variable but likely to be more acidic and favour waterlogging in places.

5.2.2 Superficial sources

Pleistocene sediments have been described in detail in the PDQM (Wenban-Smith and Bates, 2020) report and consist of a variety of sediment types along the route corridor, Holocene sediments are described in this report. These have been simplified in **Figure 3B** and **Figure 10**. Typically Pleistocene sediments are likely to supply coarser grades of material than those of the bedrock sediments (with the notable exception of the Chalk). The main bodies of Pleistocene sediment[2] can be identified as:

- Sequences of sands, gravels and finer grained sediments associated with the terraces of the river Thames predominantly on the Essex side of the river (with a broad NW to SE trend across much of the area).
- Patches of poorly sorted sediments mapped as Head by the BGS.
- Isolated patches of fine grained sediments (silts/fine sands) existing on the Chalk downlands representing once greater expanses of loess like sediments.
- Poorly sorted gravels and sands in the northern part of the route corridor associated with the glacial sediments of the Anglian Glaciation.

These sources of sediment vary not only in their grain size and mineralogy but also in their Ph (i.e. their acidity or alkalinity) thus influencing the ability of the resulting sedimentary matrix to preserved different types of fossil material.

[2] The British Geological Survey mapping has been simplified into a series of broad categories for the purpose of this report.

5.2.3 Geomorphological control

Geomorphology is the study of landforms, their processes, form and sediments at the surface of the Earth. The geomorphology of the study area will reflect the different tectonic settings, bedrock and superficial geologies, climate (including past climates) and ecologies (including impact by humans) (Tooth and Viles, undated).

Key factors to consider in the context of the study area include the long term tectonic history of Southern England (Westaway *et al*., 2002). Uplift through the Pleistocene has been responsible for the creation of the terraces of the Thames (Bridgland, 1994, 2006) and gradual uplift of the crust will have encouraged erosion of pre-existing sequences and the creation of new floodplains at elevations below previous ones (Bridgland, 2006). The result of this process (coupled with the influence of antecedent drainage patterns[3]) creates the distribution of the major and minor valley systems across the study area. This is of particular significance with respect to the origin and evolution of the Mar Dyke which is little understood at present.

Other factors to consider include the shape of the topography at the start of the Holocene, the topographic template (*sensu* Bates and Whittaker, 2004; Green *et al*., 2014). The shape of this landsurface will subsequently influence locations in the landscape in which impeded drainage will occur as sea level rise results in backing up of water in the form of mires and wetlands in front of the rising estuarine wedge. Furthermore it will dictate areas of sedimentation at the foot of slopes and the local topography such as the angle and aspect of slopes which determines the energy of the weathering system impacting on those faces. This occurs by controlling the rate at which water passes through the rock mass resulting in higher, or tectonically active areas with steeper slopes, having more dynamic weathering systems.

Finally topographic aspect is important as this will have influenced the nature and development of the valley systems. The development of asymmetric valleys in the chalk is well known in southern England (French, 1972; Catt, 2010) and south, southwestern and west facing slopes are recognised to be steeper and subject to greater degrees of erosion than those facing in a northern or easterly direction. Thus accumulation of sediments from Late Glacial periods onwards is more likely on those facing north or east rather than those facing south or west.

5.2.4 Climate control

Climate variability over the last 18,000 years (**Figure 11**) as recorded in the Greenland ice core records is well documented in by workers such as Rasmussen *et al.* (2006) and Vinther *et al*. (2006) and such shifts in climate are likely to have impacted on the study area. Regional temperature minimums and the maximum expansion of British and Irish Sea Ice Sheet has been documented by Clark *et al*. (2012) showing the retreat began around 27 k A B2K and was largely complete by 15k A B2K. This phase of deglaciation was followed around 15,200 years ago by warming into, and through, the Lateglacial Windermere Interstadial when

[3] An antecedent river is one that maintains its original course and pattern despite the changes in underlying rock topography

summer temperatures may have reached modern levels (Coope, 1977: Atkinson *et al*., 1987). Variation in the temperatures during this period have been described in South Wales (Walker *et al*., 2003). A return to cold climates during the Loch Lomond/Younger Drays Stadial then followed before rapid warming at the start of the Holocene. These changes had marked impacts on the behaviour of rivers in SE England (Gao *et al*., 2007) as well as on the floral and faunal communities. A number of sequences documenting part or all of these changes are present in southern England (Kerney, 1963; Preece and Bridgland, 1998).

Climatic variability in the Holocene has been documented by various authors. Early Holocene climates differed significantly from those of the present day with much of the country experiencing more continental climatic conditions around 10 ka A B2K (Briffa and Atkinson, 1997); this was followed by a shift towards a more maritime climate, with higher precipitation, by around 7.8ka A B2K, that appears to be associated with the final flooding of the southern North Sea Basin (Hughes *et al*., 2000; Bell and Walker, 2005; Grant *et al*., 2014). A major phase of cooling appears to have taken place globally at about 8.2ka (the so called 8.2-ka climate event (Daley *et al*., 2011; Allan *et al*., 2018) that marks the start of the Middle Holocene – *sensu* Walker *et al*., 2019).

Hughes *et al*. (2000) provide a record of wetness of mire surfaces that indicates considerable changes in rainfall throughout the Holocene. Linked to this would be the impact of climate on flooding of river systems, work undertaken by Macklin *et al.* (2010, 2012, 2014) document these likely changes. Brown *et al.* (2018) describe the changes to the river floodplains from Early/Middle Holocene to Late Holocene. During the latter part of the Late Holocene, from the Iron Age onwards, the trend towards cooler and wetter conditions prevailed. However, considerable variation has occurred in recent times including the warmer climate of the 10th to early 13th centuries (the Medieval Warm Period) followed by a period of increased storminess in the 13th and 14th centuries, when artificial sea walls and natural shingle banks were repeatedly breached by the sea (Galloway, 2009, 2010). This marked the beginning of the Little Ice Age culminating in the frozen winters of the late 18th and early 19th century (Lamb, 1995; Mann, 2002). The changes and features are summarised in **Figure 11**.

5.2.5 Human activity

Human activity and its influence on the environment including the nature and patterns of erosion and deposition as well as a history of pollution has been largely focused on S E England on the processes of vegetation clearance for agriculture and the resultant erosion of soils and deposition of colluvium in the dry valley sequences in the region (Bell, 1983; Preece and Bridgland, 1998). Little has been written on the impact of humans on patterns and processes of sedimentation in the estuary of the river although with the major reclamation of the marshes from the tidal river (Rippon, 2000) and the construction of various bridges the position of the channel and its tidal amplitude will have changed considerably from the Roman period onwards. Allied to these changes will have been other factors impacting on the rivers and floodplains. Increasingly intensive use of the valley for both agriculture and industry during the last 2000 years resulted in a deterioration in the quality of the waters in both the river and estuary and these are likely to be recorded in the sediments of the river.

5.3 Main sedimentary sequences of the route corridor

In this section the main types of sediments likely to be encountered are considered in terms of ages of the sequences, likely processes of deposition and their archaeological content.

5.3.1 Colluvium (Figures 12/13/14)

Colluvium (Wilkinson, 2003; Leopold and Völkel, 2007) is a deposit resulting from the downslope movement of sediments under a variety of processes including rain-wash, sheetwash or gradual creep of material under the influence of gravity. Colluvium typically forms a wedge shaped deposit at the base of a slope (thinning upslope) and its composition (grain size and mineralogy) usually reflects the nature of the sediments upslope of the deposit. It can therefore include elements of soils, superficial Quaternary sediments and the bedrock. Consequently colluvium may vary in grain size from clays to gravels. Colluvium is often difficult to distinguish from Head deposits where course gravel from the decay of bedrock gradually fines away from the source of the sediment (**Figure 14**).

Materials contained within the colluvium may be abraded and show weak alignments with the direction of movement of the sediment. Some crude bedding may be present within the sediments. The distinction between coarse colluvium and Head deposits (see below) may be opaque in places

5.3.1.1 Late Pleistocene colluvium (Figure 13)

Slopewash deposits dating to the cold parts of the late Pleistocene (here taken to consist of the Devensian period, Marine Isotope Stages 5d-2) have been described in north Kent (Bates and Pope, 2016) and in the Ebbsfleet Valley (Wenban-Smith *et al*., 2020). Here sediments ranging in age from the early Devensian (MIS 5d) to the Last Glacial Maximum are recorded and consist of sheets silts and sands with thin gravel bands that mantel the lower valley sides. Intermittent weak pedogenic horizons are present in places in these sediments. Similar sediments have been reported from Northfleet Water Treatment Works (Diack, 2008).

5.3.1.2 Holocene colluvium (Figure 12)

Holocene colluvial sequences are well described from the Chalk regions (Wilkinson, 2003; Whiteman and Haggard, 2018) where sequences of sediments frequently contain landsnails that have enabled the landuse and erosion histories of the Downlands to be reconstructed. Workers such as Kerney (1963), Evans (1966, 1972), Bell (1983) and Preece and Bridgland (1998) have all described complex sequences of colluvium some of which contains interstratified palaeosols (see 5.2.2 below).

Little evidence exists for colluviation in the Early Holocene period with extensive downslope movement of sediments only occurring after the widespread clearance of the Downs for agriculture. At Holywell Coombe colluviation began after tufa formation ceased around 6000 years ago but does not appear to have been continuous from this point forward as at least two periods of soil formation have been recorded in these sediments at the site (see 5.2.2 below).

5.3.2 Palaeosols (Figure 15/16)

In the Quaternary soils are frequently recognised in the stratigraphic record and are known as palaeosols (although it is noted Tabor *et al.* (2017) suggest the term palaeosol should be restricted to the pre-Quaternary record). These soils may be buried beneath other sediments such as colluvium or alluvium and are called buried soils or are present at the earths surface where they preserved elements of former pedogenic regimes (relict soils) (Macphail and Goldberg, 2018).

Identifying and subsequently determining the lateral distribution of buried palaeolandsurfaces is of critical importance in the archaeological evaluation of an area. These features represent positions within the sequence at which *in situ* assemblages of material may occur in the context of the landscape in which they were used. They may be identified by a series of features that can be used singly or in combination to determine the presence of a buried landsurface:

- Sudden changes in lithology within a core profile either seen as a sudden change in sediment types or shifts in properties such as loss-on-ignition and total phosphates (Barham, 1995).

- The presence of a palaeosol.

- The presence of zones of weathering, rooting horizons or enhancement of magnetic susceptibility signals (Allen, 1987; Barham, 1995).

- The presence of major bedding planes.

The presence of these features may imply the location of a landsurface. However, in order to determine the significance of these features their lateral extent needs to be determined through the identification and correlation of these features within a number of trtenches and boreholes. This is most easily achieved using the principles of facies analysis and the construction of a sub-surface stratigraphical model.

Considerable study has been applied to palaeosols and buried soils both in the UK and elsewhere. For example, Macphail and Goldberg (2018) discuss soils from both Late Pleistocene and Holocene situations in southern Britain while French (2003, 2015) places soil science in the broader context of development of landscape approaches to geoarchaeology. Archaeological material may occur in primary context in these soils.

5.3.2.1 Late Pleistocene soils (Figure 15)

Buried soils dating to the end of the Pleistocene, preserved in dry valleys in southern England, are relatively well known and indeed complex variation in the characteristics of some soils reflect subtle differences in the position of the soils in the landscape at the time of formation

(Catt, 2010). Typically these are dark grey rendzinas that are buried by solifluction deposits in the Loch Lomond Stadial. For example, Catt and Staines (1998) discuss the properties of the Allerod soil at Holywell Coombe, Rose *et al*. (2000) describe similar soils at Prospect Park near Heathrow airport and Whiteman and Haggart (2018) summarise them in the broader context of S E England.

5.3.2.2 Holocene soils (Figure 16)

Holocene soils have been reviewed by French (2003). Fossil soils exist in a number of locations including being preserved at the margins of wetlands (French, 2003), in colluvium in dry valley sequences as well as preserved beneath archaeological monuments (Evans *et al*., 1993; French *et al*., 2000). For example at Holywell Coombe (Preece and Bridgland, 1998) two buried soils are present within the colluvium dating to the Early Bronze Age and the Early Iron Age. These soils are associated with enhanced numbers of earthworm granules.

5.3.3 Head (Figure 14/17)

According to the BGS Head deposits consist of poorly sorted angular rock debris that occur as sheets towards the base of a slope. The deposits have accumulated through downslope movement of shattered bedrock and superficial sediments usually under cold climate conditions. Head deposits may be crudely bedded, usually dip parallel with the slope and may consist of chaotic masses of coarse sediment or alternating coarse and fine grained units.

Head deposits may be synonymous with deposits described elsewhere as Dry Valley deposits, Coombe Rock, solifluction or gelifluction deposits (Ballantyne and Harris, 1994; Ballantyne, 2018; Whiteman and Haggart, 2018). Typically these cold climate sediments are well preserved on north and east facing slopes (French, 1972; Catt, 2010) in dry valleys on the Chalk but may also form wedge shaped deposits overlying Pleistocene fluvial sequences (Bridgland, 1994). Palaeosols may also be preserved within such sequences while archaeological material tends to be in a reworked condition in these sediments.

5.3.4 Alluvium (Figures 18-20)

Alluvium typically consists of sands, silts and clays that are deposited by water in a river, or sometimes in an estuarine environment. Alluvium can vary in thickness from a few centimetres to many meters in thickness and both sequences of Holocene and Pleistocene alluvium are known in the area of the route corridor (Bates and Stafford, 2013; Wenban-Smith *et al*., 2020). Usually alluvium is restricted to the floodplains of freshwater river systems where seasonal flooding during peak river discharge results in the deposition of a sheet of sediment across the floodplain floor. In some circumstances this can also include coarse gravels in times of highest peat discharge. In the lower reaches of river valleys where the river widens, becomes tidal and enters the sea wide expanses of floodplain also exist and in such places estuarine alluvium may be deposited in tidal flats and creeks. Complex relationships between freshwater and estuarine environments may exist in such locations where minor changes in sea levels may alternate periods of freshwater with brackish waters.

Today, during times of high sea level, such areas often contain the interface between the fluvial river environments and coastal/estuarine environments; in the main Thames floodplain this interface has gradually migrated up stream during the Holocene (a feature first noted by Spurrell, 1885). Complex relationships between competing elements within these environments can result in continual local and regional change in the nature/location of the interfacial zones.

Within the depositional basin a number of key factors interact that control the overall patterns of sedimentation (**Figure 8**):

1. Sediment input/output to/from basin. Sediment may arrive downstream with the flowing fluvial channel, move on-shore and up-estuary from the marine zone, move down-slope from the valley sides or be blown in (Kirby, 1990; Baugh *et al*., 2013). More recently sediments may also be imported by humans for construction activity etc. Sediment may be removed by fluvial channel or tidal scour downstream and out to sea.

2. Sea level change. Net falling or rising sea level will influence base level changes affecting patterns of incision or deposition. Incision will usually characterize falling sea levels, deposition rising base levels (Sidell, 2000, 2003).

3. Tectonic change will influence base level changes (Westaway *et al*., 2002). Tectonic uplift will tend to result in apparent base level falls while subsidence will result in apparent base level rises.

4. Topographic template (Bates and Whittaker, 2004) of the landscape existing prior to on-set of a new set of conditions. Shape of topography, location of potential basins for infilling, channels for erosion etc. will effect areas of net sediment deposition or erosion.

5. Climate, temperature, precipitation and locally wind regimes may be significant in controlling sedimentation patterns (Macklin *et al*., 2010, 2012, 2014).

6. Normal and catastrophic sedimentation processes require consideration particularly where elucidation of the processes responsible for deposition are a study objective. Normal, background, sedimentary processes often appear to dominate the sedimentation processes however, abnormal events have been increasingly regarded as important in defining the nature of the sedimentary stack (Ager, 1993).

These Holocene sediments form a wedge thickening downstream from less that 2m thick at Tower Bridge to reach a maximum thickness of 35m east of the study area at Canvey Island (Marsland, 1986). Downstream of the Shorne Marshes the estuarine sediments probably differ considerably from those described here.

5.3.4.1 Freshwater (Figure 18)

Freshwater alluvium consists of sediments deposited by flooding on the surface of the floodplain or within channels of the river and typically these consist of fine grained silts and clays deposited by settling out of sediment from suspension in the water body. Where

alluvium infills channels (**Figure 18**) sediments may also include peats, where the peats form isolated bodies accumulating in areas of impeded drainage such as oxbow lakes and abandoned channels of the river. In areas of chalk or limestone bedrock tufa may also occur within alluvial tracts (see 5.3.6 below).
Extensive sequences of alluvium blanketing the floodplains of the river systems are normally a feature of the Middle and Late Holocene whereby rivers have shifted from the Early Holocene anabranching channel form to the single channel, braided system (**Figure 11**; Brown *et al.*, 2018). This occurs when flooding as a result of human activity is increasingly common (Macklin *et al*., 2010, 2012, 2014; Figure 11).

Freshwater alluvium is known in the Mar Dyke (Wilkinson, 1988) as well as in the Ebbsfleet (Wenban-Smith *et al*., 2020) although Late Pleistocene and Early Holocene freshwater alluvium is presently unknown in the main Thames floodplain area (pockets of freshwater sediments are likely to be present in channels incised into the surface of the Pleistocene sediments below the thick estuarine alluvium but these would be difficult to locate except in rare situations).

5.3.4.2 Estuarine (Figure 19/20/21/22)

Estuarine alluvium is well documented in the main Thames floodplain area (Spurrell, 1985; Devoy, 1977, 1979, 1980, 1982; Sidell, 2000, 2003; Oxford Archaeology, 2012; Bates and Stafford, 2013; Wenban-Smith *et al*., 2020). Typically these deposits consist of fine grey clay-silts (**Figures 19 and 22**) deposited in tidal channels or intertidal mudflats during periods of regional sea level rise or flooding. These are intercalated in the Thames with peat units (**Figures 19 and 22**) that are former reed swamps or forests (Figure 21) formed during phases of local or regional sea level fall. Complex channels may also exist in these systems (Hart *et al.*, 2015).

Peat units have been well dated in many locations throughout the Lower Thames (Sidell, 2000, 2003; Stafford, with Goodburn and Bates, 2012; Oxford Archaeology, 2012; Bates and Stafford, 2013; Spurr, with Nicholls and Yendell, 2017; Wenban-Smith *et al*., 2020) although the minerogenic clay-silts are rarely, if ever, dated.

These depositional units vary in their archaeological content. Where extensive exposers of peat across the floodplain were examined during the construction of HS 1 (Bates and Stafford, 2013) little archaeological material was recovered through much of this. Archaeological discoveries appear to be associated with locations whereby the estuarine alluvium is wedging out against rising bedrock or Pleistocene sedimentary sequences. Thus at London Gateway (Biddulph *et al*., 2012) documented extensive Iron Age and Roman activity beneath the alluvium at the margins of the floodplain (**Figure 20**) while later Prehistoric trackways are often associated with channels (Hart *et al*., 2015) or gravel islands in the floodplain (Meddens, 1996).

5.3.5 Alluvial fans

An alluvial fan is an accumulation of sediments forming a shallow cone, with its apex at a point source of sediments, such as a narrow canyon emerging from an upland area. Typically sands, gravels and silts are deposited as the gradient of streams emerging from the uplands changes on entering a basin or flat plain resulting in a reduction in the carrying capacity of the stream and the deposition of the stream load.

Steam-flow fans are characterised by shifting distributary channels across the fan where channels migrate and may during major discharge be overwhelmed by flow resulting in widespread flooding across the fan. Occasionally entrenched channels may form a network of braided channels under colder climate conditions.

None are presently described in the Lower Thames area but it remains possible that localised fan like deposits may exist on the surface of the Pleistocene gravels as well as within the Mar Dyke basin area.

5.3.6 Springs (Figure 23)

Sediments associated with springs are usually only found in limestone and chalk areas where tufa, a freshwater limestone that forms from waters rich in carbonates issuing from springs and rivers are formed. Tufas are common in S E England. These deposits occur as water emerges from the ground at springs, in cascades and barriers as water moves downslope and into river channels and around detrital material in rivers as rounded clasts called oncoids. They result from supersaturated ground water, where carbonates are present in solution in the aquifer; upon emerging at a spring interaction with the atmosphere cause the loss of CO_2 and the resultant precipitation of calcium carbonate, as tufa. Good descriptions of these deposits are given by Pedley (1990). Good examples of these have been documented in the Wye and Lathkill valleys in Derbyshire (Pedley, 1993) and in southern England at Holywell Coombe (Preece and Bridgland, 1998), at Dover (Bates *et al*., 2008, 2011) and the in the Ebbsfleet Valley (Wenban-Smith *et al*., 2020).

In southern England tufa formation typically takes place during the earlier parts of the Holocene (Preece, 1978; Willing, 1985; Pentecost, 1993; Pedley, 1990; Preece and Bridgland, 1998; Bates *et al.,* 2008). Tufa at Holywell Coombe ceased formation around about 6000 yrs. A B2K (Preece and Bridgland, 1998) although at Dover tufa formation appears to have continued into the Bronze Age where the Bronze Age boat was buried by tufa rich sediments (Clark, 2004; Bates *et al*., 2011). Tufa formation appears to cease when significant levels of soil erosion and colluviation into river systems create conditions inimical to tufa growth.

5.3.7 Lakes, ponds and mires

Natural lakes are rare in the south east of England and long records of Late Pleistocene/Holocene climate change such as those known from the north of England are absent. However, sequences are present in a small number of wetland situations such as Spartum Fen (Parker, 2000), Bagshot (Groves, 2008), Conford (Groves *et al*., 2012) Elstead Bog (Farr, 2008) Elsted Bog B and Langshot Bog (Simmonds *et al*., 2021).

6.0 Subdivision of the route corridor

Subdivision of the route corridor has been undertaken on a combination of factors including substrate (bedrock (**Figure 9**) and superficial (**Figure 10**) types)), topography (**Figure 24**) (including slope aspect (**Figure 25**)), drainage networks (including both current drainage and retrodicted drainage patterns (**Figure 26**)) and the consideration of the likely age and context of archaeological remains. These have been used to create a series of 9 zones (**Figure 27**, **Table 3**) that are illustrated in **Figures 27-31 and 33-40**. Profiles through parts of the sedimentary sequences have also been created and these are illustrated (**Figures 41-46 and 48-50**).

6.1 Zone 1: Chalk valleys, Kent (Figures 27-31)

This zone lies within the southern part of the route corridor south of the Thames floodplain (**Figures 27-31**). Bedrock consists of Chalk with discrete patches of Thanet Formation, Lambeth Group, Harwich Formation and London Clay Formation bedrock. These bedrock geologies are likely to produce clay, silt and sand matrices with flint gravel components as well as some limestone/sandstone/conglomeritic clasts and lignite fragments. Some deposits, such as the Harwich Formation, may produce rich shell faunas as well as volcanic ash while the London Clay Formation may produce carbonate nodules.

Superficial deposits include Clay-with-flints in the higher parts of the zone while Head is present in the dry valley network that drain northwards into the Thames. It is also possible that remnants of loessic sediments cap the higher ground but in most cases are either too limited in extent to be mapped or not distinguished from the bedrock geologies.

Slope analysis for west/south-west/south facing slopes (**Figure 32**) indicates where major eroded slopes are present; elsewhere superficial sediments are likely to accumulate beyond that mapped by the BGS as Head deposits on the opposite slopes. Where present these are likely to be dominated by cold climate sequences including the Late Glacial Interstadial soil. Sedimentary sequences are likely to vary depending on the source of the sediment and the position of the site within the catchment area. Holocene colluvium will be less easily modelled but may be broadly coincident with the mapped distribution of Head deposits.

Late Pleistocene Head deposits may bury, and preserve, Late Upper Palaeolithic material while such material may also be incorporated in the final depositional event associated with Head accumulation during the Younger Dryas. The relative stability of the landscape during the Early and earlier part of the Middle Holocene (**Figure 11**) would suggest Mesolithic archaeological material is unlikely to be commonly buried in this zone and may occur at the surface on the higher parts of the zone but buried and incorporated into the later Holocene colluvium on the lower slopes. Isolate patches of Mesolithic archaeological material may be buried by colluvium locally. From around 6000 yrs. A B2K increased erosion caused by woodland clearance and downslope transport of colluvium would have resulted in the reworking of Neolithic and Bronze Age material.

These sequences are relatively well known in Kent, but perhaps less well understood in the Tertiary valleys in Essex.

Key questions:

- Are the predictions based on the slope analysis correct?
- Do certain locations along a slope provide better conditions for sequence preservation?
- Can we obtain high resolution isotopic records from the preserved mollusc faunas to better model Late Glacial climates?

6.2 Zone 2: Foot of Chalk Dip slope/Thames Terraces (Figure 31)

This zone is a narrow zone immediately south of the Thames floodplain (**Figure 31 and 42**). Bedrock consists of Chalk with discrete patches of Thanet Formation. These bedrock geologies are likely to produce clay, silt and sand matrices with some flint gravel components.

Superficial deposits consist of two mapped Thames terrace units (Taplow and Lynch Hill Gravel Members) and Head deposits (Wenban-Smith and Bates, 2020). These deposits are likely to consist of sands and gravels as well as finer grained clay/silt in the upper parts of the Terrace units (**Figures 43 and 44**).

Thin sequences of Late Pleistocene Head deposits may exist in this area and bury and preserve, Late Upper Palaeolithic material while such material may also be incorporated in the final depositional event associated with Head accumulation during the Younger Dryas. The relative stability of the landscape during the Early and earlier part of the Middle Holocene (**Figure 11**) would suggest Mesolithic archaeological material is unlikely to be commonly buried in this zone and may occur at the surface on the higher parts of the zone but buried and incorporated into the later Holocene colluvium on the lower slopes. Isolate patches of Mesolithic archaeological material may be buried by colluvium locally. From around 6000 yrs. A B2K increased erosion caused by woodland clearance and downslope transport of colluvium would have resulted in the reworking of Neolithic and Bronze Age material. The precise edge of the alluvium in Zone 3 is inadequately mapped and may be extend into this zone in places.

Key questions:

- Is there Late Upper Palaeolithic and Mesolithic archaeology preserved along the margins of the zone?

6.3 Zone 3: Thames Floodplain (edge), Kent and Essex (Figures 31, 33 and 34)

This zone is a narrow zone at the edge of the Thames floodplain (**Figures 31, 33 and 34**), split into two subzones relating to the south (3a) (**Figure 31**) and north (3b) (**Figures 33 and 34**) banks of the Thames. Bedrock consists of Chalk although discrete patches of Thanet Formation may exist at the northern margin of zone 3b. These bedrock geologies are likely to produce clay, silt and sand matrices with some flint gravel components.

Superficial deposits consist of buried Thames terrace units (East Tilbury Marshes Gravel) (**Figures 43-45 and 48/49**). These deposits are likely to consist of sands and gravels as well as finer grained clay/silt in the upper parts of the Terrace units. These are overlain by wedges (**Figure 46**) of Holocene alluvium (predominantly brackish water sediments) and organic horizons dominated by peats (**Figures 43, 44, 48-50**). In places the peats rest on the surface of the underlying Pleistocene sediments (e.g. **Figure 43**) and potentially seal an intact landsurface beneath the peat.

The Holocene sedimentary wedge (**Figure 46**) overlying and abutting the rising surface of the buried Pleistocene sediments may contain important, and well preserved, archaeological material. Modelling of the flooding of this surface (**Figures 47 and 51**) indicates that preserved dryland Mesolithic archaeology may be present throughout this zone, while later Prehistoric dryland material will be preserved successively towards the margins of the modern floodplain. Sequences in this area of the floodplain have been investigated in a number of places and the organic elements of this record are relatively well known. What is less well known is the nature and dating of the minerogenic sediments in this area.

Key questions:

- Do we find archaeological material associated with the dry ground surface prior to flooding in the Holocene?
- Is there Late Upper Palaeolithic and Mesolithic archaeology preserved along the margins of the zone?
- What is the precise timing of flooding of this surface?
- Is there activity in the wetlands following flooding?
- Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?

6.4 Zone 4: Thames Floodplain (main) (Figures 31, 33 and 34)

This zone consists of the majority of the Thames floodplain (**Figures 31, 33 and 34**). Bedrock consists of Chalk.

Pleistocene sediments beneath the alluvium consist of sands and gravels of the Shepperton Gravel and the East Tilbury Marshes Gravel (**Figures 43-45, 48-50**). On the south bank the Pleistocene sediments appear to be potentially more variable in lithological content than they do in the north where a large sand body appears to form a wedge at the edge of this zone (**Figure 50**). Holocene sediments consist of interbedded clay-silts and peats on both sides of the river although it is noticeable that the sequences on the northern side of the river (**Figure 50**) appear to contain a greater number of peat beds than to the south. It is also noticeable that the sequence of Holocene sediments is thicker on the north side of the Thames that the south. The status of the thick sand deposits seen in the northern part of this zone e.g. see **Figure 48**) remains equivocal and may be Pleistocene or Holocene in age.

Previous experience at the Thames River Crossing (Bates and Stafford, 2013) suggest that archaeological material in this part of the floodplain is likely to be scare. Material may exist on the surface of the Pleistocene sediments and scattered intermittently through both the peats and the minerogenic sediments. However, the importance of this zone is in preserving a record of changing sedimentary environments and regional environmental conditions. Sequences in this area of the floodplain have been investigated in a number of places and the organic elements of this record are relatively well known. What is less well known is the nature and dating of the minerogenic sediments in this area.

Key questions:

- What is the age and environments of deposition of both the organic and minerogenic sediments?
- What is the precise timing of flooding of this surface?
- Is there activity in the wetlands following flooding?
- Is there a geochemical record preserved in the sedimentary sequence of human activity on the dry ground adjacent to the floodplain?

6.5 Zone 5: Dry Valley, Essex Tertiaries (Figure 33-36)

This zone is distinguished on the basis of the geomorphological form of a series of Head filled dry valley forms. Bedrock consists of Thanet Formation with the Lambeth Group appearing at the northern margin of this zone. These bedrock geologies are likely to produce clay, silt and sand matrices with flint gravel components as well as some limestone/sandstone/conglomeritic clasts and lignite fragments.

Superficial sediments consist of Head that is likely to be derived in part from the bedrock as well as the Pleistocene terrace sediments present in Zone 6a/b. Slope analysis (**Figure 32**) indicates a major south west facing erosional slope along the northern part of this zone substantial later Pleistocene/early Holocene sedimentary sequences may be present on the opposite trending slopes.

The nature of the archaeological signature in these sequences remains opaque. It is possible Late Palaeolithic and Mesolithic archaeology is present within and buried below/sealed by the slope deposits. This feature is poorly understood and its relationship to both the Mar Dyke (see Zone 8 below) and the Thames floodplain (Zone 3b) is equivocal. The age of the feature, its geomorphological history and archaeological context remains to be determined.

Key questions:

- Did this system for a fluvial network draining the Mar Dyke into the Thames in a southerly direction?
- Are there fluvial sediments preserved beneath the Head, or erroneously mapped as Head?
- Are Late Glacial sequences preserved in places in the zone?

6.6 Zone 6: Thames Terraces, Essex (Figures 33-39)

This zone is subdivided into three sub-zones but where all form 'plateau' surface form in the northern part of the route (**Figure 32**). Bedrock consists of Thanet Formation and Lambeth Group sediments in the southern part (Zones 6a/b) with the London Clay Formation present at the northern end of zone 6b and throughout zone 6c. These bedrock geologies are likely to produce clay, silt and sand matrices with flint gravel components as well as some limestone/sandstone/conglomeritic clasts and lignite fragments while the London Clay Formation may produce carbonate nodules.

Superficial sediments consist of the mapped Thames terraces of the Corbet's Tey/Orsett Heath Gravel likely to be rich in sand and gravel although finer grained units with clay/silt is possible while the Corbet's Tey Gravel is known to contain peat and organic rich sediments.

Although ostensibly a relatively flat, plateau like topography stream fitting (**Figure 26**) demonstrates the possibility that a series of minor channels may have existed across the area in the past and thus localised pockets of alluvium or colluvium may exist across this area.

The plateau like topography of this zone suggests little in the way of stratified sedimentary sequences are likely to have accumulated in the Holocene across much of this zone. However, the stream network fitting indicates localised pockets of alluvium/colluvium containing Holocene archaeological material may be present in places in these zones. This zone is poorly understood both in terms of the likely sequences and their associated archaeology.

Key questions:

- Do any of the putative stream systems contain Holocene sediments with associated archaeology?

6.7 Zone 7: Mar Dyke slopes (Figures 36-39)

This zone is split into two where 7a forms the southern side of the Mar Dyke valley above the alluvium (**Figures 36 and 37**) while 7b marks the western edge of the Mar Dyke (**Figures 36-39**). Bedrock consists of the London Clay Formation with possible outcrops of Lambeth Group sediments in the southern part of zone 7a. These bedrock geologies are likely to produce clay, silt and sand matrices with flint gravel components as well as some limestone/sandstone/conglomeritic clasts and lignite fragments while the London Clay Formation may produce carbonate nodules.

Superficial sediments consist of Head deposits (**Figure 52**) probably derived from the Lambeth Group as well as elements of the Thames terrace sediments in zone 6b to the south. Possible colluvial sediments may be present but are unmapped. There may be considerable difficulty in this zone in differentiating superficial sediments from weathered bedrock.

Archaeological material in this zone is likely to have been moved and transported in the Head or colluvium.

Key questions:

- Is there any stratified sediments in this zone that contain archaeological material?

6.8 Zone 8: Mar Dyke (Figures 36-38)

This zone consists of the low lying Mar Dyke Basin (**Figures 36-38**). Bedrock consists of the London Clay Formation which is likely to produce clay, silt and sand matrices with carbonate nodules.
Superficial sediments consist of alluvium likely to consist of sands, silts and organic units.

The Mar Dyke is an unusual setting and is presently a small north bank tributary of the Thames. Its peculiar status is in part a reflection of its Pleistocene history. The valley is, in part, the abandoned course of the Middle Pleistocene Thames following an east to west path around the northern side of the Purfleet anticline (Schreve *et al*., 2002).

Superficial sediments within the area mapped as alluvium (**Figure 10**) have been shown to consist of both clay/silt with organic material/peat as well as dense clays with angular clasts classified as Head (**Figure 52**). Previous work (Wilkinson, 1988) has suggested that in the lower parts of the valley around the A13 bridge (558051 180069), outside the study area, two Pleistocene gravel beds exist within the colluvium that blanket the valley sides. These gravels appear to be high energy fluvial gravels resting on terraces cut into the underlying Thanet Formation. The sequences are buried by a thick sequence of colluvium consisting of grey sand and gravel, apparently derived from the adjacent Thanet Formation. Such a scenario is reminiscent of the thick sequences of sands burying early Devensian sediments in the Ebbsfleet Valley (Wenban-Smith *et al*., 2020). The tidal reach in the Mar Dyke remains uncertain although it is known that tides reached to 1.6 km upstream of Stifford Bridge in 1760 (Allison 1966), just downstream of the study area. Around the A13 bridge two phases of marine incursion are noted the first perhaps beginning around 6000 A B2K and ending around 5200 A B2K the second beginning around 3600 A B2K and ending c 1500 A B2K (Wilkinson, 1988).

Archaeological material may be present in those parts of the sequences that are associated with the alluvium or in the Head deposits present along the margins of the Mar Dyke and within the inner part of the basin. The Mar Dyke remains an area that is poorly known in terms of its sequences, environmental history and archaeological potential.

Key questions:

- What are the different environments of deposition of sediments in the Mar Dyke?
- When were these sediments deposited?
- What is the age of the Mar Dyke basin?
- Is there any evidence of human activity in these deposits?

- Do the sediments contain a geochemical record for landscape history?

6.9 Zone 9: Essex High-ground slopes (Figures 39 and 40)

This forms the northern end of the route corridor and consists of ground rising to the north towards higher ground. Bedrock consists of the London Clay Formation with outcrops of the Bagshot Formation at the northern end of the zone. These bedrocks are likely to produce clay, silt and sand matrices with carbonate nodules, shells and occasional organic remains.

Superficial sediments consist of a variety of sediment types including alluvium of the Mar Dyke system, Head and Glacio-fluvial sediments. These are likely to be dominated by sands, silts and organic units.

Slope analysis and stream fitting suggest that both zones of increased likelihood of substantial thickness' of solifluction deposits of Late Glacial age and Holocene/Late Pleistocene alluvium away from the mapped alluvium of the Mar Dyke may be present. Archaeological material of Late Palaeolithic and Mesolithic age may be present within these sediment bodies.

Key questions:

- What are the nature of the Head deposits in this area, are they Pleistocene or Holocene in age?
- What age are the sediments in the upper reaches of the Mar Dyke system?

7.0 Methods and approaches to the stratified Late Glacial/Holocene sequences

The investigation undertaken here indicates that substantially different sedimentary sequences of Latest Pleistocene and Holocene age are present along the line of the proposed development. They range in thickness from less than 1m to greater than 20m in places, they are likely to both bury and contain archaeological material and associated palaeoenvironmental remains and the differing bedrock and superficial geologies suggest that the preservation potential for the survival of palaeoenvironmental material will vary along the route corridor. Developing strategies to investigation these sequences needs to take into consideration these factors.

A number of key issues have also been encountered during this study which provide a focus for investigation during the lifespan of this project:

- Little is known in detail about the precise timings and nature of minerogenic sedimentation in the main Thames floodplain. This is a function of the repetitive focus of palaeoenvironmental investigation on organic based sequences ("the peat obsession") where the vegetation record is easier to unravel from the pollen evidence and approaches to dating are well based. Furthermore although many studies have focused on the behaviour of the estuary the historical time depth of such investigations usually do not exceed about 100 years (e.g. Rossington and Spearman, 2009).

- Traditionally developer funded projects have relied on tried and test approaches to investigating these sequences through pollen based investigations supported by targeted ^{14}C dating and studies of diatoms, ostracods and to a limited extent molluscs. Today significant advances in the field of sedimentary DNA (Smith *et al*., 2015; Cribdon *et al*., 2020) are showing how DNA preserved in sediments can provide additional insights into both plant and animal species in past times. Furthermore new methods in Optically Stimulated Luminescence dating (Munyikwa *et al*., 2021) show allow rapid profiling of minerogenic sequences to enable suitable horizons to be identified for dating thereby mitigating unsuitable dates.

- The nature of processes within the Mar Dyke is unclear as little information is available for the area.

- Despite much present day focus on pollution in the Thames/Medway estuary (e.g. Spencer *et al*., 2003; Pope and Langstone, 2011) little is known of the history and longevity of anthropogenic pollution of the systems. Those papers examining historicity of the record tend to focus on the last 100 years (e.g. Vane *et al*., 2020) despite the likely time depth of at least 2000 years of major pollution of the water since at least the establishment of Roman London.

It is argued that the approach to Late Glacial/Holocene sequences in the Lower Thames Crossing project, while building on previous work, should seek to apply new approaches and thinking to address key human and landscape issues in this part of the Thames Basin. This forms a strategy of "Enhance not Replicate" in order to drive the field and analysis phases of the project in new and novel directions. This approach can be developed to match those themes in the regional research frameworks for Latest Palaeolithic and Mesolithic periods (see Section 2.3 above) which are identified as problematic in the regions.

The adoption of the "Enhance not Replicate" approach to investigation requires that previous approaches to investigation (e.g. Bates and Bates, 2000; Bates *et al*., 2007) consideration be given to use of cutting edge or new tools for archaeological that might include, but not be restricted to, enhanced geophysical approaches (e.g. Chambers *et al*., 2013; Newell *et al*., 2015) to model sub-surface stratigraphies, chemostratigraphic modelling of sedimentary environments to examine human/landscape interactions (Vane *et al*., 2020), examination of sedimentary DNA (Smith *et al*., 2015; Cribdon *et al*., 2020), molluscs in Fortunato (2015) and the $\delta^{18}O$ signal in freshwater mollusc shells (Pfister *et al*., 2019) to enhance palaeoenvironmental reconstructions (including hydrological, ecological, biogeochemical and atmospheric processes) to new approaches to dating to including OSL profiling (Munyikwa *et al*., 2021) and Tl dating of earthworm granules (Versteegh *et al.,* 2013). **Table 4** outlines the methods and approaches to the 9 individual zones as a starting point for this discussion.

In order to implement the "Enhance not Replicate" strategy a scheme-wide approach to investigating sequences for the novel elements (e.g. sedimentary DNA/geochemistry) will be required that sits alongside the traditional developer-led approach to tender packages whereby individual organisations are responsible for the implementation of assessment/analysis on a package by package basis. Consideration of this enhanced structure should be given high priority in the development of the project moving forward.

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Appendix 1

a b2k - years before 2000 CE (Christian era)
Anabranching systems - An anabranch is a section of a river or stream that diverts from the main channel or stem of the watercourse and rejoins the main stem downstream. Local anabranches can be the result of small islands in the watercourse.
Antecedent drainage - An antecedent river is one that maintains its original course and pattern despite the changes in underlying rock topography
Bio-stratigraphy, Bio-stratigraphic dating - dating correlation based on faunal remains, either by a distinctive assemblage of species, with key indicator species present or absent; or by distinctive characteristics of a species, such as changing root-length of water-vole molars or changing spacing of mammoth tooth enamel plates
Chronometric dating - methods of dating that rely directly upon measuring a quantifiable attribute or characteristic, such as proportions of certain chemical compounds (C14 dating or *AAR* - qv), or red light emitted when heated (*OSL dating* - qv)
Clast - a larger-sized constituent in a generally fine-grained deposit, such as a flint pebble in a silty/sandy matrix
DBA - Desk-based Assessment
DCO - Development Consent Order [Act of Parliament that supports delivery of a major project such as LTC (qv)]
Designated - when not being used in a non-specific way, this refers to particular heritage assets that have been designated as having some particular important status, such as being a Scheduled Monument or Site of Special Scientific Interest
EIA (Scoping Report) - *Environmental Impact Assessment Scoping Report* [LTC (qv) project document produced in October 2017 that reviews the general approach to assessing and mitigating environmental impact, and summarises key relevant information]
Epoch - technical term for sub-divisions of the geological record; *Pleistocene* (qv) and *Holocene* (qv) are properly epochs of the *Quaternary Period* (qv)
ES - Environmental Statement [document produced to support the DCO (qv)]
Fluvial - river-related
Glacial - a distinctly cold episode in the climatic oscillations of the *Quaternary* (qv); this is the correct term for a cold *stage* (qv), and is not synonymous with *glaciation* (qv), which specifically relates to ice-sheet development
Glaciation - ice-sheet development; this typically occurs during cold *stages* or *glacials* (qv), but is not synonymous with these broader terms
HE - Highways England
HER - acronym for *Historic environment record* (qv)
Historic environment record - lists maintained by local authorities of heritage assets in their area; these underpin curatorial decision-making, so their maintenance with up-to-date records and house-keeping for their accuracy and the inclusion of Palaeolithic remains are essential
Holocene - the warm climatic stage (MIS 1) that has continued since the end of the last glacial (the Devensian) approximately 11,700 A B2K (years Before Present) up to the present day

Hominin - the branch of the human family tree that includes all species, living or extinct, since its divergence from the line that leads to the living apes that are our closest evolutionary relatives (chimpanzees and gorillas)

Interstadial - a warm oscillation within a prolonged and predominantly cool, or cold, stage of the *Pleistocene* (qv), but not so warm or so long as to qualify for full *interglacial* (qv) status

Late Glacial - The Late Glacial is a period of rapid climate change that marks the transition from the last Glacial to the Holocene. It can be subdivided into stadial and interstadial phases, which were clearly recognized in the Greenland ice core records

Lithic - stone, or made of stone; most common raw material for Palaeolithic stone tools in the UK is flint, but other lithic raw material such as chert, quartzite and volcanic tuff were also used, so should not be overlooked

LGS (Local Geological Site) - a site that is considered worthy of protection/recognition for its Earth Science or landscape importance, but is not already protected as SSSI (qv)

LTC - Lower Thames Crossing

Marine isotope stage - numbered peaks and troughs of the global climate curve for the last two million years derived from continuous sedimentary records from the sea-bed; odd numbers represent warm episodes, and even numbers represent cold ones

Mesolithic – period between the Upper Palaeolithic and the Neolithic

MIS - acronym for *marine isotope stage* (qv)

NSIP - Nationally Significant Infrastructure Project

Optically stimulated luminescence - form of *chronometric dating* (qv) applicable to buried sand grains; natural background radiation causes changes in buried sand grains that lead to variation in how brightly they glow when given a controlled optical stimulus

OSL - acronym for *optically stimulated luminescence* (qv)

PEIR - *Preliminary Environmental Information Report* [LTC (qv) project report issued in September 2018 that reviewed the legislative framework applicable to cultural heritage in relation to the new crossing, and reiterated the requirements of the Environmental Statement (ES - qv) that will accompany the DCO (qv) application, and the proposed approach to addressing these requirements.

Quaternary, Quaternary Period - The most recent period of geological time, starting *c.* 2.6 million years ago, and containing two epochs, the *Pleistocene* (qv) and the *Holocene* (qv)

Palaeolithic, the "Old Stone Age" - the oldest cultural stage of human, or *hominin* (qv), cultural history, characterised by the manufacture of *lithic* (qv) artefacts; clearly this will occur (and in particular, <u>start</u>) at different times in different parts of the world, depending upon the spread of early artefact-making hominins - has been sub-divided into Lower, Middle and Upper phases in Britain and western Europe

Pleistocene - the older part (or *epoch* - qv) of the Quaternary Period, lasting from c. 2.6 million years A B2K through to the end of the Last Glacial *c.* 11,700 A B2K; the Pleistocene is distinguished by a series of cold and warm climatic oscillations, leading to alternating *glacials* (qv) and *interglacials* (qv), marked (in higher latitudes and more mountainous regions) by expansion and retraction of glaciers and more widespread ice-sheets

PQDM - *Palaeolithic and Quaternary Deposit Model* [LTC (qv) project document produced in February 2020 (v1) and then updated in April 2020 (v2) that provides a preliminary assessment of Palaeolithic and geo-archaeological potential for the proposed impact footprint of the LTC (qv)]

SPAA - *Standalone Palaeolithic Archaeological Assessment* [LTC (qv) project document produced in April 2020 that complements the PQDM (qv) and provides more-detailed information on the Palaeolithic potential for different zones of the proposed impact footprint of the LTC (qv), and outline approaches to evaluation]

SSSI (Site of Special Scientific Interest) - designation by Natural England, of sites that have special scientific interest, usually for geological or environmental reasons; from an archaeological heritage perspective this designation does not have the same statutory weight as being a Scheduled Monument, but it can include important Quaternary sites, and these are almost always of national Palaeolithic importance

Stadial - a cold oscillation within a prolonged and predominantly warm stage of the *Pleistocene* (qv), but not so cold or so long as to qualify for full *glacial* (qv) status

Stage - when not being used in a non-specific way, generally refers to one of the numbered *marine isotope stages* (qv)

Terrace - in the context of Pleistocene (qv) geology, a broadly horizontal landform occurring as a visible step in the side of a river valley; some larger river valleys (such as the Thames, the Trent, the Wiltshire Avon, and the Hampshire Test) can have a staircase of terraces down their valley sides, with each terrace representing a separate series of cold/warm/cold stages of the *Pleistocene* (qv), and with higher terraces being older

Thermoluminescence dating - a form of *chronometric dating* (qv) whereby the time elapsed since a crystalline mineral (such as flint or sediment) was heated can be calculated from the amount of light emitted during controlled heating

TL - acronym for *Thermoluminescence dating* (qv)

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