TELECONNECTIONS AND THEIR ARCHAEOLOGICAL IMPLICATIONS, SEVERN ESTUARY LEVELS AND THE WIDER REGION: THE 'FOURTH' AND OTHER MID-HOLOCENE PEATS

by J.R.L. Allen[1]

[1] Department of Archaeology, School of Human and Environmental Sciences, University of Reading, PO Box 227, Whiteknights, Reading RG6 6AB, UK.
Email: j.r.l.allen@reading.ac.uk

A selected total of 230 calibrated radiocarbon dates, chiefly from intercalated peats, are analysed from stratigraphically well-characterised localities in the estuarine-coastal Holocene outcrops of southern Britain (Bristol Channel-Severn Estuary (138), Southampton Water (10), Sussex coast and Romney Marsh (32), Thames Estuary-Essex marshes (26), Suffolk and East Norfolk (12), North Norfolk Barrier Coast (12). The analyses confirm the broad, tripartite lithostratigraphic subdivision of the Holocene in southern Britain, and the general similarity of the sequence to outcrops on the Atlantic and Channel coasts of France and in the Low Countries and Northwest Germany. The early Holocene sequence, dominated by silts (salt marshes, mudflats), formed when sea level was rising rapidly. The mid Holocene is characterised by intercalated silts and peats (high-intertidal to supratidal organic marshes). Sea level was rising at an intermediate underlying rate, but the rise was punctuated by several profound fluctuations (punctuations) which, moderated by local factors varying in strength from outcrop to outcrop, allowed peats/buried soils to form for periods. Silt-dominance returned in the late Holocene, at a time when sea level was rising at a low rate (excluding the last c. 150 years). In southern Britain coastal silt (but not peat) wetlands offered resources to human communities over most of the Mesolithic, but varied in areal extent and spatial stability from outcrop to outcrop. The Neolithic period, the Bronze Age and the earliest Iron Age saw wetland resources that fluctuated between siltlands and peatlands on a time-scale of a millennium or less. The two kinds of wetland, each offering a different suite of resources, interchanged spatially at rates of the order of 1-10 m/yr. The rapidity of change would have called for considerable resilience on the part of human groups that sought to exploit the coastal wetlands, and could have forced substantial changes in their economic basis, or led to migration or inter-group conflict. Environmental stability returned in the later Iron Age, when siltlands once again became widely available.

INTRODUCTION

The underlying upward trend of relative sea level in southern Britain during the Holocene was punctuated by episodes during which the rate fell significantly. These in order of decreasing profundity could have ranged from reversal (rate for a time negative), to approximate stasis as an intermediate condition (rate broadly zero), to a diminished but still positive rate. Whatever agencies and factors caused such punctuation, they combined to create a seemingly haphazard range of lithostratigraphic responses, as expressed in the estuarine/coastal Holocene of southern Britain. This is as true of the Welsh portion of the Severn Estuary Levels (Bell *et al* 2000; Allen 2001a; Yates *et al* 2001; Allen and Haslett 2002; Walker *et al* 1998, 2002), as of the Severn Estuary Levels as a whole (eg Hewlett and Birnie 1996; Housley *et al* 1999; Haslett *et al* 2000, 2001; Carter *et al* 2003), and of the coastal zone in the wider region (eg Tooley 1978; Devoy 1979; Shennan 1986; Jennings and Smyth 1987; Brew *et al* 1992; Waller 1994; Long *et al* 1998, 2000; Andrews *et al* 2000).

Often including gravel and sand, these sedimentary archives consist chiefly of silts (salt marsh, some mudflat) with subordinate peats (highest intertidal-supratidal marsh), the latter the most striking and most intensively studied expressions of punctuation. Mudflats can occur at almost any intertidal level, but salt marshes are restricted to above roughly mean high-water of neap tides (MHWNT). But were punctuating episodes coeval and, as judged lithologically, everywhere of a similar intensity? The answer rests on the identity and functioning of the possible causative factors and agencies, ranging from the global-regional to the strictly local, and on the potentially variable, competitive balance struck between them.

Coastal peatlands were widely favoured in southern Britain with the slowing of the rate of relative sea-level rise after the early Holocene (eg Haslett *et al* 1998; Shennan and Horton 2002). These sediments are the staple of those who, in recent decades, have created increasingly refined sea-level curves for the region. Evidence has been given from the Thames, Solent and Severn estuaries (Long *et al* 2000) and from Romney Marsh (Long 2000) for a substantial restriction of the tidal area because of peat growth between *c.* 3750 and *c.* 1250 Cal BC. Regarding the Severn Estuary Levels themselves, Bell (2000a) noted that growth occurred chiefly, but not continuously, during the interval *c.* 6000-200 Cal BC, and drew attention to the considerable archaeological significance of the peat environment. In the Welsh Levels peat accumulation very largely ceased between *c.* 1400 and *c.* 240 Cal BC (Allen 2000a). Van Geel *et al* (1996) argued from the Low Countries that a substantial climate shift forced the cessation of peat deposition around 700 Cal BC, a date bracketed by the upper limits identified by Long *et al* (1998) and Bell (2000a). In Central Europe, a major and widespread cooling, noted by Magny and Haas (2004), occurred *c.* 3350 Cal BC, a time little removed from the (variable) start of the main episode of peat formation in the Severn Estuary Levels and elsewhere in southern Britain. Significant climate changes have, however, occurred more frequently and also at other times (eg Magny 2004; Mayewski *et al* 2004; Turney *et al* 2005; Charman *et al* 2006), and other factors may be responsible for peat formation in the coastal zone.

This paper explores more fully than hitherto the extent to which teleconnections are registered in the mid Holocene sediments of the Severn Estuary Levels and the wider region of southern Britain. This is attempted through an examination of (1) the lithological registration of punctuation, (2) the causes of punctuation, and (3) the local and regional timing (teleconnection) and apparent duration of punctuations as expressed by radiocarbon-dated lithostratigraphy. The horizon of interest is broadly that of the mid Holocene so-called 'main' peat exposed so superbly on the Welsh side of the Severn Estuary. The investigation affords insights not only into the controls on the architecture of Holocene coastal sequences but also into the consequent opportunities and constraints that punctuation presented to the successive human groups in a position to access and exploit the wetlands in prehistoric times (eg Coles and Coles 1986; Bell 2000b; Bell *et al* 2000; Haslett *et al* 2000). It should be remembered from the outset that the evidence comes from such Holocene deposits as have survived coastal change during the post-glacial marine transgression.

REGISTRATION OF PUNCTUATION

Sediment sources

Wetlands in the Severn Estuary, which may be taken as representative, obtain sediment from two sources, one exogenous, the other endogenous. Chiefly of silt grade, mineral matter (quartz, clay minerals, detrital/diagenetic carbonate) and some partly degraded plant tissue is carried in suspension by the tidal waters to wetlands lying below the level of the highest astronomical tide (HAT). Today these waters - the exogenous source - are well-mixed and highly turbid (Hydraulics Research Station 1981; Kirby 1986; Collins 1987; Allen 1990a). Levels of turbidity may be expected to have increased throughout the Holocene, partly because of increased turbulence linked to the growth of the tidal range (Austin 1991) and partly because of increasing agriculture in the catchments (Brown 1991). Salt-tolerant plants form the endogenous source, contributing biomass to high-intertidal salt marshes in the form of roots/rhizomes (below-ground) and stems and leaves (above-ground). Because of human interference, the halophyte assemblages seen in the estuary today (Burd 1989) may not be representative of those of the past. Supratidal coastal wetlands theoretically receive no mineral sediment, although small amounts may occasionally be deposited from storm tides and a very light but continuous fall-out of atmospheric dust can be expected. Thus only the endogenous source is significant here, namely, the grasses, shrubs and semi-terrestrial trees (eg Heyworth 1986) that favour damp-wet places and can in some cases tolerate occasional tidal inundations (eg reeds, sedges, alder, willow, birch, oak, mosses, heath species).

Peat deposits

The traditional indicators of negative sea-level tendencies (eg Shennan 1982), peats have long been intensively investigated in southern Britain. Within any one Holocene outcrop, these endogenous deposits vary greatly in thickness and facies, both laterally and vertically.

Variability is especially strong in the outcrops bordering the Severn Estuary and Bristol Channel. The thinner peats typically are of alder carr and/or reedswamp facies and commonly include marine indicators, pointing in these cases to a highest intertidal or at least storm-influenced supratidal setting (eg Druce 1998; Jennings *et al* 1998; Yates *et al* 2001; Allen and Haslett 2002, 2006a; Moore *et al* 2002; Carter *et al* 2003). A wider range of facies typifies the thicker deposits. A succession from reedswamp to sedge fen followed by patterned, raised bog is widely seen in the interior of the Main Somerset Level (Beckett and Hibbert 1979; Godwin 1981; Housley *et al* 1999), except at the unique Meare and Glastonbury lakes, where detritus muds dominate and raised bog is patchy (Caseldine 1986; Housley 1988). Depending on overall scale, raised bogs could when active have stood above their surroundings as domes some metres high (Godwin 1981; Hobbs 1986). Even the most extreme storm events would not have drowned such features. Thick largely terrestrial peats also appear on the Welsh coast in the Loughor Estuary (Lillie *et al* 2003), in the Wentlooge Level (Walker *et al* 2002), and especially on the coast as well as the interior of the Caldicot Level (Smith and Morgan 1989; Walker *et al* 1998, 2002; Bell *et al* 2000; Brown 2002, 2003; Timpany 2003). In some cases with a basal reedswamp facies, thick alder carr with local coastal woodland tends to be succeeded by reed-sedge fen followed in many places by raised bog. Open fen follows strong developments of woody facies in the thick peats of the inner Severn Estuary (Lucy 1877; Prevost *et al* 1901; Hewlett and Birnie 1996).

A range of woody and reed-sedge peats mark the Holocene of Southampton Water on the Channel coast (Long *et al* 2000). The succession in the thick 'main marsh peat' of Romney Marsh to the east is reedswamp, open fen, fen carr and woodland, and finally a range of raised bog facies (Long *et al* 1998; Waller *et al* 1999; Waller 2002).

The sheltered Thames Estuary on the southern North Sea coast presents extensive peat deposits (Devoy 1979; Sidell *et al* 2000). Reedswamp and mixed reed and sedge peats are important here but woody facies occur basally. At sites on the East Anglian coast 'saltmarsh peats', reedswamp, alder carr, coastal woodland and acid bog peats are recorded (Brew *et al* 1992; Wilkinson and Murphy 1995; Andrews *et al* 2000; Brennand and Taylor 2003; Horton *et al* 2004).

These peat facies, registering the more profound episodes of punctuation, represent for the most part damp to wet supratidal environments removed from direct marine influences. Water tables remained high enough to permit the anaerobic preservation of plant matter. Except where patterned domes of raised bog rose above their surroundings, the sedimentary surface would have been comparatively level.

It seem to be invariably the case that the bases of intercalated peats - the regressive contacts - are gradational from the silts or sands below, allowing them to be meaningfully radiocarbon-dated. This is not always true of the upper surfaces, which mark transgression. Increasingly, cases are being reported of peats with evidence for a concluding depositional break (eg Allen and Haslett 2002, 2006a, 2006b; Baeteman *et al* 2002; Waller *et al* 2006), marked either by a strongly humified zone or a high-intertidal erosion surface. In these cases, some uncertainty must attach to the meaning of radiocarbon dates on either the peat immediately beneath the top or from organic matter from the base of the immediately overlying silt or sand.

Buried 'soils'

Although frequently drowned by the tide, salt marshes for most of the time are under atmospheric influences and consequently experience soil-forming processes. Pedogenesis proceeds at a very low rate and does not lead to horizonation, provided that silt is accumulating on the marshes at millimetres or centimetres annually, values which frequently obtained during the Holocene (eg Allen and Haslett 2006a, 2006b). At sub-millimetre rates, however, weak (immature) horizonation is possible and pedological features may as a result be recognisable in the field or laboratory. Only when siltation ceased entirely, either naturally because of sea-level stasis or fall, or because of human interference (eg marsh embanking), would pedogenesis have proceeded normally.

Buried soils as a mark of punctuation have only recently been recognized in the Holocene of the Severn Estuary Levels, and detailed systematic work on them remains a challenge for the future. From the Wentlooge Level Allen (1987) described using thin-section data a palaeosol created by (Romano-British) salt-marsh embanking. A similar but younger buried soil was noted from the upper-middle estuary in association with a medieval ploughed surface (Allen 1990b). From the Forth estuary, Barras and Paul (2000) described a post-embanking soil developed in estuarine silts. Of greater present interest are buried soils that appear to have arisen naturally. Again on the Wentlooge Level, a thin *Phragmites* peat with some fen carr was seen on the coast to pass laterally into silts as two roots bed associated with colour mottling (Allen 1996). Yates *et al* (2001) described from boreholes other palaeosols with organic remains, some of which extended seaward from thin peats. Buried soils, some associated with signs of human activity, occur in other parts of the Severn Estuary Levels (Locock *et al* 1998; Locock 1999a; Allen *et al* 2002; Moore *et al* 2002; Carter *et al* 2003). Among the (field) observations supporting a diagnosis as a buried soil are reduced (blue-grey) colours (gleying), colour mottling especially involving orange shades (mild oxidation), and even prismatic structures and silt-filled drying cracks. Microscopically, mottled zones often contain millimetre-scale siderite concretions and reveal evidence of clay-mineral reorientation and even illuviation.

Locock (1999a) proposed a typology for these salt-marsh soils, recognising developments indicative of different degrees of wetness. At one extreme are soils formed in what had become an effectively dryland environment, in some cases because of marsh embanking. At the other are those produced under conditions of a high water-table without drying episodes. In between are ripened, typically colour-mottled, soils arising in relatively moist environments with intermittent drying out. The general context of buried soils would seem to be an environment, sustained over a significant period, that was either highest intertidal or hovering around the intertidal-supratidal boundary, but of relatively low plant productivity.

The rise and fall of the tide significantly affects the water-table in estuarine wetlands, especially where the underlying sediments, although basically silts, are to some extent permeable because of the presence of interconnected drying cracks, empty root/rhizome channels and burrows. Near to marsh-edges and the banks of creeks, the water-table falls significantly with each fall of the tide, as groundwater drains from the wetland. The effect diminishes, however, with increasing distance away from these sites. At a distance, and especially in the interiors of wetlands, the water-table can be permanently high.

CONTROLS ON PUNCTUATION

Mean sea level

The medium- to long-term controls on mean sea level (MSL) are global to regional in their effects and operate on corresponding time scales (Long and Roberts 1997). One that is linked to climate-controlled surface processes is glacio-eustasy, the loss/gain of water from ice sheet build-up/decay. Two other components - geoidal-eustasy and tectono-eustasy - depend on the way the Earth's internal processes alter the shape of the equipotential surface through fluctuations in the gravity-field and the volume and configuration of the ocean basins.

Short- to medium-term controls are provided by changes in the stratification of the oceans as temperature and salinity vary and currents shift, and by structural changes in the atmosphere manifested by fluctuations of air pressure and wind strength and direction. The atmosphere is more variable than the oceans, and its controls tend to operate on an especially wide range of geographical and temporal scales (eg from depressions to shifts in zonal wind and pressure belts).

Vertical crustal movements

Glacio-hydro-isostacy, also a medium- to long-term control, is the gradual vertical movement of the Earth's crust in response to loading/unloading accompanying glaciation/deglaciation and the consequent draining/drowning of continental margins. The southern British crust, in the forebulge of the Devensian (last glaciation) ice sheet, is currently sinking at rates of *c.* 0.5-1 mm/yr, the larger values typifying East Anglia and the Thames Estuary and the outer Bristol Channel and Cornish peninsula (Shennan and Horton 2002).

The combined effects of vertical crustal movement and the controls on mean sea level can be deduced from the curve for relative sea-level in the Bristol Channel Severn Estuary (Figure 1), based on the present altitudes of peats formed close to HAT at the time. The curve (see also Heyworth and Kidson 1982; Haslett *et al* 1998; Jennings *et al* 1998), uses data from Porlock Bay (Jennings *et al* 1998), Minehead Bay (Jones *et al* 2004), the Main Somerset Level (Heyworth & Kidson 1982; Druce 1998; Holingrake & Holingrake 2001), the Avon Level (Moore *et al* 2002; Carter *et al* 2003), the inner-middle and inner estuary (Hewlett and Birnie 1996), the Caldicot Level (Walker *et al* 1998; Allen and Haslett 2006), the Wentlooge Level (Yates *et al* 2001; Walker *et al* 2002) and the Loughor Estuary (Lillie *et al* 2003). Also shown is the mean and range in height of the ground surface of the Wentlooge Level (surveys of Yates *et al* 2001), an extensive salt marsh 'fossilized' by embankment early in the Roman period (Allen and Fulford 1986; Fulford *et al* 1994). The modern situation is represented by the mean and range of HAT (United Kingdom Hydrographic Office 2004) at Milford Haven (4.1 m OD), Swansea (5.4 m OD) and Bristol (Avonmouth) (8.2 m OD). The curve is subject to a number of errors, the chief of which, as Haslett *et al* (1998) show, is the depressive effect of sediment compaction.

Overall, these controls caused sea level in the Bristol Channel-Severn Estuary to rise at an *underlying* rate of the order of 10 mm/yr during the earlier Holocene, gradually falling to the order of 1 mm/yr in the later epoch. Because of global warming, the rate has accelerated significantly over the last *c.* 150 years (Gehrels *et al* 2005).

Tidal range

The tide is the multiperiodic rise and fall of the sea surface about the position of mean sea level. Many factors over and above the purely astronomical control the vertical movement of the tide at a point on the coast or within a coastal wetland (Pugh 1987, 2004). These include the general hydrography of the region, the behaviour of mean sea level, the shape and scale of the estuary or tidal embayment, the distance from the wetland edge, and human interference. So far as the morphodynamics of coastal wetlands are concerned, the significant local tidal level is that of HAT over the 18.6 yr lunar-nodal cycle. It is not just a matter of definition that the upper limit of salt marshes lies at this level, but that HAT is a critical boundary for sediment procurement. Above HAT, that is, in the supratidal realm, the only effective source is the endogenous one of plant matter. Below HAT, in the intertidal zone, silt deposited from tidal waters (exogenous source) combines with endogenous plant matter to build marshes. Mudflats, normally restricted to below MHWNT, are supplied exclusively from the exogenous source.

The modern process of dredging, the historical one of mudflat/salt-marsh enclosure by embankments, of Roman introduction in the Severn Estuary (Allen and Fulford 1986), and siltation over the longer term significantly affect the local tidal range in ways that are difficult to

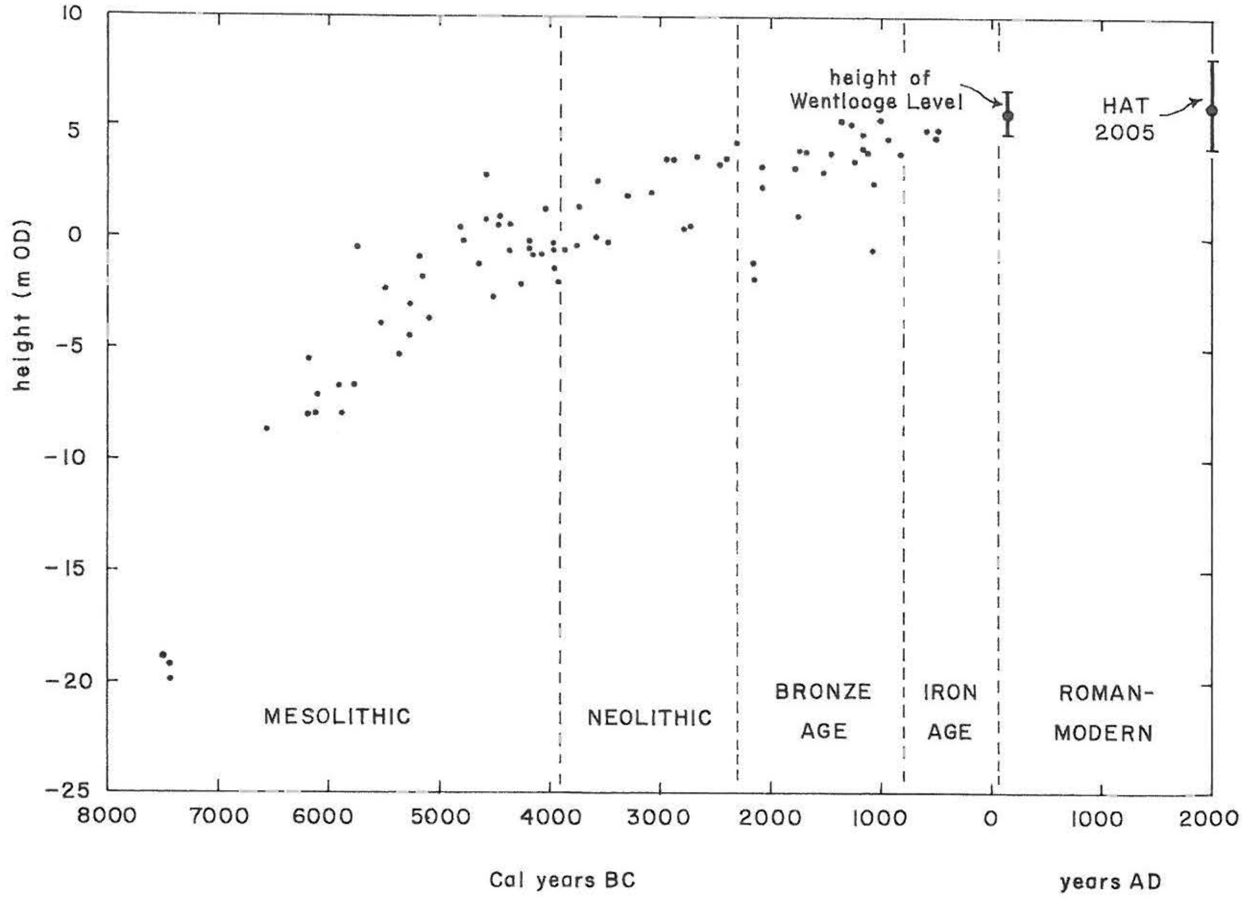


Figure 1. Calibrated age-altitude plot of non-archaeological sea-level index-points from the Bristol Channel-Severn Estuary Levels, together with altitude data from the Wentlooge Level and for modern tidal ranges. See text for details of sources. Because of the effects of compaction on intercalated peats, the upper envelope-line of the scatter of points best approximates to the true underlying trend.

predict (eg Garniel and Miervald 1996; van der Spek 1997; Kang 1999; Lee *et al* 1999). According to circumstances, dredging and embanking can either increase or decrease the local range.

Tidal waves are distorted as they enter shallowing waters constrained by land masses. Ranges tend to increase inland in sufficiently large systems such as the modern Bristol Channel-Severn Estuary (eg Allen 1990b) and The Wash, but in smaller ones (eg van der Molen 1997), and in individual marsh-creek networks, generally decrease with distance from the sea. Ranges at coastal sites on the Northwest European continental shelf today vary from the microtidal to the severely macrotidal (hypertidal) (eg Severn Estuary, extreme range Avonmouth of 14.8 m). Over the Holocene tidal ranges have tended to increase with the deepening of shelf seas (eg Bowen 1972; Austin 1991; Hinton 1995; see also Zhang and Wang 2000). Significant changes in tidal range have occurred around the British coast over the short period of the last 50-100 years (Woodworth *et al* 1991). At Avonmouth, for example, the mean tidal range is increasing about as fast as MSL. Thus such wetlands as survive in the area are responding to an increase in the morphostratigraphically effective water-level (HAT) roughly equalling that due to the rise of MSL alone.

Sediment supply

The two sources of sediment distinguished above vary substantially in their strength from one tidal system to another as well as within systems.

The endogenous supply is in the form of below-ground (roots, rhizomes) and above-ground (litter, wood) biomass, the latter normally predominating. The rate of supply on salt marshes varies considerably (reviews in Turner 1976; Good *et al* 1982; Boorman and Ashton 1997; Allen 2000b), with climate, species, frequency of tidal inundation, distance from the marsh-edge and creeks, and substrate characteristics. It is limited by the amount of rainfall (eg de Leeuw *et al* 1990) and by the availability of nitrogen (eg Kiehl *et al* 1997). Natural herbivory by mammals and birds, as well as animal grazing managed by humans - a Bronze-Iron Age practice on the Severn Estuary Levels (Bell *et al* 2000) - also constrains the availability of biomass for incorporation into sediments (eg Kiehl *et al* 1996; Ford and Grace 1998).

The exogenous supply of suspended fine sediment is set by the general level of turbidity of each tidal system, the spatio-temporal variation of turbidity within it and, in the case of sites within salt marshes, the distance from the outer marsh-edge and from creek banks. The general level seems to depend on the extent to which tidal stirring, increasing with tidal range, creates turbulence, but can be limited by the fluvial supply and the resistance to erosion offered by bed and banks. Strong spatial gradients of turbidity occur where limited tidal mixing - a feature especially of microtidal and mesotidal estuarine regimes - permits turbidity maxima to form. An analogous feature in the exceptionally well-mixed modern Severn Estuary takes the form of a suspended sediment front extending from Bridgwater Bay to near the mouth of the Avon (Kirby and Parker 1983). The locations of fronts and turbidity maxima are impossible to predict without a detailed knowledge of tidal range and coastal configuration.

Although the turbidity of a body of estuarine water can be supply-limited, it is not necessarily increased, except in the very short term, by an increase in soil erosion related to woodland clearance and cultivation.

It is well understood from many field studies, as well as from theory (Woolnough *et al* 1995), that the rate at which silt accretes on salt marshes tends to fall off with increasing distance from the marsh-edge and from creek banks (review in Allen 2000b; see also Temmerman *et al* 2003a), except for a narrow zone along the edge affected by wave-action on the margin of the open estuarine waters (eg Brown 1998). One consequence of the decline is to give a greater role to the supply from marsh plants (Culberson *et al* 2004). It is also clear, as theory explains (Woolnough *et al* 1995), that the grain-size of the deposited sediments also declines with increasing distance from marsh-edges - a catchment-wide trend - as well as from the banks of individual creeks, a pattern discernible on a sub-catchment scale (Pestrong 1972; Barillari 1977-8; Beeftink *et al* 1977; Edwards and Frey 1977; Stumpf 1983; Kastler and Wijberg 1996; Yang 1999; Christiansen *et al* 2000; Culberson *et al* 2004). The consequence is an increase in the clay content of the sediment (eg Beeftink *et al* 1977) and an increased susceptibility to compaction.

Compaction

Beginning at the moment of deposition, compaction is the continuous, progressive and irreversible process whereby sediments lose stratigraphical thickness (ie volume) partly or wholly as a consequence of their own weight. The process involves the compression and rearrangement of the mineral-organic skeleton (with concomitant expulsion of pore fluid), and the bacterial-fungal degradation and possible oxidation of plant material present (with concomitant loss of mass). Soluble materials, such as calcareous shell debris, can be lost through leaching. As field studies (Hutchinson 1980) and modelling (Allen 1999, 2000c) reveal, the process is initially rapid but slows over time towards an asymptotic condition (eg Hutchinson 1980).

Lithology strongly influences compaction rates which, in sequences of mixed composition, are unlikely to have been steady. In the case of the Holocene coastal sediments of southern Britain, silts and peats are the most voluminous deposits, but sands and gravels can contribute locally to barriers and to valley and channel fills. On the Holocene time-scale, gravels and sands are effectively incompressible, but this is not true of peats and silts. Intertidal silts are moderately compressible and their responsiveness to loading increases with declining grain-size and increasing content of plant matter. A fall in grain-size normally means an increase in the proportion of clay minerals and in the water content at deposition. Peats are highly compressible (MacFarlane 1969; Hobbs 1986), with woody facies the least so, and can be quickly squeezed to a small fraction of their initial thickness. The compaction of silts, and especially of peats, is greatly facilitated by lowering the water-table, which increases the effective weight of the sediment and allows air to enter the sedimentary pile.

Because compaction is continuous, all the lithological units in a column of Holocene coastal sediment simultaneously experience compression, the lowest and already the most compacted being the least affected, other things being equal. The process therefore causes the active depositional surface to subside while at the same time reducing the altitudes of all of the beds below (stratigraphic distortion). Hence these effects at a site depend on the lithological make-up of the column and on its thickness, in some outcrops as much as 30 m, above the Pleistocene or pre-Pleistocene 'basement' (effectively incompressible). As modelling (Allen 1999, 2000c) and field studies show (eg Schothurst 1977; Cahoon *et al* 2000; Cohen 2003), the depositional surface consequently subsides at a rate that can amount to considerably more than the rate of sea-level rise typical of the later Holocene (Figure 1). The effect on underlying beds, when considered in terms of the same, essentially isochronous units in neighbouring columns, is to give them a dip in the same direction as the known or putative basement (eg Haslett *et al* 1998; Shaw and Ceman 1999; Bell *et al* 2002; Brown 2002; Sawai *et al* 2002; see also Carminati and Santantonio 2005) and, on a wider geographical scale, a variation in altitude that closely echoes the shape of the basement and any buried sand bodies (eg Streif 1972, 2004; Devoy 1979; Smith 1985; Jennings and Smyth 1987; Wilkinson and Murphy 1995; Behre 2004). Altitude variations of a few metres on a spatial scale of a few hundred metres to a few kilometres are not uncommon (eg Long *et al* 2006), and the effect generally extends to the active surface, where it is expressed as a gentle relief. Other things being equal, the greatest subsurface distortions and rates of surface subsidence are linked to the thickest sequences. Subsidence due to compaction may be expected to have been increasingly effective as the Holocene epoch unfolded.

Significant as compaction can be, its importance in shaping Holocene sequences should not be exaggerated. Working near the River Brede on the western margins of Romney Marsh, Long *et al* (2006) ascribe the accumulation of a marine silt unit to the very rapid compaction of the underlying mid Holocene peat, claiming vertical accretion rates of the order of 0.2 metres annually. Other factors could have been more influential, however, given the context, the lack of evidence for stratigraphic architecture at the site, and the pattern of grain size (an internal hiatus is indicated), lamination and banding, and foraminiferal assemblages in the single core that was examined in detail. That the silt in question owed its high rate of vertical deposition primarily to lateral accretion would not be out of keeping with the evidence from modern estuaries with meandering channels that wander (eg Dalrymple and Makino 1989; Dalrymple *et al* 1991). Also worthy of consideration is the possibility that destructive channel wandering (eg Pringle 1995) was followed by rapid sedimentation on an erosion surface comparatively low in the upper part of the tidal frame (eg Allen and Haslett 2002). In Romney Marsh and other north-western European coastal lowlands, peat compaction may not have been the 'key driving mechanism behind rapid coastal change, far exceeding the effects of wither eustatic change or crustal uplift-/subsidence' as is contended (Long *et al* 2006).

Decalcification

Recent work has begun to reveal another process able to effect combined mass and volume reduction in Holocene estuarine deposits, namely, decalcification.

The process depends on the action of acid waters on carbonate detritus present in the silts. Those of the Severn Estuary include up to 10-15% by weight of carbonate particles (eg Allen 1987), in the form of comminuted skeletal debris, early diagenetic crystals and crystalline aggregates reworked from older Holocene sediments, and corroded calcite-dolomite rhombs derived from local Triassic rocks. In The Wash the proportion is about 20%, and in the Baie du Mont-Saint-Michel 40-50% (Larsonneur 1994). Clearly, significant reductions in stratigraphic thickness could result from the loss of this component.

Evidence is emerging from many parts of the Severn Estuary Levels to show that decalcification has occurred at least locally. Near Gold Cliff Island on the Caldicot Level, early Holocene silts are in places decalcified through thicknesses of a metre or so (Allen and Haslett 2006b). Elsewhere, bands of *poupées* have been recorded from silts at many Holocene levels, testifying to the widespread mobilisation of carbonate material. Decalcification is also known from the Essex Holocene (Wilkinson and Murphy 1995).

Coastal change

It would be simplistic to suppose that the evolution of the Holocene sequences was unaffected by coastal change. In the Bristol Channel-Severn Estuary today the coast changes from tide-dominated to wave-dominated as the water-body widens and the shore becomes increasingly exposed (Allen 2002). Consequently, a shore of mudflats and salt marshes is replaced toward the open sea by one dominated by sandy-gravelly barriers that substitute for silt and peat facies. As can be seen on the wave-dominated coast of North Norfolk (Andrews *et al* 2000; Brennand and Taylor 2003), these barriers are unstable and, in response to changes in regime, can either prograde erosively landward through backbarrier silts and peats, or shift parallel with the coast, with similar stratigraphic consequences. Muddy tide-dominated coasts are also seen to shift. One extrinsic cause of local change is the lateral wandering of tidal channels within estuaries, causing temporary marsh-edge retreat at bold cliffs (eg Pringle 1995). Another important cause of retreat on a local to district scale is the intrinsic tendency of salt marshes to evolve to a state where the seaward margin becomes cliffed and undergoes landward retreat (van de Koppel *et al* 2005). In both cases an erosional break is introduced into the evolving lithostratigraphic sequence. The presence in the prior sequence of resistant, ledge-forming peat beds partly controls where such breaks occur.

Insights from modelling

It is now possible to mathematically model fairly satisfactorily the response over time of a coastal wetland surface that is accreting under conditions of changing sea level (Randerson 1979; Krone 1987; Allen 1990b, 1995, 1997, 2003; French 1993; Callaway *et al* 1996; Pizzuto and Schwendt 1997; Day *et al* 1999; van Wijnen and Bakker 2001; Temmerman *et al* 2003b). These time-stepping, numerical models range from the exploratory, deepening morphodynamic insight, to the predictive, designed to simulate the past and future behaviour of a particular marsh. To be most effective, they require some kind of representation of all the main controls identified above (eg Allen 2003, eqs.1-3). Of the local controls, compaction is the most difficult to include in models, because it depends on a strong negative feedback from the whole of the prior sedimentary pile at a location. It is nonetheless one of the most important but also one of the most oversimplified or neglected.

Valuable insights into the morphodynamics of coastal wetlands have come from such modelling. One crucial insight is that, under conditions of steady relative sea-level rise, sediment accumulation will build a salt marsh (or mudflat) to a state of dynamic equilibrium, so that it maintains just that height relative to the tidal frame such that the total rate of accretion exactly balances water-level rise and compaction. Other things being equal, the higher the rate of rise, the lower in the tidal frame lies the equilibrium marsh. For a fixed rate of rise, however, the availability of suspended sediment strongly influences the relative position of the depositional surface. A low availability results in a depositional surface that lies comparatively low in the tidal frame, because only numerous and individually protracted inundations can yield the rate of upward growth necessary for the maintenance of equilibrium. Correspondingly, a high turbidity allows the surface to build to a high relative position, because equilibrium can be satisfied by just a few, comparatively brief inundations.

Table 1: Summary of the factors that control punctuation in Holocene coastal sequences together with their influence.

Factor and scope	**Rate/quality of influence**	
	low	**high**
mean sea level (regional, rate +ve)	promotes high intertidal marshes	Promotes low intertidal marshes and mudflats
mean sea level (regional, rate -ve)	promotes soils/some supratidal marshes	promotes supratidal marshes, but may constrain the latter through the effect on water-table
vertical crustal movement (regional rate variously -ve in southern Britain)	promotes high intertidal marshes	promotes low intertidal marshes and mudflats
changing tidal range (local, rate +ve)	promotes high intertidal marshes	promotes low intertidal marshes and mudflats
changing tidal range (local, rate --ve)	promotes soils/some supratidal marshes	promotes supratidal marshes, but may constrain the latter through the effect on water-table
exogenous sediment supply (local-district, rate +ve)	promotes low intertidal marshes and mudflats	promotes high intertidal marshes
endogenous sediment supply (local-district, rate +ve)	promotes minerogenic intertidal marshes	promotes organogenic high intertidal and supratidal marshes
Surface subsidence due to compaction (local, rate -ve)	promotes high intertidal marshes/soils/some supratidal marshes	promotes low intertidal marshes and mudflats
marsh-edge retreat followed by advance (local to district scale)	leads to the partial elimination of prior silt and peat beds, and the development of erosional hiatuses succeeded by renewed mudflat-salt marsh deposition and the eventual possibility of further peatland	
coastal barrier development (district scale)	substitutes sandy-gravelly for silt-peat facies, with migration of barriers islands and inter-island tidal channels eliminating prior silt-peat sequences and creating hiatuses	

These results are concordant with a range of field studies of active marshes, beginning with those of Pethick (1981), showing that immature marshes low in the tidal frame build up more rapidly than associated more mature ones that lie higher (eg French 1993; Haslett *et al* 2003; Temmerman *et al* 2003). Young marshes, growing up from tidal flats or wave-cut platforms at about the level of MHWNT, under current conditions can initially accrete at rates of tens of millimetres per year (eg Allen and Haslett 2006b). The current rate for mature marshes, standing high in the tidal frame, is typically a few millimetres annually. Another important insight concerns the relative roles of the endogenous and exogenous sources of sediment. Dynamic equilibrium is no longer possible if the supply from the latter falls below a critical value set by the former. The marsh then continues to grow upward relative to the tidal frame, becoming increasingly plant-rich in the process, and may break through the 'ceiling' set by the level of HAT, transforming itself into a supratidal peatland.

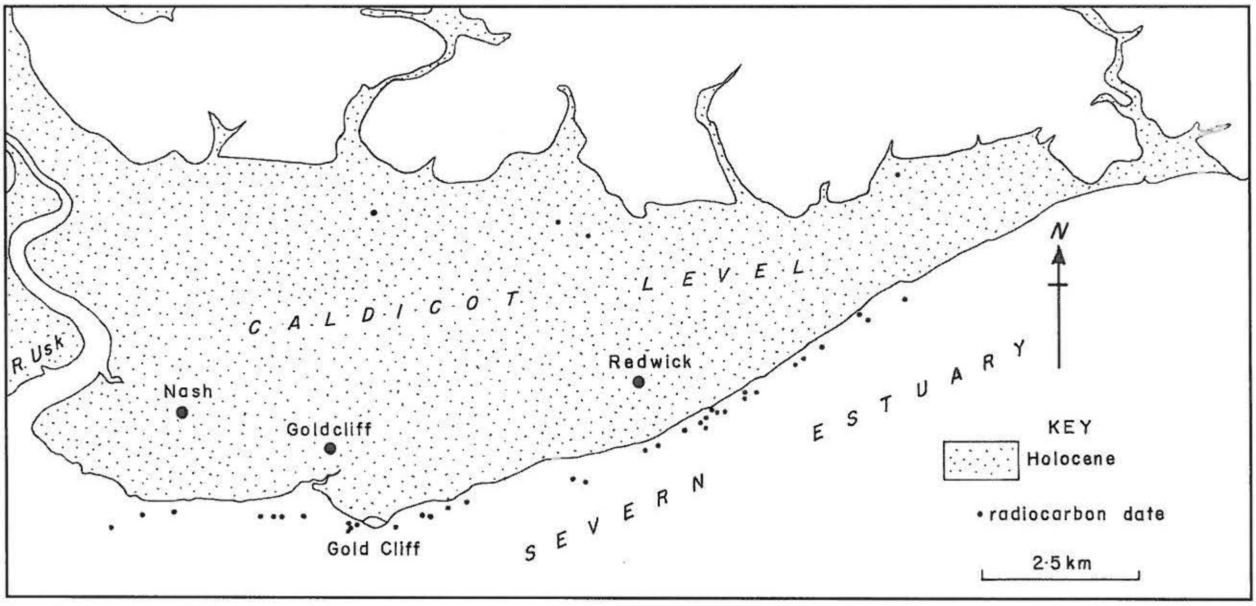


Figure 2. Locations of radiocarbon-dated samples from the coast and inner zone of the Caldicot Level, Severn Estuary. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

Summary of influences

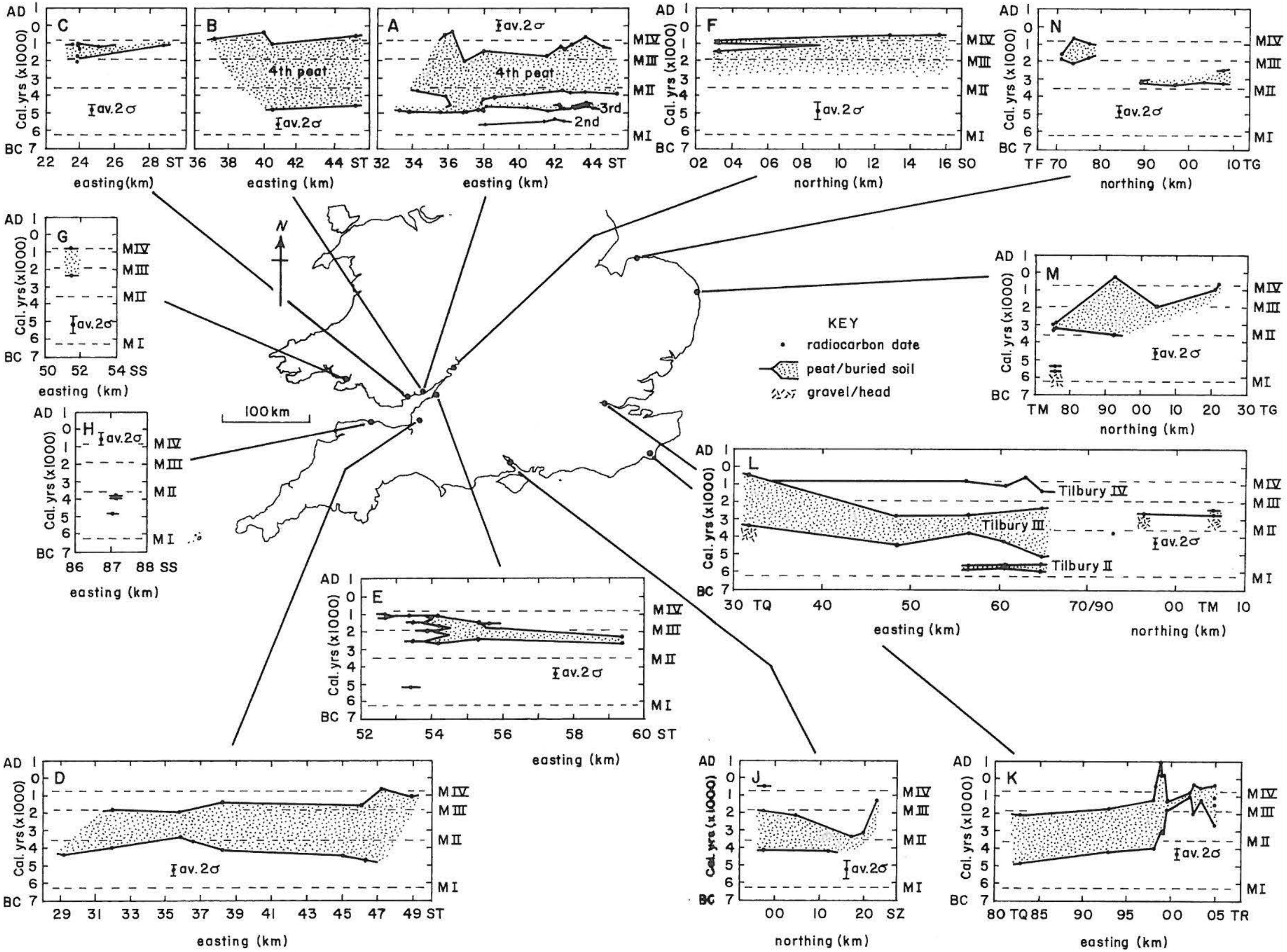
Table 1 attempts to summarise the different effects of these controls on the Holocene estuarine/coastal sedimentary surface. Mean sea level, vertical crustal movements and tidal range emerge as the main forcing factors, with compaction and sediment supply acting as the main moderating or exacerbating influences.

COASTAL CALDICOT LEVEL

The superb coastal exposures *c.* 15 km in extent (Figure 2) reveal a laterally variable sequence (Aldhouse-Green *et al* 1993; Scaife and Long 1995; Bell *et al* 2000, 2002; Allen and Haslett 2006b) which, although including important depositional breaks, is apparently fullest in the Redwick area. A complete, silt-dominated sequence has been described from here with several intercalated peats numbered one to five (Allen and Bell 1999; Allen and Haslett 2002, 2006a). A sixth peat - the 'cockle-bed peat' (Allen and Haslett 2002) - occurs between the third and the fourth beds, but is laterally restricted by a widespread erosional contact. Evidence for punctuation in the form of buried soils is limited to a late Holocene occurrence near Gold Cliff (Locock and Walker 1998).

The coastal sequence has afforded 55 stratigraphically significant radiocarbon dates (Appendix). Some dated samples - charcoal scatters and timbers from buildings - were collected for archaeological purposes, but they are also of stratigraphical value because they come from contexts at or very close to transgressive contacts between silts and peats (eg Bell *et al* 2000). It is useful to relate these dates to the first four, numbered MI-IV, of the six periods of rapid Holocene climate change identified by Mayewski *et al* (2004). An alternative climatic reference, deriving from a smaller region, is the occurrence of dryness in Ireland (Turney *et al* 2005).

The peats range from a little after Mayewski I up to an including Mayewski IV (Figures 3A, 4). The thin, diachronous 2nd peat arose in the middle of the sixth millennium BC. An interval of 200-300 years is represented by the diachronous 3rd peat which, as the sub-Holocene basement rises toward Gold Cliff Island from the east and west, fuses with the 4th peat to form a single lithostratigraphic unit around the island itself (eg Smith and Morgan 1989; Bell *et al* 2000). Typically, the 4th or 'main' peat is a metre or more in thickness and is separated from the third unit and the cockle-bed peat by silts that rest on a discordant, erosional base. It spans the interval from Mayewski II to Mayewski IV,


KEY
radiocarbon date
peat/buried soil
gravel/head
100km
N
4th peat
3rd
2nd
Tilbury IV
Tilbury III
Tilbury II
MI
MII
MIII
MIV
av.2σ
Cal. yrs (x1000)
AD
BC
easting (km)
northing (km)

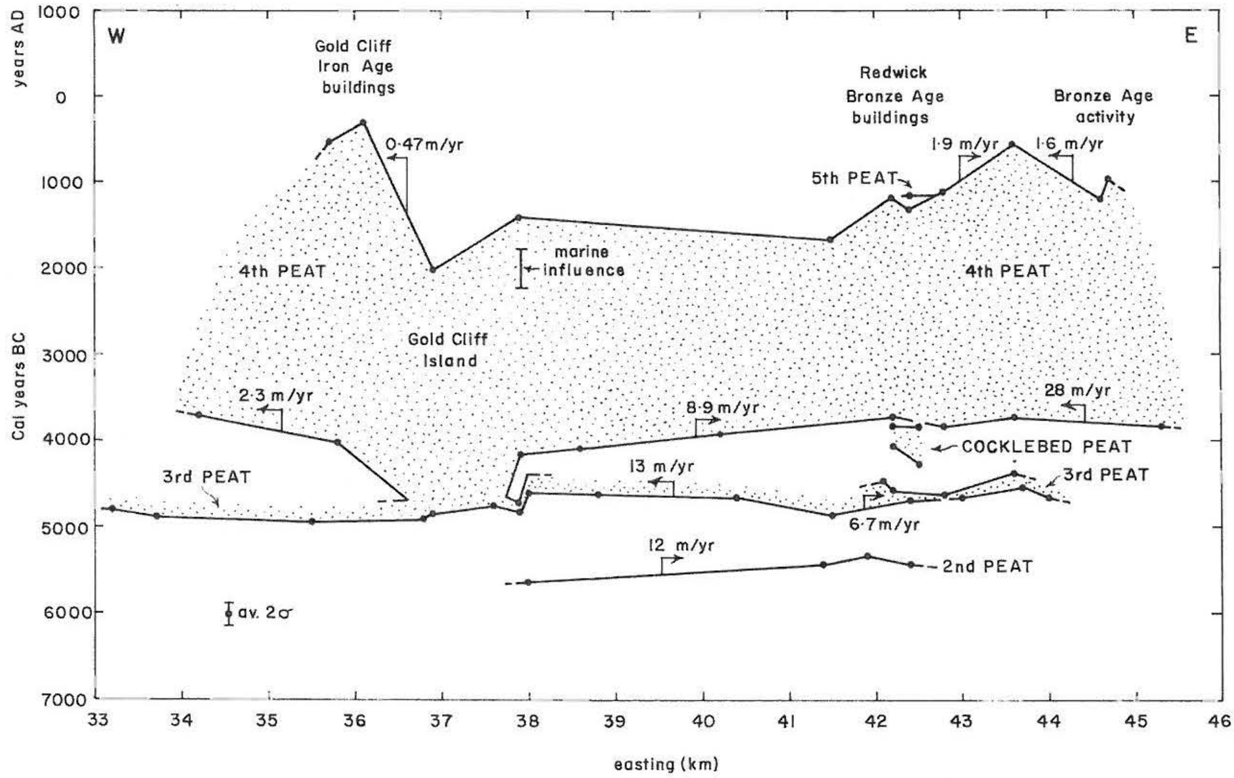


Figure 4. Detailed chronostratigraphic profile for Holocene peats exposed in the coastal zone of the Caldicot Level. For clarity, error bars (2σ) are not given for individual data points, but the average is shown as an inset.

having a systematically diachronous base (*c.* <450 yrs), and a strongly diachronous top (*c.* <1200 yrs) with upward swells at Goldcliff Pill and Magor Pill at a present altitude of *c.* 2 m OD. Thin exogenous sediments dated to between 2250 and 1750 Cal BC within the 4th peat suggest that a marine transgression was occurring at about this time (Smith and Morgan 1989; Bell *et al* 2000). At Uskmouth, on the edge of the deep palaeovalley of the Usk, the bed splits into at least two leaves. Field evidence from Gold Cliff (Bell *et al* 2000), and also from the Magor-Redwick shore, indicates that a number of thin *Phragmites* peats split off from the strongly diachronous top of the fourth bed. The 5th peat at Redwick, lying 1.75 m above the top of the fourth bed, is an early example of such a wedging leaf.

Dates for coastal archaeological contexts on the upper surface of the fourth peat have been obtained from Chapel (Tump) Farm 1 km to the northeast of Magor Pill. Whittle (1989) dated three timbers from a roundhouse all to the first half of the second millennium BC. A similar date

Figure 3. Chronostratigraphic profiles for Holocene peats and soils from localities in southern Britain. A - Caldicot Level coast. B - inner Caldicot Level. C - Wentlooge Level. D - Main Somerset Level. E - Avon Level. F - Upper-middle and inner Severn Estuary. G - Llanelli Marshes. H - Porlock Bay. J - Southampton Water. K - Romney and Walland Marshes. L - Thames Estuary and the Essex marshes. M - Suffolk and East Norfolk. N - North Norfolk Barrier Coast. For clarity of representation, some details have been omitted and error bars (2σ) are not given for individual data points (the average for each set appears as an inset.) The continuous tie lines do not necessarily imply the physical continuity of individual peat beds. The episodes of rapid climate change (Mayewski et al. 2004) are shown as MI to MIV. Each line should be understood as a diffuse zone spanning c. 300 years.

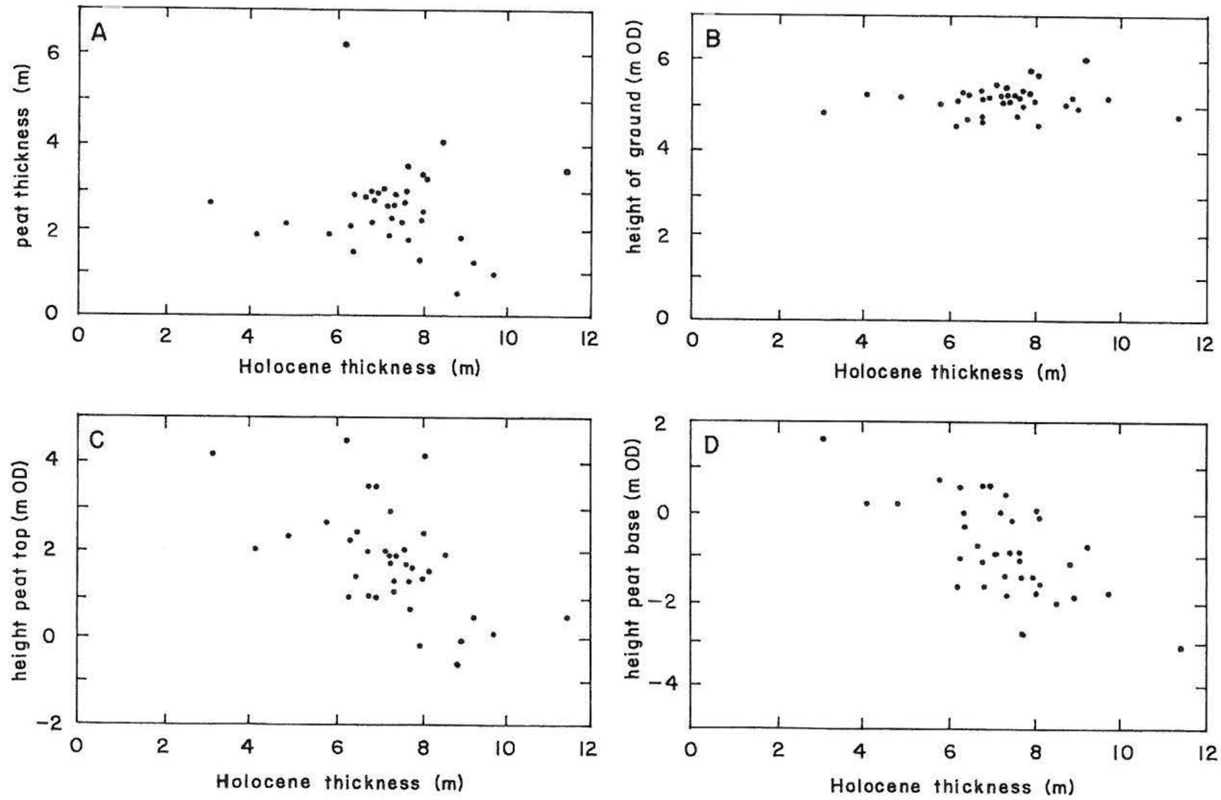


Figure 5. Stratigraphic relationships of peat in the Llandevenny area of the inner Caldicot Level (data of Allen 2001a), as a function of the thickness of the Holocene sequence. A - peat thickness. B - altitude of ground surface. C - altitude of peat top. D - altitude of peat base. Data of Allen (2001a).

was obtained on human bone from a spread of burnt material (charcoal, pottery, bone, flintwork) just 100 m away (Locock *et al* 2000). Dates up to 600 years younger, however, were given by the charcoal and worked wood. The range in age could be an indication that the site was used over a long period between the effective cessation of peat formation and the marine transgression registered by the overlying silt.

INNER CALDICOT LEVEL

The peats as a whole, as well as individual beds, increase in thickness toward the inner margin of the Level, to the accompaniment of some fusion of the deposits as the sub-Holocene basement rises (Allen 2001a). Along this marginal zone, as at Gold cliff Island intersected by the modern coast, peat occurs as a single unit which locally splits seaward into two (Andrews *et al* 1984; Walker *et al* 1998; Brown 2002). A maximum development in excess of 6 m is attained at Llandevenny (Allen 2001a; Brown 2002). The bed either directly overlies the basement (Andrews *et al* 1984; Brown 2002) or succeeds a variable development of estuarine silts (Walker *et al* 1998; Locock, 1999b). The single to double unit covers essentially the same interval as the 3rd to the 4th peats of the coast.

The available radiocarbon dates (Figures 2, 3B) show that the peat spans the period Mayewski II-IV (Appendix). At Barland's Farm and Vurlong Reen (Walker *et al* 1998) the facies appeared in the first half of the fifth millennium BC, at about the same time as the 3rd and the start of the 4th peat of the coast. Deposition ceased during the first millennium BC at a variable time linked to swells on the peat top, according to dates from Llanwern (Godwin and Willis 1964), Gwent Europark (Locock 1999b, 1999c), Barland's Farm and Vurlong Reen (Walker *et al* 1998), on the whole a few centuries later than in coastal locations. In harmony with the much shallower depth of the basement (Allen 2001a), the peat top at the innermost sites today stands a few metres higher (4-5 m OD) than the topmost coastal peats.

The strong influence of the varying altitude of the sub-Holocene surface, and the consequent variable compaction (Table 1) in the inner marginal zone, is well shown by the lithostratigraphy of 36 boreholes (Figures 5A-D) from a compact area of *c*. 275 ha to the southwest of Llandevenny (Allen 2001a). The total thickness of peat shows no statistically significant relationship to the overall thickness of the Holocene sequence (r = -0.0264, p>5%), and neither does the present altitude of the ground surface (r = 0.1653, p>5%). The altitudes of the peat top (r = -0.5596, p<0.1%) and base (r = -0.6046, p<0.1%), however, show a strong negative correlation with thickness, as is expected in an area of strong sub-Holocene relief, where differential compaction can be marked (Allen 1999).

OTHER OUTCROPS IN THE SEVERN ESTUARY LEVELS

Wentlooge Level

The Wentlooge Level (Figure 6) offers poor coastal exposures compared to the Caldicot Level, although there are many more data from boreholes and trenching (Hyde 1936; Allen 2001a; Yates *et al* 2001; Walker *et al* 2002). The basement has a similar depth to that beneath the Caldicot Level but on the whole slopes seaward more steeply. A number of peats and buried soils are recorded, chiefly from the higher parts of the laterally variable Holocene sequence. Except around Cardiff, none are as substantial as the 4th peat on the Caldicot Level, splitting southwestward at Uskmouth. Stratigraphically useful radiocarbon dates (Figure 3C) are sparse and mainly from the southwestern part of the area (Appendix).

At the proposed site of the Cardiff International Railfreight Terminal, on the inner margin of the Level, Walker *et al* (2002) dated the base and top of a 0.56 m peat at two locations. The bed spans the period from Mayewski III to the beginning of Mayewski IV, and equates to the later one-third of the 4th peat on the Caldicot Level (Figure 3A, B). It appears to thin considerably toward the coast at Rumney Great Wharf. Near the coast a bulk sample from a peat 0.13 m thick gave a date within the span of the bed at the Railfreight Terminal (Yates *et al* 2001). On the coast itself, the bed is dated by wood where it is 0.06 m thick and by timber from a Bronze Age roundhouse on the upper surface where the thickness is *c*. 0.2 m (Allen 1996). A slightly higher but much thinner peat was found to reduce and split laterally into two buried soils. A peat 0.1 m thick at St. Brides Wentlooge - the lower of a pair of beds (Yates *et al* 2001) - also dates to within the age-range of the unit at the Railfreight Terminal and apparently equates to part of the 4th peat. The probably anomalous date secured from Rumney Great Wharf (Allen 1996) is from a charcoal-rich occupation deposit intercalated among the silts of a creek levee, and is doubtful evidence of a late regressive-transgressive phase comparable to the final peats on the Caldicot Level (*cf.* Bell 2000a).

It is chiefly from the St. Brides Wentlooge area that Yates *et al* (2001) recorded buried soils (gleyed horizons) as evidence of punctuation. The lowermost, accompanying peats no more than a few centimetres thick, were correlated to the bed here equated to the later 4th peat. Undated gleyed

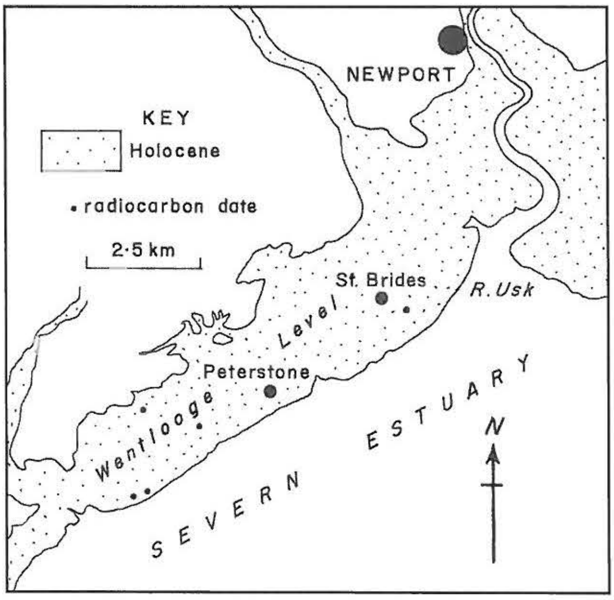


Figure 6. Locations of radiocarbon-dated samples from the Wentlooge Level, Severn Estuary. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

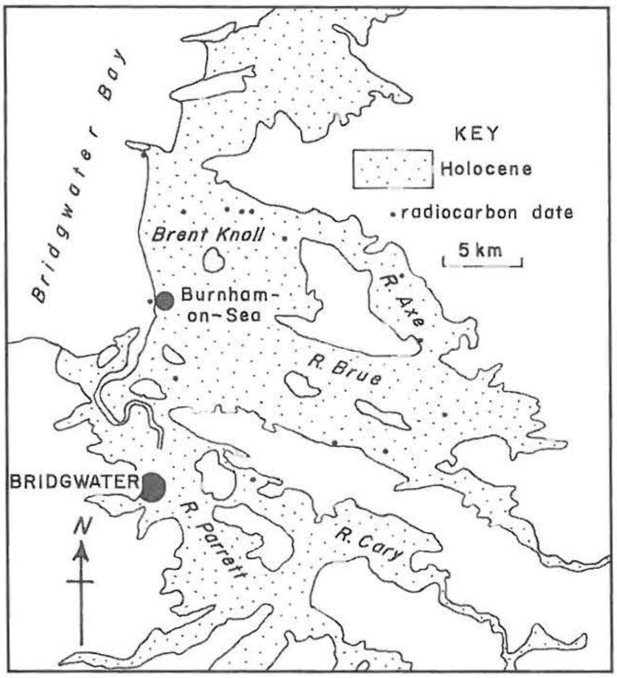


Figure 7. Locations of radiocarbon-dated samples from the Main Somerset Level. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

horizons, not always associated with peats, occur locally at a higher stratigraphic level in this area and also in the coastal transect to the southwest of Peterstone Wentlooge.

Differential compaction (Table 1) has strongly affected the development of the Wentlooge Level, as shown by contours for the modern ground surface (Allen 2000b) and the altitudes of borehole/trench sites and peat beds (Yates *et al* 2001).

Main Somerset Level

To the east and southeast of a broad coastal belt, this the largest of the Holocene outcrops of the Severn Estuary Levels (Figure 7). It reaches far inland along the narrowing valleys of the Axe, Brue and Parrett, replicated and traceable seaward on the surface of the basement below (Kidson and Heyworth 1976; Whittaker and Green 1983). The complex sequence displays two broad facies (review in Allen 2000a). The inner, peat-dominated portion, linked to the inner parts of the palaeovalleys, grades outward into the silt-dominated succession, largely of salt-marsh origin, found in the broad coastal belt. Radiocarbon dates came early from the Main Somerset Level (eg Kidson and Heyworth 1976; Heyworth and Kidson 1982; Coles and Dobson 1989), chiefly in connection with archaeological work, but in recent years attention has turned more toward stratigraphical issues.

Data gathered by Bell (1990), Haslett *et al* (1998, 2001) and Housley *et al* (1999) allow an important southeast-northwest transect based on 13 radiocarbon dates (Appendix) to be constructed across the northern Level, roughly along the course of the Axe (Figure 3D). The investigations revealed over a distance of more than 20 km a single peat unit, up to a few metres in thickness, which in the coastal belt overlay many metres of estuarine silts - an exceptional feature - apparently devoid of other peats. At the maximum development on the flanks of the bedrock 'island' of Nyland Hill (Haslett *et al* 1998, 2001), the bed spans the interval from somewhat before Mayewski II to between Mayewski III and IV, namely, the same interval as the sequence embracing the 3rd and 4th peats of the Caldicot Level (Figures 3A, B). The strongly diachronous base declines in age by more than a millennium between Nyland Hill and borehole 4 of Haslett *et al* (2001), before increasing again by a similar amount toward the coast above a locally rising basement (Bell 1990; Haslett *et al* 2001). At the coast the bed divides into three leaves, and a split into four parts occurs on a short northeast-southwest transect from borehole 4 toward Brent Knoll (Haslett *et al* 2001). The top of the bed is also strongly diachronous, decreasing in age fairly steadily from Mayewski III at the coast to Mayewski IV at the innermost site (Haslett *et al* 1998, 2001; Housley *et al* 1999).

A scatter of data (Appendix) from the southern coastal and southern interior parts of the Level (Figure 7) suggest that a peat unit similar in date and long age-range to that on the northern transect also occurs here. At an intertidal site at Burnham-on-Sea, Druce (1998) dated two very thin peats to *c.* 5300 and *c.* 4500 Cal BC respectively, making them broadly correlative with the 2nd and 3rd peats of the Caldicot Level (Figure 3A). A higher and thicker peat was dated at the base to *c.* 4180 Cal BC and at the (eroded)

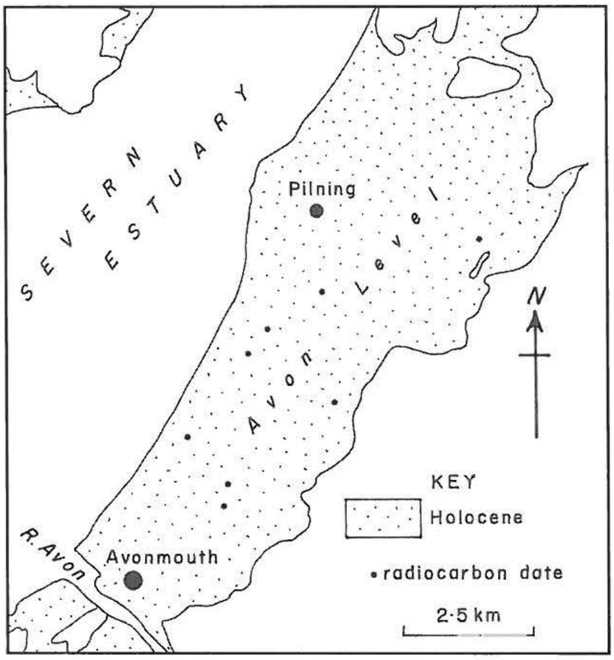


Figure 8. Locations of radiocarbon-dated peat and soil samples from the Avon Level, Severn Estuary. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

top to *c.* 3575 Cal BC. The bed is therefore equivalent to the lower part of the 4th peat. On the buried flanks of the Polden Hills near Pawlett, Holingrake and Holingrake (2001) recorded three intercalated peats dating from *c.* 4575-1500 Cal BC, that is, much the same interval as the single bed in the north (Figure 3D). Also similar in age to the base of the 4th peat is a bed overlying thick silt at Sutton Hams, at the mouth of the valley of the Cary, the chief tributary of the Parrett, that dates to *c.* 3816 Cal BC (Coles and Dobson 1989; Housley *et al* 1999). The same contact at Shapwick Heath, on the north flanks of the Polden Ridge, and at Rowland's Trackway, at the head of the Brue Valley, proved to be 700-800 years older (Coles and Dobson 1989; Wilkinson 1998 and pers. comm. 2002; Housley *et al* 1999), and therefore equates to the base of the 3rd peat of the Caldicot Level. Also from the head of the Brue Valley, at Godney, comes a date of *c.* 1055 Cal BC for the top of the 4th peat (Housley *et al* 1999).

Compaction (Table 1) strongly influenced the lithostratigraphy of the Main Somerset Level. Haslett *et al* (1998) found that the isochronous top of the main peat at Nyland Hill now dipped significantly down the buried flanks of this bedrock 'island', an effect observed elsewhere (eg Shaw and Ceman 1999) and expected from modelling (Allen 1999, 2000c). Compaction has also influenced the environmental evolution of the sequence, especially in the coastal belt, with its deep stratigraphy and exceptionally thick silts beneath the main peat. This is best appreciated by tracing the age of the base of the bed on the northern traverse across the contoured sub-Holocene surface provided by Kidson and Heyworth (1976) and Whittaker and Green (1983), beginning at the western margin of the Isle of Wedmore and ending at the 'island' of Brean Down near the coast. At these limiting sites the basement is comparatively shallow and peat growth began early, suggesting that the rate of surface subsidence due to compaction was low enough to allow an organic marsh, drawing on endogenous sediment sources, to persist over a long period. Where the base is youngest, however, the rockhead lies at least twice as deep. The higher rate of surface subsidence consequently expected was great enough to maintain salt marsh for much longer. This factor seemingly was even more potent along the transect southwestwards toward Brent Knoll, on which Haslett *et al* (2001) record the multiple splitting and passage of the peat into silt. The basement is at a depth of *c.* -30 m OD here, hard against the steep flanks of the Brent Knoll 'island'.

Avon Level

Beneath the Avon Level (Figure 8) the Holocene in places exceeds a thickness of 15 m and overlies a basement of bold, complex relief (Hawkins 1990; Carter *et al* 2003). Stratigraphical data have come from archaeological investigations (Locock 1997, 2001; Locock *et al* 1998; Allen *et al* 2002; Moore *et al* 2002; Carter *et al* 2003) and commercial boreholes (Hawkins 1962; Carter *et al* 2003), although the latter are known to have limitations. Intercalated among estuarine silts, buried soils as well as peats register punctuation during the growth of the sequence, but it is not yet clear how exactly these units should be correlated laterally. Some of the buried soils may have yielded too old a date, on account of the presence of reworked carbon (Carter *et al* 2003).

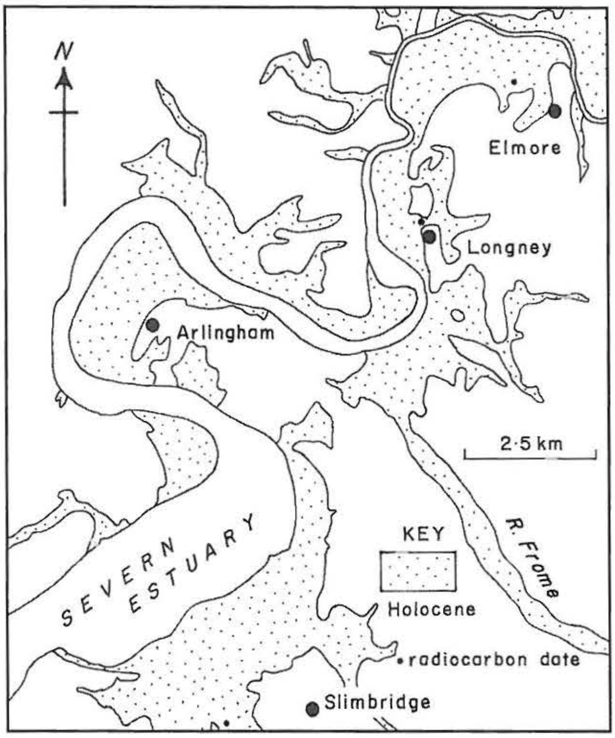


Figure 9. Locations of radiocarbon-dated samples from the upper-middle and inner Severn Estuary. See Appendix for details.

Aside from a buried soil comparable in age to the 2nd peat of the Caldicot Level, the dated peats and soils (Appendix) fall chiefly in the later half of the age-range of the fourth bed (Figure 3E), that is, from a little before Mayewski III to Mayewski IV. There is no known evidence for punctuation at the horizon of the 3rd peat. The chief bed, a metre or so thick along the inner margin of the Level (Carter *et al* 2003), apparently thins seaward and, toward the palaeovalley of the Avon, splits into even thinner leaves which seem to reduce to buried soils. Some of these carry evidence of human activity.

The weak development of peats in the Avon Level, and the apparent prevalence of buried soils, may reflect the influence of the comparatively deep basement, which would have favoured a high rate of compaction-induced surface subsidence (Table 1).

Upper-middle and inner Severn Estuary

The small, disconnected outcrops of Holocene alluvium found here are for the most part ill-known stratigraphically (Allen 2000a), although investigated from an early date (Lucy 1877; Prevost *et al* 1901).

At three sites in the upper-middle and inner estuary (Figure 9), however, Hewlett and Birnie (1996) obtained dates for the upward succession of a substantial peat into estuarine silt (Appendix). The main bed at Slimbridge (*c.* 1.15 m) overlies a thin organic-rich silt in turn on gravelly sand. A thin peat is intercalated among silts *c.* 0.2 m above the main unit. At Longney the main bed is at least 0.8 m thick. It is *c.* 3.6 m thick at Elmore, resting as at Slimbridge on silts over gravelly sand.

The peat top (Figure 3F) is similar in age to that of the 4th peat on the Caldicot Level (Figure 3A, B). Given the thickness of peat at Elmore, it seems likely that the bed here equates to much if not the whole of the interval from the 3rd to the 4th peat. Downstream beyond Longney a thin leaf seems to have separated from the top, and the base may also have grown younger.

BRISTOL CHANNEL

The detached outcrops of Holocene alluvium along the boldly cliffed shores of the Bristol

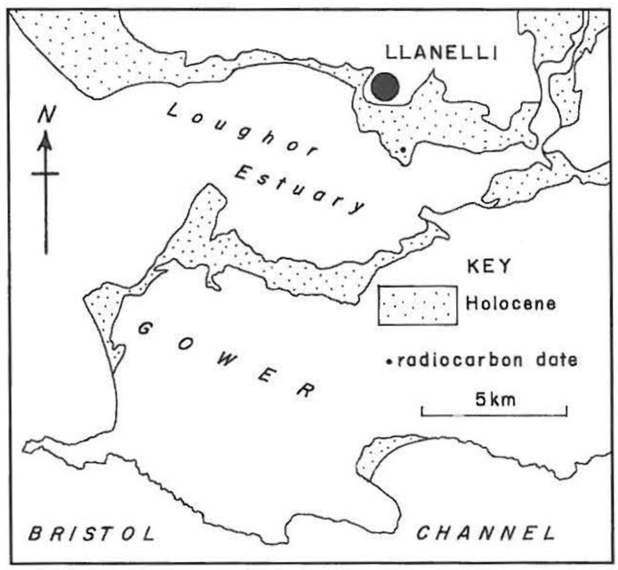


Figure 10. Locations of radiocarbon-dated samples from the Llanelli Marshes, north-central Bristol Channel. Two samples were drawn from the single location shown. See Appendix for details.

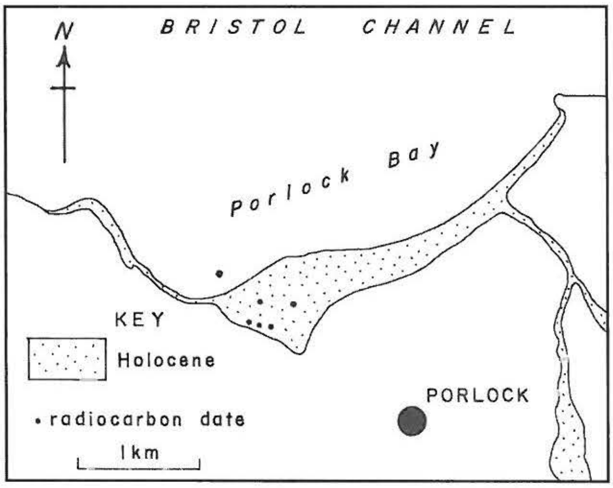


Figure 11. Locations of radiocarbon dated samples from Porlock Bay, south-central Bristol Channel. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

Channel are largely confined to the estuaries of the Taf, Tywi and Loughor (Llanelli Marshes), at the head of Carmarthen Bay, and to Minehead Bay and Porlock Bay on the south coast. Only two of these are at all well known stratigraphically.

From the Llanelli Marshes (Figure 10) Lillie *et al* (2003) reported a thick sequence of estuarine silts and some sands with three laterally persistent, intercalated peats/silty peats. Where the highest organic bed measured 2 m in thickness, dating was carried out at 0.3 m above the base and 0.15 m below the top (Appendix). Assuming steady accumulation, the bed therefore has an age-span of *c.* 1400 years, ranging from Mayewski III to Mayewski IV (Figure 3G). It equates to the upper half of the 4th peat on the Caldicot Level (Figures 3A, B). Not dated were a much thinner silty peat and a peat up to 2.3 m below the main bed. These could represent the 3rd or early 4th peat.

A small outcrop at Porlock Bay (Figure 11) is known from a dense borehole array (Canti *et al* 1995; Jennings *et al* 1998). The diachronous Holocene sequence, no more than *c.* 10 m thick, overlies a head-cloaked basement that gradually rises inland into an embayment. It consists of a lower part of silts, clays and up to three thin peats, and an upper portion, with no reported signs of punctuation, composed of clays and silts with occasional shelly silts, shelly sands and gravelly deposits. The uppermost peat is the most widespread and thickest, reaching a local maximum of 0.45 m. Dates from the lower and upper contacts (Appendix), averaging at *c.* 4200 Cal BC and *c.* 3940 Cal BC respectively (Figure 3H), clearly assign this bed to the earliest part of the 4th peat on the Caldicot Level and to the beginning of Mayewski II (Figures 3A, B). Broadly of the same date as the 2nd peat of the Caldicot Level is the chief older peat.

As the Porlock sequence is not exceptionally thick, it is a matter for comment that, compared to similar developments in the Bristol Channel-Severn Estuary, there should be no peats younger than *c.* 4000 Cal BC, and that the facies should change substantially across the top of the youngest bed. Jennings *et al* (1998) implicitly assume continuity of deposition (the upper facies lacks dating evidence), and assert the influence of a long-lived gravel barrier on the evolution of the sequence. However, the absence of young peats, and the small thickness and discontinuous character of the uppermost bed, dated to the earliest 4th peat, may alternatively reflect a major hiatus due to coastal change (Table 1). In four boreholes the uppermost peat is immediately overlain by either gravelly or shelly deposits, and in another, lacking peat, a gravelly silt occurs at about the same altitude as the bed present in nearby cores. Peats exposed in the Severn Estuary-Bristol Channel are well known to be resistant ledge-formers, as is evident at low tide at Minehead and at Porlock itself, and mid Holocene depositional breaks are not uncommon (Allen 2001a; Haslett *et al* 2001; Allen and Haslett 2006a, 2006b).

From Minehead Bay, 10 km to the east of Porlock Bay, Jones *et al* (2004) record punctuation in the form of two thin, intercalated peats of early date exposed intertidally on scattered, eroding ledges of variable altitude (Appendix). The older bed equates almost exactly to the 2nd peat of the Caldicot Level but is slightly later than the lowest peat at Porlock, the base dating to *c.* 5490 Cal BC and the top to *c.* 5160 Cal BC. The upper peat dates at the base to *c.* 4600 Cal BC, and seems to be equivalent to the main peat of the Porlock sequence.

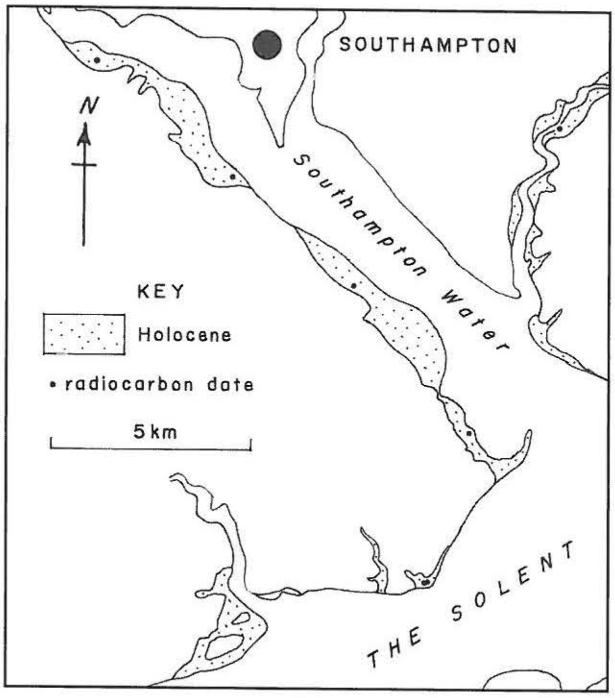


Figure 12. Locations of radiocarbon-dated samples from Southampton Water. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

SOUTHAMPTON WATER (SOLENT)

Occupying the palaeovalley of the Solent River, and joining the modern Solent from the northwest, Southampton Water on the coast of the English Channel is the partially-mixed joint estuary of the rivers Itchen, Test and Hamble (Figure 12). The palaeovalley contains a Holocene sequence up to 25 m or more thick of estuarine silts, sands and gravels with some peats (Hodson and West 1972; Long and Tooley 1995; Long *et al* 2000). The peats are very variable in development (≤2.25 m), and of the radiocarbon dates given by Long *et al* (2000), comparatively few are from critical contacts (Appendix). A number of peats are diachronous and 'basal', resting on gravels or sands. In some transects is found a single intercalated peat lying at about Ordnance Datum to a few metres below. The tops of some peats are sharp, with signs of erosion.

These data suggest that peat is largely confined to the interval from Mayewski II to III (Figure 3J), that is, to all but the latest part of the period represented by the 4th peat of the Caldicot Level (Figures 3A, B). At Stansore Point, at the mouth of Southampton Water, an intercalated peat (0.12 m) is similar in age to the youngest peat facies at Caldicot. The comparative lack of peats in the sequence could be partly a response to a low availability of fine sediment related to the modest tidal range and small catchment area (Table 1). Another factor could be a high rate of compaction linked to the considerable depth to basement.

ROMNEY MARSH AND WESTERN ENVIRONS

Walland Marsh and Romney Marsh proper, together with the floodplains of the rivers Brede, Tillingham and Rother flowing from the west (Figure 13), measure *c.* 300 km^2 and form by far the largest outcrop of Holocene estuarine and coastal deposits on the shores of the English Channel. The area has a complex post-glacial history but in essence evolved as a coastal barrier and estuary-backbarrier complex. A sequence of sediments 20-30 m thick is present, chiefly sands and gravels below, overlain in the uppermost 5-10 m by silts with a major intercalated peat (the so-called 'main peat'), and cut by sand-filled palaeochannels (Tooley and Switsur 1988; Long and Innes 1993, 1995; Long *et al* 1998, 2006; D. Long *et al* 1998; Spencer *et al* 1998; Waller *et al*

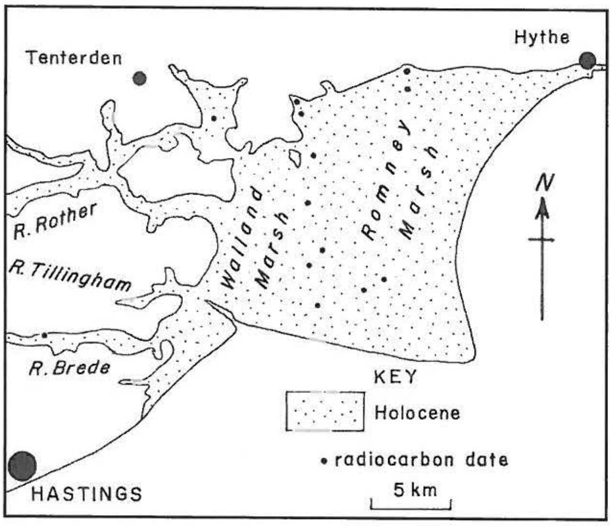


Figure 13. Locations of radiocarbon-dated samples from Romney Marsh, eastern English Channel. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

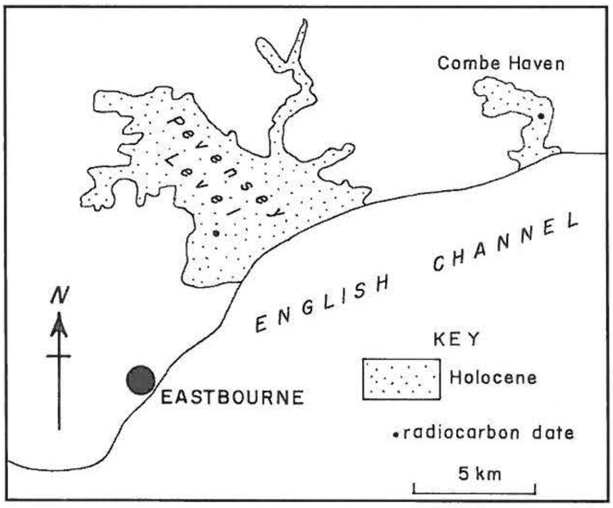


Figure 14. Locations of radiocarbon-dated samples from Combe Haven and the Pevensey Level, eastern English Channel. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

1999, 2006; Waller 2002). The peat is thickest (*c.* 6 m) in the innermost river valleys but much thinner, although locally approaching *c.* 2 m, in Walland Marsh. It is reduced to a few decimetres northeastward into Romney Marsh proper, where the bed appears to be cut out erosively by sands and silts. The bed is predominantly of poor fen and various fen-carr facies, except in the southwest-central part of the area, where it finishes in thick raised-bog deposits (Waller *et al* 1999; Waller 2002). Generalised maps (Long *et al* 1998, fig. 4.6; Long 2000, fig. 3a) suggest that the main peat formed earliest along the northwest margin of the Holocene outcrop and appeared last along the inland slopes of the Dungeness beach-plain. A second generalised map (Long *et al* 1998, fig. 4.7) indicates that peat deposition gradually came to an end over an interval of about two millennia, persisting longest in Walland Marsh, especially in the southwest-centre where it was locally continuing to form in later Saxon times.

Twenty-six selected radiocarbon dates illustrate the development of the main peat (Appendix). These define a zig-zagging but broadly west-east transect from the river valleys into Romney Marsh proper (Figures 3K, 13). A number of trends intersect, but the most striking is the west-east, broadly sympathetic diachroneity of the base and top of the main peat. The early and prolonged formation of peat in the river valleys and the western part of the area occurred in association with the estuaries of the rivers introducing sediment from catchments to the west, suggesting that sediment was in sufficient supply for high marshes to be maintained. What is not clear is why marshes, including raised bog, should have persisted for so long in the southwest-centre of the area. Eastward and also southward the main peat thins as it enters increasingly sandy regions more remote from the rivers but influenced by marine inlets and barriers in this sector.

Two further outcrops (Figure 14) of Holocene estuarine sediments similar to those of Romney Marsh occur not far to the west (Jennings and Smyth 1987). The closest, the blocked estuary of Combe Haven at Hastings, displays a thick (*c.* 20 m) sequence of silts with two intercalated peats, the lower and thinner dating to *c.* 4900-4630 Cal BC and the thicker (*c.* 4.7 m) to *c.* 3940-230 Cal BC. These peats, ranging from shortly before Mayewski II to just after Mayewski IV, are indistinguishable in age from the 3rd and 4th peats respectively of the Caldicot Level (Figures 3A, B). The uppermost bed closely matches the 'main bed' of Romney Marsh (Figure 3J). Differential compaction has clearly influenced the accumulation as well as the preservation of the Combe Haven deposits. The more distant and significantly thinner succession underlies the Pevensey Level near Eastbourne. Here the laterally persistent 'Willingdon Peat' (*c.* 1 m) dates from the relatively narrow interval *c.* 2140-1690 Cal BC, linking it to the upper part of 4th peat at Caldicot (Figures 3A, B) and placing it largely in Mayeski III. The few earlier peats recorded are thin and extremely local. The Willingdon Peat divides into two where the Holocene silts are recorded at their thickest (*c.* 10 m), but there is otherwise little sign that differential compaction influenced growth of the sequence, in contrast to Combe Haven. The catchment supplying the Pevensey Level is small, however, and the upward growth of mudflats and salt marshes could have been supply-limited (Table 1).

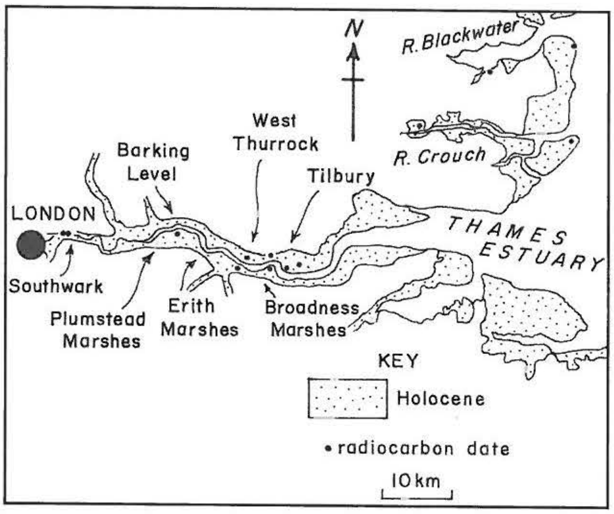


Figure 15. Locations of radiocarbon-dated samples from the Thames Estuary and the Essex marshes, southern North Sea. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

THAMES ESTUARY AND THE ESSEX MARSHES

Substantial but relatively narrow outcrops of Holocene estuarine sediments can be traced eastwards along the Thames valley from central London to the Kent and Essex marshes of the outer estuary (Figure 15). From the lower Thames, downstream of the central London sites later reported by Sidell *et al* (2000), Devoy (1979) gave an unequalled account of an eastward-thickening sequence composed of silts with up to four, persistent, intercalated peats (Tilbury II-V) that overlay a basal peat (Tilbury I) developed on gravel or the rockhead. Less well understood, however, is the generally thinner sequence in the more exposed setting of the Essex marshes (Greensmith and Tucker 1971, 1973, 1976; Wilkinson and Murphy 1995). Fewer radiocarbon dates than might be expected are available from this extensive area (Appendix). Firth (2000) has given stratigraphical accounts of the Holocene sequence at localities on the Kent marshes. Peats equivalent to Tilbury III-V seem to be present, but no radiocarbon dates are as yet available.

The thickest and most extensive peat in the lower Thames (Devoy 1979) is Tilbury III, with a local age-range of between roughly one and three millennia (Figure 3L). It spans the interval from about mid-way between Mayewski I and II to almost Mayewski III, and clearly equates to the 3rd and all but the uppermost 4th peat of the Caldicot Level (Figures 3A, B). The thin Tilbury II below is almost identical in age to the 2nd peat, but more substantial. Varying dates, falling chiefly in Mayewski IV, have come from the thin Tilbury IV, which may embrace more than one bed (Tyers 1988). Westward in the thinner sequence of central London (Sidell *et al* 2000), the gravels are directly overlain by a thick, continuous peat with the same age-range as the 4th peat of the Caldicot Level (Figures 3A, B). Like the equivalent peats of the inner Caldicot Level and Nyland Hill in the Main Somerset Level (Figure 3D), it therefore spans Tilbury III as well as Tilbury IV down-estuary to the east, into which it probably splits. The Holocene in Essex (Greensmith and Tucker 1971, 1973, 1976; Wilkinson and Murphy 1995), with much more sand and fewer and thinner peats than in the Thames, overlies an intricately dissected surface cut in the London Clay and is consequently of very variable but locally considerable thickness (*c.* 36 m). The few available radiocarbon dates - 'spot' rather than critical values from significant lithological transitions - give some indication of the general timing of peat formation in this proximal area. The oldest known bed (Foulness, intercalated) substantially antedates Tilbury II and may equate to Allen and Bell's (1999) 1st peat, or even the locally-developed basal peat, in the Caldicot Level. The remaining three dates all fall within the age-range of Tilbury III, coming from an intercalated peat at Dengie but basal deposits at the Crouch and Blackwater estuaries. From the limited thicknesses of the beds, it seems unlikely that peatlands persisted for as long as in the Thames.

According to data taken from Devoy's (1979) mainly commercial boreholes, Tilbury III in the lower Thames Estuary is related in two contrasting ways to the overall thickness of the silt-bearing part of the Holocene sequence, depending on whether the latter totals less or more than *c.* 11 m.

Records from the thin sequences at Plumstead Marshes, Erith Marshes and the Barking Level constitute the first set (Figure 15).

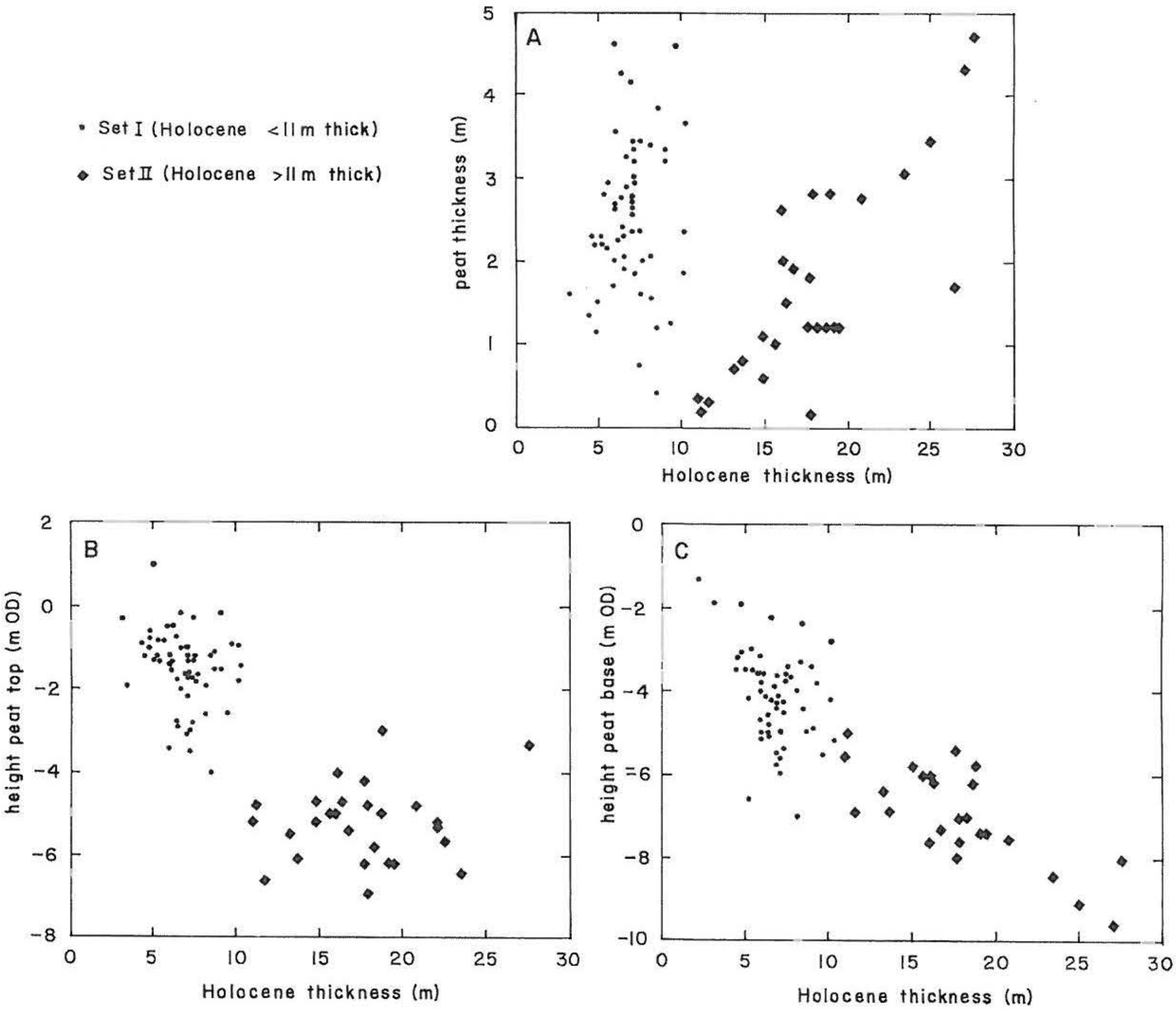


Figure 16. Stratigraphic relationships of the peat bed Tilbury III in the Thames Estuary (data of Devoy 1979), as a function of the thickness of the Holocene sequence above gravels/rockhead. A - bed thickness. B - bed top. C - bed base.

The thickness of Tilbury III is extremely variable but essentially independent of that of the Holocene (Figure 16A), as the low correlation coefficient confirms (r = 0.1629, n = 56, p>5%). A negative trend is shown by the altitude of the top of the bed (Figure 16B), as in the inner Caldicot Level (Figure 5C), but it is weak and not statistically significant (r = -0.2059, n = 56, p>5%). Rather stronger (r = -0.3391, n = 56, p<1%) is a negative trend for the altitude of the base (Figure 16C), again similar to the pattern at Llandevenny (Figure 5D).

The second set, overlapping geographically with the first, comes from sites at West Thurrock, Broadness Marshes and Tilbury (Figure 15) where the boreholes range across deeper parts of the palaeovalley and the post-gravel/rockhead sequence reaches up to *c.* 28 m in thickness. In this set the thickness of Tilbury III is strongly correlated positively (r = 0.8572, n = 26, p<0.1%) with the Holocene thickness (Figure 16A), a pattern not seen at Llandevenny (Figure 5A). Also in contrast to Llandevenny (Figure 5C), the present altitude of the top of the peat (Figure 16B) is independent of the Holocene thickness (r = 0.1428, n = 26, p>5%) and is constant within the range *c.* -3 to -7 m OD. As at Llandevenny (Figure 5D), however, the altitude of the base of Tilbury III is strongly correlated negatively (r = -0.7617, n = 26, p = <0.1%) with Holocene thickness (Figure 16C).

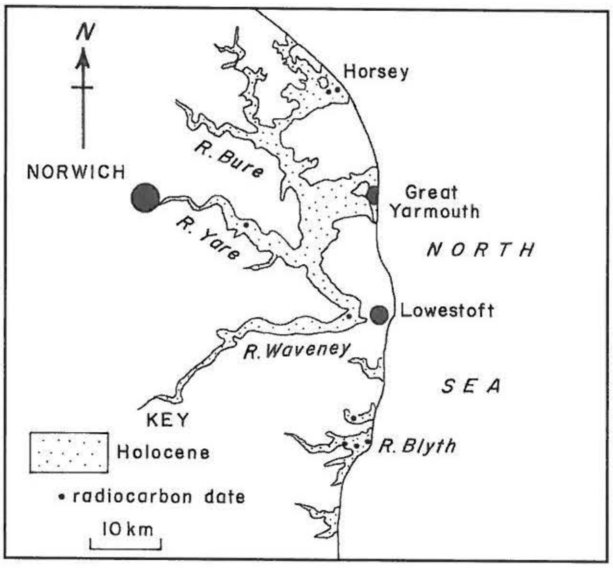


Figure 17. Locations of radiocarbon-dated samples from Suffolk and East Norfolk, southern North Sea. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

These results are difficult to interpret. Tilbury III has an older base among the second set of boreholes than among the first, but only by a matter of *c.* 600 years, which is insufficient to account for the observed wide variations in the altitude of the base and the thickness of the bed. It seems more likely that compaction was nicely balanced by other factors, such that an organic marsh could be sustained for a long period along the estuary. Consistent with the influence of the basement, the present altitude of the top of the bed lies some 4 m higher in the shallower boreholes than in the deeper set, although peat growth in the latter continued for several hundred years longer. Why the boreholes should group into two sets on the basis of Holocene thickness is not clear, for silts, sandy silts and silty sands appear to have much the same relative abundance throughout the outcrop. The peats do thin and fade out toward the outer Thames, where the Holocene is at its thickest, suggesting that the sedimentary surface, because of a high rate of compaction and possibly a weaker exogenous sediment supply (Table 1), remained comparatively low in the tidal frame.

SUFFOLK AND EAST NORFOLK

Several estuaries infilled with Holocene sediments above locally deep palaeovalleys (*c.* 20 m) break the low North Sea coast of Suffolk and East Norfolk (Figure 17), the largest and most complex being Ptolomy's 'Great Estuary' uniting the Waveney, Yare and Bure (Coles and Funnell 1981; Brew *et al* 1992; Arthurton 1994; Horton *et al* 2004). The sequences are variable but all include silts with intercalated peats, which tend to be laterally persistent and locally several metres thick. The Appendix lists 12 radiocarbon dates from these outcrops.

The Blyth Estuary has three peats (Figure 3M), of which the earliest, the Lower Peat, is basal, resting on Pleistocene gravels (Brew *et al* 1992). It is indistinguishable in age from Tilbury II in the lower Thames (Figure 3L) and the 2nd peat of the Caldicot Level (Figure 3A). Although reaching up to *c.* 4 m in thickness, the Middle Peat appears to represent a period of only 300 years or so within the span of Tilbury III and the 4th peat of Caldicot. The laterally persistent Middle Peat has a slightly older base where the bed is 1.52 m thick in the Waveney Valley, and the top is comparable in date to the youngest developments of the 4th peat at Caldicot (Figures 3A, B). At the innermost Yare valley the Middle Peat measures 6-8 m in thickness (Coles and Funnell 1981). A date within Mayewski III, later than most of Tilbury III (Figure 3L), was obtained from a site to the east, where the peat is reduced to 4.5 m. The Middle Peat, measuring up to 2.92 m thick, lies in a basal position near Horsey (Horton *et al* 2004), the top dating to Mayewski IV, similar to Tilbury IV and the uppermost 4th peat at Caldicot (Figures 3A, B, L).

The sequences in the Suffolk-East Norfolk estuaries are physically disconnected and the differences between them probably have local causes. There is evidence, however, that the peats increase in age-range and commonly thickness inland along the estuaries as the sequences thin (eg Thames), and also with the rise of the basement on the sides of the palaeovalleys (eg Main Somerset Level).

NORTH NORFOLK BARRIER COAST

For *c.* 45 km along the exposed North Norfolk coast (Figure 18) there ranges a narrow (1.5-4 km) outcrop of Holocene sediments (Pearson and

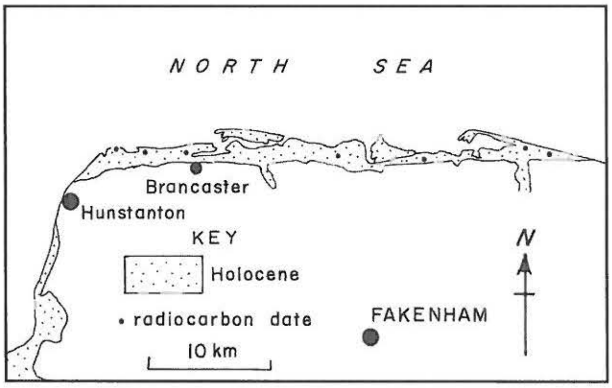


Figure 18. Locations of radiocarbon-dated samples from the North Norfolk Barrier Coast. Note that multiple samples from a site are not separately distinguished. See Appendix for details.

Funnell 1989; Andrews *et al* 2000; Orford *et al* 2000; Brennand and Taylor 2003) surmounted by a complex of salt marshes, tidal flats and channels, and sand/gravel beach-dune barriers (Pearson *et al* 1990). The sequence, thickening eastwards, mantles a deep, east-west trough cut largely in the Chalk (Chroston *et al* 1999). Overlying a strongly diachronous basal peat, the beds consist of silts with a few generally thin (<1.2 m) intercalated peats, the whole modified/interrupted by coarse-grained tidal channel-beach barrier deposits that introduce much lateral variability.

Yielding 12 radiocarbon dates (Appendix), the peats of the area fall into two main groups, each restricted to a particular sector (Figure 3N). The oldest beds are recorded to the east of Brancaster, in which direction they tend to occur at progressively lower altitudes. The marked range in development (≤ 0.73 m) and age - from Mayewksi II almost to Mayewski III - makes it likely that more than one lithostratigraphic unit is present. Whatever the actual situation of these Norfolk peats, they clearly compare as a group with Tilbury III in the Thames Estuary (Figure 3L) and the central part of the 4th peat of the Caldicot Level (Figures 3A, B). Substantial peats of a comparable age are widely recorded from the complex Holocene sequence in the Fenland Basin to the southwest, for example, the bed traceable along the palaeovalley of the R. Nene in Adventurer's Land (Brew *et al* 2000). The younger Norfolk peat is confined to the westernmost part of the outcrop. Incorporating a woodland phase, exposed on the coast, it declines in thickness from 1.12 m at Brancaster (Funnell and Pearson 1989) to not less than 0.13 m at Holme-next-the-Sea (Brennand and Taylor 2003), by which locality it seems to have split. The bed falls in the interval between Mayewski III and IV, and is about a millennium younger than the older peats to the east. In age it compares with the uppermost 4th peat on the Caldicot Level (Figures 3A, B) and with Tilbury IV in the Thames (Figure 3L).

The main aspect of these peats for comment is their lateral variability and impersistence. This can be attributed to the exposed setting, the narrowness of the outcrop, and the strong influence exerted by coarse-grained channel-fills and barriers. The early appearance of the latter probably explains the absence of the younger peat in the east.

DISCUSSION

The questions raised by peat development during the Holocene in southern Britain concern (1) the general and particular timing and time-scales of punctuation, (2) the identity and functioning of the factors that caused/influenced punctuation, and (3) the possible effects of punctuation on prehistoric human groups in a position to access and exploit the Holocene coastal wetlands, composed broadly of peatlands and siltlands.

If further proof were needed, it is clear from Figure 19 that peat in the estuarine/coastal sequences of southern Britain is essentially a mid Holocene phenomenon. Both the early and the late Holocene lack significant developments of this organic facies. Except where coarse barrier deposits interfere, the Holocene sequence is everywhere broadly tripartite, the time-scale for these stages - early, mid and late - being a few to several millennia. In this regard southern Britain does not differ from what has been understood for some time from the Channel and Atlantic coastal zones of France (eg Morzadec 1974; Ters 1987; Mellalieu *et al* 2000), the Low Countries (eg Baeteman 1991; Vos and van Heeringen 1997) and northwest Germany (eg Streif 1972, 2004; Gerdes and Watermann 2003; Behre 2004). Aside from the occurrence of basal deposits, the essentially peat-free early Holocene lasted in

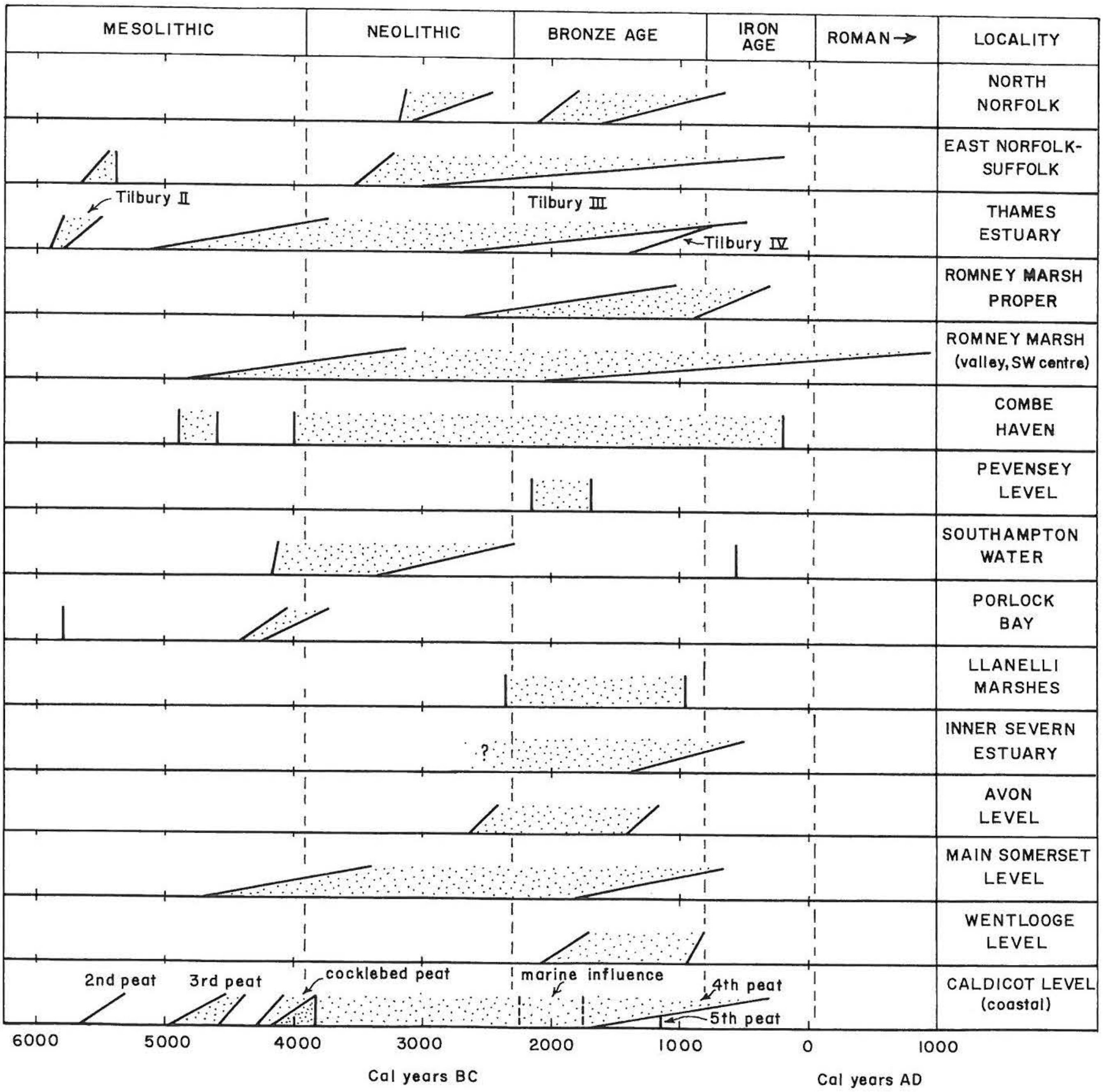


Figure 19. Comparative summary of age-ranges of peats in southern Britain Holocene outcrops For each outcrop the greatest age of each contact is plotted along the lower boundary of the shaded plot and the least age along the upper boundary. Details listed in Figures 3, 4 and the Appendix.

southern Britain until *c.* 5500-5000 Cal BC. The peat-dominated mid Holocene covers a period of roughly five millennia from then until *c.* 500 Cal BC. The third and final stage - roughly the last 2500 years - sees a return to siltlands.

The number and timing of particular punctuation events within the broad mid Holocene interval is less easily identified, because of the way the various controlling factors have interacted, but the most revealing evidence is from the Caldicot Level (Figure 4). It would appear that the sequence of lithologies encodes at least five events, centred around 5625 Cal BC (2nd peat), 4750 Cal BC (3rd peat), 4000 Cal BC ('cockle-bed peat'), 3250 Cal BC (earlier 4th peat) and 1250 Cal BC (later 4th and 5th peats). The 4th peat is suggested to register at least two events, because of the evidence for a marine influence during the interval 2250-1750 yrs (Smith and Morgan 1989; Bell *et al* 2000). The first three punctuations are separated by similar intervals, of 875, 750 and 750 years respectively. The fourth and fifth lie *c.* 2000 years apart, about twice the period of the previous three, which may be an indication that the 4th peat actually embraces more than the two events just noted. Turning elsewhere in southern Britain (Figure 3), the fourth and fifth events are widely represented, commonly within the same substantial bed, whereas the first event has a profound registration only at Porlock Bay, Minehead Bay, the Thames Estuary and Suffolk-East Norfolk. Evidence for the second event is seen at Minehead Bay, possibly Porlock Bay, and Combe Haven.

What explains the concentration of punctuation in the mid Holocene? A regionally effective forcing factor is implied, given that an essentially uniform, tripartite Holocene sequence can be traced for more than 2000 km from the Atlantic and Channel coasts of France to southern Britain, and from Belgium into northwest Germany. Table 1 lists only two factors of regional significance: mean sea level and vertical crustal movement. There is every reason to suppose that the Earth's crust - many kilometres in thickness - is relaxing unsteadily following deglaciation to the northwest and north of the region, but there is no evidence that the rate has fluctuated in any significant way on a time-scale of a millennium or less. This leaves the behaviour of sea level in the North Atlantic region as most likely to account for the mid Holocene growth of peatlands and the consequent shrinkage and retreat of estuarine water-bodies. As adduced by Long *et al* (2000, 275), however, it is 'a significant reduction in the rate of RSL [relative sea level] during the mid Holocene', implicitly the *underlying* rate, that was responsible. This cannot be correct. Figure 1 demonstrates that, as far as southern Britain is concerned, the underlying rate of sea-level rise during the mid Holocene was more than twice that in the late epoch and an order of magnitude more in the early stage. Why, then, should the late Holocene see negligible peat formation when the underlying rate of rise was significantly less than when peats arose frequently and widely?

It is much more likely that the mid Holocene peats depended on a series of sufficiently deep, regional fluctuations of sea level about the general upward path. Modelling shows that repeated fluctuations on a period of 500-1000 years and up to a metre or so in amplitude are sufficient in the presence of the mid-late Holocene underlying trend to create sequences of salt-marsh silts with intercalated peats closely comparable with those observed (Allen 1995, 1997, 2003). If correct, the late Holocene, free from peat formation, except under special circumstances, saw no fluctuations of this order of profundity. Such fluctuations of relative sea level as have been detected are minor (eg Gehrels *et al* 2005; Horton and Edwards 2005). It is not necessary to invoke a climatic cause, as proposed by van Geel *et al* (1996), although climate may have had an influence, if only because the epoch witnessed a long series of significant climatic changes (eg Mayewski *et al* 2004; Turney *et al* 2005). During the early Holocene, however, fluctuations of the modelled degree would merely change the strength of a monotonic rise, without creating peats. Whether such fluctuations actually occurred at this time remains to be established by detailed studies aimed at finding microfossil or pedological evidence for fluctuations. It has been suggested (Beets *et al* 1992) that a reduction in the exogenous sediment supply at the end of the mid Holocene caused peat formation to cease. While a strong exogenous source certainly favours high marshes (Table 1), the trend invoked probably did not occur. It is much more plausible that instead the supply grew, given increasing deforestation and arable farming from the Neolithic onward.

The variations from outcrop to outcrop depicted in Figure 19 imply that these regional controls were modulated by local influences (Table 1) which, changing in strength from place to place, determined the precise timing and degree of development of the expressions of punctuation. Which were operative, and in what combination, is hard to establish with much confidence, however, because it is not yet possible to read such factors as tidal range and rates of sediment supply from the Holocene stratigraphic record.

An important lithostratigraphic and chronostratigraphic trend noted from many outcrops calls for comment. In the Caldicot Level (Figures 3A, B, 4), perhaps the clearest instance, the peats thicken, fuse and individually widen in age-range as the basement rises toward the dryland margin of this strip-outcrop, and also toward the small, bedrock 'island' of Gold Cliff, standing well off the main dryland. It seems probable that the chief, if not perhaps the sole, factor accounting for this trend is differential compaction (Allen 1999), which tends to maintain a high sedimentary surface where the Holocene basement rises high. This is because sediments of uniform compressibility experience least surface subsidence where the compacting sequence is most reduced. A second factor should not be totally excluded, however, namely, a seaward-descending water-table maintained by dryland recharge, which would tend to favour peat-formation and the eventual growth of local swells (eg near Gold Cliff Island, Redwick-Magor Pill). The Main Somerset Level also shows these trends (Figure 3D). On the Axe valley traverse and its spur toward Brent Knoll, as well as in the south, the main peat thins and declines in age-range, eventually splitting, as it is traced from the interior and northern margin of the Level toward the thickest parts of the Holocene sequence at the coast and along the axis of the palaeovalley. In inner reaches of the palaeovalleys, high river-related water-tables are likely to have been a major factor promoting peat, including raised bog, but were probably unimportant in the coastal belt. Contradictory evidence comes from the Thames Estuary (Figures 3L, 16), the only other area at all well documented. Only in a general way do peats divide, thin and narrow in age-range down-estuary (eg Devoy 1979). On a smaller scale other factors seem to have balanced compaction.

Greater attention needs to be given to coastal change as a factor that limits the survival of the evidence for punctuation and the extent to which coastal wetlands were available for possible exploitation. Recent work on the Caldicot Level has shown that major erosional breaks, traceable over many kilometres and locally eliminating older peats, underlie the silt unit that grades up into the 3rd peat and a younger unit that passes up into the fourth bed (Allen and Haslett 2002, 2006a, 2006b). These breaks, pointing to coastal retreat followed by readvance, are subtly expressed, and often detectable, as horizons of abrupt grain-size change, only after laboratory work. Borehole analysis suggests that breaks also occur in the sequence on the Wentlooge Level (Allen 2001a). Internal breaks elsewhere in the Severn Estuary Levels are indicated by unexpected juxtapositions of peats and foraminiferal assemblages (eg Murray and Hawkins 1976; Haslett *et al* 2001), and the possibility of an internal break at Porlock Bay cannot be excluded. At younger stratigraphic levels, chiefly medieval and post-medieval, they are familiar as the extensively terraced salt marshes and other evidence for abandoned shorelines (Allen and Fulford 1986; Allen and Rae 1987; Allen 2001b). The evidence is even more widely cast. Eroded tops were found on some intercalated peats in Southampton Water (Long *et al* 2000). An erosional contact appears to bound on the west the main peat of Romney Marsh (Long *et al* 1998). The vertical pattern of grain size and foraminiferal assemblages imply the presence of a break within the post-peat sequence described by Long *et al* (2006) from the Brede valley. Barrier development has strongly influenced the development of the Holocene sequence on the exposed North Norfolk coast (Funnell and Pearson 1989; Andrews *et al* 2000).

Internal breaks, and peats eliminated/suppressed by various means, are one of the expressions within surviving outcrops of 'stratigraphic rollover' (Allen 1990a), a general process driven by sea-level rise that is affecting many coastal areas. A much more serious consequence of transgression, although one difficult to prove because the beds affected will have been very largely destroyed, was the elimination of substantial early deposits, especially where the thicker peats of inland locations had split. Intimations of this effect are provided by vestigial Holocene outliers, such as at the Tidal Reservoir on Oldbury Flats (Allen and Fulford 1992), Gravel Banks off the Avon Level (Gilbertson *et al* 1990), and off the Somerset coast (eg Kerney 1976).

In considering how punctuation could have influenced prehistoric human activities in the Holocene coastal wetlands of southern Britain, the emphasis in this paper falls on the chronology and kinematics of environmental change. The known archaeological evidence itself is extremely variable in both amount and nature, and no doubt with many profound gaps, but it is clear that activities occurred in two broad contexts as the post-glacial seas rose. Extra-sequential activity/occupation sites are those which lie within or upon the soils that formed on the sub-Holocene basement prior to the marine transgression, but which now lie beneath wetland deposits (eg Wymer and Robins 1994; Bell *et al* 2002). Whereas both wetland and dryland resources could have been exploited from those positioned at or close to the contemporaneous wetland margin, wetland resources need not have figured greatly or at all at those more distant. For topographic reasons, some strictly dryland sites have always been close to the margin but were never buried by marine deposits (eg Bell 1990). Intra-sequential sites are those preserved within the wetland sequence itself. Bell (2000b) grouped them into those in peatland contexts, especially on or associated with transgressive contacts, and those occurring within silts of mainly salt-marsh origin (vegetated platform and palaeochannel deposits). A speculative list of the ways in which siltlands could have been exploited reads: hunting, wild-fowling, fishing (in tidal creeks), shellfish-gathering, seasonal grazing on salt marshes on a range-wide basis, reed-gathering (seasonal), salt-making, the digging of shallow-lying peat, and communication by boat (tidal creeks). Many of these would have necessitated temporary encampments. Peatland contexts suggest a somewhat different speculative list, depending on the extent of tidal influence: procurement of wood, berry- and herb-gathering (seasonal), some hunting, some wild-fowling, reed-gathering (seasonal), and animal husbandry in temporary buildings and perhaps associated paddocks (?seasonal). However, it is one thing to speculate, but another to prove what activities actually occurred. In the case of the Bristol Channel-Severn Estuary Levels, Coles and Coles (1987), Bell (2000a, 2000b) and Bell *et al* (2000, 2002) have carefully evaluated the known archaeological record and the material evidence for different activities (see also Locock *et al* 2000; Locock 2001; Allen *et al* 2002). From the Thames Estuary and the Essex and Kent marshes have come accounts of many parallel activities (Bates and Barham 1995; Meddens and Sidell 1995; Wilkinson and Murphy 1995; Cotton and Wood 1996; Meddens 1996; Thomas and Rackham 1996; Buckley 2000; Firth 2000; Sidell *et al* 2000), but many areas have so far been little investigated, partly because the archaeological evidence is deeply buried.

The highlights of the intra-sequential evidence include human footprint-tracks preserved throughout the sequence from the Mesozoic onward (Caldicot Level, Wentlooge Level), hearths (Caldicot Level, Wentlooge Level, Avon Level), roundhouses (Caldicot Level, Wentlooge Level), subdivided buildings associated with cattle-dominated bone assemblages and cattle-related insect remains (Caldicot Level), paddles and log/plank boats (Caldicot Level, Main Somerset Level, Thames Estuary), trackways facilitating communication (Caldicot Level, Main Somerset Level, Thames Estuary), and wooden structures, basketry and bone assemblages indicative of fishing (Caldicot and Wentlooge Levels, Thames Estuary). Change on both the time-scales distinguished above affected human groups which attempted to exploit Holocene wetlands in southern Britain.

The slowest changes, with a time scale of millennia, are those from the silt-dominated early Holocene, to the peat-dominated middle epoch, and back to silt dominance in the late Holocene. Change on this scale is more gradual than the cultural changes implied by the conventional archaeological divisions of Holocene prehistoric time into the Mesolithic, Neolithic, Bronze Age and Iron Age. Over the greater part of the long Mesolithic period access was mainly to siltlands

(Figure 19). These environments were probably restricted in geographical extent, especially where compressed against the steep sides of narrow palaeovalleys (eg Haslett *et al* 2000), but subject in more open areas to rapid horizontal shifting driven by the high rate of sea-level rise (Figure 1). Scattered hunter-gatherer groups exploiting the wetlands are unlikely to have experienced difficulty in adapting to these shifts. Environmental stability in terms of wetland type returned in the latest Bronze Age and the Iron Age. The much reduced rate of sea-level rise would have assured also a high degree of geographical stability, an important condition for the well-being of groups now largely sedentary and contributing to a substantial population.

Throughout the coastal zone of southern Britain, and no doubt more widely in northwest Europe, the interval from the later Mesolithic to the late Bronze Age-early Iron Age was one of rapidly changing environmental opportunities and stresses in the face of repeated, forced punctuation on a sub-millennial scale (Figure 19). At least five silt-peat events are recorded from the Holocene outcrop surviving on the Caldicot Level (Figure 4), but because of modulation by factors operating on a local-district scale, and loss of outcrop due to rollover, they do not have a uniform, surviving stratigraphic expression throughout the Bristol Channel-Severn Estuary in particular or southern Britain in general (Figure 19).

The typical event, if such can legitimately be identified, sees each kind of wetland environment persisting, but subject to change, over an interval of a few to several centuries. Supported by stratigraphic evidence, modelling suggests that the transgressive replacement of peatland by siltland was accompanied by the rapid deepening, spread and elaboration of networks of tidal creeks (Allen 1997, 2003), which would have slowed overland movement but afforded excellent opportunities for fishing and communication by water. As the salt-marsh phase drew to a close, these networks rapidly infilled and shrank, with the opposite implications. While yet to be tested by high-precision dating, modelling suggests that the transition between salt marsh and peatland in a locality could be accomplished within a decade or so, that is, within the experience of a human generation. Choosing the coastal transect of the Caldicot Level as the best-recorded example (Figure 4), the dating evidence from transgressive/regressive contacts suggests impressive rates of spatial environmental change. In this two-dimensional profile, the 2nd peat was displaced northeastward by salt marsh at an *apparent* rate of *c.* 12 m/yr. From a point near Redwick, the 3rd peat displaced salt marsh northeastward and southwestward at an apparent rate of *c.* 6.7 m/yr and *c.* 13 m/yr respectively. Apparent rates of a similar order typified the spread across salt marshes of the 4th peat away in both directions from the flanks of Gold Cliff Island. The top of the 4th peat, with its wedging offshoots, is especially diachronous. In the later Bronze Age a peat swell with temporary wooden buildings for cattle in the Redwick area (Bell 2001) was encroached on by salt marsh from the southwest and northeast at an apparent rate of *c.* 1.9 m/yr and *c.* 1.6 m/yr respectively. Near Gold Cliff Island during the Iron Age salt marsh spread from the northeast, and possibly also the southwest, onto another swell underpinned by raised bog, forcing temporary wooden buildings for cattle in a further set to be frequently resited on what may reasonably be presumed to have been progressively higher ground (Bell 2000a, Bell *et al* 2000). Apparent encroachment rates of *c.* 0.47 m/yr and *c.* 2.0 m/yr for the general vicinity are suggested by the radiocarbon dates. Both swells presented ideal sites for seasonal herders keeping cattle and sheep on the surrounding but encroaching salt marshes.

Should the above rates of spatial environmental change along-strike in the Caldicot Level seem implausible, it is worth attempting to identify at what rates siltlands and peatlands were exchanged in a direction toward the main dryland? The evidence in this case is much more limited, but the available radiocarbon dates (Appendix) allow an impression to be formed for the ground roughly between eastings 40 and 45 (Figures 3A, B, 4). Indistinguishable dates (*c.* 4700 Cal BC) characterise the bases of the 3rd peat at the coast and the fused 3rd and 4th peats at Barland's Farm and Vurlong Reen inland. On that evidence, regression could have been very rapid on this part of the Caldicot Level. These two inland sites, on average 2.3 km from the coast, lack evidence of the salt-marsh silts that separate the 3rd and 4th peats and represent a period *c.* 720 years. The presence of a break beneath the silts on the coast introduces a complication, but the environments may be suggested to have replaced each other in a landward direction at rates of several metres annually. These rates are of the same order as the estimates along-strike. Taken together, the two sets of rates imply that, at any instant during the earlier stages of both transgression and regression, the mappable siltland-peatland boundary showed wide embayments and promontories.

The apparent rates of replacement of one kind of wetland environment by another cited above are not exceptional. The available data are fewer, but similar apparent rates can be shown to characterise contacts between silts and peats in, for example, the Main Somerset Level (Figure 3D), Romney Marsh (Figure 3K) and the Thames Estuary (Figure 3L).

Wetland change at the rates estimated above would have been unambiguously apparent to people on an annual scale, and would have demanded resilience (high adaptive capacity) on the part of human groups seeking to exploit these areas, increasingly so as the prehistoric population grew. Each kind of wetland resource would have evoked a different response but, as an example, it is worth speculating on the likely effects of environmental change on the cattle- and sheep-keeping pastoralists shown to have exploited the Caldicot Level (Bell and Neumann 1999; Bell 2000a, 2000b) and on groups which included fishing in their economy. The seaward advance of peatland during regression would have progressively reduced the areas of rich salt marsh available for seasonal grazing by cattle and lesser numbers of sheep, and rendered them increasingly inaccessible from permanent dryland settlements. Unless herds were made smaller, it would have been necessary to find alternative grazing, perhaps of lesser quality, on the dry hinterland of the Caldicot Level. Depending on population density, conflicts could have arisen between groups searching for new pasturing in the coastal zone. Groups which included fishing in their economy would also have been affected. Journeys to mudflats and creeks of a worthwhile size would have become longer and on a declining number of routes. Transgression, on the other hand, would have rapidly increased the area of salt marsh available for grazing, and could in places and at times have brought siltlands directly against dryland. Readily accessible space would then have been available for enlarged herds. Competition between groups seeking to expand into these emerging marshes is perhaps less likely to have led to conflict, as the resource as a whole was increasing in size. Fishing would have become increasingly attractive and profitable as salt-marsh creeks deepened, ramified and reached closer to the dryland margin, and mudflats became increasingly accessible on foot or by boat.

Whatever the cause(s) of the punctuated mid-Holocene stratigraphy encountered in the coastal zone of southern Britain - representing a time when sea level was rising at an intermediate underlying rate - it is clear that frequent and rapid shifts between peatlands and siltlands occurred in the coastal zone, and that these had profound and unavoidable implications for human groups settled there. These changes affected the activities that could be pursued and where they could be practised and demanded resilience in the human groups affected.

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Appendix follows overleaf

APPENDIX

Radiocarbon dates on mid Holocene peats from the Severn Estuary Levels and other localities in southern Britain.

The dates are as far as possible arranged by transgressive-regressive contact or soil level from the oldest to the youngest. For ease of graphical presentation, they are in most cases listed in terms of either the easting or northing of the National Grid Reference System, depending on the outcrop. The calibrations are those of the authorities cited. OxCal v3.10 was applied to dates published with no calibration.

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
Coastal Caldicot Level (100 km square ST)				
380820, second peat whole bed	Beta-188570	6750+/-50	5720-5610	This paper
413831, second peat, whole bed	Beta-103622	6500+/-50	5520-5360	This paper
419834, second peat, whole bed	Beta-188568	6340+/-40	5370-5270	This paper
424837, second peat, whole bed	Beta-193624	6470+/-50	5500-5330	This paper
332819, base third peat	Beta-193612	5920+/-50	4910-4700	This paper
337821, base third peat	Beta-193613	6020+/-70	5060-4730	This paper
355821, base third peat	Beta-193616	6080+/-50	5080-4830	This paper
368819, base third with fourth peat	Beta-193617	6030+/-60	5040-4790	This paper
369820, base third with fourth peat	Car-1501	5920+/-80	5060-4660	Bell *et al* 2000
376819, base third with fourth peat	Beta-193618	5890+/-50	4840-4680	This paper
379821, base third with fourth peat	Car-659	5950+/-80	4950-4720	Smith & Morgan 1989
380821, base third peat	Beta-188571	5770+/-60	4725-4490	This paper
404826, base third peat	Beta-201963	5830+/-60	4800-4530	This paper
415832, base third peat	Beta-193623	5990+/-50	4990-4740	Allen & Haslett 2006
424837, base third peat	Beta-193625	5850+/-40	4790-4600	This paper
430840, base third peat	Beta-193626	5830+/-70	4820-4510	This paper
437845, base third peat	Beta-73058	5680+/-70	4624-4427	Allen & Haslett 2002
440847, base third peat	Beta-193627	5820+/-40	4760-4560	This paper
379821, top third peat	Car-658	5850+/-80	4890-4570	Smith & Morgan 1989
421835, top third peat	Beta-128779	5670+/-90	4595-4380	Allen & Haslett 2002
422835, top third peat	Beta-113001	5730+/-70	4722-4448	Allen & Haslett 2002
428839, top third peat	Beta-128777	5810+/-70	4730-4560	Allen & Haslett 2002
436844, top third peat	Beta-112905	5540+/-80	4545-4224	Allen & Haslett 2002
422836, base cockle-bed peat	Beta-113003	5300+/-80	4258-3917	Allen & Haslett 2002
425837, base cockle-bed peat	Beta-112999	5430+/-70	4365-4216	Allen & Haslett 2002
422836, top cockle-bed peat	Beta-113002	5040+/-80	3974-3689	Allen & Haslett 2002
425387, top cockle-bed peat	Beta-11300	5070+/-90	3999-3661	Allen & Haslett 2002
342822, base fourth peat	Beta-193614	4890+/-60	3780-3630	This paper
358821, base fourth peat	SWAN-32	5190+/-80	4240-3780	Bell *et al* 2000
379821, base fourth peat	Car-656	5360+/-80	4360-4000	Smith & Morgan 1989
386823, base fourth peat	Beta-193619	5250+/-50	4230-3960	This paper
402826, base fourth peat	Beta-193620	5120+/-60	4040-3780	This paper
422835, base fourth peat	Beta-113004	4910+/-70	3809-3625	Allen & Haslett 2002
428839, base fourth peat	Beta-128778	5030+/-70	3945-3710	Allen & Haslett 2002
436844, base fourth peat	Beta-112996	4940+/-70	3822-3636	Allen & Haslett 2002
453854, base fourth peat	Beta-193628	5020+/-80	3980-3650	This paper
357821, top fourth peat	SWAN-27	2380+/-70	800-250	Bell *et al* 2000
361821, top fourth peat	SWAN-135	2460+/-70	780-400	Bell *et al* 2000
361821, top fourth peat	SWAN-136	2360+/-70	800-200	Bell *et al* 2000
361821, top fourth peat	Car-1351	2270+/-70	521-110	Bell *et al* 2000

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
369820, top fourth peat, slight erosion	Car-1499	3640+/-60	2200-1880	Bell *et al* 2000
379821, top fourth peat	Car-644	3130+/-70	1610-1210	Smith & Morgan 1989
415834, top fourth peat	Beta-144020	3370+/-70	1875-1505	Allen & Haslett 2002
422836, building, top fourth peat	SWAN-228	2950+/-70	1400-990	Bell & Neumann 1999
424837, building, top fourth peat	SWAN-227	3060+/-70	1500-1110	Bell 2001
424837, building, top fourth peat	SWAN-226	2940+/-70	1380-930	Bell 2001
428840, charcoal scatter, top fourth peat	Car-991	2900+/-60	1300-920	Whittle 1989
436844, top fourth peat	Beta-73059	2439+/-70	765-596	Allen & Haslett 2002
446852, building, top fourth peat	Car-992	3170+/-70	1620-1260	Whittle 1989
446852, building, top fourth peat	Car-402	2910+/-70	1370-920	Whittle 1989
446852, building, top fourth peat	Car-961	2830+/-70	1220-830	Whittle 1989
447851, human bone, top fourth peat	Car-956	3080+/-70	1508-1124	Locock *et al* 2000
447851, wood, top fourth peat	Car-961	2830+/-70	1200-822	Locock *et al* 2000
447851, charcoal, top fourth peat	Car 899	2520+/-70	800-412	Locock *et al* 2000
423837, fifth peat, whole bed	Beta-144021	2940+/-50	1300-995	Allen & Haslett 2002
Inner Caldicot Level (100 km square ST)				
405864, base 'main' peat	Beta-72511	5920+/-50	4919-4710	Walker *et al* 1998
452873, base 'main' peat	Beta-63595	5740+/-70	4776-4406	Walker *et al* 1998
c. 372868, top 'main' peat	Q-691	2660+/-200	1100-400	Godwin & Willis 1964
400866, top 'main' peat	Beta-133532	2310+/-70	525-195	Locock 1999a
405864, top 'main' peat	Beta-72506	2900+/-60	1263-909	Walker *et al* 1998
452873, top 'main' peat	Beta-64590	2470+/-60	795-397	Walker *et al* 1998
Wentlooge Level (100 km square ST)				
239797, base fourth peat	Beta-157210	3670+/-80	2290-1870	Walker *et al* 2002
239797, base fourth peat	Beta-157363	3400+/-70	1890-1520	Walker *et al* 2002
c. 288820, base fourth peat	Wk-98224	2932+/-44	1300-990	Yates *et al* 2002
239797, top fourth peat	Beta-157362	2770+/-70	1100-800	Walker *et al* 2002
239797, top fourth peat	Beta-157208	2610+/-80	850-760	Walker *et al* 2002
240779, building, top fourth peat	Beta-46951	3080+/-50	1510-1210	Allen 1996
236778, wood, fourth peat	Beta-44058	2890+/-60	1260-920	Allen 1996
c. 251793, bulk sample, fourth peat	Wk-9823	3005+/-52	1410-1050	Yates *et al* 2002
Main Somerset Level (100 km square ST)				
291584, base of peat (eroded top)	HAR-8546	5620+/-100	4720-4250	Bell 1990
319545, base fourth peat	Beta-142355	5210+/-80	4235-3800	Haslett *et al* 2001
3658546, base fourth peat	Beta-142351	4640+/-60	3625-3195	Haslett *et al* 2001
382527, base fourth peat	Beta-142353	5370+/-50	4335-4050	Haslett *et al* 2001
463504, base third with fourth peat	Beta-114969	5860+/-70	4905-4540	Haslett *et al* 2001
319545, top fourth peat	Beta-142354	3500+/-70	2010-1650	Haslett *et al* 2001
358546, top fourth peat	Beta-142350	3600+/-70	2140-1750	Haslett *et al* 2001
382527, top fourth peat	Beta-142352	3190+/-70	1620-1275	Haslett *et al* 2001
460501, top fourth peat	Beta-101741	3380+/-60	1775-1515	Haslett *et al* 1998
460501, top fourth peat	Beta-101740	3370+/-60	1765-1510	Haslett *et al* 1998
460501, top fourth peat	Beta 101742	3250+/-80	1690-1380	Haslett *et al* 1998
472458, top fourth peat	GU-3246	2590+/-50	840-530	Housley *et al* 1999
472458, top fourth peat	GU-3247	2560+/-50	810-450	Housley *et al* 1999
301485, bulk sample, second peat	Wk-5298	6340+/-70	5440-5080	Druce 1998
301485, base third peat	Wk-5297	5590+/-70	4660-4340	Druce 1998

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
301485, base fourth peat	Wk-5297	5299+/-70	4360-4000	Druce 1998
301485, fourth peat 0.13 m above base	Wk-5300	4790+/-70	3780-3370	Druce 1998
313438, peat	Wk-9017	3220+/-70	1682-1320	Hollinrake & Hollinrake 2001
313438, peat top	Wk-9018	3710+/-70	2296-1888	Hollinrake & Hollinrake 2001
313438, peat base	Wk-9019	4570+/-60	3503-3094	Hollinrake & Hollinrake 2001
313438, peat top	Wk-9020	5580+/-100	4672-4245	Hollinrake & Hollinrake 2001
313438, peat base	Wk-9021	5750+/-80	4781-4370	Hollinrake & Hollinrake 2001
365368, base third with fourth peat	HAR-1831	5650+/-70	4680-4350	Coles & Dobson 1989
418392, base third with fourth peat	OxA-11233	5745+/-45	4770-4460	Wilkinson 1998
450389, base third with fourth peat	HAR-5353	5020+/-80	3970-3660	Coles & Dobson 1989
489411, top fourth peat	Q-2459	2860+/-50	1210-900	Housley *et al* 1999
Avon Level (100 km square ST)				
527809, base upper leaf fourth peat	Beta-118378	3040+/-60	1449-1100	Moore *et al* 2002
527809, top upper leaf fourth peat	Beta-118379	2810+/-70	1210-820	Moore *et al* 2002
542830, base lower leaf fourth peat	NZA-15616	4073+/-55	2880-2490	Moore *et al* 2002
542830, top lower leaf fourth peat	NZA-15589	3966+/-60	2900-2300	Moore *et al* 2002
542830, base upper leaf fourth peat	NZA-15588	3352+/-60	1880-1510	Moore *et al* 2002
542830, top upper leaf fourth peat	NZA-15587	2900+/-60	1320-920	Moore *et al* 2002
553836, base fourth peat	NZA-15880	3917+/-55	2580-2570	Moore *et al* 2002
553836, top fourth peat	NZA-15879	3151+/-45	1530-1370	Moore *et al* 2002
594847, base fourth peat	AA-30868	4045+/-50	2860-2450	Carter *et al* 2003
594847, top fourth peat	AA-30865	3850+/-50	2470-2450	Carter *et al* 2003
534796, buried soil with occupation	NZA-12479	6860+/-50	5790-5590	Allen *et al* 2002
534796, buried soil with occupation	NZA-12478	5879+/-71	4910-4550	Allen *et al* 2002
534796, buried soil with occupation	NZA-12726	2957+/-55	1380-1010	Allen *et al* 2002
534796, buried soil with occupation	NZA-12725	2778+/-55	1070-810	Allen *et al* 2002
535800, lower buried soil	Beta-125794	4170+/-70	2905-2500	Locock *et al* 1998
535800, lower buried soil	Beta-125795	3970+/-60	2585-2280	Locock *et al* 1998
535800, upper buried soil	Beta-134901	3350+/-60	1760-1505	Locock *et al* 1998
535800, upper buried soil	Beta-134900	2970+/-60	1390-1100	Locock *et al* 1998
556817, buried soil	Wk-6234	3240+/-160	1950-1050	Carter *et al* 2003
539825, buried soil	Wk-6232	3670+/-60	2130-1740	Carter *et al* 2003
Upper-middle and inner Severn Estuary (100 km square SO)				
723033, top fourth peat	Beta-80696	3100+/-50	1520-1220	Hewlett & Birnie 1996
762129, top fourth peat	Beta-80693	2340+/-60	800-200	Hewlett & Birnie 1996
780156, top fourth peat	Beta-81686	2360+/-60	800-200	Hewlett & Birnie 1996
Bristol Channel (100 km square SS)				
515978, 0.15 m below peat top	Beta-139982	2870+/-70	1270-845	Lillie *et al* 2003
515978, 0.3 m above peat base	Beta-139984	3790+/-70	2460-1840	Lillie *et al* 2003
871478, top second peat	Beta-61544	6870+/-90	5941-5540	Jennings *et al* 1998
871478, top second peat	Beta-86775	6707+/-50	5987-5777	Jennings *et al* 1998
873474, base fourth peat	OxA-6572	5290+/-75	4340-3970	Jennings *et al* 1998
874476, base fourth peat	OxA-6569	5450+/-70	4460-4040	Jennings *et al* 1998

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
875474, base fourth peat	OxA-6571	5515+/-65	4500-4240	Jennings *et al* 1998
877476, base fourth peat	Beta-61542	5250+/-180	4458-3662	Jennings *et al* 1998
873474, top fourth peat	OxA-6402	4925+/-60	3940-3540	Jennings *et al* 1998
874476, top fourth peat	OxA-6399	5120+/-55	4040-3780	Jennings *et al* 1998
875474, top fourth peat	OxA-6401	5160+/-100	4240-3700	Jennings *et al* 1998
877476, top fourth peat	Beta-61543	5140+/-100	4225-3705	Jennings *et al* 1998
973473, base lower peat	Wk-5310	6570+/-70	5640-5370	Jones *et al* 2004
974473, base lower peat	Wk-5311	6600+/-70	5670-5380	Jones *et al* 2004
976470, base lower peat	Wk-5302	6560+/-70	5630-5380	Jones *et al* 2004
976472, base lower peat	Wk-5308	6440+/-70	5540-5290	Jones *et al* 2004
976470, top lower peat	Wk-5301	6220+/-70	5330-4990	Jones *et al* 2004
978465, base upper peat	Wk-5305	5770+/-70	4780-4460	Jones *et al* 2004
979467, base upper peat	Wk-5304	5810+/-70	4830-4490	Jones *et al* 2004
983469, base upper peat	Wk-5306	5700+/-70	4710-4360	Jones *et al* 2004
Southampton Water (Solent) (100 km squares SU, SZ)[1]				
SZ 463987, base of peat	Hv-17324	5300+/-200	4540-3698	Long *et al* 2000
SZ 463987, top of peat	Hv-17325	3570+/-105	2193-1633	Long *et al* 2000
SZ 463987, base of peat	Hv-17326	2350+/-110	790-164	Long *et al* 2000
SZ 464987, top of peat	Hv-17327	2480+/-75	883-393	Long *et al* 2000
474024, base of peat	Q-832	3563+/-96	2174-1674	Long *et al* 2000
474024, top of peat	Q-831	3689+/-120	2457-1742	Long *et al* 2000
445060, base of peat	Beta-93198	5320+/-6	4328-3985	Long *et al* 2000
416086, top of peat	Beta 106551	4650+/-70	3629-3109	Long *et al* 2000
496100, top of peat	Beta-93197	4410+/-70	3339-2887	Long *et al* 2000
382114, top of peat	Beta-93195	3080+/-60	1444-1133	Long *et al* 2000

1 - Unless otherwise indicated, the 100 km square is SU.

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
Romney Marsh and western environs (100 km squares TQ, TR)[2]				
641016, base Willingdon Peat	SRR-2455	3759+/-40	2235-2035	Jennings & Smyth 1987
641016, top Willingdon Peat	SRR-2454	3390+/-40	1774-1605	Jennings & Smyth 1987
776094, base lower peat	SRR-2683	6020+/-70	5074-4724	Jennings & Smyth 1987
776094, top lower peat	SRR2682	5780+/-80	4800-4456	Jennings & Smyth 1987
776094, base upper peat	SRR-2681	5170+/-70	4081-3794	Jennings & Smyth 1987
776094, top upper peat	SRR-2680	2170+/-60	381-88	Jennings & Smyth 1987
829174, base of peat	SRR-2646	5970+/-150	5300-4450	Waller *et al* 1988
930305, base of peat	Beta-87705	5400+/-80	4435-3981	D. Long *et al* 1998
982319, base of peat	Q-2648	5150+/-70	4214-3786	D. Long *et al* 1998
984310, base of peat	SRR-5622	4970+/-50	3934-3648	Waller *et al* 1999
989219, base of peat	SRR-5614	4410+/-45	3299-2911	Waller *et al* 1999
990257, base of peat	IUB-3730	4367+/-39	3096-2911	Long & Innes 1995
992282, base of peat	SRR-5618	4485+/-45	3348-2927	Waller *et al* 1999
996194, base of peat	Q-2649	3520+/-60	202-1690	Tooley & Switsur 1988
TR 022204, base of peat	Beta-81371	2850+/-60	1220-840	Long *pers comm* 2001
TR 026229, base of peat	UB-3582	3673+/-82	2193-1946	Long & Innes 1993
TR 034210, base of peat	Beta-81365	3010+/-60	1420-1050	Long *pers comm* 2001
TR 050328, base of peat	Beta-109579	3250+/-100	1742-1312	Long *et al* 1998
TR 050339, base of peat	Beta-109576	4070+/70	2875-2457	Long *et al* 1998
829174, top of peat	SRR-2645	3690+/-70	2290-1890	Waller *et al* 1988
930305, top of peat	Beta-87707	3390+/-79	1879-1515	D. Long *et al* 1998
982319, top of peat	Beta-87704	3060+/-80	1506-1043	Waller *et al* 1999

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
984310, top of peat	SRR-5619	2355+/-45	515-369	Waller *et al* 1999
989219, top of peat	SRR-5611	1050+/-45	AD 893-1048	Waller *et al* 1999
990257, top of peat	UB-3731	1846+/-51	AD 60-320	Long & Innes 1995
992282. top of peat	SRR-5615	1850+/-45	AD 74-321	Waller *et al* 1999
996194, top of peat	Q-2650	3060+/-60	1450-1120	Tooley & Switsur 1988
TR 022204, top of peat	Beta-81372	2690+/-80	1060-590	Long *pers comm* 2001
TR 026229, top of peat	UB-3581	2249+/-48	391-235	Long & Innes 1993
TR 034210, top of peat	Beta-81366	2380+/-60	760-370	Long *pers comm* 2001
TR 050328, top of peat	Beta-109581	2910+/-70	1309-905	Long *et al* 1998
TR 050339, top of peat	Beta-109578	2290+/-60	768-40	Long *et al* 1998

2 - Unless otherwise stated, the 100 km square is TQ.

Thames Estuary-Essex marshes (100 km squares TL, TM, TQ, TR)[3]

315801, top Tilbury III with IV	Beta-119784	2340+/-60	756-212	Sidell *et al* 2000
317801, top Tilbury III with IV	Beta-119786	2290+/-90	757-119	Sidell *et al* 2000
565759, base Tilbury II	Q-1281	6970+/-100	6020-5700	Devoy 1979
606777, base Tilbury II	Q-1283	6620+/-90	5980-5620	Devoy 1979
647754, base Tilbury II	Q-1428	7050+/-100	6100-5710	Devoy 1979
565759, top Tilbury II	Q-1335	6680+/-100	5780-5460	Devoy 1979
606777, top Tilbury II	Q-1339	6620+/-90	5720-5380	Devoy 1979
647754, top Tilbury II	Q-1429	6575+/-95	5670-5340	Devoy 1979
482815, base Tilbury III	Q1282	5640+/-75	4620-4340	Devoy 1979
565759, base Tilbury III	Q-1336	4930+/-110	4000-3500	Devoy 1979
606766, base Tilbury III	Q-1341	5220+/-65	4240-3930	Devoy 1979
606766, base Tilbury III	Q-1342	5410+/-80	4370-4030	Devoy 1979
647754, base Tilbury III	Q-1430	6200+/-90	5410-4850	Devoy 1979
482815, top Tilbury III	Q-1333	4195+/-75	2930-2570	Devoy 1979
565759, top Tilbury III	Q-1334	4085+/-85	2890-2460	Devoy 1979
647754, top Tilbury III	Q-1431	3850+/-80	2600-2000	Devoy 1979
606766, base Tilbury IV	Q-1340	2836+/-85	1260-820	Devoy 1970
647754, base Tilbury IV	Q-1432	3240+/-75	1690-1430	Devoy 1979
647754, top Tilbury IV	Q-1433	3020+/-65	1420-1050	Devoy 1979
629756, Tilbury IV whole bed	Q-793	2467+/-110	830-360	Devoy 1979
562758, middle of Tilbury IV	IGS/70	2651+/-60	920-760	Devoy 1979
562758, middle of Tilbury IV	IGS/75	2610+/-50	900-550	Devoy 1979
TR 029940, intercalated peat	?	7516+/-250	7100-5900	Greensmith & Tucker 1976
TM 043093 Tilbury III	?	4959+/-65	3950-3630	Greensmith & Tucker 1976
825962, Tilbury III near base	HAR-5227	4100+/-70	2880-2480	Wilkinson & Murphy 1995
TL 918043, Tilbury III at base	HSAR-6623	4190+/-80	2930-2490	Wilkinson & Murphy 1995

3 - Unless otherwise stated, the 100 km square is TQ.

Suffolk and East Norfolk (100 km squares TG, TM)[4]

481754 top Lower Peat	SRR-3484	6510+/-120	5665-5234	Brew *et al* 1992
499759, Lower Peat near base	SRR-3481	6755+/-70	5771-5528	Brew *et al* 1992
499759, top Lower Peat	SRR-3480	6385+/-20	5463-5310	Brew *et al* 1992
491754, near base Middle Peat	SRR-3483	4575+/-65	3414-3046	Brew *et al* 1992

Location & horizon	Laboratory code	Radiocarbon Age (yrs BP)	Age Cal. BC (2s range)	Authority
499759, near base Middle Peat	SRR-3479	4400+/-70	3336-3050	Brew *et al* 1992
489926, base Middle Peat	Q-2090	4700+/-55	3633-3460	Horton *et al* 2004
491754, top Middle Peat	SRR-3482	4300+/-65	3250-2670	Brew *et al* 1992
499759, top Middle Peat	SRR-3478	4260+/-80	3088-2590	Brew *et al* 1992
489926, top Middle Peat	Q-2086	2170+/-55	373-64	Horton *et al* 2004
TG 353042, top Middle Peat	SRR-573	1973+/-50	2045-1818	Coles and Funnell 1981
TG 459212, top Middle Peat	AA 25600	2760+/-45	999-811	Horton *et al* 2004
TG 474220, top Middle Peat	AA 25599	2490+/-45	792-405	Horton *et al* 2004

4 - Unless otherwise stated, the 100 km square is TM)

North Norfolk (100 km squares TF, TG)[5]

TG 077442, base of peat	AA-22697	4495+/-	3355-2927	Andrews et al 2000
892442, base of peat	SRR-2391	4520+/-50	2270-3020	Funnell & Pearson 1989
TG 077442, top of peat	AA-22696	3940+/-50	2567-2282	Andrews *et al* 2000
965440, top of peat	SRR-2599	4630+/-50	3650-3100	Funnell & Pearson 1989
892442, top of peat	SRR-2601	4480+/-60	3360-2930	Funnell & Pearson 1989
TG 049446, thin peat, whole bed	SRR-2603	4450+/-60	3340-2020	Funnell & Pearson 1989
712448, base of peat	OxA-10207	3530+/-40	2010-1740	Brennand & Taylor 2003
737447, base of peat	AA-22692	3785+/-50	2171-2035	Andrews *et al* 2000
772450, base of peat	SRR-2387	3470+/-50	1930-1660	Funnell & Pearson 1989
712448, top of peat	OxA-9610	3330+/-40	1690-1510	Brennand & Taylor 2003
737447, top of peat	AA-22691	2640+/-50	898-767	Andrews *et al* 2000
772450, top of peat	SRR-2386	2790+/-40	1040-830	Funnell & Pearson 1989

4 - Unless otherwise stated, the 100 km square is TF.