ROMNEY MARSH

Persistence and Change in a Coastal Lowland

Edited by
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Contents

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Romney Marsh: Persistence and Change in a Coastal Lowland
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1. The Holocene Coastal Deposits of Sussex: a Re-evaluation

Martyn Waller and Antony Long

The Holocene deposits of the Sussex coast have been described both as being relatively uniform and as exhibiting considerable differences, with regional (relative sea-level) and local (particularly barrier formation and breaching) processes respectively seen as controlling influences. We reopen this debate detailing the evidence collected over the last 25 years. Knowledge of the key processes is reviewed along with the stratigraphic data available from the Romney Marsh depositional complex, Pevensey Levels and the Eastbourne area and the valleys of East (Combe Haven, Cuckmere, Ouse) and West (Adur, Arun) Sussex. The valleys and levels of East Sussex contain tripartite sedimentary sequences, with mid Holocene peats separating clastic sediments of marine/brackish origin. Differences in the thickness of the peat beds can be attributed to a number of factors, including stratigraphic architecture and post-depositional compaction as well as the influence of local processes. Variation in the timing of the onset of peat formation at sites along the East Sussex coastline can be attributed to differences in sediment supply. Evidence is presented that much of the sand and gravel within the Romney Marsh depositional complex was transported landward with rising sea level from offshore sources close to Romney Marsh. The redistribution of gravel along the coast by longshore processes only seems to have become significant in the late Holocene. The valleys of West Sussex do not appear to contain thick mid Holocene deposits of peat, though further work is required to clarify their Holocene stratigraphies. It is argued that size of the Romney Marsh depositional complex has played an important role in the formation and preservation of a record which reflects a regional driving process, the rate of relative sea-level rise. Smaller systems, in particular the valleys of West Sussex, due to a combination of confined topography and high site exposure, seem more prone to local influences.

Introduction

The early 1980s marks the beginning of attempts to understand the Holocene evolution of the Sussex coastline by applying modern techniques of litho-, bio- and chronostratigraphy to the coastal deposits of the region. Differences soon emerged between workers, both as to the degree of stratigraphic uniformity between sites along the coast and their interpretation, with Jennings and Smyth (1982a; 1982b) emphasising differences and invoking local factors (particularly breaching of gravel barriers) and Burrin (1982; 1983) advocating a more uniform stratigraphic model for the region as first proposed by Jones (1971).

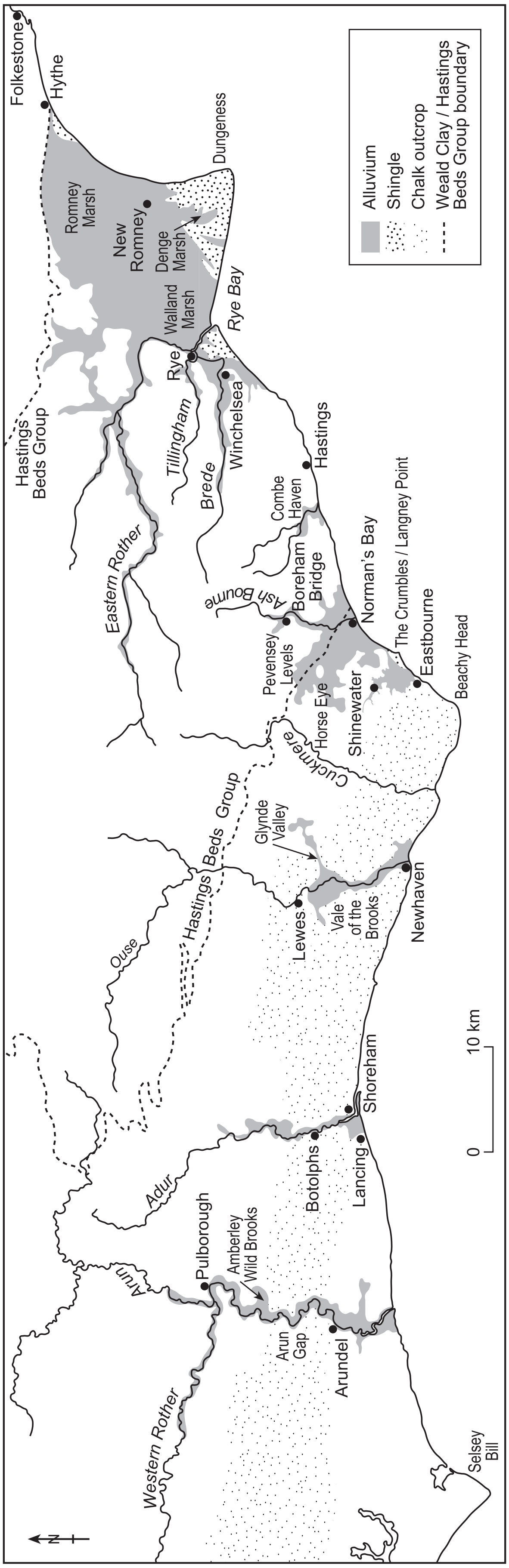

Fig. 1.1. The Sussex coast and Romney Marsh depositional complex showing the sites mentioned in the text.

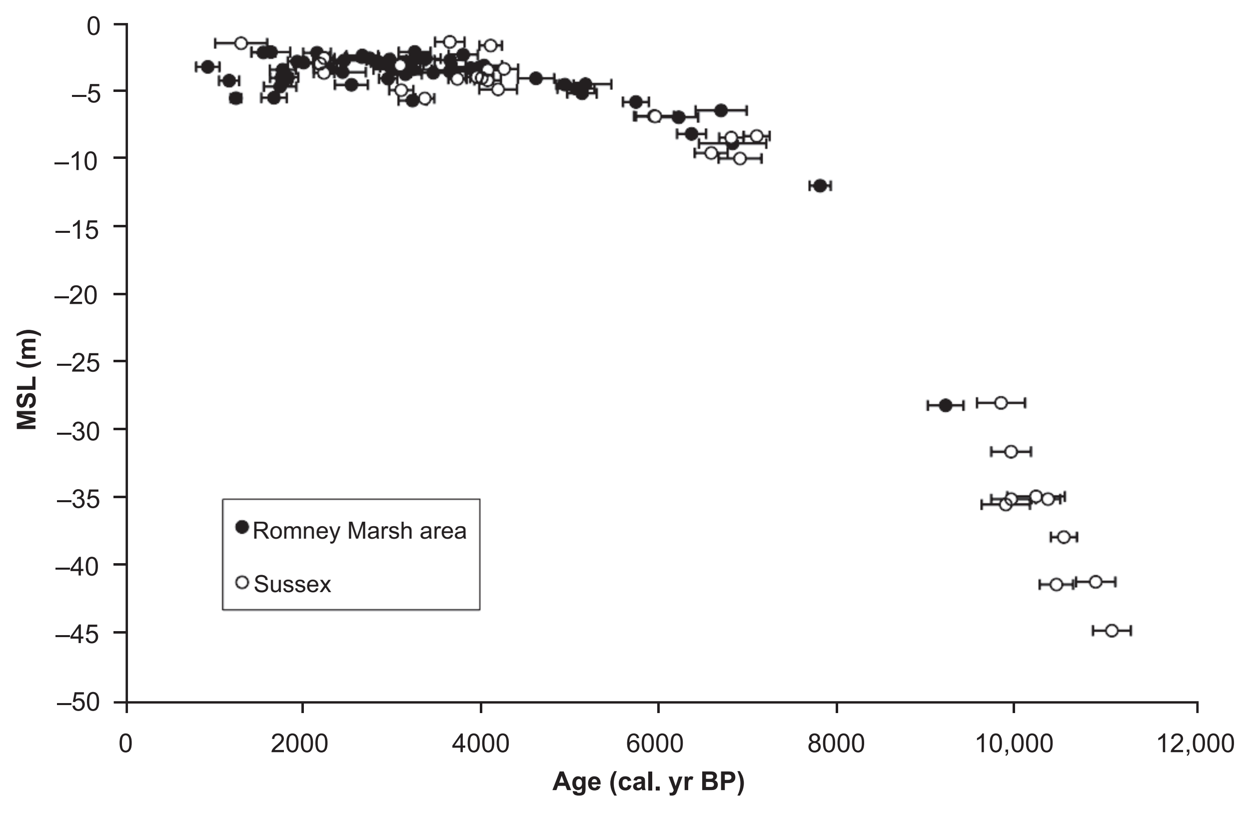

Fig. 1.2. The sea-level index points from the Romney Marsh depositional complex and the Sussex coast. These index points are from transgressive or regressive contacts, which approximate to the former position of mean high water of spring tides (MHWST). To allow for variations in present tidal range the data have reduced to mean sea level (MSL).

Following these early publications, further details of many of the sequences discussed by Jennings and Smyth and Burrin have been published (e.g. Jennings and Smyth 1987; Smyth and Jennings 1988; Burrin and Jones 1991) and new work has been undertaken, not only from the Romney Marsh area (e.g. Waller *et al*. 1988; Long and Innes 1995; Plater *et al*. 1999; Long *et al.* 2007), but also from Pevensey Levels (Lake *et al*. 1987; Jones 2002), Willingdon Levels (Jennings *et al*. 2003) and the Ouse valley (Waller and Hamilton 2000). In addition, knowledge of a number of key processes, in particular sea-level change (Long and Shennan 1993; Waller and Long 2003), the development of the gravel beaches (Jennings and Smyth 1990; Nicholls 1991) and sediment input from terrestrial sources (e.g. Smyth and Jennings 1990; Waller 1994; Waller and Schofield 2007) has been advanced. Now is therefore an opportune time to re-evaluate the coastal deposits of this region and the evidence they contain for the evolution of the Sussex coastline during the Holocene. In terms of the Romney Marsh area, this wider context is important in understanding the longshore supply of sediment as well as helping to establish the degree to which the stratigraphic sequences recorded here reflect local or regional processes.

The early debate on the Sussex coastal deposits focussed on the Ouse valley, the Eastbourne area and Combe Haven (Fig. 1.1). However, it is logical to include in any review not only the whole of the Romney Marsh deposition complex but also the coastal deposits as far west as Selsey Bill; together these all fall within a single regional sediment cell (Nicholls 1991). The Holocene coastal deposits of this coastline include those within a series of confined valleys (Arun, Adur, Ouse, Cuckmere and Combe Haven), which are relatively narrow at their mouths, and the infill of two extensive former embayments; Pevensey Levels and Romney Marsh with their associated valleys. In as much as the data allows, comparisons are made with reference to their three-dimensional stratigraphic architecture, as a number of factors mitigate against attempting to characterise the deposits in any one of these areas in terms of a single or ‘type’ sequence. At all of the above locations, inland fluvial sediments interdigitate with marine/brackish deposits, while facies variations in the latter are ubiquitous. In addition, in the Romney Marsh depositional complex, west to east progradation and retreat during the mid and late Holocene has produced diachronous surfaces, as is evident in the formation of the main Marsh peat (see *The Romney Marsh Depositional Complex*).

Radiocarbon dates are presented in calendar years BP. For consistency, all dates have been converted to calendar ages using the calibration program OxCal v.4.0 (Bronk Ramsey 1995; 2001) and the INTCAL04 dataset (Reimer *et al*. 2004). The material used for the radiocarbon dates has varied, along with thickness of the samples and methods used (conventional/AMS). The dates in the text have therefore been rounded up to nearest fifty years from the mid-point of the 2 σ calibrated age range.

Controls on Sedimentation

We start our review by introducing the main processes which have influenced coastal development.

Relative Sea-level Change

Accumulations of Holocene sediment >20 m thick exist along the Sussex coast (e.g. at Langney Point, Tilling Green Rye, Dungeness, Newhaven). Relative sea-level (RSL) rise has provided much of the accommodation space (the height difference between a sediment surface and high tide) required, with the contribution from crustal movements (subsidence) estimated at 0.9 mm/yr^{-1} (Gehrels 2010). The Holocene RSL history of the Sussex coast can be divided into three periods (Waller and Long 2003). Rapid rise occurred during the early Holocene with an average rate (assuming no significant compaction or lag between RSL rise and sedimentation) of 12 mm/yr^{-1} between *c*. 9200 and 7800 cal. yr BP (Waller and Kirby 2002). During the mid Holocene (*c*. 7800–3700 cal. yr BP) the rate of RSL rise declined to between 4 and 2 mm/yr^{-1}. Trends from the late Holocene are difficult to establish (Fig 1.2 from Waller and Long 2003, with post 2003 data added) because most of the sea-level index points are from the top of peat beds and have been lowered by varying amounts from their original elevation by sediment compaction. Data from regressive contacts (from peat that overlies clastic material and is less affected by compaction) from the Romney Marsh area indicate RSL continued to rise during this interval, but at reduced rate of <2 mm/yr^{-1} (Long *et al*. 2006a; 2006b). In addition to RSL rise, the accommodation space required for sediment accumulation can be produced by erosional phases and also sediment compaction, as in the Rye area after inundation during the 13th century AD (Long *et al.* 2006b; Long *et al.* 2007).

While emphasis is usually placed on the nature and rate of sediment accretion, the rate of RSL rise can also influence gravel-barrier dynamics by controlling the supply of sediment to, and stability of, these landforms (Orford *et al.* 1991). Jennings *et al*. (1998) indicate conditions are favourable for gravel-barrier consolidation with a RSL rise of between 2 and 8 mm/yr^{-1}; below 2 mm/yr^{-1} RSL is too slow for sediment replenishment resulting in the longshore reworking of barriers, while above 8 mm/yr^{-1} the high-tide shoreline is moving so fast that barriers will be overtopped and fail to consolidate.

As a result of the vertical scatter in the sea-level index points (Fig. 1.2), caused largely by the differential effects of peat compaction but also potentially by changes in local or regional tidal range, it is not possible to identify smaller amplitude, metre-scale fluctuations in RSL. This is an important limitation to current knowledge since fluctuations of this scale over timescales of centuries to millennia can cause significant changes in coastline position by, for example, destabilising coastal barriers of sand and gravel (Orford *et al.* 1991) and also by drowning coastal wetlands.

Coastal Processes

Water and sediment movement along the Sussex coast is largely controlled by tidal-wave conditions at the eastern end of the English Channel. Prior to the opening of the Strait of Dover *c*. 8200 cal. yr BP this region is likely to have been a low energy, low tidal-range embayment. The subsequent shift to a meso-macro tidal environment, with high tidal-stream velocities through the Strait of Dover, most probably initiated the easterly nearshore drift of sediment (Austin 1991; Long *et al*. 1996). Nicholls (1991) argued that under modern conditions sediment moves predominately eastward from Selsey Bill to a regional depocentre at Dungeness (the Sussex ‘master cell’).

Located at the downwind end of the English Channel, the Sussex coast experiences frequent storms originating in the adjacent North Atlantic (Lozano *et al.* 2004). Storms are potentially important in enhancing the rate of littoral drift (Nicholls 1991) and can therefore promote episodes of barrier initiation, consolidation and breakdown depending on whether particular stretches of coastline are sources or sinks of sediment. Both variations in storm frequency and the magnitude of storm events will influence sediment movement. Attempts to use sand-blowing as a proxy indicator of storminess in the North Atlantic suggest variations in frequency may be related to major climatic shifts (Clarke and Rendell 2009). Episodes of sand drift appear to correspond with periods of Northern Hemisphere cooling and might therefore be expected to coincide with Bond events (approximately cyclical cooling episodes recorded at *c.* 1500 yr intervals; Bond *et al.* 1997). Historical records also provide valuable information regarding periods of high storm magnitude/frequency, such as during the 13th century AD when storms ravaged much of the south coast of England and the North Sea Low Countries (Lamb 1991; 1995).

It is not certain whether the modern longshore drift system is typical of the past, even the late Holocene. Jennings and Smyth (1990; 1991) noted the coastline would have been more crenulated in the early Holocene and that the presence of large estuaries (such as Pevensey Levels) would have resulted in numerous closed sediment cells even in the late Holocene. However, while acknowledging short-term interruptions, Nicholls (1991) regards longshore transport as being fundamental in determining gravel supply during the Holocene, with the episodic movement of gravel around headlands occurring during stormy periods.

The Supply of Gravel

The modern Sussex shoreline consists mostly of sand and gravel, with flint the dominant component of the latter. There are three potential sources of flint, the first of which is from erosion of the chalk during the Holocene. Dornbusch *et al.* (2006), from investigations of proportion of flint in the chalk and measurements of cliff erosion, calculate that 7700 m^3/yr^{-1} of flint is produced by cliff erosion and platform downwearing along the East Sussex chalk coastline. This value is lower than the approximations made by earlier authors (e.g. the 25,000 m^3/yr^{-1} calculated in Jennings and Smyth 1990) and if supplied at a constant rate over the last 5000 years would only account for approximately one fifth of the volume of shingle on Dungeness Foreland (Dornbusch *et al.* 2006). The volume of flint released is therefore insufficient to account for the amount presently stored in the main gravel depositories which also include The Crumbles, Rye Harbour and Hythe. A second source is from sediment transported by rivers to the floor of the English Channel during Pleistocene cold phases when RSL was low. Jennings and Smyth (1990) proposed that such material was reworked into the nearshore zone by rising sea level and then subsequently moved onshore by storm waves. A third potential source (Nicholls 1991) is the reworking of gravel stored in the Pleistocene raised beach deposits of West Sussex, although this material would mainly have been accessible during the late Holocene when RSL was close to present.

A decline in supply of gravel as the result of the exhaustion of one or more of these sources can be expected to have led to barrier reworking and potentially changes in the position and permanence of tidal inlets. Changes to the position of mouths of the Sussex rivers are well-documented for the historic period (e.g. Lake *et al.* 1987; Woodcock 2003). It would also have altered the morphological and sedimentary characteristics of the barriers, which in itself may have made them more vulnerable to overtopping in major storms (Jennings *et al.* 1998). A critical question is whether there is a relationship in the timing between phases of initiation, consolidation and breakdown of different barriers along the Sussex coast. Cannabilisation of older barriers may, for example, correlate to episodes of down-drift barrier initiation and consolidation, assuming sediment pathways, including those around headlands, were open.

Catchment Influences and Human Activity

The catchment characteristics of the levels/valleys within the study area differ significantly, in terms of their area, their topography, as well as their geology and geomorphology (Fig. 1.1). These differences will have combined to influence the supply of clastic sediment and freshwater to the coastal zone and, thereby potentially patterns of coastal evolution. Analysis of alluvial sediment sequences across Britain suggests a strong link between episodes of flood-related sedimentation and the Northern Hemisphere cooling events noted above (Macklin and Lewin 2003; Macklin *et al.* 2005). The number of flood units increases markedly after *c.* 4500 cal. yr BP, suggesting clearance and larger-scale agriculture increased sediment supply from river catchments; indeed Macklin and Lewin (2003) argue that land-use change made catchments more responsive to climate change. The quantity and quality (in terms of dissolved mineral nutrients) of freshwater supplied via the river systems has been shown to influence the development of wetland vegetation in the coastal zone (e.g. Waller *et al.* 1999; Long *et al.* 2007). The supply of water from the river catchments is likely to have increased following defor-

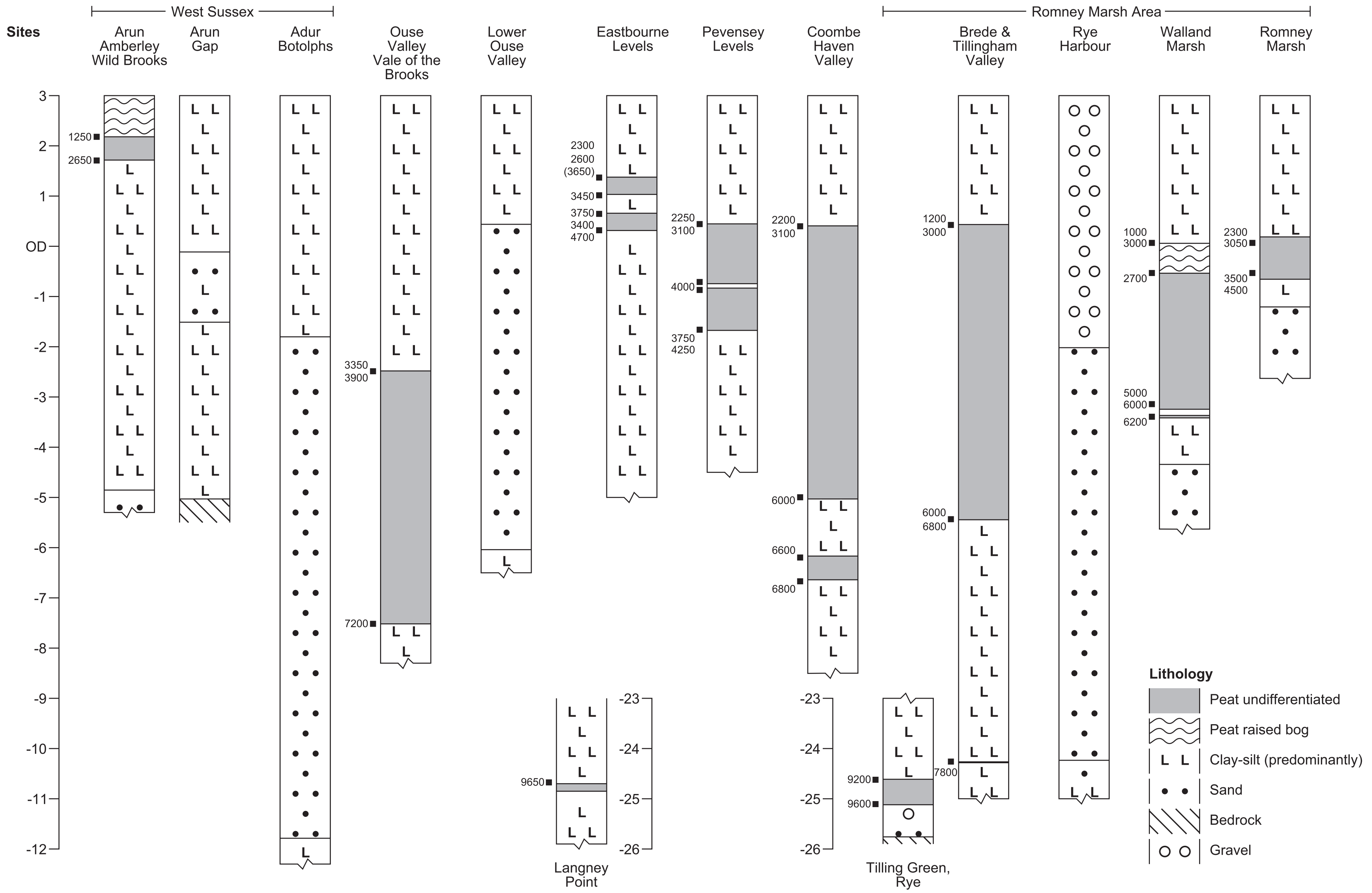

Fig. 1.3. Schematic stratigraphies of the Holocene deposits of the Sussex coast and the Romney Marsh depositional complex. Age ranges (cal. yr BP) are given for the peat contacts where lithostratigraphic continuity has been established between sites.

estation due to a reduction in evapotranspiration and the destabilisation of soils.

Inter-tidal environments, particularly in protected back-barrier settings, have long been prime targets for reclamation. Reclamation has two main geomorphological consequences (Long *et al*. 2007). Firstly, the accompanying reduction in the tidal prism promotes sediment infilling and the ultimate closure of tidal inlets. Secondly, the space available to accommodate storm water is reduced and this raises flood-water levels. When combined with the lowering of drained land surfaces by compaction, this can greatly increase the likelihood of sudden and extensive inundation.

Models of Coastal Evolution

A number of conceptual models have been applied to the coastal deposits of southern England and more specifically to the Sussex coast. The model of Jennings and Smyth (1990) emphasises barrier formation and variations in the quantity and nature of the sediment supply as the key local control on the nature of back-barrier and valley-fill coastal sedimentation. They envisage, for the latter part of the Late Glacial, rising RSL reworking sand and gravel landwards across the floor of the English Channel and into the river channels. During the early Holocene through to *c*. 6000 cal. yr BP, this sediment moved progressively shoreward, with numerous river channel/tidal inlets preventing the development of an open littoral drift system until the offshore river valleys were infilled with sediment and overtopped. From *c*. 6000–300 cal. yr BP, relatively stable RSL and shallow nearshore environments encouraged the landward transfer of sediment, particularly gravel, resulting in extensive barrier formation and shoreline progradation. Jennings and Smyth (1990) argue that the last 300 years has seen the longshore redistribution of sediment.

A broadly similar three-phase model of barrier development was applied by Long and Innes (1995) to Romney Marsh/Dungeness, although the chronology differs significantly to that of Jennings and Smyth (1990). Based on an interpretation of barrier and back-barrier records, they proposed that barrier initiation occurred *c*. 6500–5000 cal. yr BP as a result of an initial influx of sediment, with stabilisation and consolidation *c*. 5500–2000 cal. yr BP indicating continued or increasing sediment supply. Barrier breakdown, the segmentation and reorientation of the barrier, in the last 2000 cal. yr BP resulted from a decline in the supply of sediment, an increase in storm magnitude/frequency or accelerated RSL rise (Long and Innes 1995).

Lastly, Long *et al*. (2000) proposed a three-phase model of estuary development from work in Southampton Water, which by emphasising regional changes (RSL), may be applicable to southern England, including the Sussex and Kent coasts (Long 2001). During the early Holocene, estuary expansion, driven by rapidly rising RSL, resulted in the formation of basal peats and thick deposits of estuarine sediment. Estuary contraction occurred in the mid Holocene as peat formation, dependent upon continued but slowly rising RSL, became widespread. Wetland inundation, coinciding with relatively stable RSL in the late Holocene, was the result of conditions being unfavourable for the continued accumulation of organic material due to either the negligible RSL rise or peat compaction (Long *et al*. 2000).

The Coastal Deposits

We now outline the stratigraphic information available (summarised in Fig. 1.3) on the Holocene deposits of the valleys and former embayments of Sussex, starting at the eastern end of the regional sediment cell and working westwards.

The Romney Marsh Depositional Complex

The Romney Marsh depositional complex (Fig. 1.1) comprises the now reclaimed back-barrier wetlands of Walland Marsh, Romney Marsh proper and Denge Marsh, a series of valleys which feed into the western side of the Marshland (Eastern Rother, Tillingham and Brede), and the gravels of a degraded barrier system (at Rye Harbour, Dungeness and Hythe).

Away from the valleys, few boreholes have fully penetrated the back-barrier deposits of the area and knowledge of the pre-inundation land surface is therefore limited. Investigations from the Tillingham near Rye indicate the presence of a palaeo-valley at a depth of *c*. 25 m from the modern surface (Waller and Kirby 2002). The upper contact of a thin basal peat from Tilling Green Rye provides the earliest sea-level index point (*c*. 9200 cal. yr BP at –24.68 m OD) from the complex (Fig. 1.2). This confirms that tidal waters had extended into this part of the eastern English Channel by this date. The overlying sediment, indeed the bulk of the fill in the valleys (e.g. Waller *et al*. 1988), consists of blue-grey silty-clays, which microfossil evidence suggests was deposited in a low-energy intertidal marsh or tidal-flat environment. A thin peat, dated to *c*. 7800 cal. yr BP at –10.24 m OD, is only recorded from the lower Brede and Tillingham and seems to record a local episode of wetland expansion and then retreat (Waller and Kirby 2002). In the lower valleys a coarsening-upwards sequence is apparent with marine sands of tidal-flat or tidal-channel origin deposited after *c*. 8000 cal. yr BP. In most of the boreholes sunk across Walland Marsh and Romney Marsh proper (e.g. Long and Innes 1995; Long *et al*. 1998) sand (impenetrable by hand-coring) is recorded at a depth of *c*. –3 m OD. Termed the 'Midley Sand' by Green (1968), these deposits are now known to be stratigraphically distinct from the surface sand deposits regarded by Green as part of the same unit (Long and Innes 1993). Blue-grey silts and clays above these lower sands indicate a decline in environmental energy before peat formation, most probably due to the development of a protective coastal barrier across Rye Bay.

Across the western side of Walland Marsh (from Horsemarsh Sewer to Pett Level) a thin (*c*. 10 cm) layer of peat occurs, intercalated between clay layers, prior to the formation of the main Marsh peat (Tooley and Switsur 1988; Waller *et al*. 1988; Long and Innes 1995). The latter is a laterally persistent peat bed which varies in thickness from *c*. 6 m in the valleys to <1 m on Romney Marsh proper, though locally in one of the small tributary valleys (the Pannel), it is thicker and extends to the surface (Waller 1993). Radiocarbon dates from the base of this layer (where it overlies clays and silts of marine/brackish origin) range from *c*. 6800 cal. yr BP in the Brede valley (at Brede Bridge) to *c*. 3500 cal. yr BP on Romney Marsh proper near Newchurch (Long *et al*. 2007). After a short-lived transitional reedswamp phase, eutrophic fen carr communities became established in the valleys, with alder the dominant taxa (Waller 2002). In the late Holocene, the peat-forming communities on Walland Marsh indicate progressively more acidic conditions, with an area likely to have been isolated from nutrient-rich waters eventually (*c*. 2750 cal. yr BP) developing into a raised bog (Waller *et al*. 1999; Long *et al*. 2007). Dates from the upper surface of the peat range from *c*. 3200 to 1300 cal. yr BP in the Brede valley alone, and are not, in general terms, thought to be a reliable guide to the timing of the end of peat formation or the beginning of the deposition of overlying marine/brackish sediments (Waller *et al*. 2006).

The post-peat sediments of the Romney Marsh depositional complex, the 'Young Alluvium' of Green (1968), accumulated in tidal inlets with entrances at Hythe, New Romney and Rye. They comprise a complex sequence of grey or brown clays, silts and sands and are frequently laminated. The Hythe inlet existed during the Roman period from *c*. 1800 cal. yr BP with reclamation certainly well advanced by *c*. 1200 cal. yr BP (Long *et al*. 2007), though the Rumensea Wall (enclosing Romney Marsh proper in the southwest) may date from as early as *c*. 1400 cal. yr BP (Allen 1999). The tidal area associated with the New Romney inlet, which dates from *c*. 1400 cal. yr BP, appears to have been relatively small, confined by the Rumensea Wall and the Walland Marsh raised bog. A large tidal channel, the Cheyne Channel, extends in a north-westerly direction (Long *et al*. 2007), and the tidal channels in which the near-surface 'Midley Sands' were deposited (Kirby *et al*. this volume) seem also to be related to this inlet. The first breach of the coastal barrier at Rye probably occurred as early as *c*. 1200 cal. yr BP, though it was certainly considerably widened by the storms of the 13th century AD. Here, barrier failure is associated with widespread peat erosion (see below) and the movement of gravel and sand inland. Sediment, including gravel, appears to have been driven into the area which became the Rother estuary and the gravel was subsequently redistributed eastward along the northern arm of the Wainway Channel to form small beaches as observed at Moneypenny Farm (Long *et al*. 2007). Both reclamation and the regrowth of the coastal barrier in the Rye Harbour area from *c*. 600 cal. yr BP (Lovegrove 1953; Long *et al*. 2007) are implicated in the reduction of the tidal area of the Rye inlet and the consequence demise of New Winchelsea and Rye as major ports.

The post-peat sediments might be expected to have been derived from terrestrial catchment sources. However, primary woodland clearance in the river catchments occurred largely in the period from 4000 to 3300 cal. yr BP (Waller and Schofield 2007). With no immediate response to land-cover changes evident, it appears that any sediment released either passed into temporary sediment stores or was transported directly to the coastal zone. However, a phase of arable activity during the Roman period around Rye resulted in the deposition of thin (<0.5 m) slopewash deposits between the peat and overlying marine/brackish sediments at a number Marshland edge locations (Long *et al*. 2007).

Recent work on the back-barrier deposits of the Romney Marsh area (e.g. Long *et al*. 2007; Plater *et al*. 2009) cautions against assuming continuous incremental sediment accumulation and gradual coastal change. For example, the peat-accumulation rate in the Brede valley declines after *c*. 4000 cal. yr BP and accumulation appears to have ceased *c*. 1000 cal. yr before inundation and the deposition of the bulk of the post-peat sediments (Waller *et al*. 2006). Phases of exceptionally rapid sedimentation are also evident, with the analysis of tidal rhythmites (finely laminated beds of sand and mud) suggesting that in certain circumstances (e.g. tidal channels) sediment accumulation rates of >0.5 m/yr^{-1} may be attained (Stupples 2002; Long *et al*. 2007). In addition, post-depositional factors, notably erosion and sediment compaction, need to be considered. For example in the Rye Harbour area, the 13th-century AD breach resulted in the erosion of peat from a 4 km wide corridor and in peripheral locations subsequent compaction lowered the peat surface by at least 3 m (Long *et al*. 2006b). Dating the upper surface peat layers is considered particularly problematic, as the sediment dated may have accumulated slowly, experienced compaction or the peat layer may have been erosionally truncated (Waller *et al.* 2006).

In addition to work in the back-barrier area, optically stimulated luminescence (OSL) dating has provided a direct chronology for the evolution of Dungeness Foreland (Long *et al*. 2007; Roberts and Plater 2007). Dates from the underlying shoreface sands constrain the timing of the emplacement of the overlying the gravel. These shoreface sands accumulated as an inter-tidal or subtidal spit, under conditions of high sediment supply, with the overlying gravel deposited soon after their emergence under the influence of storms and waves. The most westerly exposed beaches at Broomhill Level are the oldest and date to *c*. 4100 yr BP, probably forming as part of a bay bar (Long *et al*. 2007). The beaches between Broomhill and Holmstone accumulated between 4000 and 2000 yr BP. From *c*. 2000 yr BP, there was a change in the rate and direction of progradation with rapid easterly growth, which may be a result of the updrift cannibalisation of sediment. A second phase of north-easterly extension occurred from *c*. 1300 to 400 yr BP with barrier reorientation and further cannibalisation probably due to the updrift breach in the barrier system at Rye (Roberts and Plater 2007; Plater *et al*. 2009).

The Combe Haven Valley

The deposits of the lower Combe Haven valley (Fig. 1.1) have been subject to extensive investigation (Jennings and Smyth 1987; Smyth and Jennings 1988). Three main Holocene units are recognised. The deepest, silty clay (from above *c*. –19 m OD) accumulated in a marine/brackish environment. An overlying peat is, at mid-valleys sites, divided into two by an intervening wedge of the silty clay. The lower thin (<0.8 m) peat layer formed between *c*. 6800 and 6600 cal. yr BP and the upper layer after *c*. 6000 cal. yr BP. The latter thickens (maximum *c*. 5 m) upstream and is overlain by silty clays (<1 m thick) or, adjacent to the coast, gravel. Dates from the transition between the peat and the upper silty clay range from *c*. 3100 to *c*. 2200 cal. yr BP. Pollen evidence suggests that the upper silty clay can be divided into an upstream freshwater facies and downstream marine facies, with a shift to freshwater conditions at downstream locations recorded *c*. 0.25 m below the surface (Jennings and Smyth 1987).

Smyth and Jennings (1988; 1990) report further investigations of the peat/upper silt transition, noting the coincidence between changes in pollen stratigraphy (declines in tree pollen, particularly alder, and rises in herbaceous pollen) and the switch to minerogenic sedimentation. At the upstream locations this shift was attributed to forest clearance *c*. 3100 cal. yr BP, with the later (*c*. 2200 cal. yr BP) inundation at downstream sites seen as a consequence of this activity; increased river discharge following clearance would have produced a widening in the estuary mouth and promoted an extension of the tidal limit up-valley (Jennings and Smyth 1987; Smyth and Jennings 1988; 1990).

Pevensey Levels

Lake *et al*. (1987) outline the alluvial deposits of Pevensey Levels (Fig. 1.1) which are described as being 15 m thick (and deeper near the coast) overlying a complex basal surface. Bedrock ‘islands’ occur adjacent to the coast (Hooe Level) and at a number of inland locations (e.g. Horse Eye). The alluvial deposits typically comprise four units. The basal deposit consists of firm clayey silts with various inclusions including peat fragments. A basal peat was recorded near Normans’ Bay at a depth of –6.4 m OD. The overlying clay with sand (maximum thickness >9 m) is of marine/brackish origin at New Bridge (Horse Eye Level) where foraminifera indicate sand-flat associations initially, tending towards a high salt-marsh environment in the upper levels (Lake *et al*. 1987). A peat bed follows with a maximum thickness of 1.8 m, though it is absent from the former river courses. North and west of Horse Eye peat occurs extensively at 0.9 to 1.5 m below ground surface and locally outcrops at the surface in several small tributary valleys. *Cerastoderma* shells occur in the uppermost deposit, clay. In addition, sand bodies within the sequences are recorded to the south and east of Horse Eye and extending northwards towards the Ash Bourne valley. Lake *et al*. (1987) suggest they represent channel fills though they could not exclude the possibility that some originated as barrier-bars.

Moffat (1984; 1986) and Jones (2002) report palaeoenvironmental investigations from the main peat bed and adjacent sediments. In pollen diagrams from eastern Pevensey Levels alder appears to be dominant, with sedge values increasing in the overlying sediment, though a diagram from a more central location indicates more open and wetter conditions. At the latter site foraminifera indicate the under and overlying silty clays are of marine/brackish origin along with a thin (8 cm) intercalated clay layer which was also recorded in adjacent boreholes (within *c*. 1 km).

Given the architecture of the deposits of the valleys feeding into the western side of the Romney Marsh depositional complex and Combe Haven, the Pevensey Levels peat bed could be expected to thicken considerably in the lower Ash Bourne valley. This appears not to be the case. A borehole (sunk to test this hypothesis) at Boreham Bridge, revealed a sequence of blue-grey clay (between 8 m and 3.79 m below the surface), overlain by 2.17 m of peat with clayey intercalations and 1.62 m of silty clay.

Six radiocarbon dates from lower (regressive) contacts of the peat bed range from *c*. 4250 to 3750 cal. yr BP (Moffat 1984; Jones 2002), and although from geographically disparate locations including a tributary valley (Court Lodge), towards the coast (near Normans' Bay) and inland (Horse Eye), show no obvious spatial trends. The thin intercalated clay reported by Jones (2002) appears to have been deposited over a short period (<100 cal. yr) at *c*. 4000 cal. yr BP. Three dates from the upper (transgressive) contact of the peat bed range from *c*. 3100 to 2250 cal. yr BP (Jones 2002). Doubts as to whether the latter accurately reflect the age at which the bulk of the upper clays were deposited are raised by the founding grant (AD 1180) of Otham Abbey (on the western edge of the marshland) which gave the Abbey the right to take '60 cart loads of peat yearly from the manor of Pevensey' (Salzmann 1910). The caveat 'so long as the moor may last' suggested to Salzmann (1910) realisation of a gradual extension of tidal conditions at this time, though might alternatively reflect recognition that the resource was dwindling under the pressure of peat cutting. Two dates from organic detritus within the upper clay (within 0.4 m of the surface) of *c*. 500 cal. yr BP were obtained by Moffat (1984), although the dated material may be reworked or have been contaminated by the vertical penetration of roots.

The reclamation history of Pevensey Levels is detailed by Salzmann (1910), Dulley (1966) and Rippon (2000). Although reclamation appears to have started relatively late (Rippon 2000), by the mid 13th century AD most of the wetland had been drained and three major tidal inlets embanked; Pevensey Haven, Old Haven/Waller's Haven (into which the river Ash Bourne flowed) and Esthaven. The storms of AD 1287 caused flooding at a number of locations and were followed by several attempts to improve the sea defences and drainage system, which included damming Pevensey Haven. Subsequently, and presumably as consequence, the tidal flow appears to have been insufficient to keep the mouth of Ash Bourne (Old Haven) open and the lower Ash Bourne (e.g. Hooe Levels) experienced extensive freshwater flooding from the mid 14th century AD. Old Haven was then abandoned and several cuts made through to Esthaven, with the current outflow at Normans' Bay dating to AD 1455 (Dulley 1966; Lake *et al*. 1987).

The Eastbourne Area

The Holocene deposits of the Eastbourne area occupy a short valley/basin (Willingdon Levels/Lottbridge Drove) between the Chalk in the west and, in the east, a ridge of Weald Clay which rises to a maximum 35 m OD and separates this area from Pevensey Levels (Fig. 1.1). At the coast is an accumulation of gravel known as The Crumbles. Deep boreholes indicate bedrock at a depth of 33.4 m beneath The Crumbles at Langney Point and *c*. 12 m at Lottbridge Drove. Stratigraphic investigations from Langney Point, Eastbourne Level and Southbourne Level (Lottbridge Drove) and Willingdon Levels are reported in Jennings (1985), Jennings and Smyth (1985; 1987) and Jennings *et al*. (2003).

The Langney Point sequence starts with a basal peat (with dates of *c*. 10,850 and 9800 cal. yr BP; Harkness and Wilson 1979) or minerogenic sediment overlain by a thin peat (Jennings 1985). The transgressive contact of the latter is dated (at –24.7 m OD) to *c*. 9850 cal. yr BP (Jennings 1985). The overlying clay is replaced by sand at –14.2 m OD which in turn is followed by *c*. 8 m of gravel above –3.7

m OD. The biostratigraphy of the clay suggests an estuarine origin with more fully marine conditions during the deposition of the sand (Jennings and Smyth 1987). At Lottbridge Drove, valley gravels are overlain above –6.08 m OD by silty clay, which again contains a biostratigraphy indicative of estuarine conditions. An overlying peat occurs over most of the Lottbridge Drove/Willingdon Levels area and is a maximum 1.17 m thick. At some locations it is divided in two by estuarine clay. An upper silty clay (1.75 m thick at Lottbridge Drove) was divided by Jennings and Smyth (1987) into a lower estuarine and an upper freshwater facies.

As a result of the discovery of a late Bronze Age occupation platform within the upper part of the peat at Shinewater in 1995 (Greatorex 2003), further investigations were undertaken from the peat from a number of sites across Willingdon Levels (Jennings *et al*. 2003). The four dates obtained from lower (regressive) contacts range from *c*. 4700 cal. yr BP on the western edge of Willingdon Levels at Hydneye to *c*. 3400 cal. yr BP at Mornings Mill Farm on the northern edge. The thin intercalated clay was dated at Shinewater to between *c*. 3750 and 3450 cal. yr BP. The four dates from upper (transgressive) contacts on Willingdon Levels (Jennings *et al*. 2003) are relatively consistent (*c*. 2600–2300 cal. yr BP), while a much earlier date (*c*. 3650 cal. yr BP) was obtained from Lottbridge Drove (Jennings and Smyth 1987). The pollen stratigraphy from the Willingdon Levels peat is dominated by taxa indicative of open and wet conditions. Only at Mornings Mill Farm does alder attain frequencies indicative of the development of fen woodland. Jennings *et al*. (2003) attribute the open conditions to anthropogenic activity.

Jennings and Smyth (1987) suggest development of the gravel foreland at The Crumbles occurred from the 12th century AD and initiated the freshwater facies in the upper silty clay. Cartographic evidence suggests The Crumbles has experienced sediment depletion and shoreline retreat since *c*. AD 1600 (Jennings and Smyth 1990).

The Ouse and Cuckmere Valleys

The deposits of the Ouse valley (Fig. 1.1) were first reported by Jones (1971) and Thorley (1971), with further details of these investigations provided in Thorley (1981) and Burrin and Jones (1991) and additional information available from Lake *et al*. (1987) and Waller and Hamilton (2000). The bedrock surface in the lower valley, shown in detail by Burrin and Jones (1991), extends below –25 m OD at Newhaven, shallowing to *c*. –10 m OD in the Vale of the Brooks. Basal sands and gravels (a maximum 3 m thick) of uncertain origin are widespread. Burrin and Jones (1991) divide the overlying fill into an inland sequence and, from the Chalk outcrop downstream, a perimarine sequence. The former comprise fluvial and colluvial derived deposits and locally peat (Robinson and Williams 1983). The latter include estuarine sediments clays with interbedded peats which are thickest (*c*. 10 m) in the Vale of the Brooks. Overlying sand and clay units thicken downstream of the Vale of the Brooks. Above the basal unit, the only gravel encountered was that forming the contemporary beach (estimated a *c*. 5 m thick) across the valley mouth.

Bio- and chronostratigraphic information is available from the Vale of the Brooks and from a tributary, the Glynde valley. The deepest sediment (at *c*. –9 m OD) investigated by Thorley (1981) is a peaty clay at Lewes I which appears from the pollen stratigraphy (Waller and Hamilton 2000) to have been deposited under salt marsh or tidal-flat conditions. This is followed by a phase of freshwater peat formation which began at Lewes I *c*. 7200 cal. yr BP (Thorley 1981) and prior to *c*. 7100 cal. yr BP in the Glynde valley (Waller and Hamilton 2000). Peat formation was evidently extensive during the mid Holocene, from *c*. 6500 to 3350 cal. yr BP at Lewes II and spanning *c*. 5800 to 4900 cal. yr BP from a sequence reported from the Vale of the Brooks by Lake *et al*. (1987). The peat is consistently described as consisting of a basal woody unit and an upper detrital peat, though alder pollen values are high throughout the three published sequences. Two dates have been obtained from top of the peat; at Lewes II *c*. 3350 cal. yr BP and *c*. 3900 cal. yr BP from the Glynde valley. At both these sites the pollen stratigraphies suggest that contacts with the overlying marine/brackish deposits are undisturbed and continuous, though the variation in the altitude of the peat surface across the Vale of the Brooks (Thorley 1981; Waller and Hamilton 2000) suggests that at least some locations that the overlying clastic unit (largely clayey silts in the Vale of the Brooks) sits unconformably on the peat.

Knowledge of the deposits of the lower Cuckmere valley is limited. Burrin (1983) reports boreholes from Cuckmere Haven and Litlington that suggest a similar stratigraphy to the lower Ouse. At Cuckmere Haven basal gravels are replace *c*. 28 m below the surface by silty clays (to *c*. 20 m), then sands (to *c*. 3 m) followed by an upper silty clay.

The Adur and Arun Valleys (West Sussex)

The Holocene deposits of the lower Adur are detailed in Young and Lake (1988) from borehole records held by the British Geological Survey. The deepest part of the bedrock channel (overlain by basal gravels of unknown origin) at the mouth of the Adur (below –23 m OD) lies mid-way between Lancing and Shoreham (Fig. 1.1). Where the A27 crosses the valley and near Botolphs (c. 2 and 6 km inland respectively) a tripartite Holocene sequence can be distinguished. Lower silts and clayey sands (maximum *c.* 10 m thick) are replaced by fine- to medium-grained sands (maximum *c.* 10 m thick) and by further silts and clayey sands (at the A27) and clays (at Botolphs). In a borehole log from Lower Beeding (just north of Botolphs) traces of peat are reported from the sand unit and the overlying clay is described as organic (Young and Lake 1988). A section immediately inland of the coastal outcrop of gravel, shows a *c.* 10 m gravel bed resting on bedrock and sand, overlain by a few metres of sand or clay. Gravel (<1 m thick) was also recorded within and overlying the sand unit in two boreholes near the A27. Details of the development of the gravel spit at the Adur mouth from the mid 17th century AD are provided in Ward (1922) and Young and Lake (1988).

Litho-, chronostratigraphic and seismic data are available for the offshore palaeo-Arun valley (Gupta *et al.* 2004; 2007; Bayliss *et al.* 2007). The Holocene infill includes thin (up to 20 cm thick) organic layers, some of which are intercalated within estuarine deposits. Radiocarbon dates from these peats range from 11,300–9750 cal. yr BP with peat age related to altitude (Fig. 1.2). Brief details of the stratigraphy of the lower Arun valley are provided in Aldiss (2002). Boreholes indicate the buried valley extends to a depth of 36 m below surface at the mouth of Arun and 31 m at Arundel. The overlying sediments are said to comprise silty clay, silt and fine sand, which is consistent with the schematic stratigraphies presented in Castleden (1982). Boreholes sunk for the purpose of palaeoenvironmental reconstruction from near the edge of the floodplain in the Arun gap at North Stoke reveal an 8 m sequence above the chalk comprising clayey silts with a sandier unit *c.* 3 to 4 m below the surface (Fig. 1.3). Organic material (wood etc.) is scarce and clearly not *in situ*. Although investigations focussed on the near-surface peat deposits, Waton (1983) provides some details of the deeper stratigraphy of Arun upstream of the chalk at Amberley Wild Brooks. On the western side, peat is underlain directly by sand. To the east peat is underlain by clay (the upper layers of which are rich in *Phragmites*) which extends to depth of *c.* 8 m beneath the surface where sand was encountered. The pollen assemblage from the upper metre of the clay beneath the peat suggests deposition in a marine/brackish environment, with the onset of peat formation dated to *c.* 2650 cal. yr BP (Godwin and Willis 1964). The presence of *Sphagnum* and *Molinia* layers indicate that after *c.* 1250 cal. yr BP (Waton 1983) the peat formed in an oligotrophic environment, a raised bog (Godwin 1943). Tributary valleys, the Western Rother and the Chilt (near Pulborough), contain organic fills, with peat forming in the Chilt from *c.* 4300 cal. yr BP to the present (Groves 2008) and over 5 m of peat reported in the Western Rother (Aldiss 2002).

Comparison of the Coastal Sequences

The stratigraphies detailed above are represented schematically in Fig. 1.3. The altitudes are indicative; where detailed lithostratigraphic information is available the altitude of peat beds is shown to be locally influenced by the thickness of overburden and the depth of the Holocene sequence (e.g. Long *et al.* 2006b).

Both basal and, below *c.* –24 m OD, intercalated peats are common both offshore and inland in the buried valley systems found along the Sussex coast. The latter, reported from Langney Point and the Arun, are thin and appear to be short-lived episodes (invariably only one radiocarbon date is available) dating prior to *c.* 9000 cal. yr BP. The sediments deposited from *c.* –24 to –10 m OD appear to be largely fine-grained clastics, clays and silts, though the data available are largely derived from commercial boreholes at locations inland. These sediments are compatible with low energy, probably low tidal-range environments, before the opening of the Strait of Dover. The coarsening-upwards sequence that follows, giving rise to the deposition of sands in the Romney Marsh area after *c.* 8000 cal. yr BP, may also be evident in Adur valley and possibly the lower Ouse (though see below).

The peats which are consistently recorded in the coastal deposits of East Sussex began to accumulate *c.* 7200 cal. yr BP, though interruptions during the early stages of peat growth appear common with marine conditions returning to Combe Haven and western side of the Romney Marsh depositional complex. Neither the onset of peat formation nor the age of the intercalated clays appears consistent along the coast. Distinctions between the valleys and levels (e.g. Jennings and Smyth 1987) are difficult to justify since where data are available the continuity of the sequences is clear. Intercalations within the main peat bed have only been recorded from Pevensey Levels and the Eastbourne levels where clay layers of marine/brackish origin dating to *c*. 4000–3500 cal. yrs BP have been consistently recorded from some areas.

During the mid Holocene, alder-dominated vegetation occurs in valleys and is replaced spatially by communities indicative of wetter conditions on central Pevensey Levels (Jones 2002) and by more acidic conditions on Walland Marsh (Waller *et al*. 1999). At the seaward end of some sequences, peat is absent. In the case of the Rye Harbour area, widespread erosion occurred during a phase of post-peat inundation, destroying the peat and creating the accommodation space for the deposition of sands. The relationship between the peat deposits of Vale of the Brooks and the sands recorded by Burrin and Jones (1991) in the lower Ouse is unclear and the latter unit could also have been deposited after extensive peat erosion.

In contrast to East Sussex, thick mid Holocene peat layers have not been recorded from the lower Adur and Arun valleys. There are three possible explanations. Firstly, peat may in fact exist but has yet to be discovered, either due to the relative scarcity or nature (mostly commercial borehole) of the lithostratigraphic data. Secondly, as seems possible in the lower Ouse, peat may have been removed by erosion. Thirdly, peat may never have formed, with the lower valleys remaining as open estuaries characterised by intertidal and subtidal conditions into the late Holocene (see *Coastal Processes and Evolution*).

In the late Holocene, marine-brackish conditions returned to the valleys and levels of East Sussex. Dates from upper (transgressive) contacts range from *c*. 3650 to 1000 cal. yrs BP and are locally inconsistent, as has been most clearly demonstrated in the Brede valley (Waller *et al*. 2006). There is no reason to regard the problems associated with the dating of transgressive contacts to be confined the Brede and such dates can only be regarded as providing a maximum age for the deposition of the overlying sediments. Archaeological and historical evidence in some cases provides additional dating evidence (Long *et al*. 2006a). Peat formation continued at some locations during the late Holocene, including the edges of both the Romney Marsh complex (e.g. the Pannel valley; Waller 1993) and Pevensey Levels, and inland valley locations in the Ouse and Arun. In addition, peat initiation occurred on Amberley Wild Brooks (the Arun valley) with a raised bog developing here (*c*. 1250 cal. yr BP) and over southern Walland Marsh (*c*. 2700 cal. yr BP), though peat formation ceased in the latter area following marine inundation probably associated with the 13th-century AD storms.

Coastal Processes and Evolution

In this section we reappraise the roles of regional and local processes in controlling the Holocene evolution of the Sussex coast using the stratigraphic information previously detailed.

Relative Sea-level Change

The data now available (updated from Waller and Long 2003) to reconstruct RSL changes in the study area are shown in Fig. 1.2. The 65 index points divide roughly evenly between the Romney Marsh depositional complex (35 dates) and the rest of the Sussex coast (30 dates). The deepest dates are mostly from the palaeo-Arun (Gupta *et al*. 2004; Bayliss *et al*. 2007) and indicate RSL rose from –45 m to –25 m mean sea level (MSL) between *c*. 11,500–10,000 cal. yr BP. The RSL plot assumes constancy in tidal range between the present and the time of sample formation. As noted above, the tidal range in the eastern English Channel is likely to have increased after the opening of the Strait of Dover and, for this reason, these older dates probably plot slightly above their true elevation (though by not more than 2 m). However, these deeper samples also lack detailed biostratigraphic supporting data from which to determine their precise elevation with respect to contemporaneous sea level, being derived from a range of materials including peat, leaf and plant-stem fragments as well as herbaceous plant remains (Gupta *et al*. 2004). They probably formed at or above contemporaneous mean high-water spring tide (MHWST), but the precise reference water level is not known. In our analysis we assume that they formed at MHWST but if they formed below or above this level, their elevations would require adjustment. In practice, the rate of RSL rise (*c*. 20 m in less than 2000 cal. yrs) was so fast during this interval that these corrections are probably of secondary importance.

There is a significant gap in data between the deepest population of samples, below *c*. –25 m MSL, and the second group above *c*. –12 m MSL. This gap records the division between the offshore and deeply buried samples and the organic sediments that are within easy coring reach from terrestrial settings across the region. The majority of the data after this interval are derived from the Romney Marsh depositional complex and, as noted previously, they record an upwards rise in sea level at a decelerating rate until *c.* 3700 cal. yr BP, after which the rate slowed significantly. Much of the height and age scatter in the dates after this interval reflect the effects of sediment compaction (all data points are from intercalated deposits) and for this reason the trend in the RSL data does not pass through 0 m at the present day.

The coastal deposits of East Sussex, with thick mid Holocene peats present, are broadly consistent with the three-phase model of estuary development of Long *et al.* (2000), with the availability of accommodation space, governed by changes in RSL, being the regional underlying controlling process. During the early Holocene the creation of accommodation space generally outstripped sediment supply and terrestrialisation and peat formation were therefore rare. During the mid Holocene, although the rate of RSL rise declined, the continued creation of accommodation space resulted in the accumulation of peats, with the eutrophic alder dominated communities indicative of high groundwater levels. During the late Holocene, the rate of RSL rise and sedimentation rates decline and thick accumulations of sediment are rare except for locations where accommodation space was created by erosion and compaction or where peat formation occurred independently of the groundwater table.

However, variations in the occurrence and timing of peat formation in East Sussex and in particular the apparent absence of mid Holocene peats from the West Sussex valleys suggest that other processes, which operated variably in time and space, were able to override the influence of RSL. Given the pattern of RSL rise, it might be expected that such processes would become increasingly influential as the Holocene progressed. The processes which may locally have determined the nature and timing of sedimentation include the supply clastic sediment, the degree of protection (the evolution of gravel barriers), the morphological and size characteristics of catchments, climate change/storm activity and human activity. These are considered separately below though many of these processes are interlinked and separating their respective contributions through time is not yet possible.

Sediment Supply

Basal peats and thick sequences of clastic sediment, as recorded in many of the offshore samples and deeper boreholes from the region (e.g. the palaeo-Arun, Tilling Green Rye, Langney Point), are consistent with rapidly rising RSL. However, the presence of intercalated peats during a period of rapid RSL rise, at Langney Point and offshore in the Arun, is noteworthy. It is possible that these formed under temporary slow-downs in RSL, not evident from the rather coarse RSL data available at this time. Evidence from beyond the study area indicates that the rate of 'eustatic' sea-level rise was not constant during the early Holocene, with for example a possible abrupt rise in sea level associated with the drainage of glacial lakes that surrounded the former Laurentide Ice Sheet at *c.* 8200 cal. yr BP recorded in the coastal deposits of the Netherlands (Törnqvist *et al.* 1998; Hijma and Cohen 2010). However, the early Holocene peats observed in the Sussex coastal lowlands are generally older than this event and inconsistent in age suggesting that they reflect local and not regional or global processes. These layers seem likely to have formed behind ephemeral barriers reflecting both an abundance of clastic sediment (the sediment transported by rivers to the floor of the English Channel during the Devensian) and the presence of channels associated with the braided rivers of the Late Glacial.

The timing of the onset of widespread peat formation in the East Sussex valleys varies and is therefore unlikely to be the product of fluctuations in RSL. In these protected locations the point at which the accumulation of clastic material (which became the platform necessary for peat growth) was able to exceed the creation of accommodation space will have been strongly influenced by sediment supply. Fine-grained sediments will have ultimately derived from the Wealden catchments, however, sediment may have been supplied directly from the catchment and reworked in the tidal estuaries or have originated from the movement of material onshore. Investigations of the fluvial deposits of the Ouse valley led Burrin and Scaife (1984) to suggest woodland clearance resulted in increased sedimentation from the Mesolithic. However, these deposits were not directly dated and later work on the vegetation history of Weald (e.g. Waller 1993; 1994; Waller and Schofield 2007; Groves 2008) suggests catchments remained well-wooded and the yield of sediment was probably therefore low until at least the early Bronze Age (*c.* 4000 cal. yr BP). This is consistent with an increase in flood-related sedimentation noted across Britain after *c*. 4500 cal. yr BP by Macklin and Lewin (2003) and Macklin *et al*. (2005) and suggests offshore sources of sediment were important well into the mid Holocene. Spatial differences in the supply of sediment from offshore, across any coastal barrier into the back-barrier areas/valleys, therefore provide the most likely explanation for variations in the timing of the onset of peat formation.

The proportion of clastic sediment derived from the catchments is likely to have increased in the late Holocene and Jennings and Smyth (1987) refer to the Combe Haven floodplain acting as a major sediment store following late Bronze Age/Iron Age clearance. However, not only are these clastic sequences difficult to date, but gross sedimentation rates both in the Combe Haven valley and parts of the Brede valley were considerably lower than the early and mid Holocene. The upper silts and clays of these valleys often form a thin veneer (<1 m) over thick sequences (>10 m) of early Holocene clastics and mid Holocene peats. The contribution of catchment derived material to estuary infill (e.g. Pevensey Levels, Romney Marsh proper) may have increased in the late Holocene, though thick clastic sequences which formed in the Rye Harbour area following barrier failure are likely to contain material derived from reworking. The relative contributions of offshore and catchment sources to the sediment budget are therefore difficult to determine even during the late Holocene. However, the likely increase in sediment supply in the late Holocene from the catchments did not lead to gross increases in sedimentation rates on the floodplains. Moreover, in some valley locations peat formation continued uninterrupted, suggesting that the supply of catchment sediment was not the underlying reason behind the widespread switch from the deposition of peat to clastic material in the late Holocene.

Amberley Wild Brooks may provide an exception to this pattern and an example of an increase in sediment supply from the catchment in the late Holocene leading to peat formation. The Wild Brooks occupy a protected setting beyond the chalk and if the absence of peat in the mid Holocene was the result of a failure to fill accommodation space, then terrestrialisation and peat formation did not occur (*c*. 2650 cal. yr BP) until the catchment had been extensively deforested (Groves 2008).

The Degree of Protection/Gravel-barrier Evolution

Gravel has been found beneath but not within the early Holocene marine deposits of the region. RSL rise is likely to have been too rapid for gravel-barrier consolidation and the wave and tidal conditions, together with the crenulated coastline created, unsuitable for the long-shore transfer of gravel during this period (Jennings and Smyth 1990).

The only accumulations of beach gravel dated from the region to mid Holocene are those at Broomhill (from *c*. 4700 cal. yr BP; Roberts and Plater (2007). Indeed gravels have only been recorded within the Holocene sequences inland of the present coastline from the Romney Marsh area (where the early beaches have been protected by the easterly development and extension of the cuspate foreland) and from two boreholes in the Adur. Elsewhere shorelines (and any gravel beaches) may have been seaward of the present coastline, which is confirmed east of Beachy Head by exposure of peats on the foreshore at various locations. Longshore sediment movement during the late Holocene appears to have been sufficient to remove any other direct evidence of these mid Holocene barriers.

Headlands can act as anchor points for barriers (Jennings *et al*. 1998) and Pevensey Levels and, in particular the Eastbourne area, lying immediately east of Beachy Head (itself a potential source of gravel) would also be expected to record early peat formation. However, the stratigraphic review above shows that this is not the case with peats here dating from after *c*. 4700 cal. yr BP. The limited extent of peat formation at these sites probably reflects site exposure, though that the input of freshwater is likely to have been relatively low (see below) may also be important. The lack of open-water lagoonal deposits, such as those deposited behind other south coast barriers (e.g. Slapton Ley, Devon) certainly suggest that barriers, if they existed at all, failed to exert a strong control on patterns of sedimentation. The similarity of the sedimentary sequences of Eastbourne and Pevensey Levels and the presence of estuarine conditions for long periods (Jennings and Smyth 1987) may also record a connection between these areas prior to the late Holocene landward advance of the coastline.

The apparent absence of mid Holocene peats from the West Sussex valleys may be attributed to more exposed conditions caused by open-coast conditions in this area. This would imply that at this time the Pleistocene raised beaches of West Sussex made a minor contribution to the supply of gravel along the coast. Although the chalk cliffs begin east of Brighton, the recent studies on rates of erosion also indicate that the gravel sourced from cliff erosion may not be a major source. Much of the gravel currently stored along the East Sussex coast appears then to have originated from sources further east, either reflecting the distribution of sediments stored during the sea-level lowstand of the Late Devensian, presumably largely in the palaeovalleys of the English Channel which are now empty of sediment (Hamblin *et al.* 1992), or possibly from a precursor of Dungeness formed by the transfer of gravel eastward during the last interglacial.

In broad terms the history of the back-barrier environments and historical coastal changes along the East Sussex coast conform to the pattern that might be expected given the major controls on gravel-barrier evolution. The mid Holocene was a period of peat formation and infilling with the rate of rising RSL providing conditions suitable for barrier consolidation. Late Holocene instability can be attributed to the slowing down in the rate of RSL rise and the exhaustion of the supply of (stored) gravel. The evidence of updrift cannibalisation and downdrift initiation of barriers during this period comes not only from Dungeness Foreland (Long *et al*. 2007; Roberts and Plater 2007; Plater *et al*. 2009) but also the Rye Harbour area. The latter gravel body accumulated rapidly at the western end of the Romney Marsh depositional complex from the 14th century AD until the middle of the 19th century AD (Lovegrove 1953; Long *et al*. 2007). Although the cartographic evidence for depletion of the gravel foreland of The Crumbles at Eastbourne dates only dates from the early 17th century AD (Jennings and Smyth 1990), the problems experienced in keeping the mouth of the Ash Bourne open from the mid 14th century AD (Lake *et al*. 1987) suggests depletion commenced earlier, with the storms of the 13th century AD probably initiating the movement of the gravel which was eventually deposited at Rye Harbour.

Catchment Characteristics

Along with the supply of sediment and the degree of site exposure, the supply of freshwater from the catchments could potentially have been a local influence in determining the timing the shift between clastic sedimentation and peat formation during the mid and late Holocene in the East Sussex valleys. Unfortunately insufficient data on the Holocene discharges of the rivers (present-day data are unreliable due to groundwater extraction) and sub-alluvial geometry of the valleys, makes it difficult to determine whether differences in freshwater discharge could have had significant influence. The lack of freshwater input (aside from the Ash Bourne) may be a contributory factor in the late development of peat on Pevensey Levels and in the Eastbourne area. However, that extensive peat formation occurred in relatively small catchments such Combe Haven, while apparently not in Arun and Adur valleys, argues against the supply of freshwater being a major factor. Valley morphology is potentially also of interest; the valleys in the west of the study area tend to have rather large catchments with narrow lower valleys, resulting in greater potential for channel migration and sediment reworking compared with the wider coastal valleys in the east, notably Pevensey Levels and the Romney Marsh depositional complex.

Climate Change/Storm Activity

The lack of consistency in the timing of major changes in sedimentation in the coastal deposits and in the vegetation changes which occurred in the peat forming communities (Waller *et al*. 1999) argues against a strong climatic influence. However, it may be possible to detect some climatic influences. Increased run-off, due to climate change and clearance activity, may be responsible for the eventual formation of peat in the Eastbourne area and at Amberley Wild Brooks. Ombrotrophic bog development over southern Walland Marsh *c*. 2800 cal. yr BP certainly coincides with wetter conditions as recorded at many sites around north-western Europe (van Geel *et al.* 1996), though both vertical and spatial isolation from base-rich water appear to be prerequisites for this occur (Waller *et al*. 1999). The importance of local factors in determining the shift to ombrotrophic conditions is, however, demonstrated by bog development occurring much later at Amberley Wild Brooks (*c*. 1250 cal. yr BP). Western Pevensey Levels might also be expected to have become isolated from base-rich water in the late Holocene. Unfortunately stratigraphic information is particularly lacking from this area, though the records of peat cutting may be significant in this respect (ombrotrophic peat is likely to have been preferred).

Clear evidence for barrier breaching as a result of storm activity during the Holocene is only available from the Rye and New Romney areas. Here recognition of barrier failure is facilitated by the historical record. Nevertheless the stratigraphic evidence from Rye, which includes the erosion of peat from a 4 km wide corridor and deposition of a substantial gravel deposit at Moneypenny Farm, demonstrates the scale of this event. The thick sand unit found in the lower Ouse appears to sit unconformably on the underlying sediment (Burrin and Jones 1991) and as noted previously this deposit may be the product of a similar event. However, the sand deposits of Pevensey Levels appear to be associated with the tidal channels and comparable sediments are also absent from Combe Haven and the Eastbourne Levels. The thin estuarine clay (dated *c*. 4000 cal. yr BP) found intercalated in the peat in both the Eastbourne and Pevensey Levels appears not to occur elsewhere and could represent an overtopping event or possibly even the landward extension of clastic sedimentation after breaching during a storm event. However, if linked to the presence of a barrier it might be more simply explained by a change in the mouth of the Ash Bourne as a gravel barrier migrated eastward. That the only unequivocal example of barrier breaching as a result of a storm is from the late Holocene may be a preservation issue. However, it is likely that during this period, even when storms can be demonstrated to be the proximate cause, the diminishing supplies of gravel are likely to have been the ultimate cause of barrier failure.

Human Activity

In addition to influencing sediment and water supply through changes in the vegetation of the catchment, human activity may have had a direct influence on floodplain sedimentation. As well as peat cutting, activities such as vegetation cutting and grazing, for which there is evidence from the Bronze Age onwards (Waller and Schofield 2007), may have retarded the accumulation of peat and promoted a shift from organic to clastic sedimentation in the East Sussex valleys. Lowering the water table by drainage, would have caused peat compaction, a process which may also have occurred naturally as a result of tidal creek extension following inundation (Baeteman *et al*. 2002). These processes could all have provided accommodation space in the late Holocene, though the absence of thick post-peat deposits in valleys such as the Brede and Combe Haven, in contrast to the some of the levels, suggests that coastal processes (inundation followed by erosion and sediment compaction), were of greater significance in this respect. As noted in the introduction the reclamation of inter-tidal areas is likely to have enhanced the impact of inundation. It is unlikely to be purely coincidental that widespread inundation in the 13th century AD in both the Romney Marsh area and Pevensey Levels was preceded by episodes of reclamation.

Implications for the Evolution of the Romney Marsh Area

During the early Holocene the Sussex coast evolved in a comparatively uniform way, the rapid rate of RSL rise providing a unifying force. Differences began to emerge from *c*. 7000 cal. yr BP with the onset of peat formation in some areas, notably in the east. From the perspective of Romney Marsh area, topography might appear to have played a significant role in this, with the protected east facing palaeovalleys providing locations where peat forming vegetation could become established. However, that peat formation occurred in some of the apparently more exposed valleys (the Ouse, Combe Haven) earlier suggests that the supply of fine-grained sediment, in terms of the infilling of accommodation space and providing a platform for salt marsh and then freshwater peat formation, was crucial.

During the mid Holocene, the wetlands of Romney Marsh extended in an easterly direction, enclosed by and protected from the high energy of the English Channel by a coastal barrier. The size of the wetlands created far exceeds those created in the topographically restricted bedrock valleys and levels to the west. Again the supply of sediment, though now sand and gravel, appears to have been crucial. With the earliest evidence for the barrier formation coming from Rye Bay and progradation beyond the current shoreline seemingly limited to the eastern end of coastline (beyond Eastbourne), the source of much this gravel appears to been offshore and closer to the Romney Marsh area than previously suspected. The growing importance of longshore supply of sediment during the late Holocene can be attributed to many of the valleys to the west of the Romney Marsh area being infilled with sediment, with the coastline between them straightened and less crenulated. This change in regional coastal morphology would have favoured increased longshore drift. Moreover, the reduction of offshore sediment sources of sand and gravel during the late Holocene made the reworking of onshore sediments and the easterly transport more likely.

In the Romney Marsh area, the main Marsh peat bed is testament both to the spatial extent of, and the length of time over which back-barrier areas, were protected. These wetlands would have acted as traps for precipitation, effectively doubling the catchment area of the Eastern Rother. Moreover, although traversed by large rivers and tidal channels, the development over large areas of acidophilous vegetation suggests that these water courses were peripheral to the much of the Marshland, indeed this is confirmed by stratigraphic studies

(Long and Innes 1995). In West Sussex, the confined topography, combined with relatively large catchment areas, meant that the propensity for sediment reworking or non-deposition due to channel processes was considerably higher. The message that emerges is that size matters; large depositional complexes, especially those unconstrained by topography, are instrumental in creating and maintaining conditions conducive to prolonged periods of wetland development.

In the late Holocene, the slowing down in the rate of RSL rise is likely to have created the necessary underlying conditions for the return of tidal environments to the valleys and levels of East Sussex by triggering a decline in peat accumulation rendering them increasingly susceptible to inundation. This process was later aggravated by human activities. The difficulties in accurately dating the upper contact of the peat layers make it difficult to determine precisely when marine conditions returned. In the Romney Marsh area deposition was related to the sequential opening of tidal inlets, with the overall resilience of the Marshland and its capacity for internal readjustment a product of the size of the complex (Long *et al*. 2006a). More widely, in the absence of a strong regional driving force (RSL), it is likely that other processes became increasingly influential. With the decline in sediment supply and reworking of gravel breaches, the Romney Marsh area became more vulnerable to influences, such as storms and variations in the longshore movement of sediment, which have left their imprint along the coastline.

Finally, size is probably also important in explaining why the deposits of the Romney Marsh area bear a greater resemblance, in terms of gross stratigraphic architecture, to the other large depositional complexes in southern England (the Thames Estuary and the Solent) and the southern North Sea (the Belgium coastal plain). Smaller systems, it would seem, are more prone to local influences in controlling their spatial and temporal patterns of sedimentation in response to variations in terrestrial and marine processes. From this perspective, perhaps it would be more appropriate to describe the coastal stratigraphies of West Sussex as atypical, reflecting a particular combination of topography/spatial extent and site exposure.

Conclusions

A considerable body of data on the coastal deposits of the Romney Marsh area and Sussex has been amassed over the last 25 years. Perhaps not surprisingly, comparison between sites does not support a stratigraphic model where there is a high degree of uniformity (Burrin 1982) or one which can be explained largely by reference to local processes (Jennings and Smyth 1982). For East Sussex/the Romney Marsh depositional complex a tripartite model (with mid Holocene peats separating clastic sediments of marine/brackish origin) is applicable, over which a regional driving process, changes in the rate of RSL rise, provided the ultimate control. Here the main differences are in the thickness of the peat, which in part reflects local influences on the onset and end of peat formation. However, these differences in thickness are also the product of post-depositional changes and the stratigraphic architecture of the deposits (with peat formation occurring earlier in valleys and at upland margins).

From the Romney Marsh perspective, comparison of the Holocene stratigraphies of this region with areas to the east throws new light on the origin of the gravel. Certainly the source of the older (mid Holocene) gravel beaches here appears to have been offshore and closer to Romney Marsh than had previously been assumed. Many of the differences between Romney Marsh and the Sussex valleys/levels can be attributed to size. By virtue of its size, the Romney Marsh complex appears both to have been conducive to prolonged periods of wetland development and resilient, with large parts of the sedimentary protected from subsequent destruction.

Despite the considerable progress made in our understanding of the coastal deposits of Sussex over the last 25 years, it remains possible that some of the apparent differences (e.g. in the presence, thicknesses and age range of the peat) and discrepancies may turn out to be the product of the uneven distribution of stratigraphic information (now heavily biased in favour of the Romney Marsh area). In particular, further work is required to clarify whether the Holocene stratigraphies of the Adur and Arun valleys are atypical.

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