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The Geology of the Wicken Vision Area, lower Cam valley, Cambridgeshire, UK

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Abstract

The geology of the Wicken Vision Area in the lower Cam valley is described with reference to a stacked series of ten cross-sections through Holocene and Pleistocene deposits, and Cretaceous/Jurassic bedrock across the region. A detailed cross-section through a Holocene palaeochannel, with radiocarbon dating and pollen analyses is also presented. The structural geology of the bedrock and the stratigraphic arrangement of the Pleistocene and Holocene deposits are used to describe landscape development for the area. This study offers a new understanding of the stratigraphy and context of the Holocene, Weichselian and earlier Pleistocene deposits of the lower Cam valley, and provides a unique view of sediment architecture in valley-fill sediments at the fen edge.

Keywords: Holocene, Weichselian, Pleistocene, Cam valley, Wicken Vision

Introduction

This paper aims to describe the lithostratigraphy and sediment architecture of Holocene, Weichselian and earlier Pleistocene deposits in the transitional area between the River Cam valley and southern Fenland by adding new geological observations by the author to archival borehole data. Understanding the geology of the lower Cam valley, known as the Wicken Vision Area, is crucial for articulating two disparate sedimentary systems, where the deposits are sometimes cryptic, and outcrops and topography are often mantled beneath an overgrowth of late Holocene peat.

The Wicken Vision is a hundred-year scheme by the National Trust, a British conservation and heritage charity, to create a new 53 km^2 nature reserve in eastern England between Cambridge and Wicken Fen (Fig. 1). Much of the Wicken Vision area is privately-owned farmland, although the National Trust currently owns 808 ha (March 2013).

Situated at the point where the lower River Cam valley and the south-eastern part of Fenland meet, the area is characterised by its flat, low-lying topography and by soils developed on Holocene peat overlying clay-rich bedrock. However, such a simplistic description masks a wealth of geological complexity in the district.

The area included in this study stretches from North Fen, Upware and Wicken Fen in the north, to Reach, Swaffham Bulbeck and Lode in the east, Fen Ditton to the south, and Milton, Horningsea and Waterbeach to the west (Fig. 1). The study area encompasses Adventurers' Fen, Swaffham Prior Fen and Bottisham Fen. The River Cam runs southwest to northeast across low lying fenland (<5 m O.D.) to the west of the study area, and part of Adventurers' Fen to the east is below Ordnance Datum. Several canalised tributary streams (lodes) including Bottisham Lode, Swaffham Bulbeck Lode, Reach Lode and Burwell Lode drain northwest towards the River Cam from Chalk springs at the edge of the fenland area.

Geological setting

Drainage and bedrock

The River Cam is a tributary of the River Great Ouse, which flows for ca 50 km north of Cambridge through Fenland in a largely artificial channel to enter the southern North Sea at

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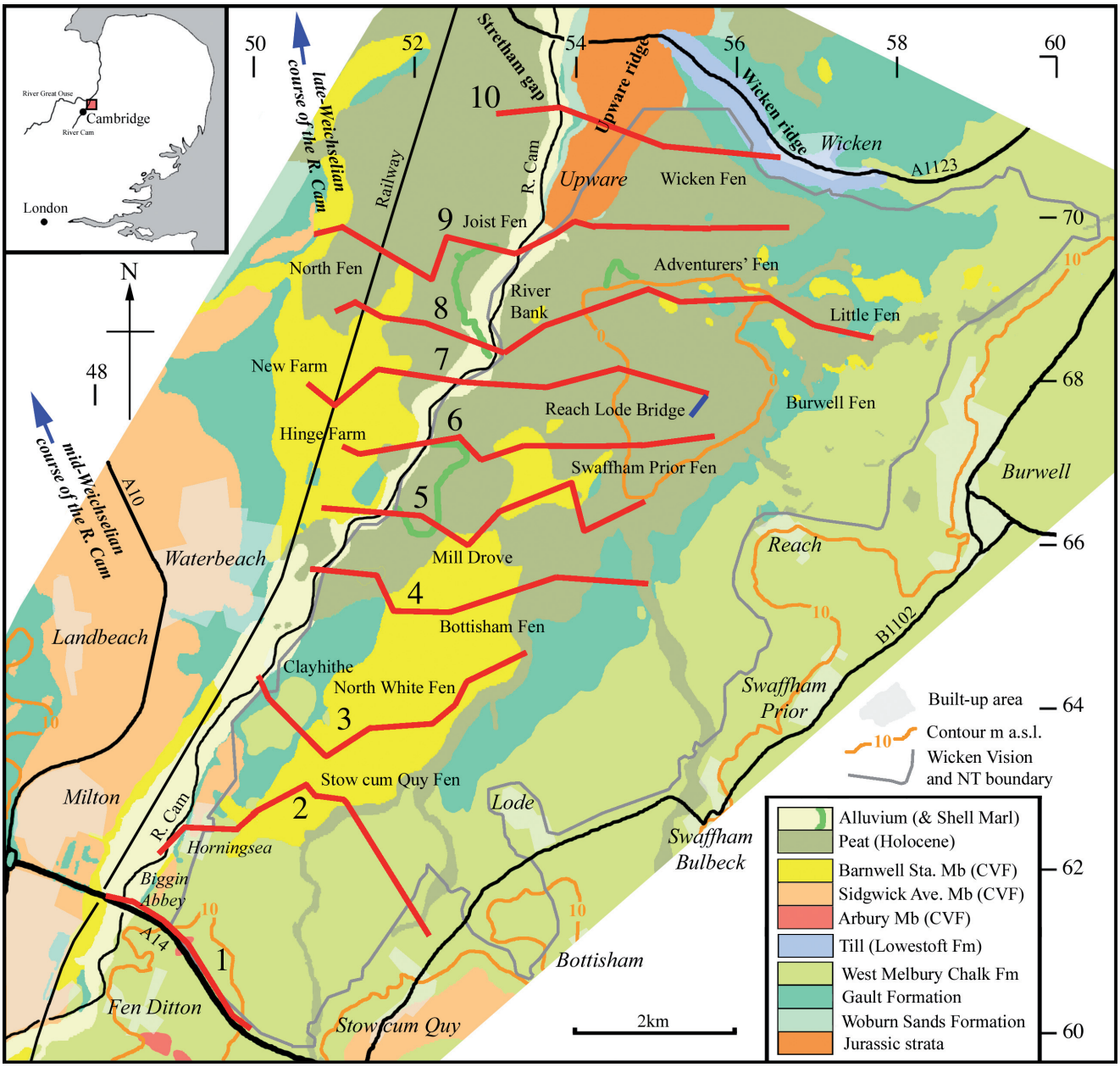

Fig. 1. Map of the lower Cam valley and the Wicken Vision area showing the simplified geology taken from the Cambridge Sheet (188), and geological sections 1-10 shown in Figs 2-11. Note that Quaternary deposits are mapped only where >1 m in thickness. The location of the geological section at Reach Lode Bridge (Fig. 12) is also shown. The Ordnance Survey grid at 2 km intervals is included for reference. Reproduced with the permission of the British Geological Survey ©NERC. CP13/024 All rights Reserved. 1981. Cambridge Sheet. England and Wales Sheet 188 Solid and Drift Geology. 1 : 50,000. British Geological Survey.

King's Lynn on the Wash. At Cambridge the River Cam drains a ca 1000 km^2 catchment of low chalky hills to the south. The geology of the upper Cam valley has been described by Boreham & Rolfe (2009). Northeast of Cambridge the River Cam enters the Wicken Vision Area, a region of low-lying fen, before joining the Old West River (River Great Ouse) just south of Ely.

The geology of the lower valley of the River Cam was first described in detail by Worssam & Taylor (1969), who recognised north-south trending anticlinal and synclinal structures (the Upware Axis) in the Cretaceous and Jurassic bedrock broadly aligned with the course of the modern river and disturbing the general dip of the bedrock strata to the southeast. The bedrock in the Wicken Vision area comprises the Cretaceous West Melbury (Marly) Chalk Formation (soft limestone), Gault Formation (mudstone), Woburn Sands Formation (sandstone) and the Jurassic West Walton Formation (limestone) and Ampthill Clay Formation (mudstone) (Moorlock et al., 2003), which are equivalent to the Lower Chalk, Gault Clay, Lower Greensand, Upware Limestone and Ampthill Clay of the former classification (Matthews & Harvey, 1965; Forbes, 1965).

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Pleistocene and Holocene lithostratigraphy and depositional history

Glacial till (boulder clay) was identified by Worssam & Taylor (1969) as one of the oldest Pleistocene deposits of the district. The 'valley gravels' of the Cam system were separated by elevation into numbered terraces (4th, 3rd, 2nd, 1st) using a morphostratigraphic paradigm (Dixon, 1980; Clayton, 1981). The oldest Pleistocene courses of the River Cam (3rd and 4th terraces and the Observatory gravels) pass through north Cambridge and continue northwest towards Willingham, the River Great Ouse and southern Fenland (Gao & Boreham, 2011).

The lithostratigraphy of the Pleistocene deposits in the valley of the River Cam was described by Boreham in Bowen (1999). Glacial till was attributed to the Barrington Works Member of the glaciogenic Lowestoft Formation (LF) of presumed Elsterian (MIS 12) age. Post-Elsterian fluvial sediments were placed in the fluviogenic Cam Valley Formation (CVF). Within this formation, the 3rd Terrace early-Weichselian deposits of the River Cam were correlated with the Arbury Member (CVF).

In mid-Weichselian times the River Cam avulsed to the east, presumably into a pre-existing strike-aligned tributary valley also joining the River Great Ouse to the north, and formed a new ca 1 km wide braidplain indentified as the 2nd terrace. This terrace feature runs to the west of the River Cam from Milton to Landbeach and Waterbeach (Fig. 1). The 2nd terrace is dated from the classic site at Sidgwick Avenue, Cambridge (Lambert et al., 1962) where plant macrofossils and molluscs from silty and sandy bands within gravel indicate cool to cold climatic conditions. The author carried out radiocarbon dating on a skull of *Bison priscus* from the site, held at the Sedgwick Museum, University of Cambridge (Boreham, 2002). The uncalibrated radiocarbon (AMS) age for bone from the bison skull was 37,746±420 years BP (Wk-9388), calculated using the Libby half-life of 5568±30 years (Stuiver & Polach, 1977) with correction for isotopic fractionation applied. Reliable calibration at this age is fraught with difficulties (Van der Plicht, 2000; Bard, 2001), and Briant & Bateman (2009) highlight the difficulties with radiocarbon dating material older than ca 35,000 years calBP. It at least seems likely that the 2nd terrace deposits date from the mid-Weichselian (MIS 3-4).

The 1st terrace of the River Cam appears to be late-Weichselian in age, and occupies a separate more easterly course than the 2nd terrace. At this time, the river avulsed to the east again (ca 14,000 years calBP), presumably into another strike-aligned valley, although this time the course breached a west-east trending ridge taking the new course of the River Cam to the east of Ely and into southern Fenland by a more easterly route (the 'Stretham gap'). The 1st terrace is dated from another classic site at Barnwell Station, Cambridge. Marr & Gardner (1916) described plant, mollusc and vertebrate remains from the site as indicative of a cool climate. Chandler (1921) made a detailed study of the plant macrofossils, and Coope (1968) identified beetle remains indicating an arctic environment. Later, Bell & Dickson (1971) reappraised the identifications of Chandler. The uncalibrated radiocarbon age calculated for plant material from the site was 19,500±650 years BP (Godwin & Willis, 1964). This radiocarbon date calibrates using OxCal (Bronk Ramsey, 2009) to 23,375±778 years calBP and places the 1st terrace into the late Weichselian (MIS 2).

The Holocene deposits of the lower Cam are represented by floodplain alluvium, palaeochannel silts, shell marls from cut-off river meanders, fen peat (Nordelph Peat), and by intertidal silts and clays (Barroway Drove Beds) from an early Bronze Age episode (ca 3,700 years calBP) (Waller & Hall, 1991) of marine inundation, which reached the northern part of the Wicken Vision Area. Several southern tributaries of the River Cam were diverted and canalised in post-Roman times to form artificial 'lodes'. Many of the lodes run in raised embankments above the level of the surrounding fenland, and most have been straightened or run in completely artificial courses, leaving older abandoned palaeochannels meandering across the fen, such as the one encountered at Reach Lode Bridge.

Within the Cam Valley Formation, the 2nd Terrace mid-Weichselian deposits of the River Cam are correlated with the Sidgwick Avenue Member (CVF). The late-Weichselian 1st Terrace deposits are correlated with the Barnwell Station Member (CVF) when exposed at or above the floodplain, and with the late-Glacial Midsummer Common Member (CVF) where present in a buried channel-form beneath the floodplain surface. All Holocene deposits, including peat and alluvium, were placed in the Fenland Formation (FF) (Bowen, 1999).

In general the stratigraphy of the lower Cam valley corresponds with other parts of the Cam valley system. The stratigraphic units proposed in Bowen (1999) allow correlation with the neighbouring East Anglian and Fenland river valleys such as the Great Ouse, Nene and Lark, although the details are sometimes problematic (Boreham et al., 2010).

It should be noted that the geology shown in Fig. 1 is adapted from the British Geological Survey map (Cambridge Sheet 188), but the geological sections 1-10 (Figs 2-11) present some more recent data from boreholes that occasionally does not agree with the BGS mapping. In these instances, the discrepancy will be noted.

Cross-sections of the Wicken Vision Area

Geological Section 1 (Fig. 2)

This 2.5 km-long section is aligned northwest-southeast along the course of the A14 Road, from the River Cam floodplain to Fen Ditton. The dip of the bedrock to the southeast can be clearly seen, with the West Melbury Chalk Formation overlying the Gault Formation. In this location, the River Cam floodplain is relatively narrow and characterised by thin alluvial silty clay overlying both peat, and at the valley sides, gravel and sand up

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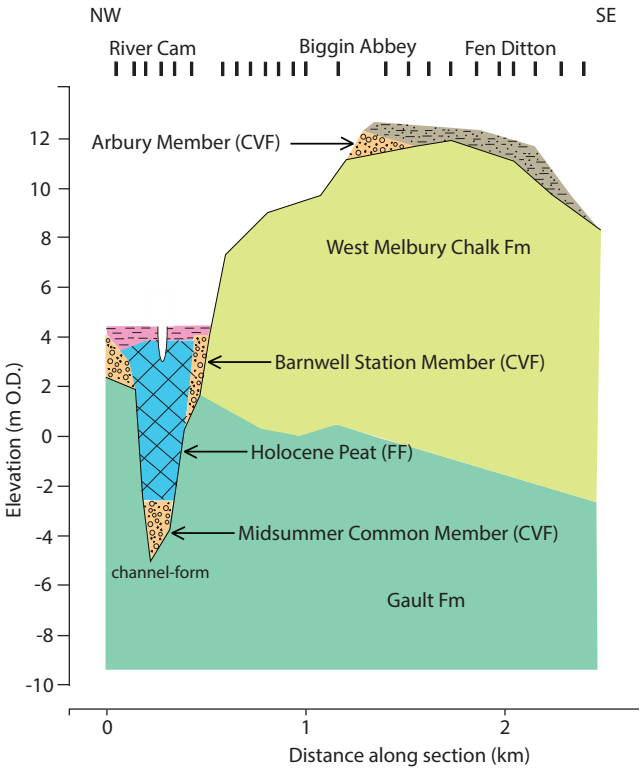

Fig. 2. Geological section 1 across the southern part of the Wicken Vision area along the line of A14 road constructed from borehole records. A key to the lithological symbols used in Figs 2-11 is included.

to ca 3 m thick (1st Terrace deposits - Barnwell Station Member (CVF)). The floodplain is underlain by a channel-form ca 9 m deep incised into the Gault Formation, filled by ca 2.4 m of late-Weichselian basal sand and gravel (Midsummer Common Member (CVF)) and ca 6 m of peat (Holocene (FF)). At Biggin Abbey, the West Melbury Chalk Formation forms a small but noticeable 'scarp' feature, which to the north and east of Fen Ditton, is capped by thin gravel and sandy silt deposits at ca 12 m O.D. that correlate with 3rd Terrace deposits (Arbury Member).

Geological Section 2 (Fig. 3)

This 4.7 km-long section is aligned west-east from the River Cam floodplain through Horningsea village to Stow-cum-Quy Fen, and then northwest-southeast to Quy Water, north of Stow-cum-Quy village. The dip of the bedrock to the southeast can be clearly seen, with the West Melbury Chalk Formation overlying the Gault Formation. The River Cam floodplain north of Biggin Abbey is underlain by a ca 4 m deep channel-form filled by ca 2.2 m of alluvial silty clay overlying ca 1.5 m of peat (Holocene (FF)). To the east of the river at Horningsea village, a low ridge of Gault Formation bedrock separating the River Cam from Stow-cum-Quy Fen is capped by gravel and sand (6-8 m O.D.) up to ca 1 m thick, and overlain by sandy silt of variable thickness (2nd Terrace deposits – Sidgwick Avenue Member (CVF)). These deposits are only partially mapped by the BGS at this location (Fig. 1). It appears that some parts of this area and parts of Stow-cum-Quy Fen have been disturbed by 19th Century mining operations for coprolites (phosphatic nodules) occurring in the Cambridge Greensand, a thin stratum at the junction of the Gault Formation and the West Melbury Chalk Formation. In Stow-cum-Quy Fen, thin sandy silt overlies gravel and sand (mostly 1st Terrace deposits – Barnwell Station Member (CVF))

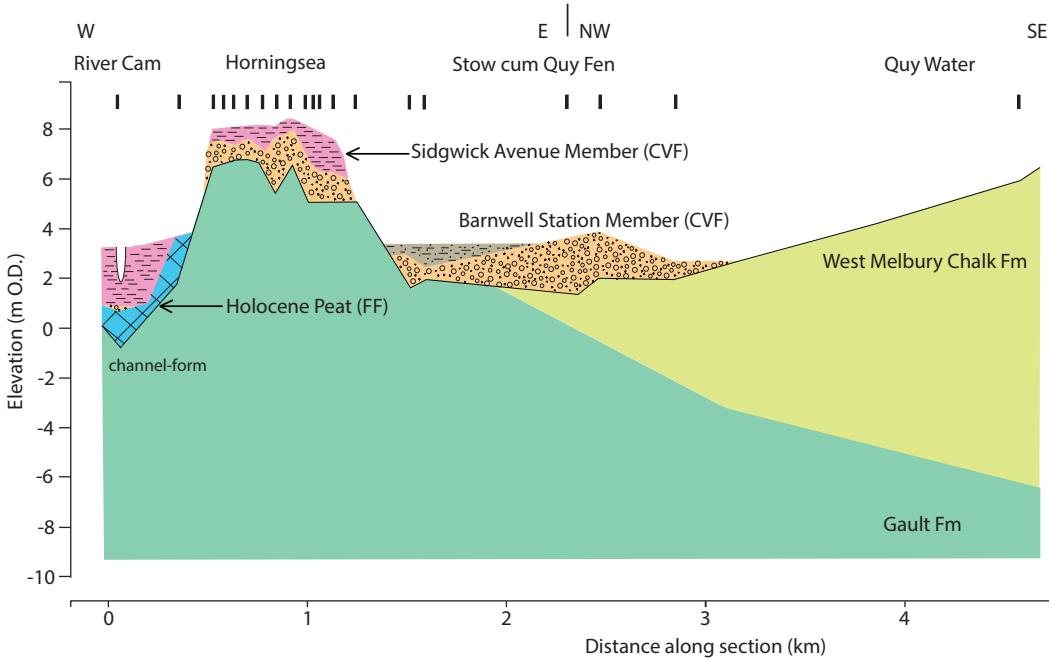

Fig. 3. Geological section 2 across the southern part of the Wicken Vision area (Horningsea to Quy Water) constructed from borehole records.

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up to ca 2 m thick, which rest directly on the West Melbury Chalk Formation bedrock. To the southeast, the rising land towards Quy Water is directly underlain by Chalk.

Geological Section 3 (Fig. 4)

This 5.3 km-long section is aligned northwest-southeast from the River Cam at Clayhithe to Stow-cum-Quy Fen, and then southwest-northeast through North White Fen to Bottisham Fen. There is clear evidence of a minor synclinal form in the bedrock from the arrangement of the West Melbury Chalk Formation overlying the Gault Formation. Much of this area has been disturbed by coprolite mining. At Clayhithe village, a low ridge of Gault Formation bedrock separating the River Cam from Stow-cum-Quy Fen is capped by thin sandy clay of uncertain origin. To the southeast in Stow-cum-Quy Fen, a spread of gravel and sand (mostly 1st Terrace deposits – Barnwell Station Member (CVF)) ca 2 m thick rests directly on West Melbury Chalk Formation bedrock. In North White Fen, a thin basal silty clay unit was overlain by ca 1.2 m of gravel, which thins to the east against a bedrock high at Jack of Clubs Farm. In Bottisham Fen thin basal gravel was overlain by ca 1.2 m of peat (Holocene (FF)).

Geological Section 4 (Fig. 5)

This 5.2 km-long section is aligned west-east from the River Cam at Bottisham Lock, near Waterbeach, to Bottisham Fen. This area is entirely underlain by Gault Formation bedrock. On the

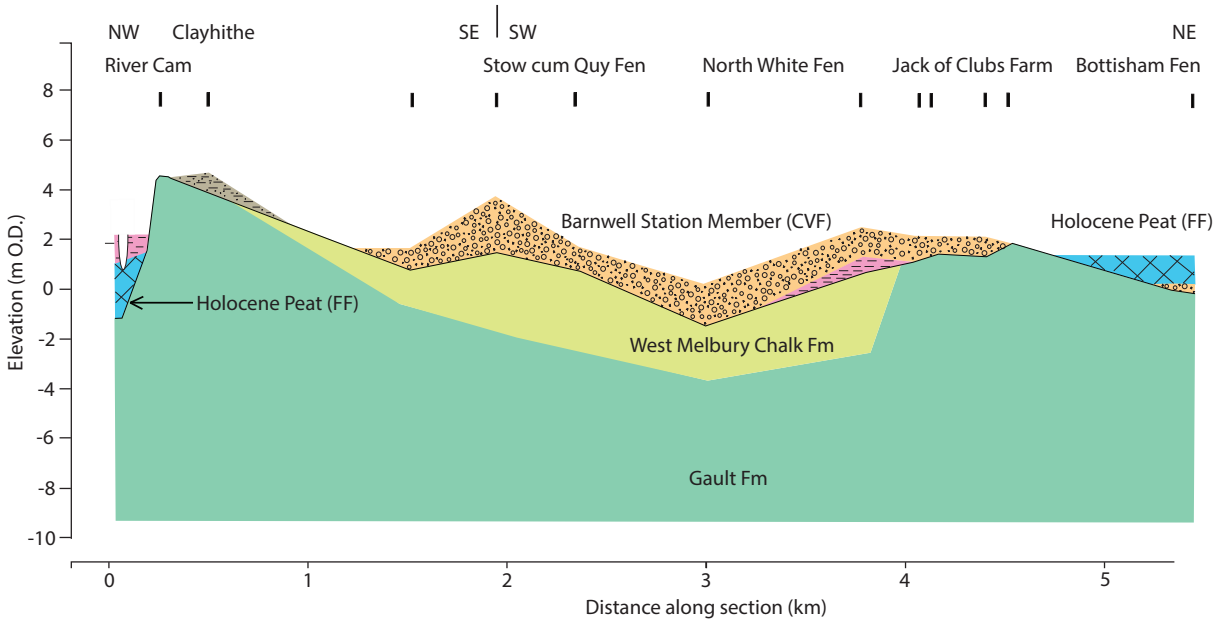

Fig. 4. Geological section 3 across the southern part of the Wicken Vision area (Clayhithe to Bottisham Fen) constructed from borehole records.

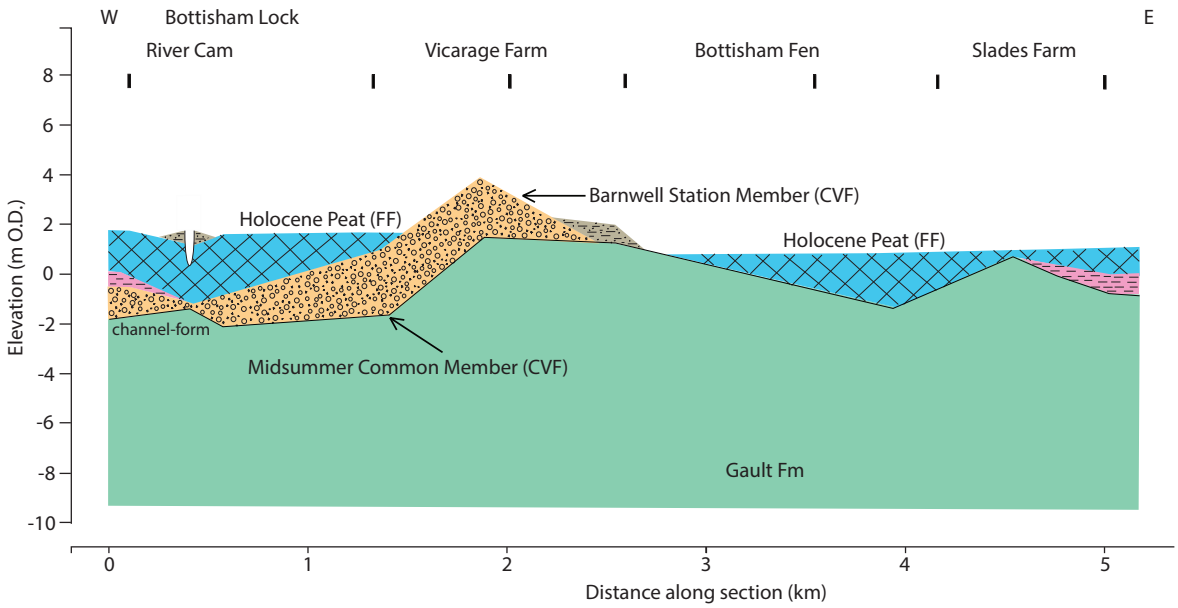

Fig. 5. Geological section 4 across the central part of the Wicken Vision area (Bottisham Lock to Slades Farm) constructed from borehole records.

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floodplain of the River Cam in the vicinity of Bottisham Lock, ca 1.2 m of gravel and sand (Midsummer Common Member (CVF)) is overlain by thin silty clay and ca 2.2 m of peat (Holocene (FF)), occupying a shallow channel-form. A low ridge at Vicarage Farm separates the River Cam from Bottisham Fen and is capped by ca 2.2 m of gravel and sand (1st Terrace deposits – Barnwell Station Member (CVF)). The western edge of Bottisham Fen is marked by thin sandy clay overlying bedrock close to the surface, although to the east there is ca 2 m of peat. A bedrock high near Slade's Farm separates Bottisham Fen from a small palaeochannel where a thin basal silty clay unit is overlain by ca 1 m of peat.

Geological Section 5 (Fig. 6)

This 5 km-long section is aligned west-east from Midload, north of Waterbeach, across the River Cam to Swaffham Prior Fen. This area is entirely underlain by Gault Formation bedrock. At Midload ca 2 m of gravel and sand (1st Terrace deposits – Barnwell Station Member (CVF)) is overlain by thin silty clay and peat (Holocene (FF)). Close to the River Cam floodplain, a ca 5 m deep channel-form contains ca 2.5 m of basal gravel (Midsummer Common Member (CVF)) overlain by ca 1 m of silty clay and ca 1.3 m of peat (Holocene (FF)). A bedrock-high at Mill Drove, capped by thin gravel, appears to separate the Cam Floodplain from Swaffham Prior Fen to the east. At Lord's Ground Farm in Swaffham Prior Fen very thin basal gravel is overlain by thin silty clay and peat. Nearer the fen-edge the ca 1 m thick sequence comprises thin silty clay overlain by thin peat.

Geological Section 6 (Fig. 7)

This 5 km-long section is aligned west-east from Hinge Farm, north of Waterbeach, across the River Cam to Swaffham Prior Fen. This area is entirely underlain by Gault Formation bedrock. At Hinge Farm ca 3.8 m of gravel and sand (1st Terrace deposits – Barnwell Station Member (CVF)) outcrops at the surface. In contrast, on the River Cam floodplain at Swaffham Lock, a ca 5.8 m deep channel-form contains a very thin basal gravel (Midsummer Common Member (CVF)) overlain by ca 5.7 m of peat (Holocene (FF)). However, a bedrock high, capped by thin gravel appears to separate the Cam Floodplain from Swaffham Prior Fen to the east. North of Lord's Ground Farm in Swaffham Prior Fen ca 1 m of basal gravel is overlain by thin silty clay and peat. Nearer the fen-edge at Headlake Drove, the ca 1 m thick sequence comprises thin silty clay overlain by thin peat.

Geological Section 7 (Fig. 8)

This 5.5 km-long section is aligned west-east from New Farm, north of Waterbeach, across the River Cam to Sedge Fen (Swaffham Prior Fen). This area is underlain by Gault Formation bedrock. At New Farm thin peaty deposits overlie gravel and sand (1st Terrace deposits – Barnwell Station Member (CVF)), which outcrop close to the surface. To the east beneath the floodplain of the River Cam, a ca 7 m deep channel-form contains ca 1 m of basal gravel (Midsummer Common Member (CVF)) overlain by ca 1.2 m of silty clay and 4.8 m of peat (Holocene (FF)). To the east of the buried channel-form, near Reach Lode, the basal gravel is overlain by thin silty clay and thin peat. The Holocene palaeochannel at Reach Lode Bridge is described in a separate section below (Fig. 12).

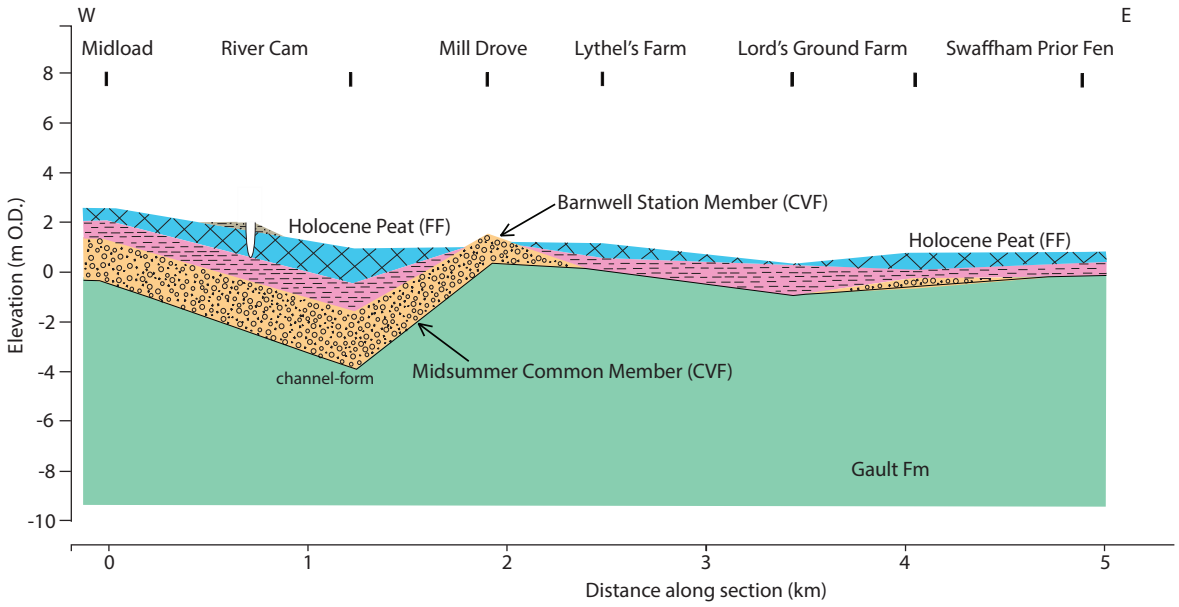

Fig. 6. Geological section 5 across the central part of the Wicken Vision area (Midload to Swaffham Prior Fen) constructed from borehole records.

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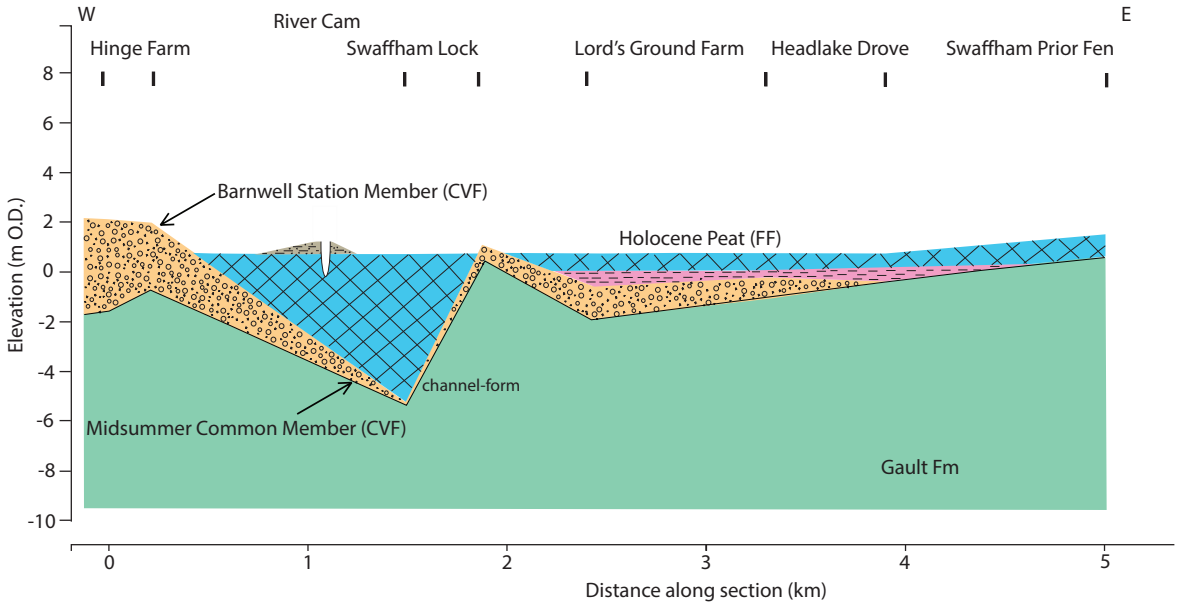

Fig. 7. Geological section 6 across the central part of the Wicken Vision area (Hinge Farm to Swaffham Prior Fen) constructed from borehole records.

Geological Section 8 (Fig. 9)

This 6.7 km-long section is aligned west-east from Halls Farm near Denny Abbey, across North Fen and the River Cam to Adventurers' Fen. Most of this area is underlain by Gault Formation bedrock, although a minor anticlinal flexure beneath the River Cam brings the Woburn Sands Formation closer to the surface. At Halls Farm a thin gravel unit (1st Terrace deposits – Barnwell Station Member (CVF)) is overlain by silty clay and peat. Close to Heron Farm, the same gravel and sand unit outcrops close to the surface, and appears to separate the southern part of the North Fen basin from the course of the River Cam. Beneath the floodplain of the River Cam, a ca 5 m thick sequence comprises ca 2 m of basal gravel (Midsummer Common Member (CVF)) overlain by ca 1 m of silty clay and ca 2 m of peat (Holocene (FF)). At River Bank, a ca 8 m deep channel-form contains thin basal gravel, ca 2.2 m of silty clay overlain by ca 4.8 m of peat. To the east of the buried channel-form in Adventurers' Fen, ca 1.5 m of silty clay was overlain by ca 1 m of peat. Close to Burwell Lode and Little Fen ca 2 m of gravel (1st Terrace deposits – Barnwell Station Member (CVF)) is overlain by ca 2 m of peat (Holocene (FF)).

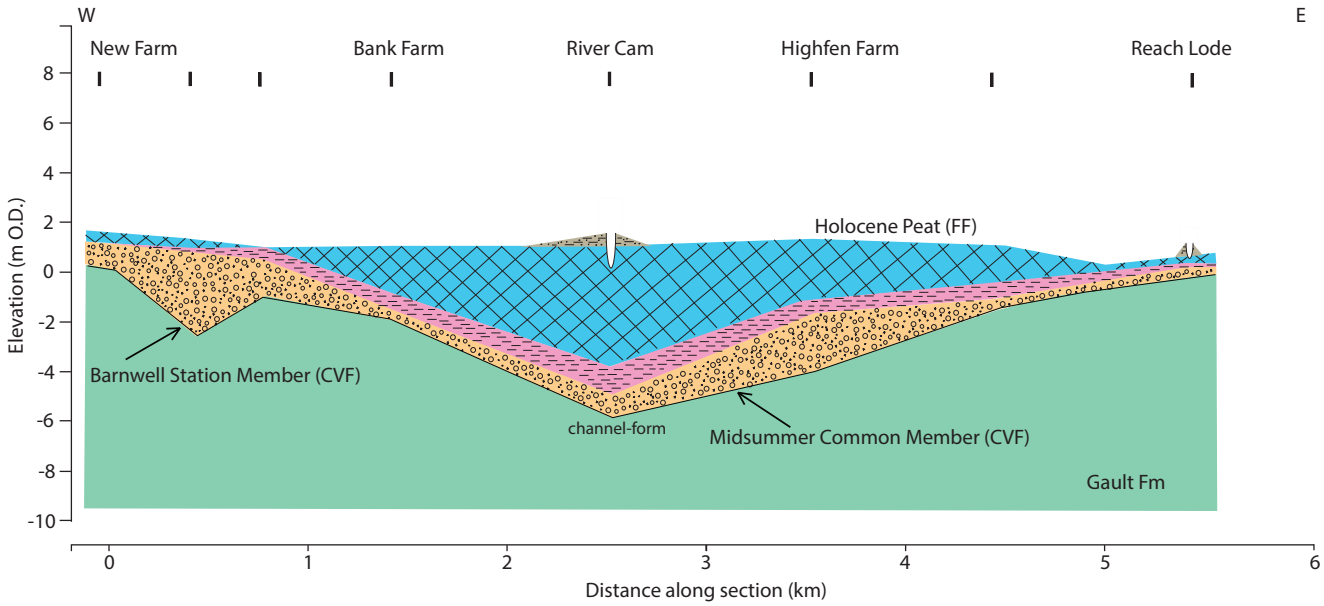

Fig. 8. Geological section 7 across the central part of the Wicken Vision area (New Farm to Reach Lode) constructed from borehole records.

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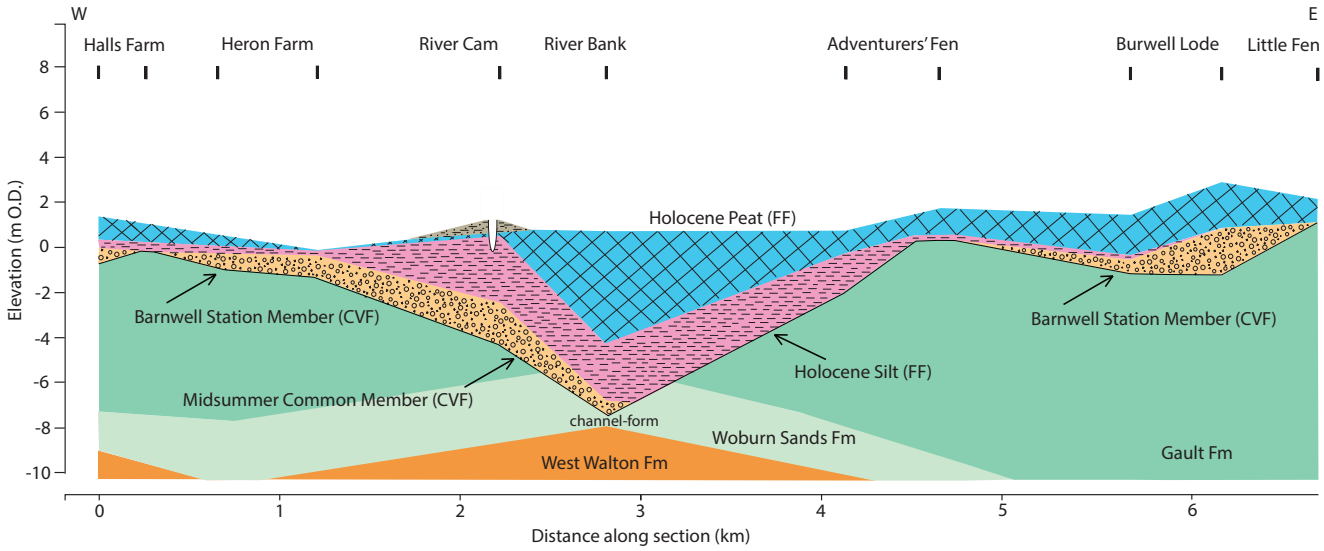

Fig. 9. Geological section 8 across the central part of the Wicken Vision area (Halls Farm to Little Fen) constructed from borehole records.

Geological Section 9 (Fig. 10)

This 6 km-long section is aligned west-east from the Varsity Mink Farm at Denny Lodge, across North Fen and the River Cam to Far Away Farm, at Upware. Most of this area is underlain by Gault Formation bedrock, but an interesting anticlinal flexure at Upware brings the Woburn Sands Formation and Jurassic West Walton Formation (Upware Limestone) close to the surface. A minor adjacent synclinal fold takes the Woburn Sands Formation to considerable depth at Joist Farm, and it appear that the River Cam has exploited this structural anticlinal-synclinal weakness during incision of its Late-Glacial course. At Varsity Mink Farm a thin gravel and sand unit (1st Terrace deposits – Barnwell Station Member (CVF)) outcrops at the surface. To the east in North Fen, this thin gravel unit is overlain by silty clay and peat (Holocene (CVF)); the sequence is at maximum ca 3 m thick. A small bedrock high at Joist Farm appears to separate the North Fen basin from the course of the River Cam. Beneath the floodplain of the River Cam, a ca 6.5 m deep channel-form contained thin basal gravel (Midsummer Common Member (CVF)) overlain by ca 2 m of silty clay, ca 3 m of peat and an upper layer of sandy clay (Holocene (FF)). At Far Away Farm, Upware, the ca 8 m deep channel-form contained ca 1.8 m of basal peat overlain by ca 5 m of silty clay (Barroway Drove Beds) and almost 2 m of upper peat and sandy alluvium. The Barroway Drove Beds represent tidal creek and mud flat deposits from an early Bronze Age (ca 3,700 years calBP) marine incursion into this area. These deposits are widely distributed across southern Fenland where they are often known by the generic name 'Fen Clay'. Beyond the buried channel-form, the shallow fen stratigraphy of silty clay overlain by peat was restored.

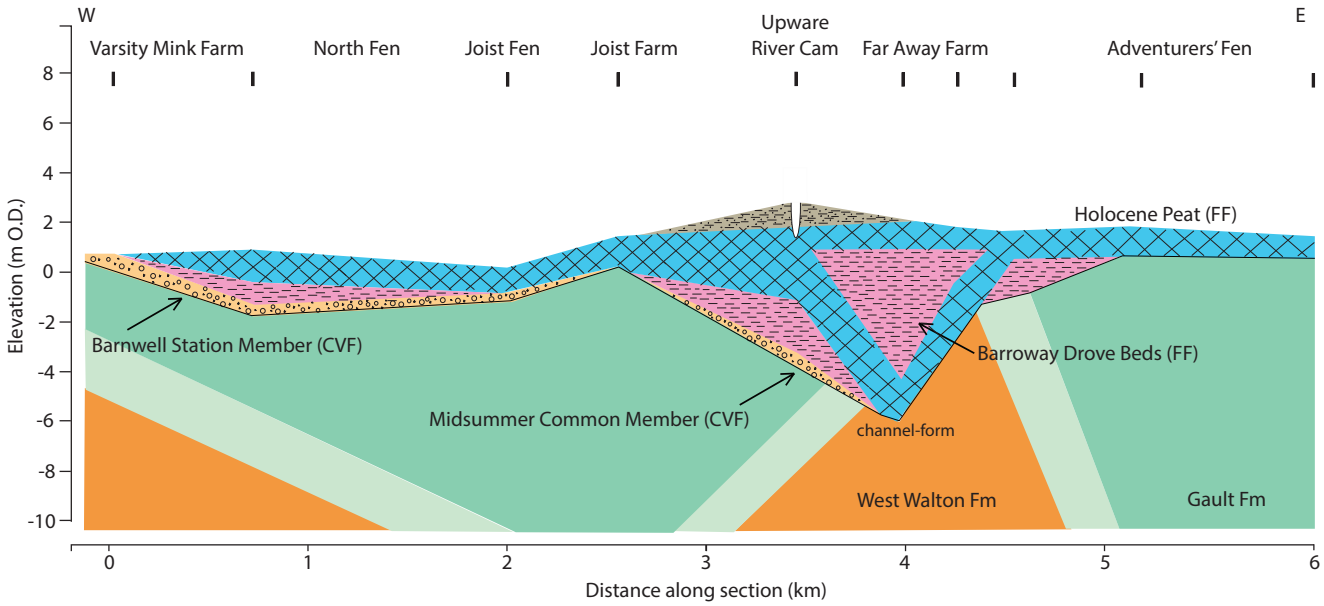

Fig. 10. Geological section 9 across the northern part of the Wicken Vision area (Varsity Mink Farm to Adventurers' Fen) constructed from borehole records.

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Geological Section 10 (Fig. 11)

This 3.5 km-long section is aligned west-east from Middle Farm, across the River Cam to Wicken Fen and Wicken Lodge. This area exhibits a well-developed anticlinal feature also seen in Section 9, that brings the Woburn Sands Formation and Jurassic West Walton Formation (Upware Limestone) close to the surface to form the 'Upware ridge'. At Middle Farm a thin gravel and sand unit (Midsummer Common Member (CVF)) occupies a shallow buried channel-form, and is overlain by thin silt and ca 1 m of peat (Holocene (CVF)). To the east beneath the River Cam, the Holocene peat reaches ca 3 m thick. To the east of the 'Upware ridge' at Spinney Drove, there is also ca 3 m of peat, which thins across Wicken Fen to the east. At Wicken Lodge ca 2 m of glacial till (probably belonging to the Barrington Works Member – Lowestoft Formation) overlies Gault Formation bedrock and forms the 'Wicken ridge', which forms the northern and eastern limit of the Wicken Fen basin.

Reach Lode Bridge palaeochannel (Figs 12 & 13)

Introduction

This ca 175 m-long section (based on eight boreholes) was aligned southwest-northeast across Reach Lode, and provides details of a palaeochannel, most likely in this context of late-Glacial age, filled by Holocene sediments. In general, the Holocene sediments from the palaeochannel at Reach Lode Bridge comprised silts and organic detrital muds, with occasional layers of detrital wood peat and detrital peaty marl (see Fig. 12). Excluding the Late-Glacial basal sand and gravel of the palaeochannel (Midsummer Common Member (CVF)), five units (I-V) have been identified filling the channel form (Holocene (FF)). Unit I comprised basal silty and sandy clays with wood fragments and peat with marl. This was overlain by organic silt and detritus mud of unit II, followed by the silty clay of unit III. Unit IV comprised woody detritus mud and was overlain by the autochthonous peat of unit V.

Three radiocarbon dates (two bulk and one AMS date by The University of Waikato) were obtained from the sequence to determine the age and depositional history of the palaeochannel sediments.

Twelve samples from the sequence at BH6 produced useable counts for pollen analysis; the upper part of the sequence above 150 cm was barren due to oxidation of the sequence. Pollen preparation, counting and identification were as described by Bennett (1983). Plant taxonomy follows Stace (1991), and incorporates the suggestions of Bennett et al. (1994). Where possible, a minimum of 300 land-pollen and spores was counted at each level.

Pollen analysis

This sequence (Fig. 13) has many features of a typical Holocene pollen diagram. However, it must be remembered that this sediment sequence is from a fluvial environment rather than a lake or bog, so that although a dry-land signal from the catchment is present, much of the pollen is derived from the local in-channel vegetation of the river (for example reeds and sedges). It is clear that the basal pollen samples (410 cm & 380 cm) have modest proportions of birch (*Betula*) and pine (*Pinus*), which represent boreal scrub from the early Mesolithic period (ca 10,000 years calBP) at the start of the Holocene. It is interesting to note that alder (*Alnus*) is also present in these samples and throughout the entire sequence indicating wet woodland or carr growing continuously along the river channel. The basal samples also have a herb-rich assemblage dominated by grass (Poaceae) and sedges (Cyperaceae). The grass pollen

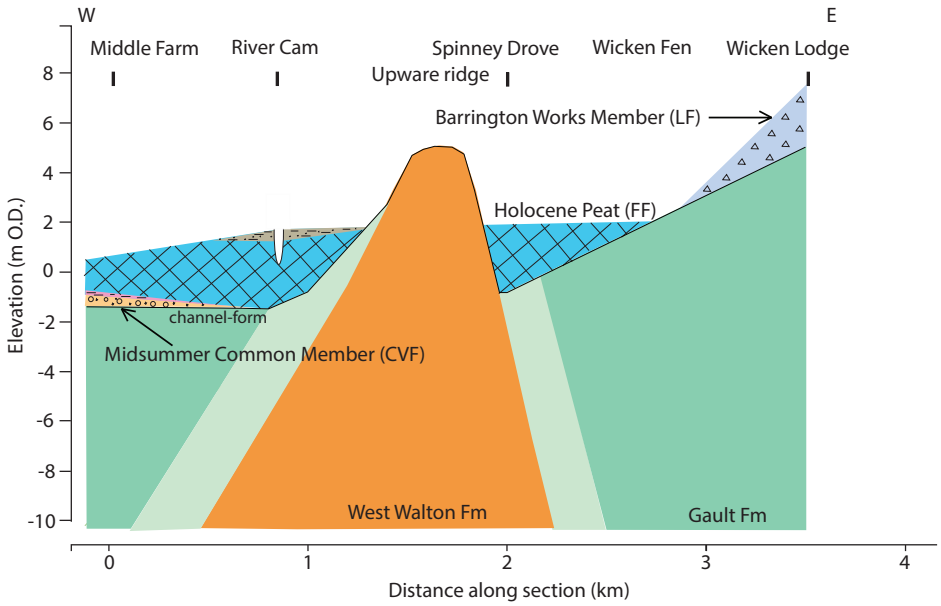

Fig. 11. Geological section 10 across the northern part of the Wicken Vision area (Middle Farm to Wicken Lodge) constructed from borehole records.

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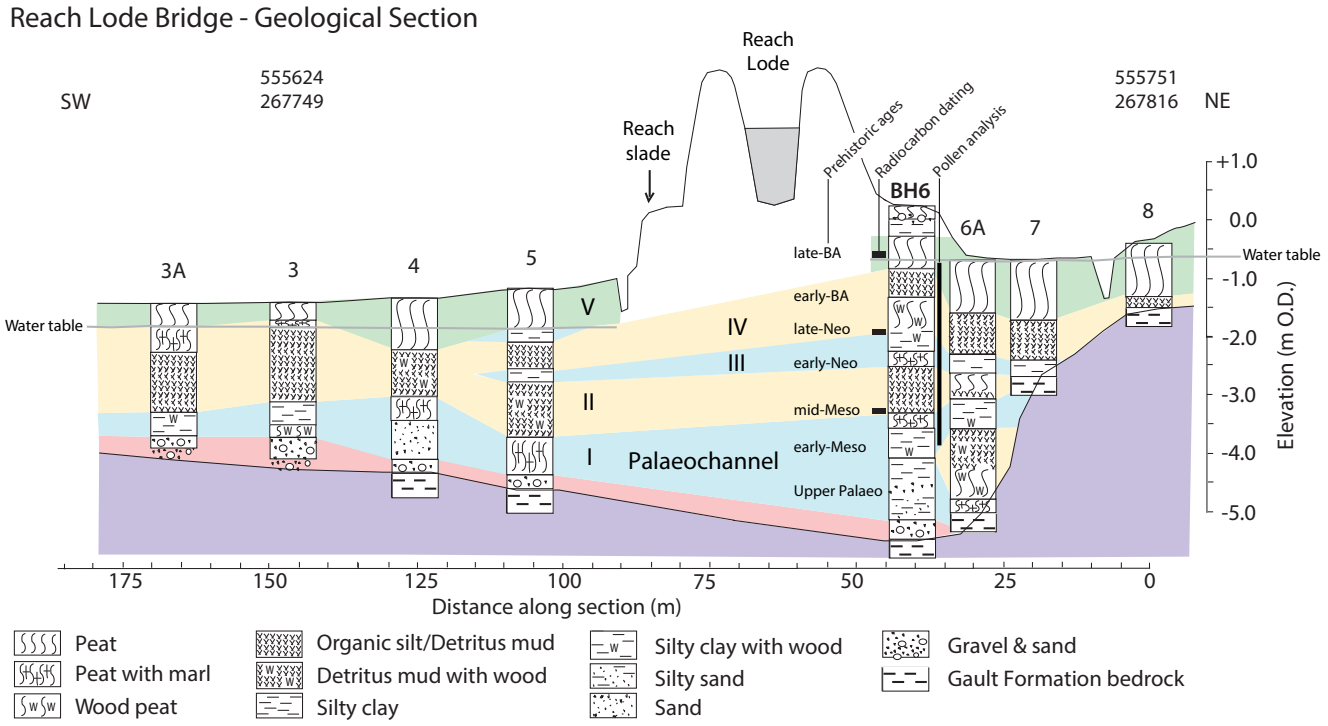

Fig. 12. Detailed stratigraphy of sediments in the Reach Lode Bridge palaeochannel, showing the position of samples for pollen analysis and radiocarbon dating in BH6.

may represent common reed (*Phragmites*) rather than grass growing in a meadow or floodplain.

In the three pollen samples above the boreal zone (348 cm, 325 cm & 300 cm) birch and pine decline, alder remains present at ca 10% and juniper (*Juniperus*) briefly reaches values in excess of 2%. Although grass remains abundant, Pteropsid fern spores reach a peak in excess of 25% suggesting damper conditions. Hazel (Corylus), lime (*Tilia*), oak (*Quercus*) and ash (*Fraxinus*) begin to make an appearance in the samples from 325 cm and 300 cm, and spores of the polypody fern (*Polypodium*), often associated with mature woodland also occur. A rise in hazel pollen is usually associated with the mid Mesolithic (ca 9,000 years calBP), but in this case such an increase is not seen until the sample from 275 cm, which must be at least late Mesolithic in age (ca 8,000 years calBP).

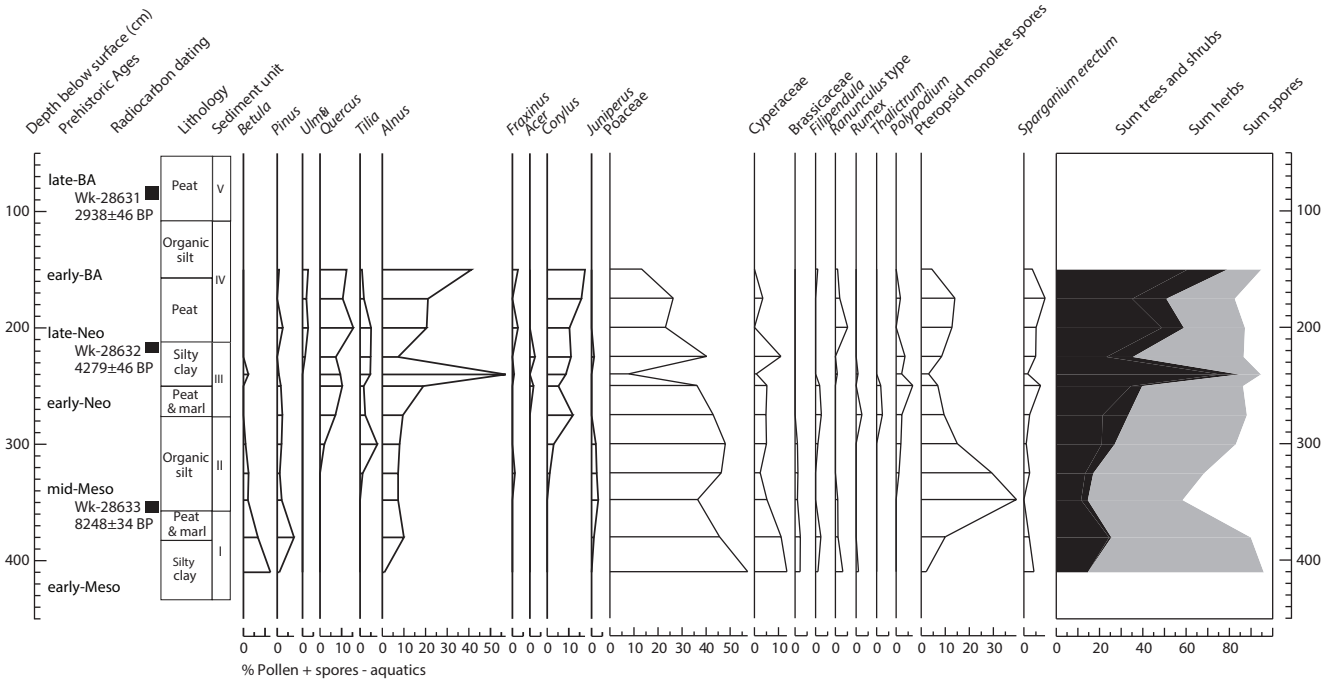

Fig. 13. Skeletal percentage pollen diagram of selected taxa from Reach Lode Bridge BH6.

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The pollen assemblages towards the top of the sequence (250 cm - 150 cm) appear to represent typical mixed-oak woodland with oak, elm (*Ulmus*), lime, ash, hazel and maple (*Acer*). The proportion of grass and Pteropsid fern spores generally declines and polypody fern spores are present throughout. Herb pollen such as meadowsweet (*Filipendula*), dock (*Rumex*) and meadow-rue (*Thalictrum*) suggests riparian (bank-side) and tall-herb communities nearby. There is apparently no evidence of arable activity or tree clearance in the upper pollen samples, which based on the radiocarbon dating must represent the early Bronze Age (ca 4,000 years calBP). The pollen sample from 240 cm is unusual in that it is dominated by alder pollen. This would suggest that alder carr was growing at the site within the river channel, and the late Neolithic (ca 4,500 years calBP) silty clay at this level certainly contains abundant wood fragments.

Radiocarbon dating

The basal AMS date (350-359 cm) is 8248±34 BP (Wk- 28633), which calibrates using OxCal (Bronk Ramsey, 2009) at 87.8% probability to 9329.5-9089.5 Cal BP, places the organic silt (detrital mud) unit (unit II) in the mid-Mesolithic (early Holocene), and records the onset of organic-rich sedimentation following earlier minerogenic deposition at the base of the palaeochannel (see Table 1).

The bulk date from the middle part of the sequence (210-219 cm) is 4279±46 BP (Wk-28632), which calibrates using OxCal (Bronk Ramsey, 2009) at 83.6% probability to 4979.5-4799.5 Cal BP, places the unit of organic silt with wood fragments and shells (unit IV) in the late-Neolithic (mid Holocene) (Table 1).

The upper bulk date (82-90 cm) is 2938±46 BP (Wk-28631), which calibrates using OxCal (Bronk Ramsey, 2009) at 95.4% probability to 3249.5-2949.5 Cal BP, places the unit of detritus mud with wood (unit V), just beneath the overlying mantle of degraded peat, in the late Bronze Age (Table 1).

Table 1. Radiocarbon dates from the Reach Lode Bridge BH6 sequence.

Sample (cm)	Number Wk	$\delta^{13}C$ ‰	Result y BP	Sediment Unit	Archaeological age
82-90	28631	−27.6±0.2	2938±46	V	Late-Bronze Age
210-219	28632	−30.1±0.2	4279±46	IV	Late-Neolithic
350-359	28633	−29.9±0.2	8248±34	II	Mid-Mesolithic

The three radiocarbon dates clearly show that the palaeochannel sediments span most of the Holocene. The average rate of sediment accumulation was approximately 0.5 mm per year, although changes in lithology could affect this average figure greatly.

Interpretation

It seems likely that the basal silty clays (unit I) date from the Upper Palaeolithic (late Weichselian – older than 11,500 years calBP), and that the onset of organic-rich sedimentation (unit II) began with the stabilisation of soils and development of vegetation cover in the mid-Mesolithic (early Holocene – ca 9,000 years calBP). It is clear that the silty clays of unit III originate from increased sediment transport and deposition during the Neolithic (ca 6,500-4,500 years calBP), possibly as result of human activity in the hydrological catchment. The organic sediments of unit IV date from the early Bronze Age (ca 3,700 years calBP) and show no sign of the first marine incursion that laid down tidal creek deposits (the Barroway Drove Beds) in the Cam valley at Upware just 2 km to the north (cf. Fig. 10). The peat of unit V dates from the late Bronze Age (ca 3,000 years calBP) and the Iron Age (ca 2,750-2,000 years calBP). It seems that sedimentation in the palaeochannel ended abruptly around 2000 years calBP, presumably as a result of the Romans constructing Reach Slade, the first artificial water course (lode) leading directly from Reach village to the River Cam.

The radiocarbon dating and pollen analyses from this sequence have shown that Reach Lode Bridge palaeochannel represents the course of a river first established in the Late Weichselian period and occupied by an active stream or fen conditions throughout the Holocene, until its drainage was superseded by a Roman canal. The Reach Lode Bridge palaeochannel sequence is of local and regional significance, since it provides a securely dated record of changing vegetation and depositional environments over much of the Holocene. The pollen diagram (Fig. 13) clearly shows a succession of vegetation from early Mesolithic boreal scrub through to Neolithic and early Bronze Age mixed-oak woodland. Although there is no pollen evidence for human activity, the Neolithic silty clay (unit III) may hint at soil disturbance (tree-felling or early agriculture) in the catchment. It also seems that the early Bronze Age marine incursion, present in much of southern Fenland, did not extend as far inland as this site. The overgrowth of peat in the Iron Age at the top of the sequence is common across much of southern Fenland.

Discussion and Conclusions

The geology map (Fig. 1) and geological sections (Figs 2-11) provide a valuable insight into the Holocene and Pleistocene stratigraphy and the bedrock structures beneath different parts of the Wicken Vision area. The pollen analysis, radiocarbon dating and stratigraphy of the palaeochannel at Reach Lode Bridge (Figs 12 & 13) give a detailed view of the changing Holocene palaeoenvironments across this area of southern Fenland.

Much of the study area is underlain by Gault Formation bedrock, with the gently dipping West Melbury Chalk Formation forming a low 'scarp' or rampart at the fen edge to the south

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and east. A synclinal-anticlinal flexure in the bedrock (the Upware Axis of Worssam & Taylor (1969)) runs NNE-SSW across the area and is followed by the modern course of the River Cam. The anticlinal flexure brings the Jurassic West Walton Formation (limestone) and Ampthill Clay Formation (mudstone) to the surface in the north of the area to form the 'Upware ridge', which separates Wicken Fen from the River Cam. The Wicken Vision area is 'closed' to the northeast by a low bedrock ridge (the Wicken ridge) capped by till attributed to the Lowestoft Formation. Thus, the low-lying fen area of the Wicken Vision resembles a broad embayment confined on three sides by bedrock landforms. Similar embayments have been identified elsewhere in southern Fenland (Burton, 1987; West, 1991; Boreham, 1996), where they have been attributed to Weichselian thermokarst activity under periglacial conditions. Thermokarst landforms are represented by near circular depressions and flat-bottomed embayments cut into clay- or silt-rich bedrock and surrounded by low rounded hills. It appears that these features were formed during the Weichselian by the same processes that operate in the arctic today. Their formation has been largely independent of fluvial processes which have formed separate terrace aggradations.

Apart from a fragment of the 3rd terrace (Arbury Member (CVF)) at Biggin Abbey (ca 12 m O.D.), and an area of 2nd terrace (Sidgwick Avenue Member (CVF)) at Horningsea (6-8 m O.D.), the remaining Pleistocene fluvial deposits in the Wicken Vision area belong to the 1st terrace. The 1st terrace deposits (Barnwell Station Member (CVF)) associated with the late-Weichselian course of the River Cam outcrop to the west of the modern river. However, a spread of 1st terrace deposits separated from the River Cam by a prominent southwest-northeast trending bedrock ridge and occupying a separate 'valley' is also present in the southern part of the study area at North White Fen (Fig. 1). These gravels and sands cannot be from the River Cam itself, but must represent the braidplain of a spring-fed tributary stream, named here as the Quy River, the ancient course of the modern Quy Water, that once ran northeast across the shallow periglacial embayment to join the main river as it flowed NNW to join the River Great Ouse. The Late-Glacial (ca 14,000 years calBP), avulsion of the River Cam through the Stretham gap created a deep channel incised to at least -8 m O.D. at Upware. The gravel and sand occupying this late-Glacial channel is the Midsummer Common Member (CVF).

In the early Holocene, deeply incised late-Glacial palaeochannels from the River Cam and its tributary streams crossed the Wicken Vision area. It appears that fluvial deposition from the Upper Palaeolithic through to the mid-Mesolithic period (ca 11,500-9,000 years calBP) is represented by a unit of basal silty clay (e.g. unit I in Fig. 12). The landscape in this boreal period was dominated by birch and pine scrub in a largely grassland setting. Later Mesolithic and Neolithic (ca 9,000-4,500 years calBP) organic sediments at first accumulated in deeper palaeochannels forming the 'lower' detrital peat (e.g. unit II in Fig. 12). These sediments are coeval with the spread of mixed-oak woodland across the area. There was a brief period of silt accumulation in the mid-Neolithic (ca 5,500 years calBP) (e.g. unit III in Fig. 12). However, due to rising water tables as a result of the approaching marine influence in the early Bronze Age (ca 3,700 years calBP), freshwater fen and marsh conditions spread across most low-lying areas allowing the accumulation of detrital peat (e.g. unit IV in Fig. 12). Tidal creek and saltmarsh deposits (Barroway Drove Beds) can only be seen at Upware, close to the limit of the marine inundation.

During the late Bronze Age and early Iron Age (ca 2,500 years calBP), freshwater fen environments persisted, allowing continued peat accumulation equivalent to the 'upper' (Nordelph) peat across the Wicken Vision area (unit V in Fig. 12). In parts of the Cam floodplain, the 'upper' peat is overlain by an alluvial silty clay often referred to as the 'Romano-British silt'. This material began accumulating in the mid-Iron Age (ca 2,250 years calBP), and represents over-bank sedimentation from flood events driven by tree clearance and soil erosion in the hydrological catchment of the River Cam. Boreham & Rolfe (2009) provide a discussion of these events in the Cam catchment. Straightening of the River Cam and the tributary lodes, together with the 17th Century drainage of the fen peats for agriculture has led to elevated artificial levee banks, which carry flood-waters away from low-lying areas. Across the study area, apart from Wicken Fen nature reserve, the land surface has become much lower (ca 2 m reduction in elevation) as peat has become oxidised, desiccated and deflated due to drainage and agricultural activities (Friday & Rowell, 1997). Little or no peat cover remains over the 1st terrace deposits at Bottisham Fen and Stow-cum-Quy Fen, and at the fen margin.

It is clear that the Wicken Vision area has been moulded by a unique combination of the structural bedrock geology, Late Weichselian periglaciation and fluvial activity, and by the overgrowth of Holocene peat, to form a discrete area of Fenland with unique characteristics. However, the configuration of Weichselian and Holocene deposits at the entry of the River Cam into southern Fenland is a microcosm of the situation where larger rivers such as the Great Ouse, Nene and Lark also enter the Fenland Basin, which is effectively a southward extension of The Wash and the southern North Sea (cf. Boreham et al., 2010).

The Wicken Vision has a rich and varied landscape history that manifestly deserves recognition in the current conservation efforts of the National Trust, and the author hopes that this study will assist with the interpretation and future management of the Wicken Vision area.

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