

The anatomy of a Fenland roddon: sedimentation and environmental change in a lowland Holocene tidal creek environment

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SUMMARY: A Holocene sand/silt-filled tidal creek, locally called a roddon, excavated at Must Farm near Whittlesey, Cambridgeshire, within the English Fenland, preserves an unprecedented record of Fenland tidal creek evolution. The tidal creek was formed sometime between c. 4735BP and c. 3645BP. Its infill comprised centimetre-scale, laminated, tidal sand-mud couplets, numbering some 600 in total, with microfossils that show marine and coastal derivation of the sediment. The nature of the infill suggests rapid sedimentation that choked the creek system, perhaps in as little as a few years. At least three successive generations of roddons are present in the Fenland, suggesting at least three distinct episodes of tidal creek formation. The Must Farm roddon belongs to the first

generation. A later, mud-filled channel was subsequently incised into the roddon, perhaps initiated by a marine surge. It quickly transformed into a slowly flowing river, as suggested by molluscs, ostracods and diatoms. Infill of this late-stage channel was slow, perhaps over about 1200 years between c.3250 and 2050BP (c.1300 -100cal BC), as shown by archaeological finds. The mud-filled channel superficially resembles late-stage, organic-rich, channel infills visible on aerial photographs, but is wider and deeper and might have been part of a more substantial long-lived 'river', perhaps a tributary of the proto-Nene.

SUPPLEMENTARY: material is available at: <http://www.geolsoc.org.uk/SUP18584>.

The mid to late Holocene deposits of the Fenland of eastern England include exceptionally preserved tidal creek networks, locally known as roddons (Smith *et al.* 2010). Roddons represent former watercourses in the Fens and are now raised banks of silt and fine sand. They have proved ideal for human settlement as they are firm, stable and slightly elevated. Over the last century, roddons have become progressively exposed as the former thick layer of overlying peat has been stripped away by wind erosion, oxidation and modern farming methods, following the drainage of the Fenland (Godwin 1978; Waller 1994). While the overall stratigraphy and spatial distribution of the roddons can be determined by a combination of field mapping, auger sampling and the analysis of aerial photographs and IFSAR and LiDAR images (Horton 1989, Smith *et al.* 2010), details of sedimentary structures and textures have only occasionally been visible. Rare exposures are available immediately after drain/ditch sections are cleaned, and even then only the deposits above the water table may be observed. However, during 2006–2007, excavations at Must Farm, Whittlesey, Cambridgeshire (National Grid Reference [TL 235 968]), were carried out by Cambridge Archaeological Unit (University of Cambridge). The excavations revealed an ancient river channel with evidence of a Bronze Age settlement. Further excavations in 2009 revealed that this had been incised into a large roddon (Figs 1-3).

This paper describes the three-dimensional geometry, sedimentology and palaeontology of the roddon deposits and of the later freshwater late-stage channel at Must Farm (Figs 3, 4). These data are used to infer the mechanism of roddon formation and the late-stage channel and the provenance of the sedimentary infill, as well as to establish a model of the evolution of this low-lying, marine-influenced wetland during the Holocene.

1. GEOLOGICAL CONTEXT

The Fenland of eastern England covers areas of Lincolnshire, Cambridgeshire, north Norfolk and parts of Suffolk, and comprises the largest area of Holocene deposits (c. 4000 km²) in Britain. The Holocene succession, which is up to 15 metres thick, preserves a complex palaeoenvironmental history. The marine transgression that flooded 'Doggerland', 8000–6000BP (Ward *et al.* 2006; Weninger *et al.* 2008), reached its maximum extent between 4000 and 3000BP (Brew *et al.* 2000). Clay units, which broadly represent marginal marine salt marsh palaeoenvironments, are interbedded with peats that are the remains of freshwater reed beds, and accumulated ca 6000 to 2000BP (Zalasiewicz 1986; Smith *et al.* 2010 and references therein). Superimposed on the salt marsh clays are networks of silt/sand-filled tidal creeks, the roddons or 'silt hills', which are preserved as a dendritic system of ridges, the result of differential compaction following the drainage of Fenland in the 1600s (Smith *et al.* 2010). Regional mapping by the British Geological Survey identified at least three stratigraphically discrete generations of roddons, suggesting three major marine incursions into the Fenland (Horton 1989; Smith *et al.* 2010). The Must Farm roddon is identified as a first generation roddon (Smith *et al.* 2010) and is situated at least 34 km inland from the contemporaneous palaeocoastline.

Must Farm is situated on the southern side of the Flag Fen Embayment (Hall & Coles 1994; Pryor 2001) and adjacent to King's Dyke, a man-made water course, at the western end of Whittlesey 'island' (Hall 1987; Waller 1994; Pryor 2001). The area is underlain mainly by Pleistocene

gravel, sand and till that rest on the underlying bedrock, the Jurassic Oxford Clay Formation (Booth 1982; British Geological Survey 1984; Hall 1987).

The oldest deposits seen at Must Farm are unconsolidated Pleistocene gravels (Figs 3, 4). They contain carbonate clasts that range in size from coarse sand to sub-angular to rounded clasts up to 7cm in maximum dimension. The thickness of the Pleistocene gravels was not determined as the base was not seen. Overlying the gravels are two units, each a few centimetres thick, which archaeologists term 'buried soil' and 'flood silts' (Fig. 4). Above these lies the regional Holocene Fenland succession (Hall 1987; Horton 1989), in which the Basal Peat (Lower Peat of Horton 1989) and Nordelph Peat are separated by clays of the Barroway Drove Beds. The Basal Peat is 10–15 cm thick and is made up of fibrous material including fragments of wood and plant material. It has been dated in this area over a distance of c.2.5km to between c. 5090± 30BP (SUERC-22222), or 3970-3790cal BC, to the south and east of Must Farm, and 4735±30BP (SUERC-22202), or 3640-3490cal BC, to the west of Must Farm (Dr. B. R. Gearey, Birmingham Archaeo-Environmental, Birmingham University, pers. comm., 2010).

The roddon at Must Farm cuts through the Barroway Drove Beds and Basal Peat to rest on the Pleistocene gravels and is blanketed by the Nordelph Peat and alluvium. The Nordelph Peat is a brown desiccated peat containing many plant and root fragments. It has been dated over a distance of c.2.5km to between 3645±30BP (SUERC-2219), 2060-1920cal BC, to the south and east of Must Farm, and 2090±30BP (SUERC-22218), 200-40cal BC, to the west of Must Farm (Dr. B. R. Gearey, Birmingham Archaeo-Environmental, Birmingham University, pers. comm., 2010).

Other roddons in the area are found along the River Nene Counter Drain, the best example being at National Grid Reference [TF298002], near the Dog and Doublet road bridge, c. 5km NE of Must Farm. These are also underlain by Quaternary gravels and identified as first generation roddons (Smith *et al.* 2010).

2. METHODOLOGY

For this study, the roddon face was cleaned using a draw hoe and trowel so that the sedimentary succession became visible and the primary surfaces could be logged at centimetre-scale. Logging was undertaken at three points (Fig. 4, L1-L3) to determine the sedimentological patterns in the centre and along the margins of the roddon channel. The entire sedimentological succession of the roddon was photographed in order to make a detailed and permanent record prior to the removal of the roddon by quarrying. The deposits of the late-stage channel (Fig. 4) were also logged and photographed.

Thirty-one sediment samples, each comprising c.1kg of sediment, were collected from the roddon. Nineteen samples were analysed in the laboratories of the University of Leicester following the Buoyocos (1928) system of particle analysis (40g for each sample) in order to determine grain size distribution in the roddon. Nine samples from the late-stage channel (Fig. 4) were also prepared for particle analysis. The sediment fractions recovered are stored in the Department of Geology, University of Leicester.

Nine samples, each 50–60g, were selected for microfossil analysis, four from the roddon (MPA 61281-61284) and five from the late-stage channel (MPA 61285-61288, plus MPA 61673 from c.200m further upstream). Samples were soaked in warm water in order to disaggregate them and were then wet-sieved in nested sieves of 500, 355, 212, 180, 125, 90 and 63 μ m mesh. The dry residues were picked for foraminifera and ostracods using a Leica binocular microscope and selected specimens were studied using a Hitachi 3 – 3600N scanning electron microscope in the Department of Geology, University of Leicester, UK. Samples and specimens are housed in the museum collection of the British Geological Survey, Keyworth, Nottingham, UK. Diatoms were also noted and a few samples were prepared using standard methods (Batterbee *et al.* 2001) in order to undertake

a preliminary study. At least 300 specimens were counted for each slide at 1000× magnification, with results expressed as percentages of the total diatom sum. The diatom slides are housed in the museum collection of the British Geological Survey, Keyworth, Nottingham, UK.

Other fossils recovered include leaf tissue of willow (*Salix* spp.), fragments of wood, molluscs (gastropods and bivalves), fish and cyprinid pharyngeal teeth, and scolecodonts (Mark Purnell, pers. comm., 2011,). Occasional beetle carapaces were noted in the microfaunal samples.

3. SEDIMENTOLOGY OF THE RODDON

3.1. Geometry

The roddon channel at Must Farm measures c. 60m across the Y-Y' section and is c. 4.5m deep at its maximum point (Figs 3, 4). In cross-section, the roddon is flat-bottomed. On the basis of its size, it appears to be a tributary roddon; trunk roddons are typically much larger (Smith *et al.* 2010). A trunk roddon at Popley's Gull [TF299001], c. 7.5km ENE of Must Farm, for example, is c. 270 to 346m wide, depending on the section measured (Hall 1987, fig. 29; Horton 1989, fig. 14). It cuts through the Barroway Drove Clay Beds and the Basal Peat. The roddon channel has now been excavated away, but it was mapped out for c. 70m in the adjacent area.

3.2. Roddon lithofacies

The Must Farm roddon channel was filled with unconsolidated fine sand and silt that was rhythmically interlaminated with silty mud. Grain size varied from clay to medium sand (212µm) and showed a fining-up motif at the top of the channel (Fig. 5), consistent with the regional trend (Smith *et al.* 2010). The coarser layers were well sorted, contained sub-rounded quartz grains and were mica-rich. Sediments exposed in section Y-Y' (Fig. 4) contained some organic detritus within a fine-

grained matrix. The channel deposits seen in sections X-X' and Y-Y' (Fig. 4) were pale grey in colour but those towards the top of the roddon in Z-Z' were pale brown/yellow and orange.

Sedimentary structures were clearly visible on the cleaned roddon surface. The most striking pattern was a primary sedimentary interlamination or interbedding of mud and fine sand to produce sand-mud couplets. This varied from mm-scale to cm-scale with distinct stratigraphic variations that we describe further and analyse below. The sand layers varied from approximately continuous over the scale of a cleaned section to being lenticular and discontinuous, the lenticularity in part at least representing ripple-forms (Fig. 6F, H). Sand-mud contacts typically appeared sharp, though they were commonly obscured by smearing associated with cleaning.

The lower part of the roddon channel-fill appeared to show continuous sedimentation of the sand/mud couplets with no obvious breaks or truncations. The upper part of the infill included clear evidence of episodic sedimentation, with truncation surfaces separating substantial packets of continuous sedimentary deposit (Fig. 6C).

Commonly, the sand/silt bedding in the upper part of the roddon successions also showed wet sediment deformation (Fig. 6B, D, E). All three sections (Fig. 4, L1-L3) showed evidence of slumping that included slid blocks and plastically folded and convolute bedding at the northern channel margins (Fig. 6D), but no such evidence was seen on the exposed southern side. The slumping and convolute bedding indicated soft sediment deformation of partially lithified sediment soon after rapid deposition (Leeder 1982; Nichols 1999) and that the beds were unstable (Prothero & Schwab 1996).

There was no evidence of bioturbation within the roddon channel-fill itself, although there was pervasive burrowing into the roddon at the base of the superimposed late-stage channel (see below).

3.3. Interpretation

Given a marine-influenced tidal setting, it is most likely that the repeated alternation between mud and sand ripple deposition reflects an alternation of suspension settling of mud during high/low water stillstands and tractional transport and deposition of sand with ebb/flood currents. Therefore, the sand-mud couplets most plausibly are tidal bundles (Visser 1980; Kreiser & Moiola 1986; Stupples 2002; Choi & Dalrymple 2004).

The uninterrupted succession in the bottom of the roddon section suggests continual deposition in subtidal conditions. The higher part of the succession, with visible breaks, was probably deposited in intertidal conditions once the roddon had aggraded sufficiently for subaerial conditions to develop intermittently during ebb phases. Similarly, the local slumping in the higher parts of the succession suggests the development of gravitational instabilities and wet sediment deformation, especially during phases of emergence. However, no evidence, such as desiccation cracks or flat pebble conglomerates, was found of the channel drying out for any length of time.

Visual inspection of the cleaned surface of the roddon showed that the sand/silt-mud couplets are arranged in clusters of alternately thinner and thicker couplets (Fig. 6F), each cluster comprising between 10 and 20 couplets, and with the boundaries between the clusters typically being gradational. Thus, the couplets progressively thicken and then thin from one cluster to another. Sequential variations in the laminae were seen in cleaned roddon sections.

To analyse this phenomenon further, the thickness of the couplets was measured from scaled photographs at three sections and plotted into time-series diagrams (Fig. 7). Counts of the individual sand/mud couplets were taken from the base to top of the roddon section from the photographic evidence, as exactly as possible, with special regard to the numbers of thicker and thinner couplets. This showed that clusters comprise 8 to 19 sand-mud couplets, with an average of just over 13. This is reasonably close to a diurnal tidal cycle of 14 (Visser 1980; Kreiser & Moiola 1986; Stupples 2002; Choi & Dalrymple 2004), perhaps consistent with spring-neap influence on

sedimentation. This interpretation is tentative. The tidal currents in any event were likely modified by such factors as local weather patterns, including storms, influence of the semi-diurnal tidal period, and the possibility that not every incoming-tide reached so far inland, given the length of the tidal path (cf. Skertchly 1877).

Thus, we propose that there is good evidence for tidal control on these deposits, in the form of tidal bundles, and that there is some evidence, though not conclusive, that these are clustered into spring-neap cycles, each cluster relating to an increase and decrease in tidal velocities (Visser 1980; Kreiser & Moiola 1986; Choi & Dalrymple 2004). Given this interpretation, order-of-magnitude estimates of the rates of aggradation and roddon infill may be made.

A count of the tidal couplets from the base to the top of the exposed roddon numbered c. 600. Using this estimate, an inference that 14 bundles approximate on average to one lunar month of sedimentation, and assuming a local system that is dominantly diurnal, the roddon channel infill represents less than a decade of deposition, not including sedimentary breaks higher in the succession. In the lower part of the channel, aggradation appears to have been essentially continuous, with up to a few centimetres of sediment accumulating over the course of a single tidal cycle (Fig. 7). Higher in the channel, the evidence of erosional breaks and slumps indicates breaks in sedimentation. Nevertheless, the successions preserved within individual cross-sets and slump packets in the upper part of the succession continue to show approximately centimetre-scale tidal couplets, while the general absence of bioturbation further suggests that rates of sedimentation were too rapid to allow colonization by a burrowing benthic community. This suggestion of rapid infilling is consistent with regional evidence for a rate of infill that was too rapid for point-bar development during roddon formation (Smith *et al.* 2010), hence preserving the pristine meandering channel form in plan view.

4. MICROPALAEONTOLOGY

In order to further constrain the environmental setting of the roddon, the sedimentary deposits were analysed for calcareous and siliceous microfossils (foraminifera, ostracods and diatoms).

4.1. Foraminifera

Foraminifera from the four roddon samples analysed (MPA 61281–61284; Fig. 4, R1–4) were typical of environments that ranged from high marsh to inner marine shelf (Fig. 8). The hyaline species *Ammonia beccarii* and *Haynesina germanica* are frequent (10–24%) to common (25–50%) or abundant (>50%) in all four samples, and *Elphidium williamsoni*, another hyaline species, is frequent in MPA 61283 and rare (2–9%) or very rare (c.1%) in the other three samples (Fig. 9). Agglutinated taxa are less common, but include *Jadammina macrescens*, which is frequent in MPA 61281 and rare in the other three samples, and *Trochammina inflata*, which is rare or very rare throughout. These forms are considered to be autochthonous and their association clearly indicates a low marsh setting (Fig. 8). Marine taxa (e.g. species of *Bulimina*, *Oolina*, *Lagena*, *Rosalina* and *Quinqueloculina*) are present throughout the roddon, and although they are diverse (27 species), they are considered to be allochthonous; individual species are generally patchily distributed through the succession (Fig. 9), are rare or very rare, and form a relatively low proportion of the assemblages as a whole (Supplementary data, table 1).

The autochthonous foraminiferal assemblages in the Must Farm roddon thus suggest that deposition took place in a low marsh setting and that the microfauna would have been living somewhere within the roddon channel environment: *Jadammina macrescens*, *Miliammina fusca*, and *Trochammina inflata* can be considered as typical of coastal salt marshes (e.g. Phleger 1970, 1977; Murray 1971; Evans *et al.* 2001; Horton & Edwards 2003; Gehrels & Newman 2004; Boomer *et al.* 2007). The allochthonous marine taxa were probably carried up the creek system, within the fine grained sediment, by tidal currents. The assemblages appear to have little damage and specimens

are of very small dimensions, suggesting that they were transported by low energy currents. A few tests show borings and may have been predated upon by gastropods.

An uncalibrated radiocarbon age for foraminifera gave a date of $5345 \pm 30\text{BP}$ (Fig. 11). This appears to be too old for this part of the sequence and possibly indicates the presence in the dated material of older, reworked calcareous forams. A very few taxa, forming a low proportion of the assemblage from each sample, were reworked from Jurassic, Cretaceous and Pleistocene deposits (Fig. 9, Supplementary data, table 2).

4.2. Ostracods

Twenty species of ostracods were recovered from the roddon silts (Fig. 9), although they were generally rare and no sample yielded more than 48 specimens. As with the foraminifera, the preservation was good with occasional articulated carapaces being recovered, some of which show borings. Unlike the foraminifera, ostracods are rare in the roddon samples so it was not possible to determine their population structure or to distinguish the allochthonous from the autochthonous species.

The ostracod assemblages, like the foraminifera, include both marine and brackish species (Fig. 9, Supplementary data, table 2). Six species were marine, seven estuarine, four marine/estuarine and two estuarine/saltmarsh (cf. Supplementary data, table 2). The one freshwater ostracod specimen *Cytherissa lacustris*, recovered from MPA 61282 (Fig. 9), was probably reworked. Shallow marine species, which include *Callistocythere littoralis*, *Hemicytherura cellulosa*, *Neocytherideis subulata* and *Sarsicytheridea bradleyi*, form a small proportion of the overall fauna. Brackish species, found in salinities associated with estuarine and estuary mouth environments, are more numerous and include *Cytherois fischeri*, *Leptocythere lacertosa* and species of *Semicytherura*. Three estuarine to low marsh ostracods are worthy of note. *Leptocythere castanea* is a brackish-

water species found in estuarine and salt marsh environments on mud and algal substrates.

Leptocythere porcellanea is confined to brackish waters and is generally found on muds in sheltered creeks. *Loxoconcha elliptica* is confined to brackish estuaries, lagoons and pools, usually on mud and algal substrates. Therefore, although it is not possible to recognize the ostracod biocoenosis, the preponderances of estuarine and brackish water species complements the conclusions drawn from the foraminiferal associations.

4.3. Diatoms

The roddon silts (sample MPA 61282) yielded a microflora dominated by marine-brackish taxa (82%), especially *Delphineis minutissima* (46%) and *Cymatosira belgica* (15%) (identifications follow Krammer & Lange-Bertalot 1986, 1988, 1991a, b; Hartley 1966; Witkowski *et al.* 2000). Freshwater taxa were also found in the sample (18%) and included *Gomphonema olivaceum* (3%) and a number of species in the genera *Navicula*, *Achnanthes* and *Fragilaria*. The dominance of marine-brackish taxa suggests a tidal channel, consistent with data from analysis of the foraminifera and ostracods (Fig. 9).

4.4. Summary of micropalaeontological data

The foraminifera and ostracods recorded in the roddon samples were a mixture of marine and brackish water species. A high percentage of the Holocene foraminifera species are considered to be autochthonous and indicative of a low marsh (mud/silt) environment. Ostracod species found in salinities associated with estuarine and estuary mouth environments are also more numerous than shallow marine species. The marine forms are considered to be allochthonous and to indicate that the microfaunas were transported into the roddon tidal creeks by relatively low energy currents. A diatom assemblage recorded from one sample is dominated by marine-brackish taxa, which also

suggest a tidal channel. A low proportion of foraminifera present were reworked from Jurassic, Cretaceous and Pleistocene deposits.

5. LATE-STAGE CHANNEL SEDIMENTARY DEPOSITS

The late-stage channel lies towards the northern side of the roddon and is c.33m across and c. 2.8m deep (Figs 3, 4). This section of the channel is asymmetrical with a steeper northern margin (see Fig. 3). The channel is the first such late-stage channel that we have analysed in detail. The contact between roddon and late-stage channel is sharp and erosional. The late-stage channel appears at first sight to be representative of a regional pattern in final diminution and closure in Fenland roddon channels, apparently corresponding to late-stage organic-rich infills seen in aerial photographs of many roddons in the region. In one such example near Thorney (Fig. 1), identified as a second generation roddon (Hall 1987, Waller. 1994), the closure is seen as a thin sinuous dark line running along the roddon channel. However, the Must Farm late-stage channel also appears to be significantly wider and deeper than these other regional late-stage features (Smith, Zalasiewicz, pers. obs.) and may represent a different phenomenon.

At the base of the late-stage channel, burrowed into the roddon tidal creek deposits, were *Thalassinoides*-like trace fossils (Fig. 10B, C). *Thalassinoides* is typically ascribed to the feeding and dwelling burrows of marine crustaceans (Lindholm 1987). Above this burrowed surface there is a striking change in sedimentary composition to dominantly fine, dark grey, organic-rich sediments that infill the late-stage channel and indicate a change in sediment source and flow regime. The bioturbated erosional interface represents an interlude, likely brief, as or just after the late-stage channel was incised.

The Must Farm late-stage channel was filled largely with unconsolidated silt and mud. Very fine lamination was visible in the lower part of the section with fine layers (< 1mm scale) that were

richer in black organic material. The clays in the upper part of the succession appeared massive, apart from the shelly layers described below. Grain size varied from clay to medium sand (>212µm). The sediments contained some mica, detrital material, sea-transported coal and charcoal (J. and S. Boreham, pers. comm., 2012,) and the particle analyses showed an overall fining-up signature (Fig. 5).

The late-stage channel succession comprised fine mud with distinct layers of shelly material in the lower section of the channel (Figs 4, 10A). At least four shelly layers were present, showing up as pale bands against the darker grey muds (Fig. 3). They were composed of mostly intact shells, many of which were freshwater mussels. Many of the smaller gastropods and bivalves remained intact too. Scattered mussel shells, mostly complete, lay within the deposits higher up the channel. Some specimens were edged with blue colouring from vivianite, an iron phosphate mineral locally occurring in clays and glauconitic sediments, replacing organic material, peat and forest soils (<http://www.mindat.org/min-4194.html>, accessed 7/5/2012). Borings were noticeable in several specimens.

The overall character of the sediment suggests much slower currents than those that characterized the roddon. However, detailed interpretation is made here via a combination of sedimentological and palaeontological evidence, and is given below following the description of the fossil content.

6. PALAEOLOGY OF THE LATE-STAGE CHANNEL

6.1. Foraminifera

A major change in the foraminiferal association takes place across the junction between the roddon silts and the late-stage channel muds. Foraminifera are rare in the late-stage channel, are of small dimensions, and the species recorded are almost entirely calcareous. A single specimen of the

agglutinated form *Jadammina macrescens* was found. Five species of foraminifera were recovered from the late-stage channel clays (Supplementary data, table 3), although they were rare and no sample contained more than 24 specimens. The most abundant are *Ammonia beccarii* and *Haynesina germanica* at levels MPA 61285 and MPA 61286. A lone specimen of *Planularia* sp., possibly reworked from Jurassic sediments, was retrieved from the uppermost clay sample (MPA 61288), together with *Elphidium exoticum*, an estuarine species and fairly common in the roddon silts. The most common forms are index species for low marsh/tidal flat and estuary environments (Fig. 8), as described in previous microfaunal studies on estuaries and tidal creeks (Macfadyen 1938; Murray 1983, 1991, 2006; Boomer & Godwin 1993; Waller 1994; Boomer 1998; Frenzel & Boomer 2005; Boomer & Horton 2006). These specimens are considered to have been reworked from the roddon silts during periodic high energy conditions, such as during the formation of the shell lags.

6.2. Ostracods

A list of ostracod taxa recovered is given in Supplementary data, table 4. *Candona neglecta* is a common and widespread species, tolerant of brackish conditions but preferring cooler waters in streams and ponds fed by spring water (Meisch 2000). *Limnocythere inopinata* is another wide-ranging species, occurring in ponds, swamps, ditches, lakes and slow moving waters. It can also be found on muddy or sandy substrates. *Darwinula stevensoni* also prefers freshwater streams with a preference for sandy or muddy substrates at depths of 0–12 metres (Meisch 2000). *Cyclocypris ovum*, one of Britain's commonest and smallest ostracods, is abundant in still freshwaters, but has not been found in flowing or brackish waters (Henderson 1990).

The ostracods all indicate a freshwater environment. The majority of the species favour clean, slow-flowing or still waters and some prefer to have vegetated environs. The thin-shelled ostracods show good preservation and little evidence of transportation. The fact that the more

common species are represented by several moult stages suggests that they were living in the freshwater channel.

6.3. Diatoms

The clay of the channel (sample MPA 61286) yielded a diatom assemblage entirely dominated by freshwater periphyton, especially *Staurosira pinnata* (41%), *Amphora pediculus* (12%), *Staurosira construens* var. *venter* (8%) and *Pseudostaurosira brevistriata* (6%). Forty species were recorded, especially in the genera *Gomphonema*, *Cocconeis*, *Achnanthes* and *Navicula*. The predominance of periphytic diatoms suggests shallow water with abundant aquatic macrophytes.

6.4. Molluscs

Some 17 species were recovered from the late-stage channel, with 47 specimens from MPA 61285, 86 from MPA 61286, 10 from MPA 61287 and 22 from MPA 61288 (Supplementary data, table 5). Several bands of *Unio tumidus*, seen extending across the channel in section X-X' (Fig. 3), showed as paler beds against the darker clays. Many of the shells were well-preserved and complete, though they were not in life-position, and even fragile taxa such as *Acroloxus lacustris* were recovered whole. The mollusc species in greatest abundance were *Pisidium nitidum*, *P. moitessierianum*, *Valvata cristata* and *V. macrostoma*. *P. nitidum* and *V. macrostoma* were recorded from all four levels sampled. *Viviparus viviparus* and *Radix labiata* were also found frequently. One freshwater mussel has been radiocarbon dated to 3687BP \pm 35 (SUERC-37485) (Fig. 11).

All 17 mollusc species present in the late-stage channel are exclusively freshwater taxa. The most abundant are *Acroloxus lacustris*, *Pisidium henslowanum*, *P. moitessierianum*, *P. nitidum*, *Radix balthica*, *Valvata cristata*, *V. macrostoma* and *Viviparus viviparus*. There is much cross-over in environmental preferences from species to species and these are summarized below (Ellis 1926; Jokinen 1992; Glöer & Meier-Brook 1994; Visser & Veldhuijzen van Zanten 2000; Welter-Schultes

2009). *Acroloxus lacustris* is a small, very delicate river limpet that inhabits slowly flowing, highly vegetated, highly oxygenated and clean water, and lives by attaching itself to the stems of aquatic plants. It prefers pH levels of 6 to 8.9, can tolerate both hard and soft water, and has a depth range of <13m. The good preservation of the shells is interpreted as further evidence of a low-energy environment.

Pisidium henslowanum and *Pisidium nitidum* can inhabit both flowing and still water, as long as it is also clean, highly vegetated and well oxygenated. Along with *Valvata macrostoma*, they can also be found in marsh drains in the present day, although in the case of *V. macrostoma*, this is its only habitat. *Pisidium henslowanum* and *Pisidium nitidum* are tolerant respectively of moderately hard, and hard and soft water, and have respective maximum depth tolerances of 25m and 20m.

The other taxa share similar characteristics. *Pisidium moitessierianum* inhabits slow-flowing or still water, with a substrate of sand to fine mud and high oxygen content. *Radix balthica* is slightly more unusual in that it prefers gravel or sand as its substrates, but otherwise prefers similar conditions. *Valvata cristata* inhabits slow-flowing or still water, with a muddy substrate, high oxygen content and salinity of $\leq 0.5\%$. Finally, *Viviparus viviparus* prefers a pH range of 6.8 to 8.6, and has a salinity tolerance of up to 3%.

This assemblage clearly suggests that the late-stage channel represents a body of slowly flowing, clean, highly vegetated, well oxygenated and moderately hard freshwater, with, most likely, a muddy substrate of approximately neutral pH, and a depth of only two or three metres, indicated by the depth ranges of *Radix balthica* and *Bythinia leachii* of 0.2–2m and <3m, respectively (Supplementary data, table 6). The position of the shells in lags suggests that these were washed in during higher energy events in the channel. A freshwater mussel gave a radiocarbon date of $3687 \pm 35\text{BP}$ (SUERC-37485) (Fig. 11). The date is questionable and may be too old due to reworking of the specimen.

6.5. Archaeology of the late-stage channel

The roddon produced no archaeological finds other than human and animal footprints along a trackway on its surface. In contrast, the late-stage channel yielded a number of Bronze Age artefacts, providing significant new evidence for patterns of Fenland life (Symonds 2012) during occupation over about a thousand years. Amongst the finds are a number of log boats (nine in September 2012), discovered at different levels in the late-stage channel. The channel also encloses eel traps and willow fish weirs, and a number of Bronze Age and later Iron Age swords and spears were recovered. Several bowls containing charred food were found near to a timber platform built into the channel, which had been burnt in a catastrophic fire before the site was abandoned (Fig. 11).

7. DISCUSSION

The tidal channel now represented by the roddon at Must Farm was incised into the Basal Peat and Barroway Drove Bed clay deposits (Fig. 6G). The mechanism for incision of the tidal channel remains unclear, but it would have presumably acted to supply seawater and sediment to the mud flats and salt marshes towards the end of this local marine-dominated phase, as was the case regionally in the Fenland (Smith *et al.* 2010). The roddon deposits exposed at Must Farm clearly show that once infill began, it was accomplished rapidly. The lower part of the fill is continuous, the tidal couplets suggesting that it took some 1–2 years to partially choke the channel. Subsequent infill includes erosional and slump events and erosional gaps. As the overall character of the tidal deposits in the preserved packets is very similar to that of the lower deposits, however, with cm-scale sand-mud couplets inferred as tidal bundles and an absence of bioturbation, we suggest that complete infilling of the roddon was accomplished over at most a few decades. The archaeological dates suggest that this had been completed some time before 3250BP (1300cal BC), though the wide range of

radiocarbon dates obtained for the peats suggest that these do not provide a close constraint on events. With this conduit to the sea now cut off, marine influence would have receded and the area presumably converted into freshwater reed swamp that began the prolonged deposition of the Nordelph Peat across this area. The sediment-choked roddon then effectively acted as a pathway for the Bronze Age inhabitants of the area, its compacted sandy deposits offering a firmer and drier surface than the surrounding swamps and saltmarsh.

Some undetermined time after roddon infill, incision of the late-stage channel took place. This seems to have been abrupt and we infer that the inrush of waters that caused this pronounced erosional event likely derived from the sea, perhaps as a catastrophic storm surge, rather than as a fluvial flood. The notion of initial marine incision is supported by the probable marine bioturbation horizon at the channel base.

Subsequent infill of the late-stage channel, in contrast to that of the roddon, was exceedingly slow, as shown by the rich archaeological stratigraphy, though the system became a freshwater one very shortly after incision, as indicated by the palaeontological evidence. The channel acted as a conduit for very slow-moving fresh waters for over a millennium, being filled in with fine silty clays, with occasional shelly material perhaps swept in during storms, and seasonal leaf fall from the willows that grew on its banks. There is no evidence for further marine incursion via this conduit. Its relation to the late-stage, dark organic-rich structures that are commonly visible along roddons in aerial photographs is uncertain. Initial examination of the latter suggest that they are thinner and shallower (Smith, Zalasiewicz, pers. obs.), but systematic comparison has yet to be made.

More widely, the interpretation of roddons as fossilized tidal creek systems is generally accepted but their development has been subject to much discussion (see Smith *et al.* 2010 for a review). The incision of the channels and the infill must be regarded as two separate events, related to two different combinations of environmental factors. In between the two events of incision and

infill, the balance between erosion and the scouring of the roddon floor, which tended to maintain it as an effective channel, and the landward transport and deposition of the silts and sands, tending to block the channel, must have shifted markedly. The cause of the choking and silting up of the channel might be ascribed to events external to the local Fenland at this time in the Holocene. Plausibly, storm activity in the North Sea may have redistributed large amounts of sediment in the Wash area. Changes in tidal geometry of the sand flat/tidal inlet region may have influenced the sedimentation/erosion balance in the creek system, with silting up as a consequence of regional sedimentary accumulation also affecting the tidal geometry. This model fits the Dutch Holocene pattern of sedimentation ascribed to shifting tidal inlets in a barrier-bar system (De Mulder & Bosch 1982). Very large volumes of silt and sand have clearly been brought inland to fill the roddon networks, including the example described here, the microfossils showing that all the silt and sand are from marine sources with no significant land-derived material being present. This study adds to the regional evidence (Smith *et al.* 2010) that suggests very rapid, indeed, geologically instantaneous, infill of the roddon system once conditions had changed to allow systematic aggradation. It is all the more striking given that the Must Farm roddon is near the most distal, inland part of the Fenland roddon network.

The river channel that formed after the roddon was infilled was navigable and formed part of the life of a community that probably depended on it for food, trade and transport. This late-stage channel may have been part of the ancient River Nene system, one of Fenland's four major rivers (Nene, Great Ouse, Witham and Welland). This section of the early Nene, if such it is, then became a backwater in the Late Bronze Age as it began to silt up, a more southerly course then being taken, linked to Whittlesey Mere, which was beginning to form (David Hall, pers. comm., 2012).

8. CONCLUSIONS

Detailed sedimentological and palaeontological assessment of the tidal and late-stage channels at Must Farm in the English Fenland indicate:

1) The rapid sedimentation and choking of the tidal channel, perhaps in as little as a few years.

Microfaunas and microfloras in the roddon silts show marine influence, despite the fact that published palaeogeographies (Smith *et al.* 2010) place Must Farm at least 34 km from the palaeocoast. Overall, the allochthonous element of the foraminiferal population is diverse, although individual species are represented by only rare individuals that are patchily distributed through the succession. Their small dimensions reflect transportation by low velocity tidal currents. The autochthonous association indicates that a low marsh environment had been established during the infill of the roddon system. The sparse ostracods and the preliminary investigation of the diatoms support this conclusion.

2) Once the tidal creek system around Must Farm was infilled with silt and fine sand, it was used as a relatively dry pathway for humans through the Fenland swamp. Sometime after infill, a channel was incised into the tidal creek deposits, perhaps by a storm surge that converted into a long-lived, slow-flowing, freshwater body, perhaps of the proto-Nene river system. Once established, this lasted over a thousand years before it finally silted up and peat formation blanketed the area of study. In contrast to the tidal creek system, the late-stage channel at Must Farm yielded a microfauna dominated by freshwater ostracods such as *Candona*, *Limnocythere* and *Darwinula*, and by freshwater molluscs. Rare foraminifera are interpreted as a consequence of reworking of the roddon silts that formed the channel banks.

3) Overall, this temporary exposure strikingly demonstrates the alternation, within the enormous former coastal wetland of the mid-Holocene Fenland, of long periods of stability separated by brief intervals of profound environmental change. Given the continued vulnerability of this region, despite and in part because of human engineering, further episodes of environmental change cannot be excluded.

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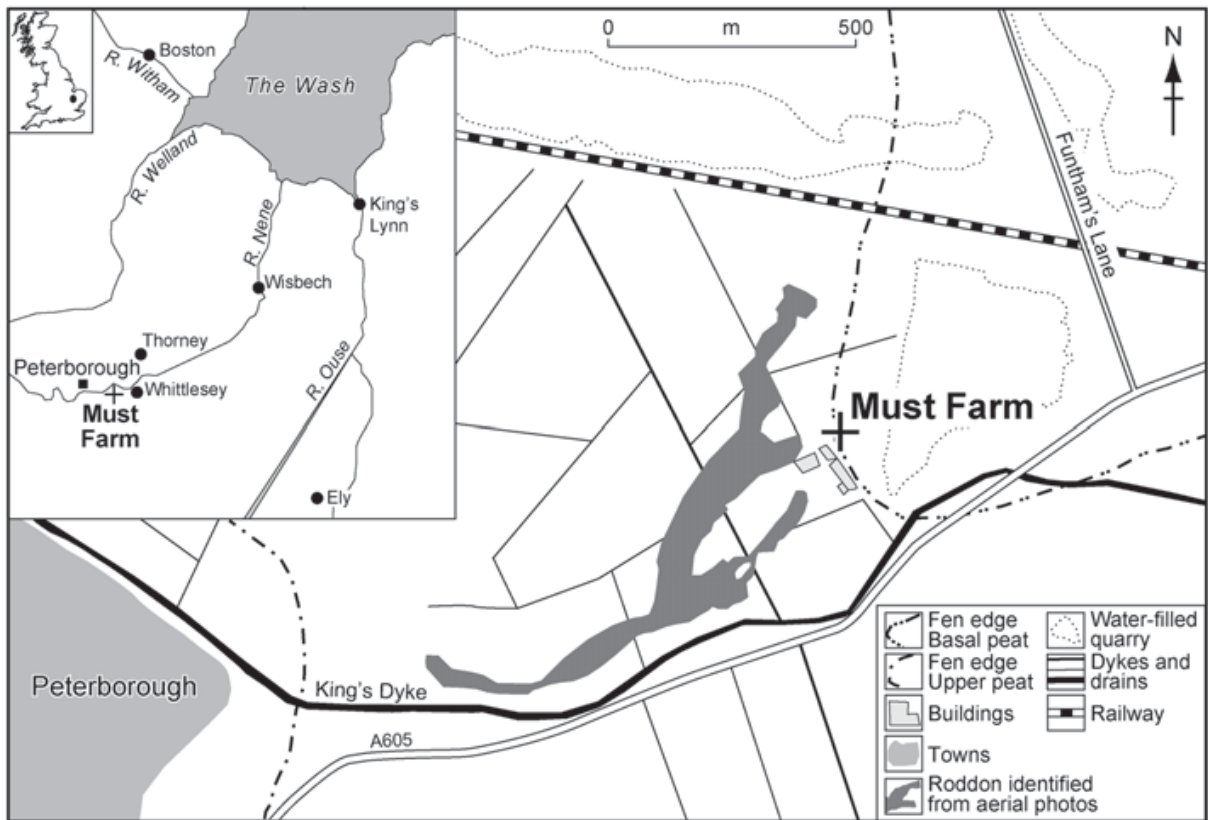


Fig 1

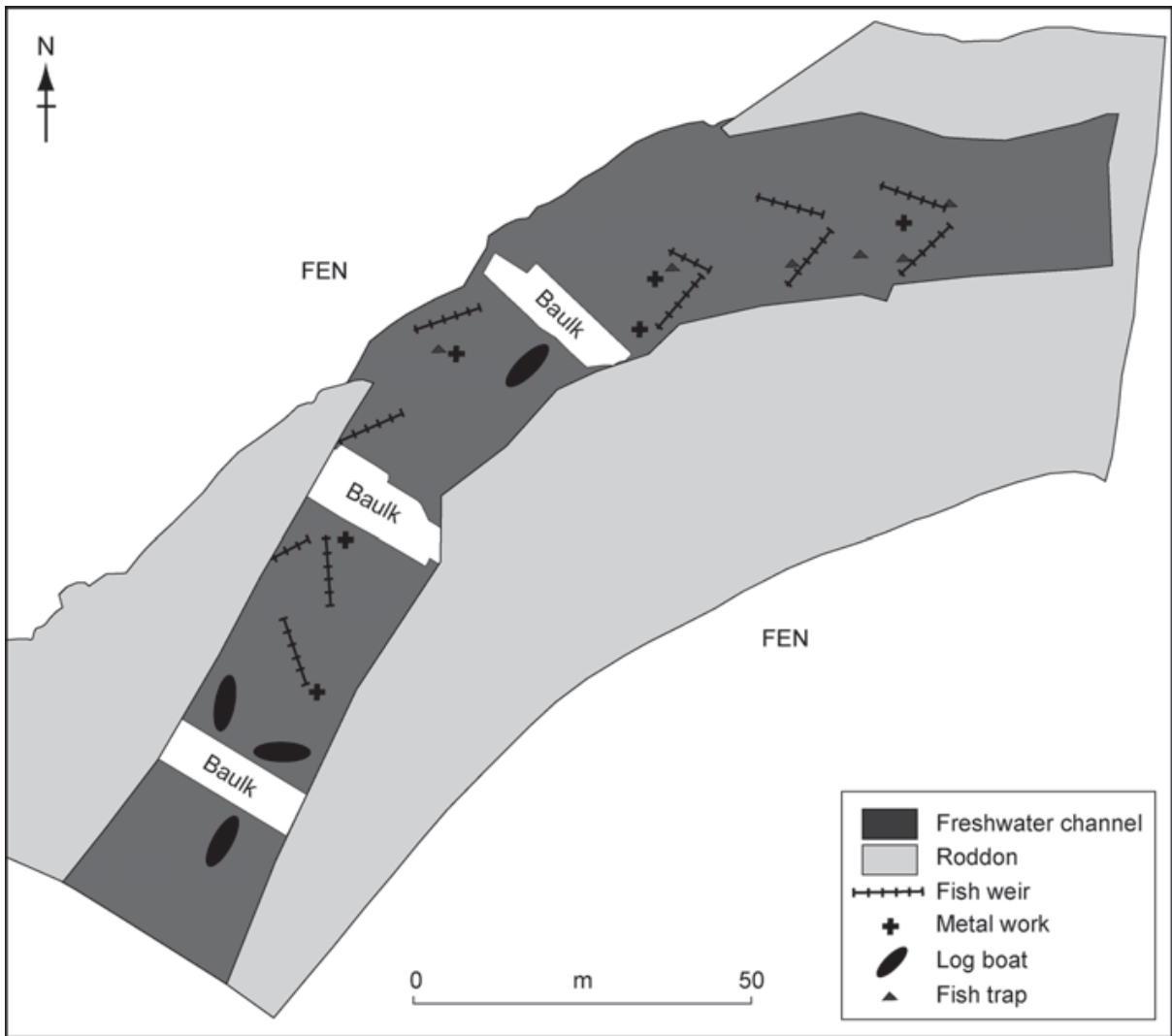


Fig. 2

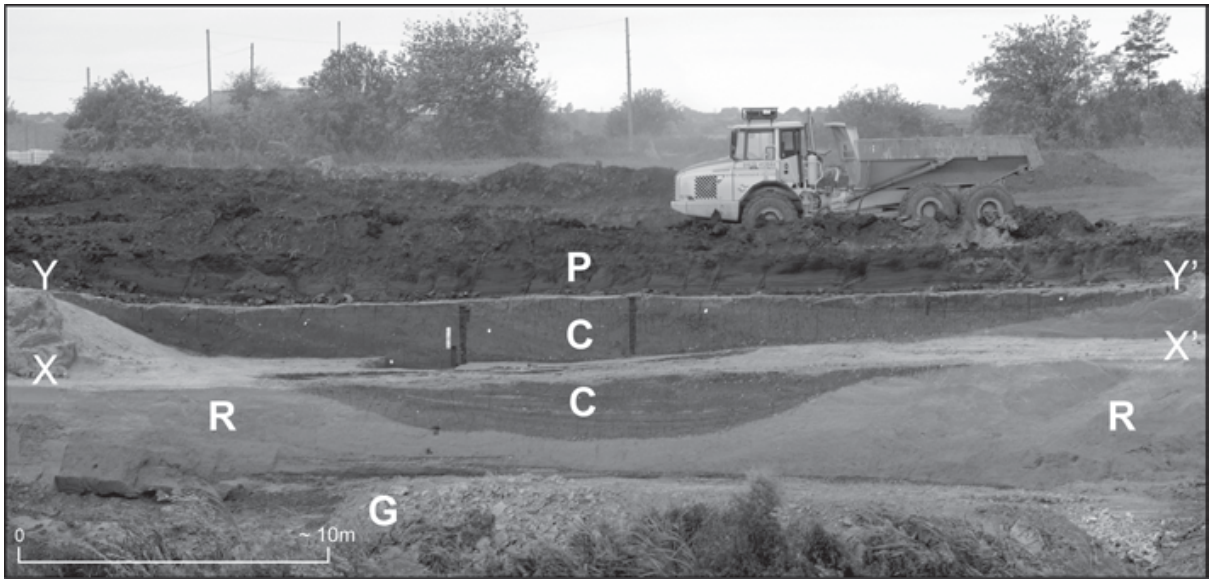


Fig. 3

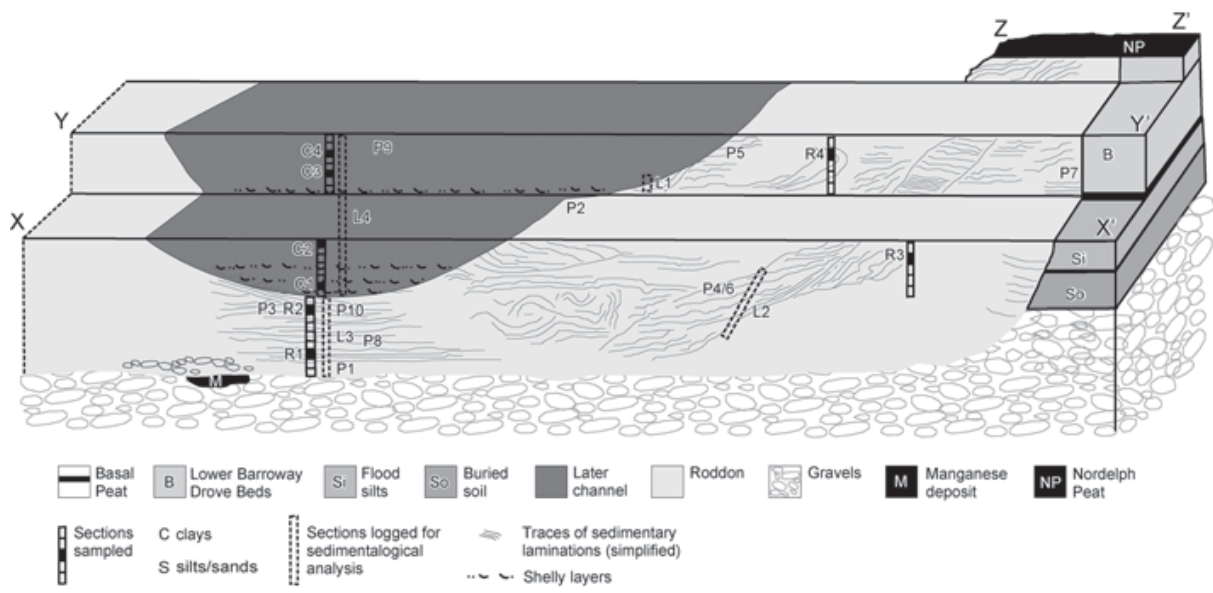


Fig. 4

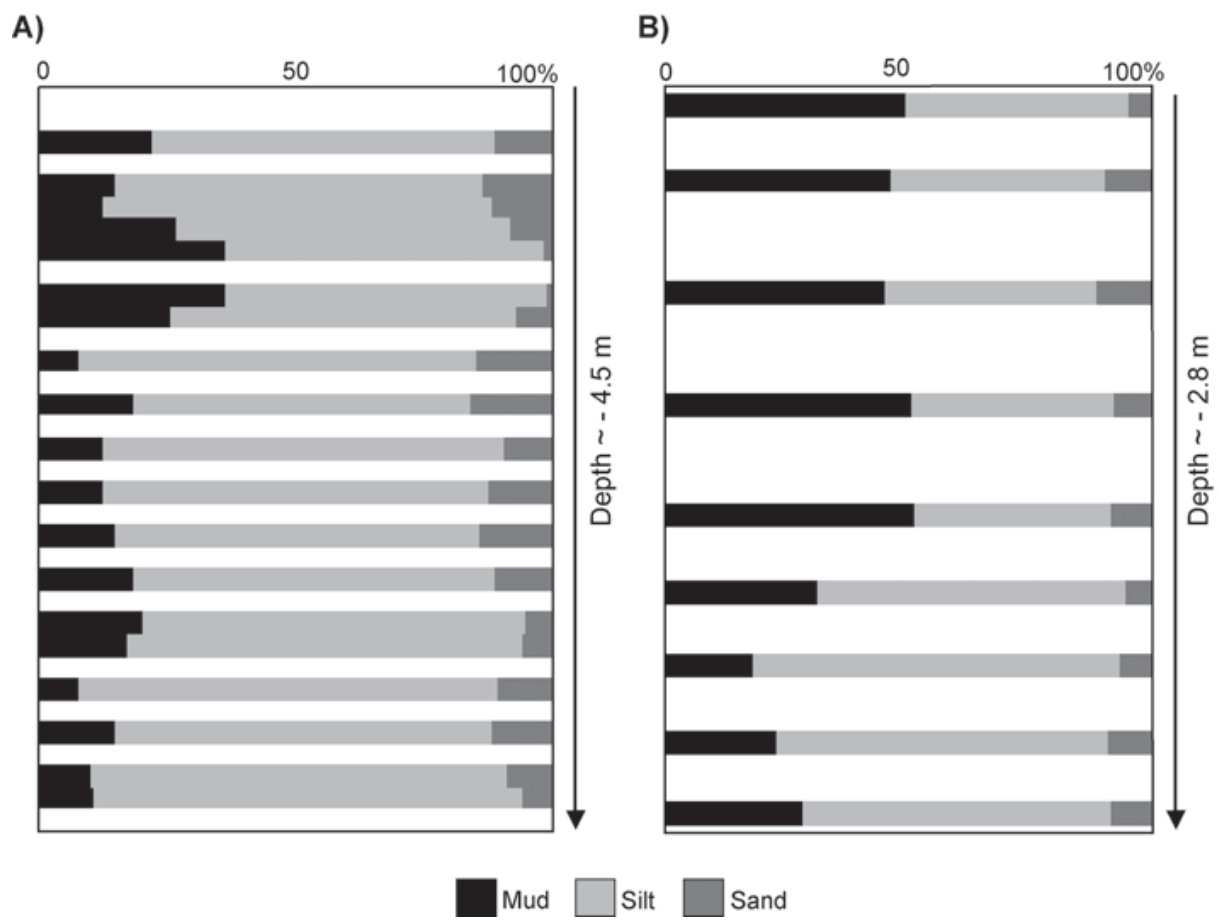


Fig. 5

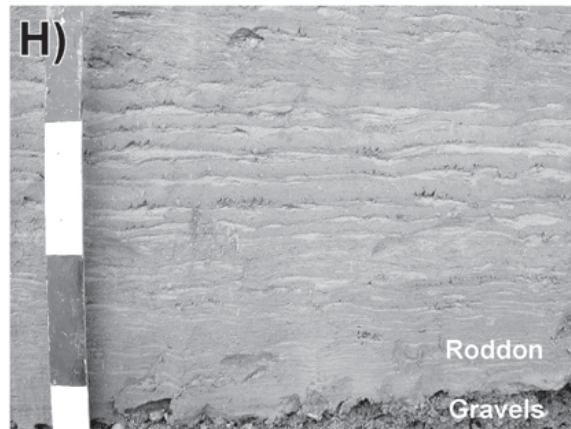
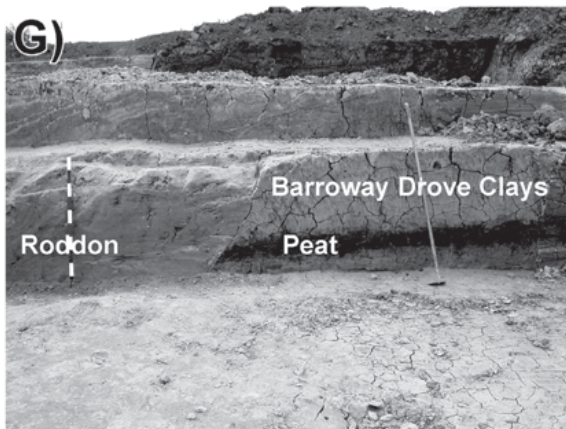
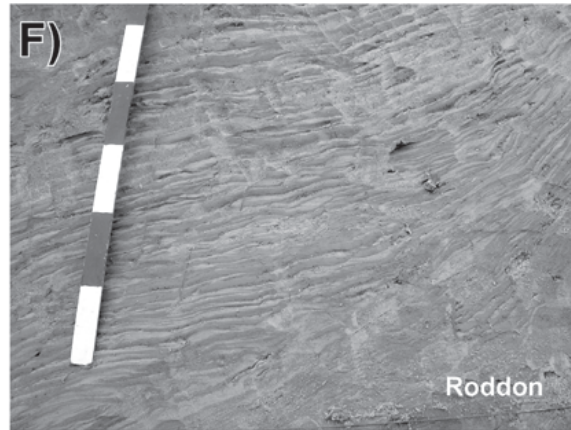
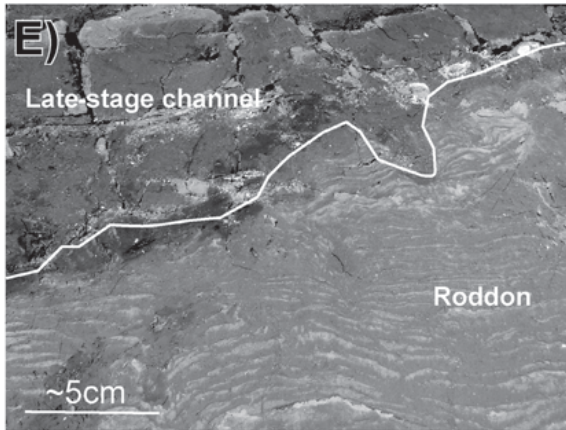
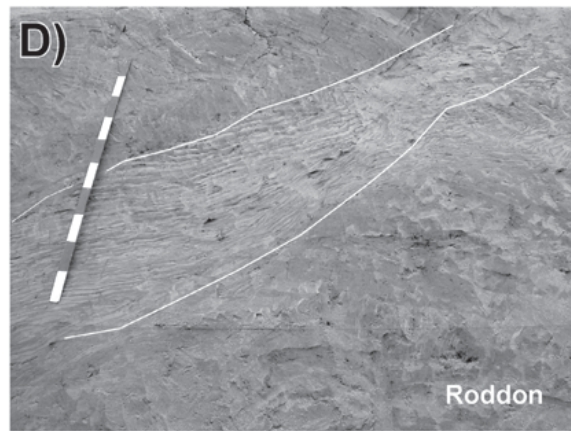
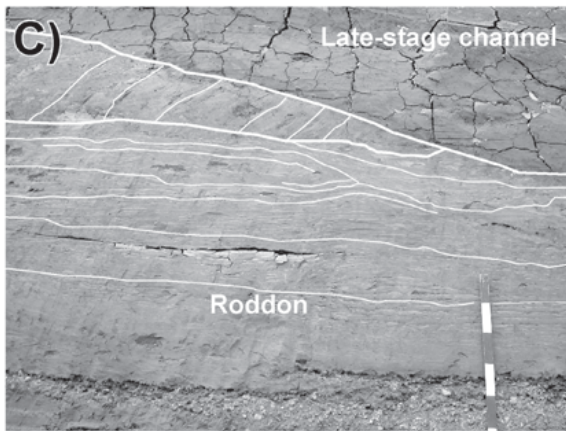
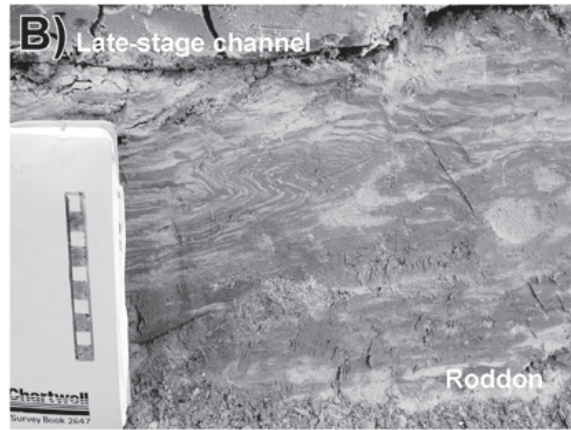
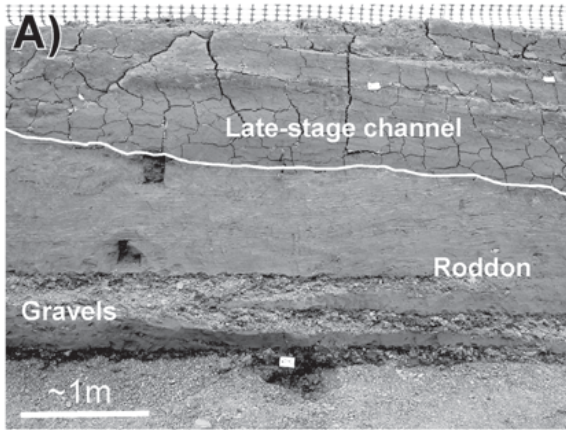


Fig. 6

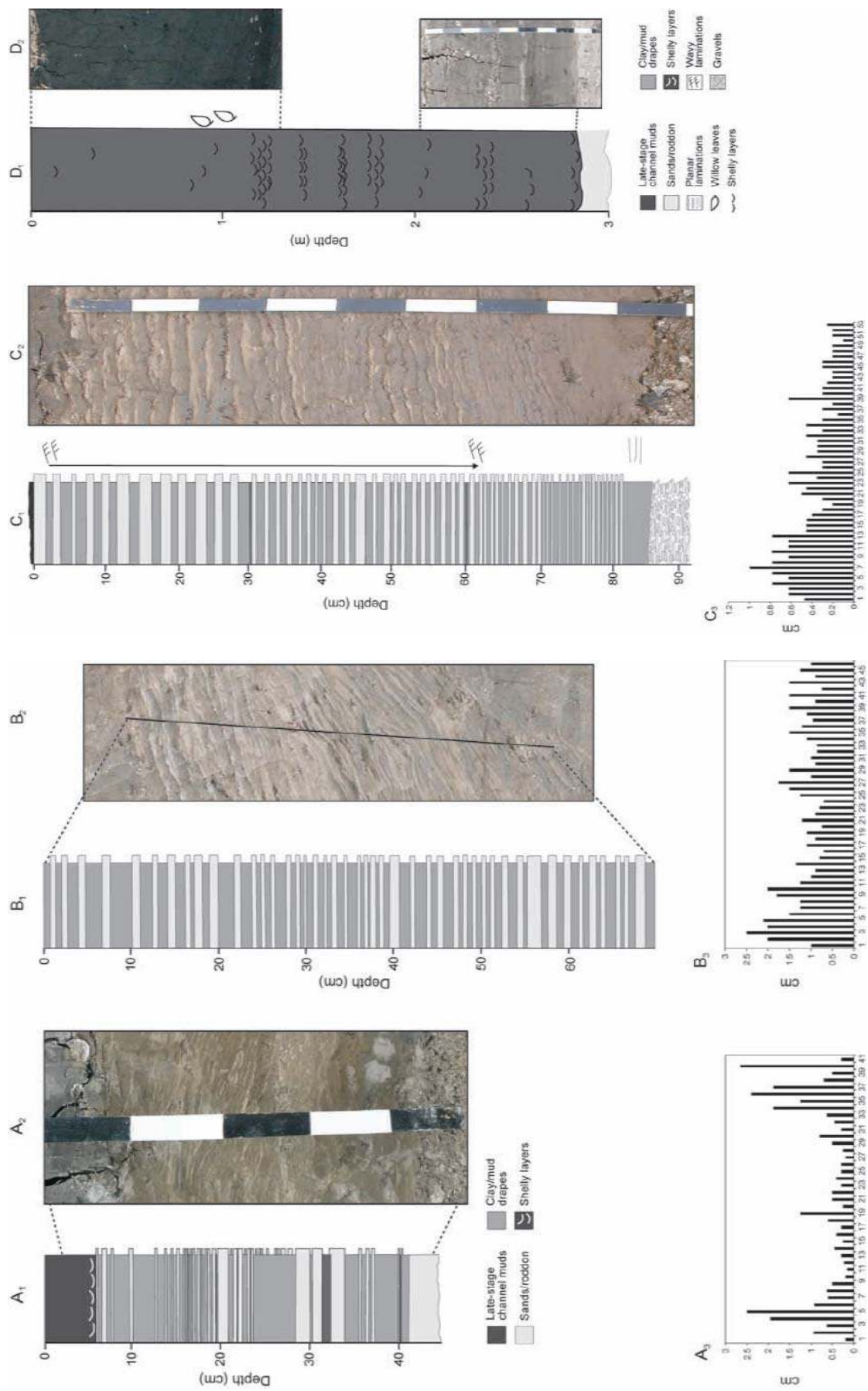


Fig. 7

	High Marsh	Middle Marsh	Low Marsh	Tidal flat/ Estuary	Inner Shelf
<i>Haplophragmoides wilberti</i>	■				
<i>Trochammina inflata</i>	■				
<i>Jadammina macrescens</i>	■				
<i>Miliammina fusca</i>		■			
<i>Elphidium williamsoni</i>		■			
<i>Haynesina germanica</i>			■		
<i>Ammonia beccarii</i>					■
<i>Elphidium exoticum</i>					■
<i>Elphidium albiumbilicatum</i>					■
<i>Elphidium excavatum</i>					■
<i>Cibicides lobatulus</i>					■
<i>Miliolinella subrotunda</i>					■
<i>Elphidium margaritaceum</i>					■
<i>Cyclogyra selseyensis</i>					■
<i>Quinqueloculina</i> spp.				■	
<i>Rosalina</i> spp.					■
<i>Asterigerinata mamilla</i>					■
<i>Planorbulina distoma</i>					■
<i>Nodosariids (Lagena, Oolina, Nodosaria, Lenticulina)</i>					■

Fig. 8

		Palaeoenvironment	Freshwater channel					Roddon			
Foraminifera	Autochthonous	<i>Ammonia beccarii</i> (Linnaeus, 1758) <i>Elphidium williamsoni</i> (Haynes, 1973) <i>Haynesina germanica</i> (Walker and Jacob, 1798) <i>Jadammina macrescens</i> (Brady, 1870) <i>Trochammina inflata</i> (Montagu, 1808) <i>Elphidium exoticum</i> (Haynes, 1973) <i>Cibicides lobatulus</i> (Walker and Jacob, 1798)									
	Predominantly allochthonous	<i>Cyclogyra selseyensis</i> (Reuss, 1850) <i>Fissurina lucida</i> (Williamson, 1848) <i>Lagena clavata</i> (d'Orbigny, 1846) <i>Lagena semistriata</i> (Williamson, 1848) <i>Rosalina williamsoni</i> (Chapman & Parr, 1932) <i>Elphidium albumbilicatum</i> (Weiss, 1954) <i>Planorbulina distorta</i> (Terquem, 1876) <i>Quinqueloculina</i> sp. cf. <i>clariensis</i> (Heron-Allen & Earland, 1930) <i>Quinqueloculina lata</i> (Terquem, 1876) <i>Asteriginata? mamilla</i> (Williamson, 1858) <i>Bucella frigida</i> (Cushman, 1921) <i>Elphidium</i> sp. cf. <i>selseyense</i> (Heron-Allen & Earland, 1909) <i>Elphidium macellum</i> (Fichtel & Moll, 1798) <i>Elphidium</i> spp. <i>Guttulina lactea</i> (Walker and Jacob, 1798) <i>Miliolinella subrotunda</i> (Montagu, 1803) <i>Oolina williamsoni</i> (Alcock, 1865) <i>Rosalina praegeri</i> (Heron-Allen & Earland, 1913) <i>Elphidium margaritaceum</i> (Cushman, 1930) <i>Bulimina gibba</i> (Fornasini, 1902) <i>Elphidium incertum</i> (Williamson, 1858) <i>Oolina hexagona</i> (Williamson, 1848) <i>Oolina squamosa</i> (Montagu, 1803) <i>Bucellina marginata</i> (d'Orbigny, 1826) <i>Elphidium excavatum</i> (Terquem, 1875) <i>Nodasaria</i> sp.									
	Reworked	<i>Elphidium excavatum clavatum</i> (Cushman, 1979) <i>Elphidium subarticum</i> (Cushman, 1944) <i>Heterohelix</i> sp. <i>Planularia</i> sp.									
Ostracoda		<i>Leptocythere lacertosa</i> (Hirschman, 1912) <i>Loxconcha</i> sp. <i>?Sarsicytheridea</i> sp. <i>Semicytherura angulata</i> (Brady, 1868) <i>Xestoleberis nitida</i> (Liljeborg, 1853) <i>Semicytherura</i> sp. <i>Callistocythere littoralis</i> (Müller, 1894) <i>Cytherissa lucustris</i> (Sars, 1866) <i>Cytherois fisheri</i> (Sars, 1836) <i>Leptocythere porcellanea</i> (Brady, 1869) <i>Semicythere nigrescans</i> (Baird, 1838) <i>Leptocythere castanea</i> (Sars, 1866) <i>Loxococoncha elliptica</i> (Brady, 1869) <i>Cytheropteron</i> sp. cf. <i>nodosum</i> (Brady, 1868) <i>Hemicytherura cellulosa</i> (Norman, 1865) <i>Leptocythere</i> sp. <i>Neocytherideis subulata</i> (Brady, 1868) <i>?Sarsicytheridea bradii</i> (Norman, 1865) <i>Semicytherura sella</i> (Sars, 1866) <i>Loxococoncha rhomboidea</i> (Fischer, 1855) <i>Candona negelecta</i> (Sars, 1887) <i>Darwinula stevensoni</i> (Brady & Robertson, 1870) <i>Limnocythere inopinata</i> (Baird, 1843) <i>Candona candida</i> (Müller, 1776) <i>Cypria ophthalmica</i> (Jurine, 1820) <i>Herpetocypris chevreuxi</i> (Sars, 1896) <i>Limnocythere sanctipatricii</i> (Brady & Norman, 1869) <i>Candona angulata</i> (Müller, 1900) <i>Herpetocypris chevreuxi</i> (juveniles) <i>?Nannocandona</i> sp. cf. <i>faba</i> (Ekman, 1914) <i>Cyclocypris ovum</i> (Jurine, 1820) <i>Eucypris</i> sp. <i>Candona</i> sp. (juveniles) <i>Potamocypris</i> sp. <i>Aurila</i> sp. <i>Dolerocypris</i> sp. cf. <i>fasciata</i> (Müller, 1776) <i>Herpetocypris reptans</i> (Baird, 1835)									
		Sample depth:- (Roddon) from Bench Z- Z' (Late stage channel) from Bench Y- Y'	Samples from 200 m (south) along late-stage channel	~ -0.3m	~ -0.9m	~ -1.5m	~ -2.5m	~ -1.4m	~ -2.6m	~ -3.8m	~ -4.2m
	Sample number (MPA)	MPA 61673	MPA 61288	MPA 61287	MPA 61286	MPA 61285	MPA 61284	MPA 61283	MPA 61282	MPA 61281	
	■ Abundant >50% ■ Common 25-50% ■ Frequent 10-24% — Rare 2-9% — V. Rare ~1%										

Fig. 9

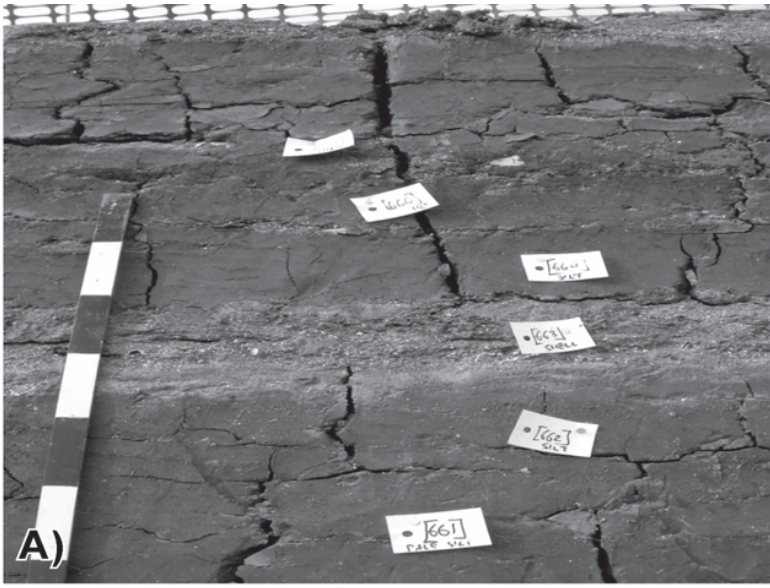


Fig. 10

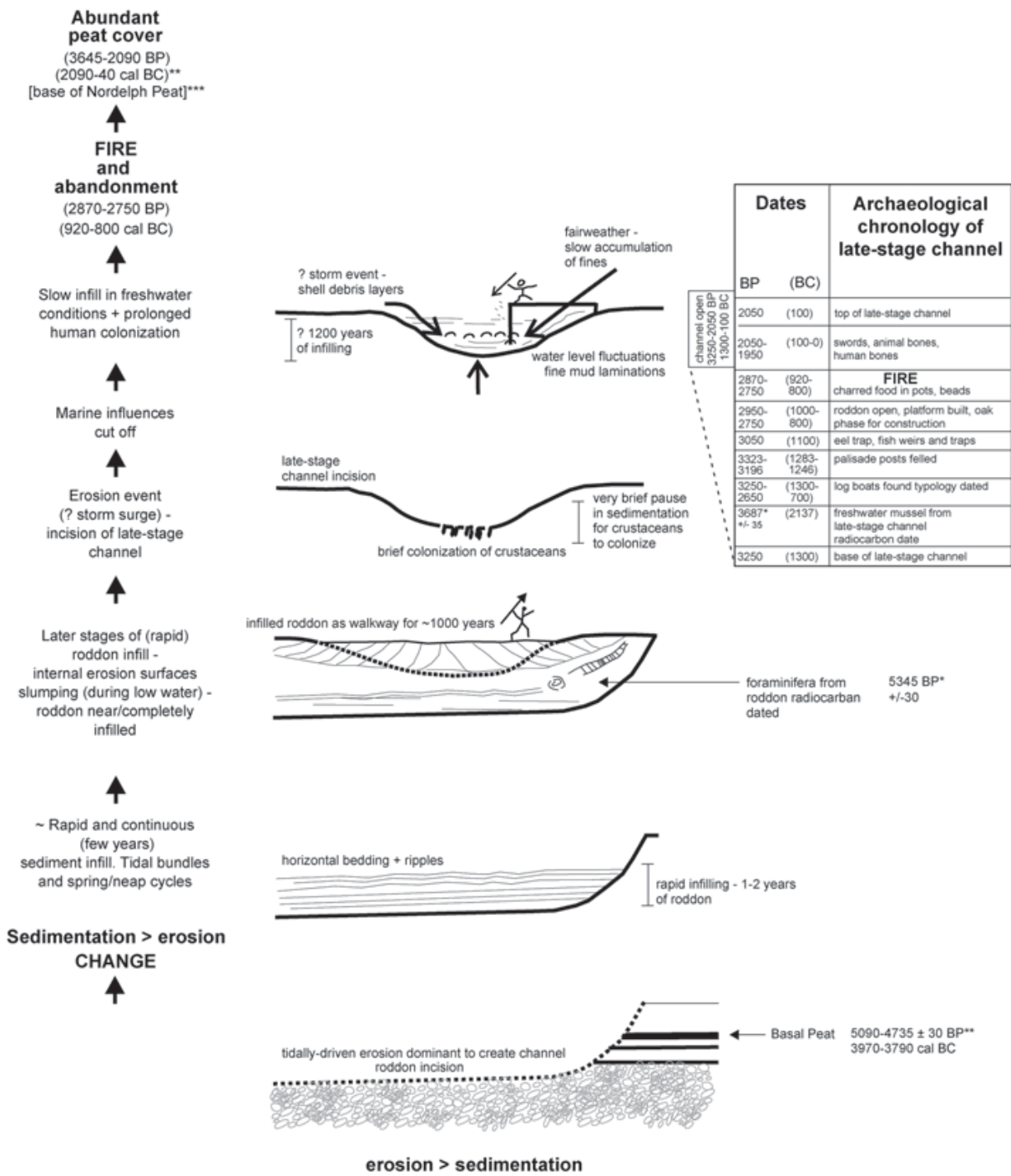


Fig. 11

Environment	Shelf	IS/TF/Est	Est-LM	LM-HM	MH-HM	HM	RW	No.of specimens per 1g
% of foraminifera species in each environment								
MPA 61281 ~-4.2m	13.6	0.8	66.0	11.1	5.7	0	2.3	612
MPA 61282 ~-3.8m	13.0	4.8	75.0	2.6	3.0	0	1.3	1094
MPA 61283 ~-2.6m	12.6	6.8	78.8	1.4	0.13	0	0.3	5109
MPA 61284 ~-1.4m	7.0	1.0	79.4	9.7	2.9	0	0.1	1212

	Marine	Marine/estuary	Estuary	Estuary/saltmarsh
MPA 61281	<i>Callistocythere littoralis</i>	<i>Semicytherura angulata</i>	<i>Loxoconcha</i> sp.	<i>Leptocythere lacertosa</i>
~-4.2m	<i>Xestoleberis nitida</i>	<i>Semicytherura</i> sp.	? <i>Sarsicytheridea</i> sp.	
MPA 61282		<i>Semicytherura nigrescens</i>	<i>Loxoconcha</i> sp.	<i>Leptocythere lacertosa</i>
~-3.8m			<i>Cytherois fisheri</i>	<i>L. Porcellanea</i>
			<i>Loxoconcha elliptica</i>	
MPA 61283	<i>Cytheropteron</i> sp.cf. <i>nodosum</i>	<i>Semicytherura sella</i>	? <i>Sarsicytheridea bradii</i>	<i>Leptocythere lacertosa</i>
~-2.6m	<i>Hemicytherura cellulosa</i>			<i>Leptocythere</i> sp.
	<i>Neocytherideis sublata</i>			
MPA 61284	<i>Neocytherideis sublata</i>	<i>Semicytherura nigrescens</i>	<i>Loxoconcha elliptica</i>	<i>Leptocythere lacertosa</i>
~-1.4m	<i>Xestoleberis nitida</i>		<i>Loxoconcha rhomboidea</i>	<i>Leptocythere</i> sp.
			? <i>Sarsicytheridea bradii</i>	

	Marine	Marine/estuary	Estuary	Estuary/saltmarsh
MPA 61281	<i>Callistocythere littoralis</i>	<i>Semicytherura angulata</i>	<i>Loxoconcha</i> sp.	<i>Leptocythere lacertosa</i>
~-4.2m	<i>Xestoleberis nitida</i>	<i>Semicytherura</i> sp.	? <i>Sarsicytheridea</i> sp.	
MPA 61282		<i>Semicytherura nigrescens</i>	<i>Loxoconcha</i> sp.	<i>Leptocythere lacertosa</i>
~-3.8m			<i>Cytherois fisheri</i>	<i>L. Porcellanea</i>
			<i>Loxoconcha elliptica</i>	
MPA 61283	<i>Cytheropteron</i> sp.cf. <i>nodosum</i>	<i>Semicytherura sella</i>	? <i>Sarsicytheridea bradii</i>	<i>Leptocythere lacertosa</i>
~-2.6m	<i>Hemicytherura cellulosa</i>			<i>Leptocythere</i> sp.
	<i>Neocytherideis sublata</i>			
MPA 61284	<i>Neocytherideis sublata</i>	<i>Semicytherura nigrescens</i>	<i>Loxoconcha elliptica</i>	<i>Leptocythere lacertosa</i>
~-1.4m	<i>Xestoleberis nitida</i>		<i>Loxoconcha rhomboidea</i>	<i>Leptocythere</i> sp.
			? <i>Sarsicytheridea bradii</i>	

Samples	MPA 61285	MPA 61286	MPA 61287	MPA 61288
Fractions (μm)	500	500	500	500
<i>Acroloxus lacustris</i> (Linné, 1758) % of fraction	5 10.63			1 4.54
<i>Bathynomphalus contortus</i> (Linné, 1758) % of fraction				1 4.54
<i>Bithynia tentaculata</i> (Linné, 1758) % of fraction		5 5.81		1 4.54
<i>Bithynia leachii</i> (Sheppard, 1823) % of fraction		6 6.97		
<i>Pisidium amnicum</i> (Müller, 1774) % of fraction		1 1.16		
<i>Pisidium henslowanum</i> (Sheppard, 1823) % of fraction	4 8.51	6 6.97		
<i>P. Moitessierianum</i> Paladilhe, 1866 % of fraction	3 6.38		4 40	1 4.54
<i>P. nitidum</i> Jenyns, 1832 % of fraction	13 27.65	11 12.79	1 10	3 13.63
? <i>P. pseudospaerium</i> ? (Favre, 1927) % of fraction	2 4.25			
<i>Planorbis carinatus</i> Müller, 1774 % of fraction	1 2.12	7 8.13		
<i>Radix balthica</i> (Müller, 1774) % of fraction		3 3.48		
<i>Radix labiata</i> (Rossmässler, 1835) % of fraction	5 10.63		1 10	
<i>Unio tumidus</i> Philipsson, 1788 % of fraction			1 10	
<i>Valvata cristata</i> (Müller, 1774) % of fraction	1 23.40	14 16.27		3 13.63
<i>Valvata macrostoma</i> Mörch, 1864 % of fraction	1 2.12	20 23.25	2 20	5 22.72
<i>V. piscinalis</i> (Müller, 1774) % of fraction	2 4.25	2 2.32		4 18.18
<i>Viviparus viviparus</i> (Linné, 1758) % of fraction		11 12.79	1 10	3 13.63
Total %total	47 100	86 100	10 100	22 100

Mollusc spp.	Water: still/flowing?	Water purity: clean/polluted?	Substrate	Oxygen content	pH range	Salinity tolerance	Water hardness	Depth (m)
<i>Acroloxus lacustris</i>	slowly flowing	clean (highly vegetated)	plant stems	high	6.0 to 8.9	-	hard and soft	<13
<i>Bathyompalus contortus</i>	slowly flowing and still	clean? (highly vegetated)	-	high?	5.2 to 9.6	-	-	?2 rarely >20
<i>Bythinia tentaculata</i>	slowly flowing and still	clean? (highly vegetated)	all particle sizes and occasionally plants	high?	6.6 to 8.4	-	-	<15
<i>B. leachii</i>	slowly flowing	very clean (highly vegetated)	-	high?	-	?5% salt	-	<3
<i>Pisidium amnicum</i>	flowing and still	clean	soft? (near water plants)	high?	-	-	-	usually 10-35
<i>P. henslowanum</i>	flowing and still, including marsh drains	highly vegetated	sandy, rich in organic matter	very clean (highly vegetated)	-	-	moderately hard	usually <25
<i>P. Moitessierianum</i>	slowly flowing and still	clean	sand to fine mud	high	-	-	-	-
<i>P. nitidum</i>	flowing and still, including marsh drains	clean	mud or sand, with plants	high	-	-	hard and soft	usually <20
<i>?P. pseudo sphaerium?</i>	swamps and ditches, mostly still	very clean (highly vegetated)	calcareous	high?	-	-	-	-
<i>Planorbis carinatus</i>	slowly flowing and still	clean? (highly vegetated)	mud	high	-	-	-	-
<i>Radix balthica</i>	flowing and still	-	gravel and sand	-	5.8 to 9.9	?1.4%	-	usually 0.2-2
<i>Radix labiata</i>	slowly flowing and still	-	plants, gravel or sand	-	-	-	-	-
<i>Uni tumidus</i>	flowing	clean	-	-	-	-	-	-
<i>Valvata cristata</i>	slowly flowing and still	clean? (highly vegetated)	mud	high	-	?0.5%	-	-
<i>V. macrostoma</i>	exclusively marsh drains and ditches	clean? (highly vegetated)	-	-	-	-	-	-
<i>V. piscinalis</i>	flowing and still	clean	mud or silt	high	-	0.4%	hard and soft	usually 3-10
<i>V. viviparus</i>	slowly flowing and still	-	mud	high	6.8 to 8.6	3%	-	-