Driving mechanisms of coastal change: peat compaction and the destruction of late Holocene coastal wetlands

A.J. Long*, M.P. Waller[1], P.Stupples[2]

Department of Geography, University of Durham, Science Site, South Road, Durham DH1 3LE, U.K.

Email: A.J.Long@Durham.ac.uk, Tel: +44 191 334 1913, Fax: +44 191 334 1918

[1]*Centre for Earth and Environmental Science Research, School of Earth Science and Geography, Kingston, University, Penrhyn Road, Kingston upon Thames, Surrey KT1 2EE, U.K.*

Email: M.Waller@kingston.ac.uk

[2]*Department of Geography, University of Liverpool, Roxby Building, Liverpool L69 7ZT, U.K.*

Email: paulstupples@supanet.com

*Corresponding author.

E-mail address: A.J.Long@Durham.ac.uk (A.J.Long)

Abstract

This paper examines the role of peat compaction as a driving mechanism behind a widespread inundation of a late Holocene coastal wetland in southeast England, UK. Detailed stratigraphic and dating evidence (lithology, grain size, foraminiferal, pollen and radiocarbon dates) from a sample site in Romney Marsh documents the gradual inundation of a coastal wetland after 1263-1085 cal. yr BP (c. 700-850 AD) and the establishment of a saltmarsh. Shortly thereafter there was a rapid increase in water depth that was associated with the deposition of nearly 4 m of laminated intertidal mudflat and tidal channel sediments, prior to site reclamation from the sea by AD 1460. Grain-size data and statistical analysis of sand and mud laminae thicknesses suggest the laminated sediments accumulated rapidly (c. 0.2 m per year) as heterolithic tidal rhythmites. Rapid compaction of the thick peat bed that underlies the study site provided the accommodation space for their deposition. This process began with the gradual tidal inundation of the site, but accelerated following the widening of a breach in a coastal barrier in the 13th century. Compaction lowered the peat surface by at least 3 m and was associated with widespread landscape change. The study demonstrates the powerful influence that compaction had on the evolution of the late Holocene landscape at this site and, we believe, at many other coastal lowlands in northwest Europe. This process is likely to have been a key driving mechanism behind rapid late Holocene coastal change, far exceeding the longer-term effects of either eustatic change or crustal uplift/subsidence.

Keywords: Compaction; tidal rhythmites; sea-level change; salt marsh; coastal wetland.

1. Introduction

Along the coast of much of the southern North Sea and English Channel, beds of peat attained their maximum thickness (typically between 1 m and 3 m) and lateral extent (up to c. 100 km^2) during the mid Holocene. During the late Holocene almost all of these peatlands were destroyed by marine flooding and they now lie buried beneath 1 to 4 m of minerogenic sediment. Several driving mechanisms have been proposed to explain this inundation. One suggestion is that there was a rise in relative sea level (RSL), a second that there was an increase in sediment delivery from terrigenous sources caused by prehistoric landscape disturbance (Smyth and Jennings, 1988; Plater et al., 1999). A third suggestion is that sediment exhaustion caused coastal erosion and the re-entrance of tidal systems (Beets et al., 1994). A fourth proposal is the drainage of the late Holocene wetlands, either by tidal creek extension or by watertable lowering, made them vulnerable to tidal flooding (Roep and van Regteren Altena, 1988; Beets et al., 1992; Baeteman and Denys, 1995; Baeteman et al., 2002; Baeteman, in press). Finally, Long et al. (2000) argue that the generally slow rate of late Holocene RSL rise (typically <1 mm a^{-1}) meant that conditions for organic accumulation and preservation were poor.

In this paper we explore the role of peat compaction on the destruction and deep burial by mineral sediments of a late Holocene coastal wetland in the Rye area of Romney Marsh, a large coastal lowland in the eastern English Channel. The process of compaction, which lowers the sediment surface relative to the tidal frame, has the effect of creating significant accommodation space that is additional to that provided by any RSL rise. In the example detailed here, this accommodation space was rapidly filled by heterolithic tidal rhythmites.

2. Sediment compaction

Sediment compaction deforms the entire stratigraphic column in a complex manner. Highly compressible peat generally compacts more than almost incompressible gravels and sands, with the actual amount of compaction influenced by the thickness and composition of the sediments, their proximity to incompressible bedrock strata, their time since deposition, and their initial water content (Tooley, 1978; Bennema et al., 1954; Skempton, 1970; Hobbs, 1986; Paul and Barras, 1998; Pizzuto and Schwendt, 1997; Allen, 1999, 2000). Compaction is, therefore, a contaminant of almost all studies of vertical sea-level change that involve peat, lowering index points from their original elevation and causing much of the scatter observed in RSL graphs.

From a palaeogeographic perspective, sediment compaction (including peat as well as underlying minerogenic sediments) complicates efforts to reconstruct the geometry of former land surfaces that often undulate by several metres despite being of broadly similar age (e.g. Waller, 1994a; Haslett et al., 1998; Bell et al., 1999; Streif, 1972). Moreover, the process of compaction contributes directly to the dynamics of landscape change by lowering the height of a sediment surface relative to the tidal frame and thus encouraging tidal inundation, independent of any absolute change in sea level. This is an active process that, like the better studied changes in ocean volume and crustal motions, can exert a profound influence on the height of the land relative to the sea.

3. Aims

In this paper we explore the role of peat compaction in controlling landscape and sea-level change on Romney Marsh. We have three aims:

1. To present litho-, bio- and chronostratigraphic data from a site, West Winchelsea, that documents the late Holocene submergence of a regionally extensive peat bed.
2. To examine the compaction-induced distortion of this peat surface in the Rye area and across the Romney Marsh depositional complex more widely.
3. To explore the significance of this compaction for reconstructing the late Holocene RSL and coastal evolution.

4. Regional setting and previous work

The Romney Marsh depositional complex is a large coastal lowland located in the eastern English Channel, and includes the gravel and sand beaches Dungeness Foreland and Romney Marsh and Walland Marsh (Figure 1). These marshes are formed by c. 25 m of unconsolidated sediment, most of which is Holocene in age. An example of the full Holocene sedimentary sequence in the vicinity of Rye, in the southwest of the complex, is provided in Figure 2. A prominent element of the stratigraphic architecture of these sediments is a laterally extensive bed of peat (Green's (1968) "main marsh peat"). Across Walland and Romney Marsh this peat overlies marine sediments that accumulated in intertidal sand- and mudflats as well as tidal channels (Waller et al., 1988; Tooley and Switsur, 1988; Long and Innes, 1995; Long et al., 1996; Long, A. et al., 1998).

The main marsh peat varies in composition. In the valleys of the Brede, Tillingham, Pannel and Rother, and also in the north of Walland Marsh between Horsemarsh Sewer and Snargate (Figure 1), it is dominated by alder carr deposits and contains abundant detrital wood remains (Waller et al., 1988; Tooley and Switsur, 1988; Waller et al., 1999). Across southwest Walland Marsh, *Sphagnum* macrofossils are common within the peat and indicate the former presence of a large raised bog (Long and Innes, 1995; Waller et al., 1999; Waller, 2002). This bog formed a physical barrier that, for part of the late Holocene, separated the south-western part of Walland Marsh (including the Rye area) from areas to the east. In addition, on the margins of Dungeness Foreland, between the gravel and sand beach ridges, are thin (typically <1 m) shallow-water reedswamp peats (e.g. Tooley and Switsur, 1988; Spencer et al., 1998; Long and Hughes, 1995).

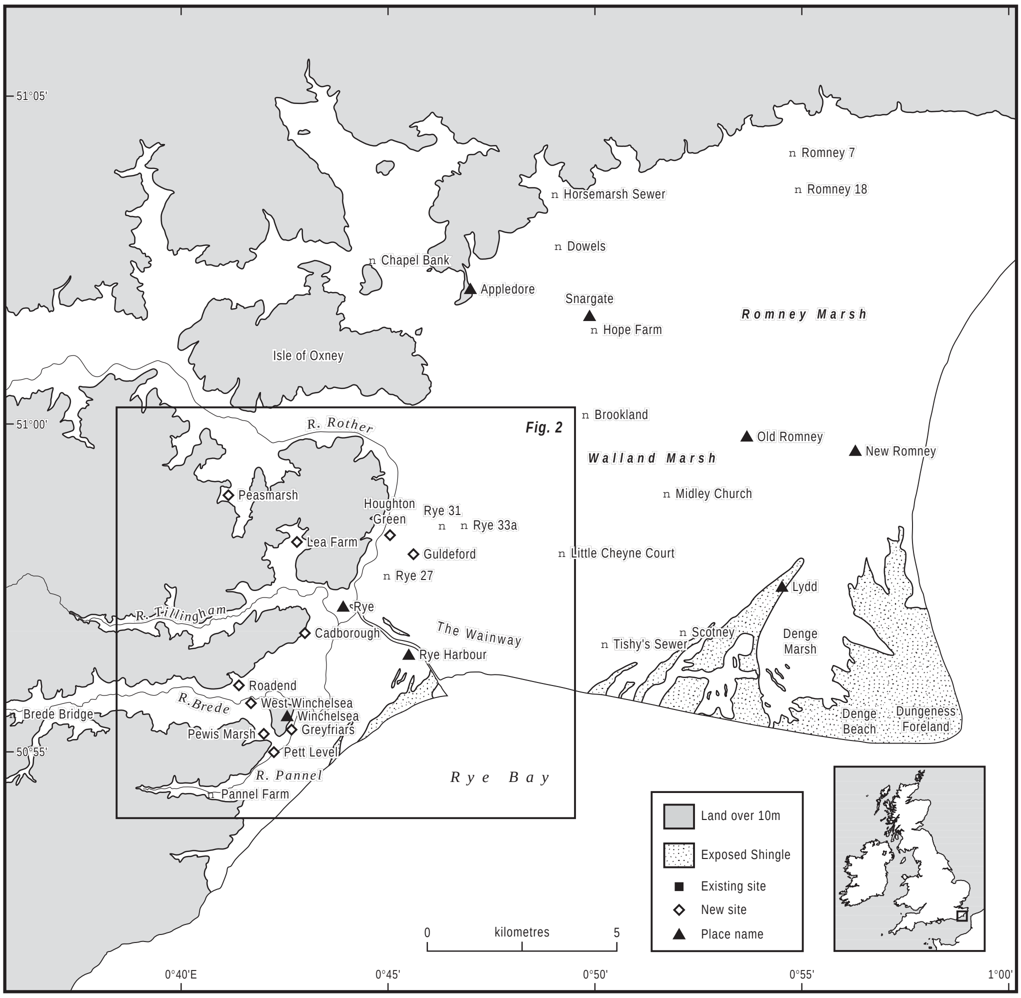


Fig. 1. Location map showing the Rye study area and the Romney Marsh depositional complex.

The main marsh peat began to form after c. 6000 cal. yr BP in the valleys that drain into the west of the study area. The rate of RSL rise slowed during the mid Holocene and at the same time the coastal barrier of Dungeness Foreland grew to provide protection for the freshwater peat-forming communities that expanded to reach their maximum extent c. 3200 cal. yr BP (Long, A. et al., 1998). The timing of the late Holocene inundation of the main marsh peat is difficult to establish. Long et al. (1998) suggest that the peat was inundated first on Romney Marsh, after c. 3200 cal. yr BP, with Walland Marsh being completely submerged by c. 1700 cal. yr BP. However, this chronology is not entirely reliable because ages from the surface of the peat do not necessarily date when deposition of the overlying clastic sediments occurred. The rate of vertical peat accumulation slowed significantly during the late Holocene and this largely caused the deposition of organic material to cease away from the raised bog, while the oxidation and erosion of the upper surface of the peat may have caused the loss of peat via wastage (Waller et al., 1988).

Long *et al.* Figure 2

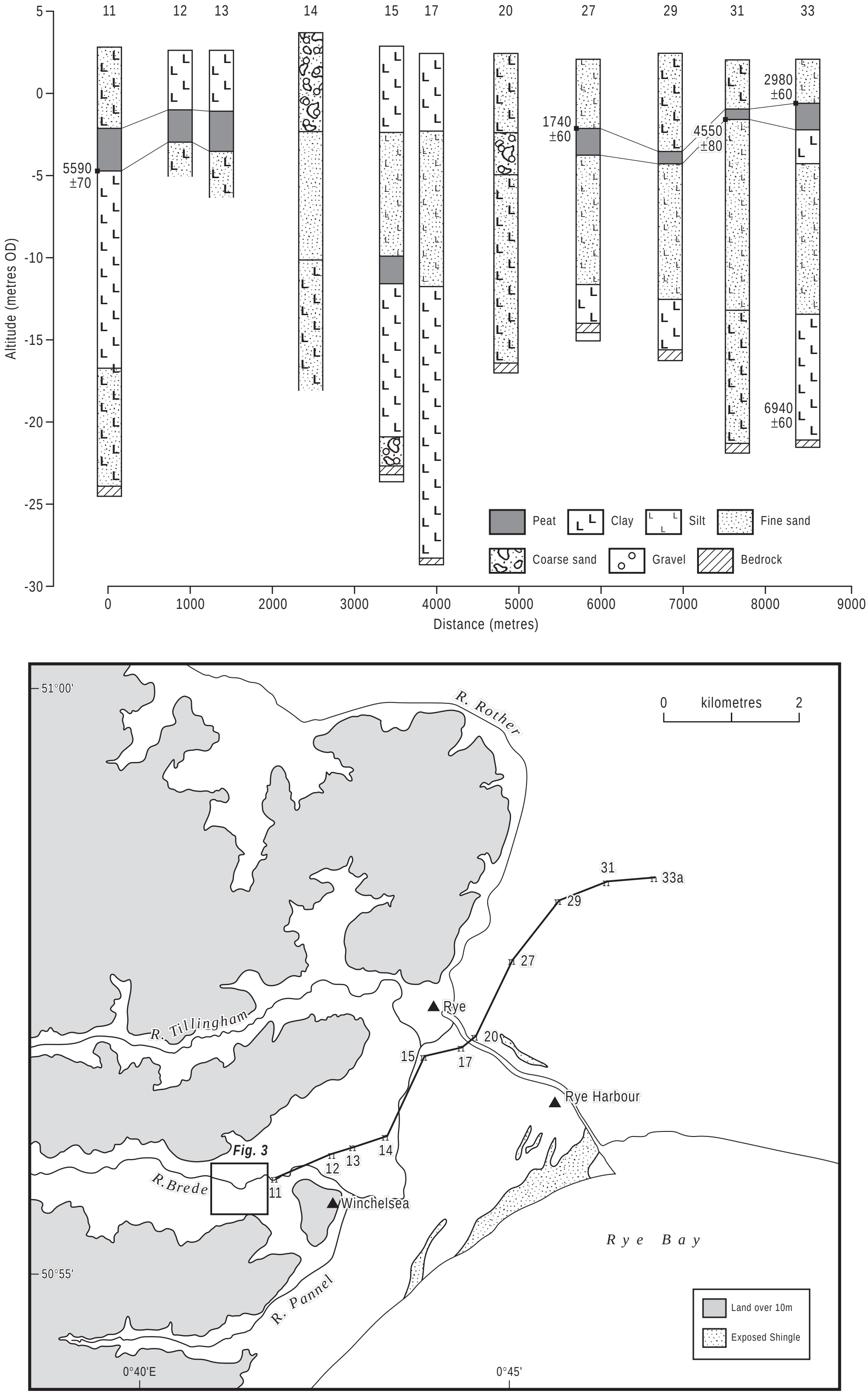


Fig. 2. Holocene stratigraphy at Rye. The main marsh peat occurs between c. 0 and _ 4 m OD. The peat has been eroded between core 14 and core 20, probably during breaching of the Rye barrier beach during the storms of the 13th century (from Long et al., 1996).

Historical records document a major change in coastal configuration that occurred in the medieval period, when a series of large storms in AD 1250, 1252, and particularly 1287 and 1288, breached the south coast near Rye (Eddison, 1998). This was accompanied by widespread erosion of the marsh sediments in the immediate vicinity of the initial breach, and the creation of two large tidal inlets known as the Wainway Channel and the Rother Estuary. The area flooded was extensive on Walland Marsh, reaching as far north as Appledore and a line of sea walls known as the "great cordon" (Eddison and Draper, 1997). Over time, this breach was healed by the regrowth of the sand and gravel beaches and the progressive reclamation of the former tidal channels and salt marshes during the 14^{th} to 16^{th} centuries (Gardiner, 1995; Eddison, 1998; Gardiner, 2002).

5. Methods

As part of a wider study into the Holocene history of the Rye area (Long et al., 2004; Waller and Schofield, in press; Waller et al., in press), we collected stratigraphic data from 10 field sites (Figure 1) using a hand-operated gouge auger, and retrieved sample cores with a "Russian" or mechanically operated piston corer. One site, West Winchelsea (core 3), was sampled for pollen, foraminifera, grain size, laminae counts and radiocarbon dating of the peat, with a duplicate core sampled for radiocarbon dating of plant macrofossils from Unit 2 (see below). Note that there are slight depth differences between the two cores, although the stratigraphy is identical. Our primary focus was on the nature of the upper levels of the peat and the overlying clastic sediments. Previously collected deep boreholes provide information regarding the overall sediment depth and composition (e.g. Figure 2). All cores were levelled to Ordnance Datum (OD = mean sea-level) using a level and staff.

Samples for grain size analysis were digested in H_2O_2 in a hot water bath for 2 to 4 hours and washed and centrifuged to remove the H_2O_2. We added 0.2 mg of an aqueous solution of sodium hexametaphosphate to help disperse the sample, which was examined using a Coulter LS 230 laser granulometer with polarization intensity differential scattering. Heterolithic tidal rhythmites comprise thin intercalated layers of sand and mud which may be wavy, flaser or lenticular bedded (Archer et al., 1995; Archer, 1998). Silty tidal rhythmites may develop where mud is dominant, comprising of thin, planar laminated silts, with clay drapes._In heterolithic tidal rhythmites it is the coarser, sandy layers which record the higher resolution record of tidal periodicities (Dalrymple et al., 1991). We measured the thickness of sand and mud laminations using a x40 binocular microscope, mounted over a moving stage controlled by a micrometer. Layer thickness was adjusted for linear compression before Fast Fourier Transform (FFT) spectral analysis and more straightforward graphical techniques were applied to the resultant time series, using SPSS and Excel, in an attempt to break down the complex cycles of layer thickness into their constituent sinusoids (e.g. Martino and Sanderson, 1993; Archer, 1994). Periodograms generated by the FFT were smoothed using a Tukey-Hamming window, with a span of five data points, to create spectral density plots.

Pollen analyses followed standard techniques and are described in Waller et al. (in press). Samples for foraminiferal analysis were wet-sieved at 63μ and examined under a binocular microscope. Foraminiferal identification and classification follows that of Murray (1971, 1979) and Loeblich and Tappan (1988). The microfossil data are plotted using the *Tilia* and *Tilia* Graph* packages, with cluster analysis performed using the CONISS package (Grimm, 1987, 1993). Radiocarbon dates (Table 1) include both bulk and AMS analyses.

6. Results

Of the new field sites studied, we select West Winchelsea for detailed analysis in this paper. This is because the site stratigraphy is the most complete and is representative of sediments across much of the Rye area. West Winchselsea is located on the valley floor of the Brede valley, approximately 1 km west of the town of Winchelsea (Figure 3).

6.1 Lithostratigraphy

The stratigraphy at West Winchelsea defines the margin of a former tidal channel, with peat preserved to the south of the study site and thick sequences of laminated channel sediments towards the north._The "main marsh peat" is restricted to cores 7, 5 and 3 (Figure 3). We only recovered the upper 38 cm of this deposit, although previous cores show the peat to be between 2 and 3 m thick in the West Winchelsea area (Waller et al., 1988; Long et al., 1996). Elsewhere, coarse tidal channel sands fine upwards into a well laminated sand silt, which passes (above c. 1 m OD) into an iron-stained silt clay that extends to the present surface. Where peat is present we defined four main lithostratigraphic units in the field:

Table 1.
Radiocarbon dates from transgressive and regressive contacts of mid and late Holocene age in the Rye area and the Romney Marsh depositional complex. Dates are calibrated using the intercept method and bi-decadal dataset of Stuiver et al. (1998). Where two laboratory codes are given, the humin and humic acid fractions were dated separately, the results presented here being the pooled mean.

Site	Laboratory code	Radiocarbon age ± 1σ	Calibrated age range (2σ range)	Altitude (m OD)	Transgressive (T) or regressive (R) contact	Source	Dated material
Broomhill Church	Q-2753	2160 ± 50	2003-2312	1.34	R	Tooley and Switsur (1988)	Sandy silty limus
Broomhill Church	Q-2752	2600 ± 50	2489-2845	1.14	R	Tooley and Switsur (1988)	Laminated silty limus
Horsemarsh Sewer	Q-2647	5500 ± 70	6003-6444	-3.42	R	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Brede Bridge	SRR-2646	5970 ± 150	6450-7208	-5.35	R	Waller (1994b)	Humified peat
Horsemarsh Sewer	Q-2648	5150 ± 70	5720-6168	-3.33	R	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Tishy's Sewer	Q-2649	3520 ± 60	3638-3964	1.2	R	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Tishy's Sewer	Q-2561	3410 ± 60	3478-3828	0.8	R	Tooley and Switsur (1988)	Limus with gravel
Midley Church	UB-3852	3673 ± 82	3726-4243	0.28	R	Long and Innes (1993)	Humified peat
Midley Church	UB-3854	3054 ± 58	3077-3382	0.73	R	Long and Innes (1993)	Humified peat
Brookland	UB-3730	4367 ± 39	4847-5041	-1.01	R	Long and Innes (1995)	Well humified peat

Site	Laboratory code	Radiocarbon age ± 1σ	Calibrated age range (2σ range)	Altitude (m OD)	Transgressive (T) or regressive (R) contact	Source	Dated material
Rye 11	BETA-75451	5590 ± 70	6204-6532	-4.64	R	Long et al. (1996)	Humified peat with some *Phragmites*
Rye 31	BETA-65453	4550 ± 80	4883-5466	-0.98	R	Long et al. (1996)	Organic sand with some silt and detrital wood
Horsemarsh Sewer 2	BETA-87700	5890 ± 110	6413-6986	-2.92	R	Waller et al. (1999)	Dark brown detrital peat
The Dowels	SRR-5622	4970 ± 50	5598-5887	-2.29	R	Waller et al. (1999)	Detrital wood-rich peat
Hope Farm	SRR-5618	4485 ± 45	4972-5302	-1.65	R	Waller et al. (1999)	Dark brown detrital peat
Little Cheyne Court	SRR-5614	4410 ± 45	4860-5277	-1.3	R	Waller et al. (1999)	Black highly humified peat
Romney 7	BETA-109576	4070 ± 70	4415-4823	-0.55	R	Long, A. et al. (1998)	Humified peat with some clay
Romney 18	BETA-109579	3250 ± 100	3213-3715	-0.14	R	Long, A. et al. (1998)	Humified wood peat
Scotney	BETA-81363	3020 ± 70	2996-3376	-2.28	R	Spencer and Woodland (2002)	Humified peat
Scotney AY17	BETA-81365	3010 ± 60	3000-3355	0.57	R	Spencer and Woodland (2002)	Humified peat
Scotney AB27	BETA-81367	2610 ± 60	2471-3852	1.01	R	Spencer and Woodland (2002)	Humified peat

Site	Laboratory code	Radiocarbon age ± 1σ	Calibrated age range (2σ range)	Altitude (m OD)	Transgressive (T) or regressive (R) contact	Source	Dated material
Scotney AW63	BETA-81368	3410 ± 40	3490-3825	0.05	R	Spencer and Woodland (2002)	Brown clayey peat
Scotney AW63	BETA-81369	2950 ± 60	2930-3323	0.66	R	Spencer and Woodland (2002)	Humified peat
Scotney	BETA-81370	3580 ± 60	3694-4077	0.21	R	Spencer and Woodland (2002)	Humified peat
Scotney AW-AX67	BETA-81371	2850 ± 60	2787-3160	0.85	R	Spencer and Woodland (2002)	Humified peat
Allen's Bank, Lydd	BETA-170764	2040 ± 40	1898-2115	0.61	R	Plater and Turner (2002)	Humified peat
Brede Bridge	SRR-2645	3690 ± 70	3833-4236	0.4	T	Waller (1994b)	Clay-rich humified peat
Rye 33a	BETA-754354	2980 ± 60	2967-3335	-0.25	T	Long et al. (1996)	Humified peat with some roots and detrial wood
Rye 27	BETA-75452	1740 ± 60	1531-1816	-1.98	T	Long et al. (1996)	Humified peat
Chapel Bank	BETA-87707	3390 ± 70	3470-3827	-0.03	T	Long, D. et al. (1998)	Well humified peat
Tishy's Sewer	Q-2652	3160 ± 60	3211-3548	0.9	T	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Tishy's Sewer	Q-2650	3060 ± 60	3077-3435	1.4	T	Tooley and Switsur (1988)	Silty limus with detetrital plant remains
Midley Church	UB-3851	2249 ± 48	2149-2346	0.8	T	Long and Innes (1993)	Humified peat

Site	Laboratory code	Radiocarbon age ± 1σ	Calibrated age range (2σ range)	Altitude (m OD)	Transgressive (T) or regressive (R) contact	Source	Dated material
Midley Church	UB-3583	2762 ± 49	2762-2954	0.63	T	Long and Innes (1993)	Humified peat
Brookland	UB-3731	1846 ± 51	1627-1917	0.09	T	Long and Innes (1995)	Well humified peat with *Phragmites*
Horsemarsh Sewer 2	BETA-87704	3060 ± 80	3000-3348	0.09	T	Waller et al. (1999)	Dark brown detrital peat with wood.
The Dowels	SRR-5619	2355 ± 45	2183-2707	-0.09	T	Waller et al. (1999)	
Hope Farm	SRR-5615	1850 ± 45	1631-1883	-0.51	T	Waller et al. (1999)	Dark brown peat with silt inclusions
Little Cheyne Court	SRR-5611	1050 ± 45	799-1060	0.3	T	Waller et al. (1999)	Humified moss peat
Romney 7	BETA-109578	2290 ± 60	2123-2464	0.18	T	Long, A. et al. (1998)	Clay-rich humified peat
Romney 18	BETA-109581	2910 ± 70	2865-3316	0.27	T	Long, A. et al. (1998)	Well humified peat with roots
Scotney G60	BETA-81364	3050 ± 60	3074-3388	-2.185	T	Spencer and Woodland (2002)	Humified peat
Scotney AY17	BETA-81366	2380 ± 60	2212-2711	0.77	T	Spencer and Woodland (2002)	Humified peat
Scotney Q32	BETA-157460	1730 ± 70	1422-1856	1.39	T	Spencer and Woodland (2002)	Humified peat
Scotney AW-AX67	BETA-81372	2690 ± 80*	2498-2997	0.94	T	Spencer and Woodland	Humified peat

Site	Laboratory code	Radiocarbon age ± 1σ	Calibrated age range (2σ range)	Altitude (m OD)	Transgressive (T) or regressive (R) contact	Source	Dated material
Allen's Bank, Lydd	BETA-170763	1990 ± 40	1828-2039	0.69	T	Plater and Turner (2002)	Well humified silty peat
Old Place	SRR-2893	1830 ± 80	1558-1926	-1.165	T	Waller (1998)	Humified peat
Pannel Farm	GrN-28586/ GrN-28587	1654 ± 45	1418-1691	1.365	T	This study	Organic-rich silt
Pewis Marsh	GrN-27875/ GrN-27910	1842 ± 30	1707-1867	-0.725	T	This study	Organic-rich silty clay
Greyfriars	GrN-28101/ GrA-24065	2837 ± 28	2853-3059	-0.57	T	This study	Well humified Peat
Pett Level	GrN-27875/ GrN-28108	1895 ± 51	1710-1947	-0.47	T	This study	Organic-rich silty Clay
Cadborough	GrN-28105	2480 ± 60	2360-2730	-1.02	T	This study	Well humified peat
East Guldeford	GrN-28104	1240 ± 50	1056-1283	-0.72	T	This study	Well humified peat
Roadend	GrN-28106	2860 ± 60	2793-3205	0.12	T	This study	Well humified peat
West Winchelsea	GrN-28734/ GrN-28735	1348 ± 27	1186-1307	-2.01	T	This study	Well humified Peat

Dates are calibrated using the intercept method and bi-decadal dataset of Stuiver et al. (1998). Where two laboratory codes are given, the humin and humic acid fractions were dated separately, the results presented here being the pooled mean.

Unit 1 (peat): Unit 1 is a dark brown, compact and well-humified deposit with some woody detritus and fine rootlets. The upper contact of the peat varies between -1.84 and -2.29 m OD and is generally sharp, but not obviously erosive.

Unit 2 (clay/silt): Above the peat is a grey clay-silt that contains abundant remains of *in situ* plant roots. This unit is thickest in core 3 (c. 1.80 m) and thinnest in core 7 (c. 0.10 m).

Unit 3 (laminated sands and silts): This is a thick deposit (c. 1 to 3 m) of grey, well-laminated sands and silts. In boreholes closest to the Brede, where Units 1 and 2 are missing, these sediments are black and water saturated below c. -2.50 m OD.

Unit 4 (iron-stained silt clay): The uppermost unit in most cores, above c. 1.10 m OD, is a silt clay that is weakly laminated and contains rare rootlets. The unit is orange-brown in colour due to the presence of iron-staining.

6.2 Pollen analysis

Samples for pollen were taken from the uppermost levels of the peat and the immediately overlying organic clay (Units 1 and 2 from core 3) (Figure 4). Three local pollen assemblage zones are identified (Table 2)

6.3 Foraminiferal analysis

Samples for foraminiferal analysis were collected from Units 2, 3 and 4 from core 3.

CONISS defines six assemblage zones within the sample core (Figure 5, Table 3).

Long *et al.* Figure 3

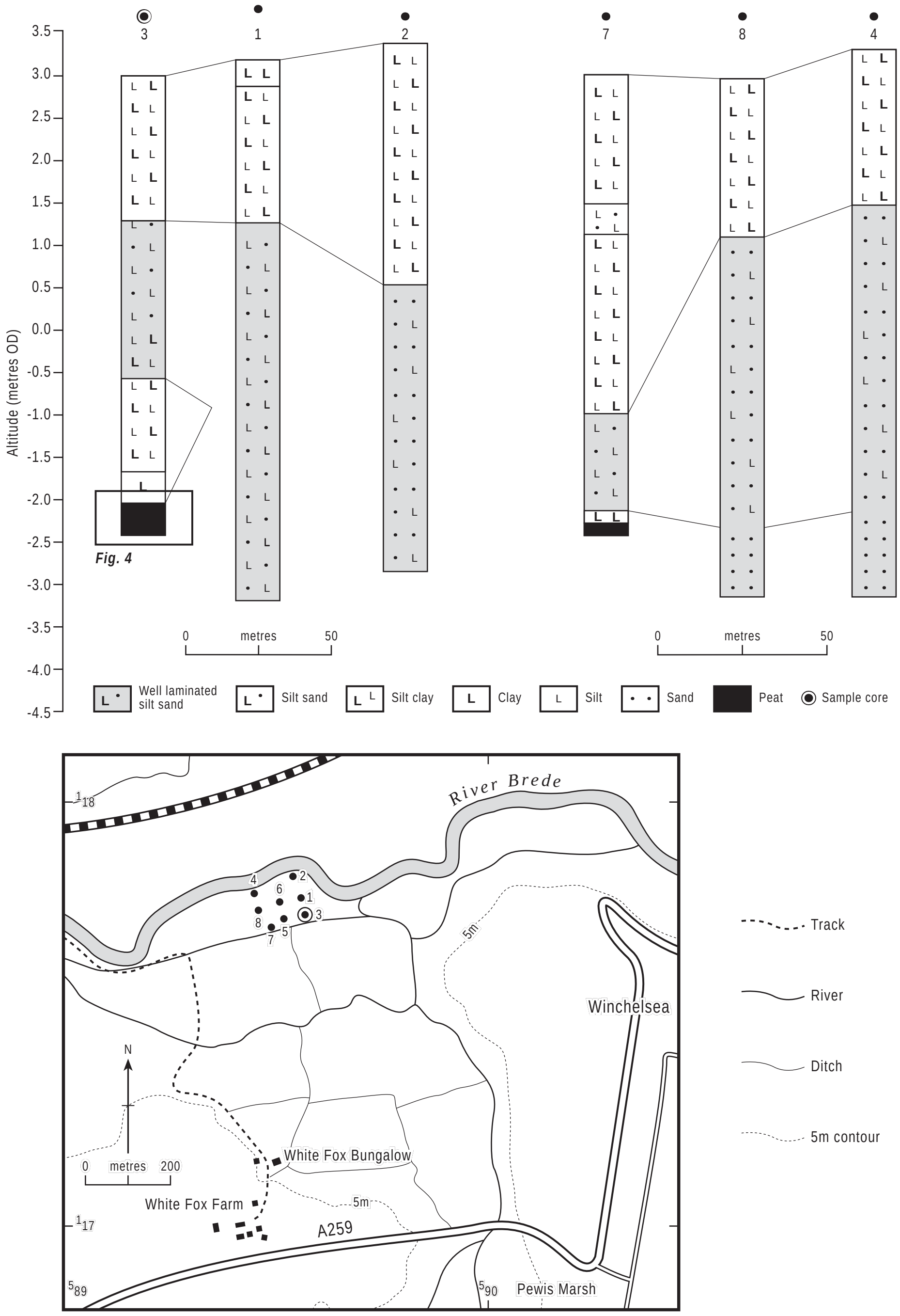


Fig. 3. Lithostratigraphy recorded at the West Winchelsea sample site.

6.4 Particle size analysis

Two hundred and twenty-seven samples were analysed for their grain size characteristics. Three textural zones (Table 3) can be identified from the mean particle size data (Figure 6a), modal particle size (not shown) and the percentage sand-silt-clay plot (Figure 6b). These zones do not coincide with the lithologic boundaries defined in the field (Section 6.1 above). This is because of the general homogeneity of the sediment (a sandy mud) which undergoes continuous and subtle changes up-core. It also reflects the fact that field logging was influenced largely by changes in the character of the laminations – particularly frequency and thickness - rather than any marked change in texture.

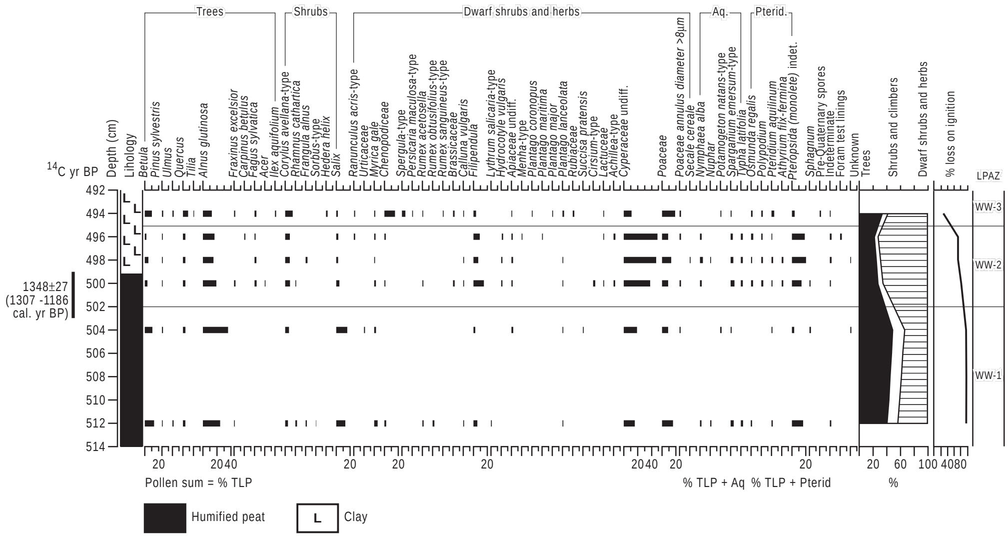


Fig. 4. Pollen diagram from the upper levels of the peat at West Winchelsea. The radiocarbon date is a pooled mean of two dates (see text for details and Table 1).

Mean particle size data (Figure 6a) record a clear, high frequency cyclicity, especially in textual zone 2. But the sand-silt-clay plot shows how, even in this coarser zone, regular phases of mud dominated sedimentation occurred (Figure 6b). Selected particle size frequency distributions identify the typically bi- or tri-modal character of the sediments. These are indicative of the amalgamation of several mm scale sand-mud couplets in each sample. The distributions confirm the cyclical, nested character of the deposits which are best defined by a suite of curves bounded by relatively coarse and fine end- members rather than a single sample statistic such as mean or mode.

6.5 Laminae thickness

Laminated sands and muds occur in the sample core between –1.97 and +1.74 m OD. Around 65% of the sequence, which comprises 350 sand/mud couplets, is classified as mud with an average layer thickness of 3.17 mm. The sand layers are thinner and have an average thickness of 1.79 mm.

Table 2. Pollen assemblage zones from West Winchelsea

Zone (core depth cm)	**Characteristics**
WW-3 (above 495 cm)	Herbaceous pollen forms >50% TLP, with Poaceae, Chenopodiaceae, Cyperaceae and *Spergula*-type the main taxa.
WW-2 (502-495 cm)	Herbaceous pollen (particularly Cyperaceae) dominates. Minor taxa include both freshwater (e.g. *Filipendula*, *Hydrocotyle vulgaris* and brackish (e.g. Chenopodiaceae, *Plantago maritima*) indicators.
WW-1 (512-502 cm)	A mixture of arboreal (notably *Alnus glutinosa*, *Betula* and *Salix*) and herbaceous pollen (Cyperaceae and Poaceae).

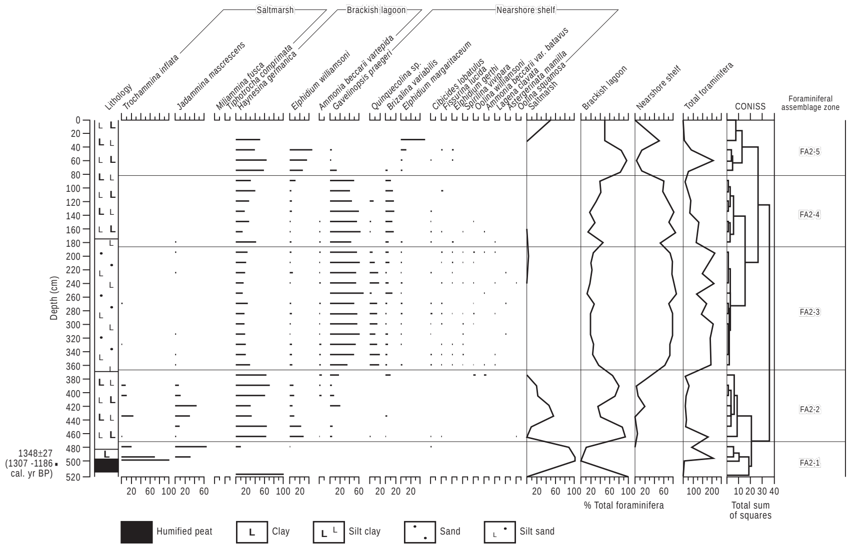


Fig. 5. Foraminiferal diagram from West Winchelsea.

Despite the somewhat noisy appearance of the raw data, plotting on a log scale and selecting discrete sections for analysis show that two relatively well developed high frequency cycles are preserved in the sequence (Figure 7a). Thicker sand layers seem to repeat every few layers, but more prominently every 7-10 layers or so. A three point moving average highlights the slightly longer wavelength periodicities and provides a good indication of the changing character of the signal through the core (Figure 7b). At depth the longer 7-10 layer cycles dominate with the 3-5 layer period appearing to be very much subordinate e.g. layers 140-160. However, in the upper half of the sequence a more consistent, higher resolution record is preserved. Thus, from around layer 240 the 3-5 layer cycle is more pronounced and is nested within the distinct alternation of relatively higher and lower peaks that corresponds to the longer 7-10 layer periods (Figures 7a, b). The unusually thick layers around 271 and 281 are disturbed and almost certainly were originally deposited as several thin laminae. The clarity of the signal degrades towards the top of the sequence.

The spectral density plot (Figure 7c) identifies three broadly defined high frequency cycles with wavelengths of 3-5, 7-9 and 10-12 layers/cycle respectively. Two longer period harmonics (not shown) are also recorded as broad (± 8-10 layers) peaks centred on 26 and 50 layers/cycle. Some sense of these long wavelength cycles is evident in Figure 7b, but is most clearly demonstrated by smoothing out the higher order cycles with a seven point moving average (Figure 7d).

6.6 Radiocarbon chronology

Four radiocarbon dates were collected from the upper peat contact and the immediately overlying sediment in core 3. The lower pair of dates from the main sample core are on the humin and humic fractions from a bulk sample of well-humified peat (GrN-28734, 1360 ± 60 BP and GrN-28735, 1300 ± 60 BP respectively, pooled mean age 1348 ± 27 BP (1307-1186 cal. yr BP)). Replicate samples on fine root material in Unit 2, extracted by sieving bulk samples between -1.82 and -1.92 m OD from a duplicate sample core (core depths 492 to 482 cm), yielded similar ages (GrA-25302, 1170 ± 35 BP and OxA-13460, 1297 ± 100 BP, pooled mean age 1248 ± 22 BP (1263-1085 cal. yr BP)).

Table 3. Foraminiferal assemblage zones from West Winchelsea

Zone (core depth cm)	**Characteristics**
5 (85-0 cm)	Dominated by the brackish lagoon species *Haynesina germanica* and *Elphidium williamsoni*. Above 45 cm, only two species and a total of six foraminifera. Little palaeoenvironmental significance.
4 (185-85 cm)	*Gavelinopsis praegeri* is the dominant species, but the overall species diversity is much lower that in Zone 3. *Brizalina variabilis* occurs in higher numbers.
3 (365-185 cm)	A range of species dominated by nearshore shelf types, notably *Gavelinopsis praegeri*. The highest and most consistent number of total foraminifera found in the sample core occur in this zone.
2 (470-365 cm)	Brackish water lagoon taxa dominate, particularly *Haynesina germanica*, with low numbers of saltmarsh and nearshore shelf foraminifera.
1 (495-470 cm)	Low frequencies of the saltmarsh taxa *Trochammina inflata* and *Jadammina macrescens*.

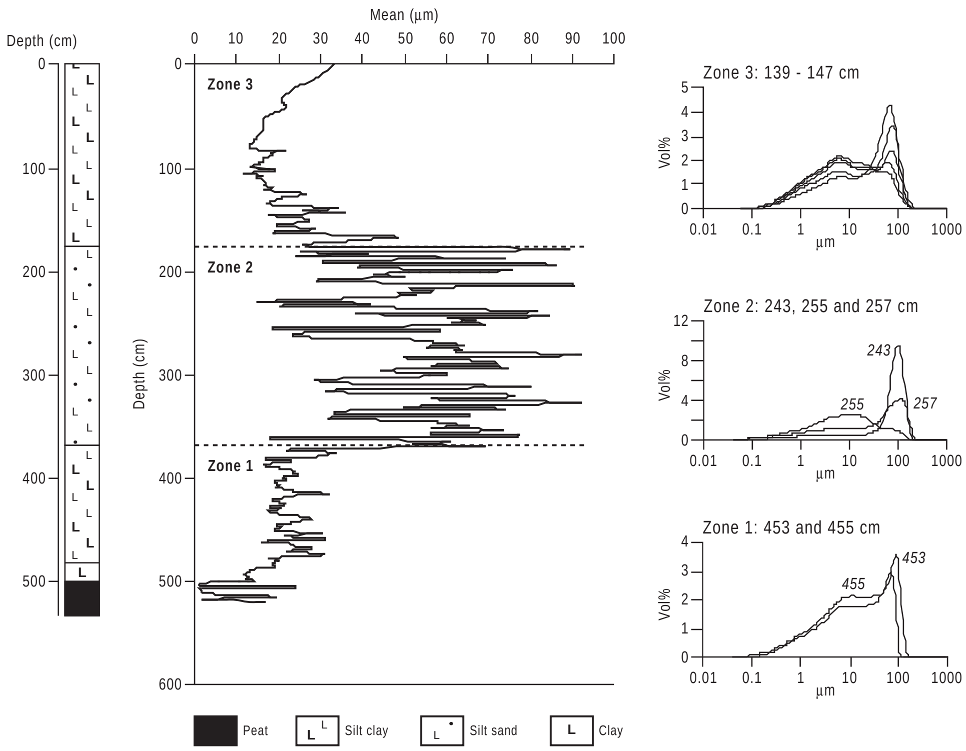
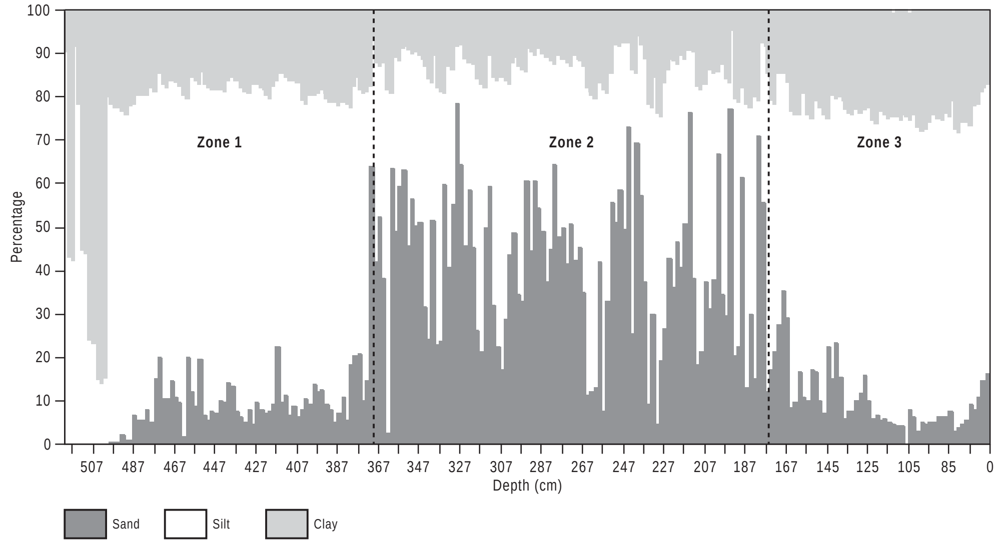


Fig. 6. (a) Mean particle size profile, simplified lithostratigraphy and representative particle size frequency distributions from the three textural zones identified in the West Winchelsea sample core.



6 (b) Percentage sand/silt/clay plot from the West Winchelsea sample core.

Long *et al.* Figure 7a

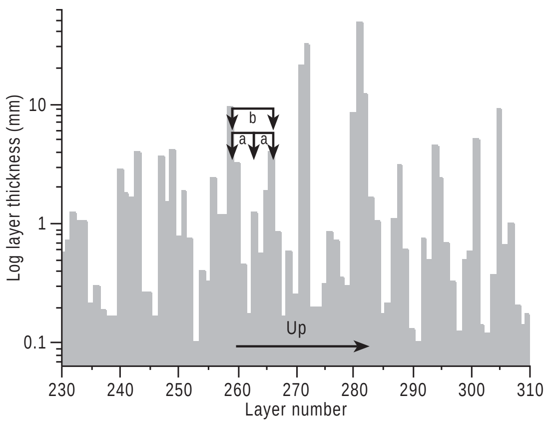
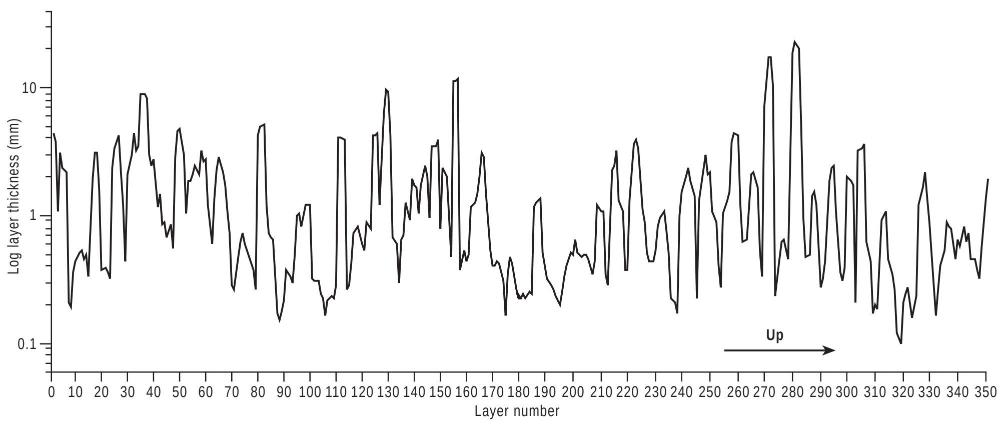
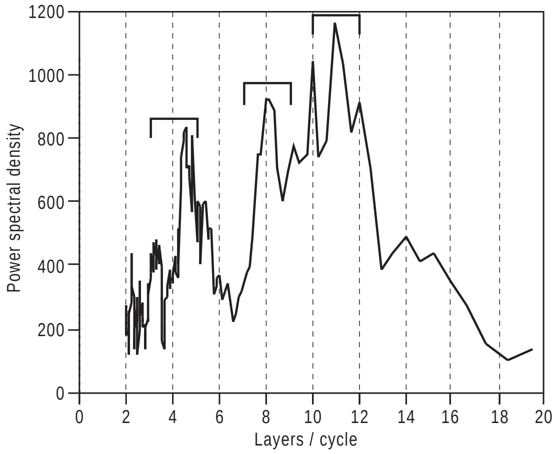


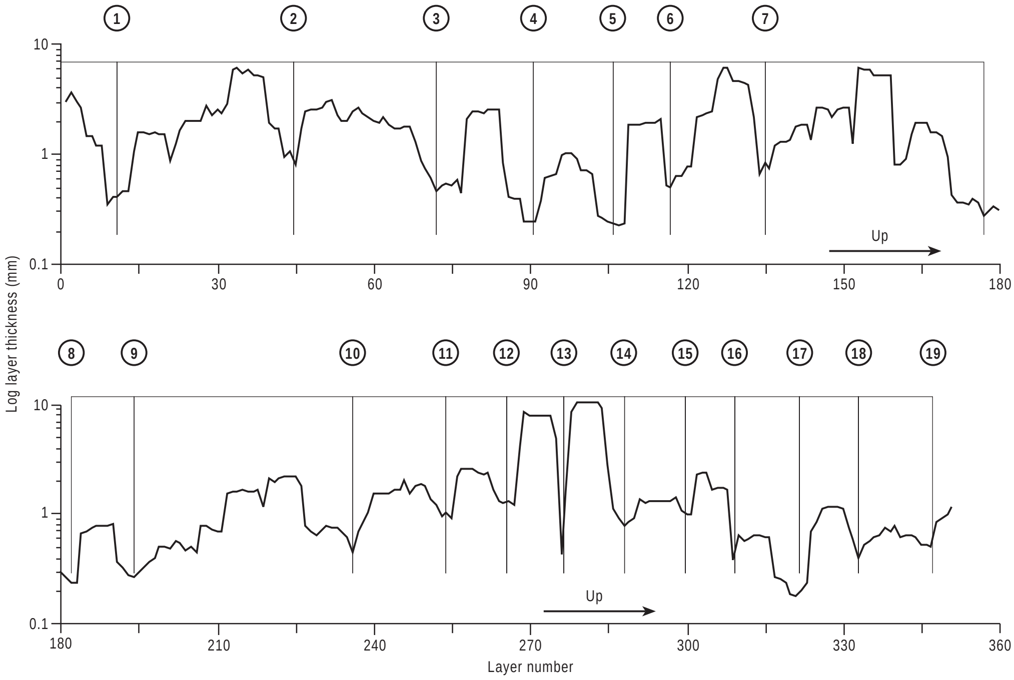
Fig. 7. (a) Short sequence of sand layer thickness data from the West Winchelsea sample core with preservation of nested high frequency cycles highlighted (a=3–5 layers/cycle; b=7–9 layers/ cycle).



7 (b) Smoothed (three point moving average) plot of sand layer thickness for the whole sequence from West Winchelsea sample core. Note the three broadly defined high frequency wavelengths of 3–5, 7–9 and 10–12 layers/cycle respectively.



7 (c) Spectral density plot of high frequency cycles in sand layer thickness from the West Winchelsea sample core.



7 (d) Smoothed (seven point moving average) plot of sand layer thickness with estimated position of twice yearly equinoctial peaks marked from the West Winchelsea sample core.

7. Interpretation

7.1 Changing palaeoenvironments at West Winchelsea

Pollen preserved in the top of the peat at West Winchelsea indicate that a fen carr environment with alder (LPAZ WW-1, Figure 4) was initially replaced by a transitional fresh / brackish water sedge dominated community (LPAZ WW-2). The high Chenopodiaceae and *Spergula*-type frequencies above 495 cm (LPAZ WW-3) record the development of salt marsh. The occurrence of low frequencies of foraminifera that occur today on salt marshes indicates that such conditions prevailed immediately above the peat (LFAZ 1). Sedimentation across the end of peat accumulation and into the overlying salt marsh sediments appears continuous. Above 470 cm a more mixed foraminiferal assemblage occurs that contains salt marsh and brackish lagoon taxa (Figure 5, Table 3). Rootlets preserved throughout this sediment (Unit 2) indicate that water depths were sufficiently shallow for the continued *in situ* growth of halophytes and for this reason we interpret this sediment as of lower salt marsh origin. The radiocarbon dates show that the initial inundation of the peat surface by tidal waters occurred after c. 1307-1186 cal. yr BP. The pooled ^{14}C data from the roots in Unit 2 of 1263-1085 cal. yr BP confirm continuous sedimentation during this interval.

An important change in environment is recorded above 367 cm by foraminiferal and grain size data. Most obvious is a decline over 10 to 20 cm of the salt marsh / brackish lagoon taxa and an increase in those from nearshore shelf environments, especially *Gavelinopsis praegeri*, *Quinquecolina sp.* and *Brizalina variabilis*. A range of other minor taxa indicative of nearshore shelf also increases. This change in assemblage records a shift to more strongly marine conditions. The grain size data (Figure 6a, b, Table 4) record this change in environment by a coarsening of the sediment and a change from a fine silt to a well-laminated sandy mud / muddy sand. These changes in stratigraphy may record some erosion at the boundary between Unit 2 and 3. Laminae counts through Unit 3 provide information regarding the process responsible for deposition of these sediments, water depth, as well as duration of sedimentation.

The repetitive thickening and thinning of the sand layers in this unit, forming a long sequence of nested sinusoids of increasing wavelength, is strongly indicative of a tidal control on deposition (Kvale and Archer, 1991; Kvale et al., 1994, 1999). We interpret the higher frequency cycles of layer thickness as representing deposition over the neap-spring and lunar month respectively. The fact that the wavelengths of these cycles are not precisely defined on the spectral density plot (Figure 7c) can be attributed to the natural variation within the system. The apparent dominance of the lunar monthly cycles, particularly in the smoothed data (Figure 7b), agrees with previous modelling of truncated rhythmite sequences whereby the fortnightly inequality becomes more pronounced as the number of layers preserved declines (Archer and Johnson, 1997). As position in the tidal frame is a key control on the number of layers preserved, this site must have been in a relatively elevated (i.e. shallow) position.

The number of layers recorded in each cycle does not match the theoretical number of tides in any given period. This implies that conditions suitable for the preservation of distinct sand and mud laminae were restricted to just a few tides, focussed on the highest spring tides, during any neap-spring cycle. Particularly energetic tides may lead to the amalgamation of successive sand layers due to erosion of the intervening muddy layer. At other times in the tidal cycle, such as the low solsticial tides, deposition either did not take place at all or was restricted to the accumulation of mud, the net result being the low number of layers preserved. This pattern is reflected in the textural data (Figure 6b).

The most favoured conditions for rhythmite deposition - thicker layers and a higher resolution signal - probably coincided with the biannual equinoctial peak in tidal energy. The seven point smoothing of the layer thickness data highlights these equinoctial peaks in sand layer thickness (Figure 7d) with wavelengths of between 10 and 46 layers in each equinoctial bundle. We can use this pattern to estimate accumulation rates. Figure 7d contains approximately 18-19 equinoctial peaks, around nine years, which equates to a deposition rate for this 1.75 m long sequence of 0.2 m/y. This is perhaps higher than would previously have been anticipated from a sheltered back-barrier environment but is in accordance with other tidal rhythmite sequences both on Romney Marsh (Stupples, 2002) and elsewhere (e.g. Dalrymple et al., 1991; Archer, 1991; Kvale and Archer, 1991; Martino and Sanderson, 1993; Tessier et al., 1995).

Table 4. Grain size zones from West Winchelsea core

Zone (core depth cm)	**Characteristics**
Zone 3 (175-0 cm)	A sandy mud or mud, with a mean grain size comprising fine to medium silt. Typically sand (10%), silt (70%) and clay (20%). Very poorly sorted. Mean grain size 5-10µ.
Zone 2 (369-175 cm)	A sandy mud to muddy sand, with a mean grain size comprising medium to coarse silt. Typically sand (50%), silt (40%) and clay (10%). Poorly to very poorly sorted. Seven packages (A-G) of coarser and finer sediments (0.10 to 0.30 m thick). Mean grain size 10-60µ.
Zone 1 (519-369 cm)	A mud, with a mean grain size comprising fine to medium silt. Typically sand (10%), silt (70%) and clay (20%).

	Poorly sorted. Several of the lowermost samples are very clay-rich. Mean grain size 5-15μ.

Alternative, non-tidal, driving mechanisms for laminated sequences must also be considered. These include the potential for misinterpretation of statistical data (e.g. Tessier, 1998) and the possibility of a tidal signature being disturbed by a secondary physical or biological process (e.g. Dalrymple et al., 1991). Here, the clearly nested character of the high frequency signal, textural evidence which supports both the high frequency variability and the longer period cyclicity, and the consistency of the signal through nearly 2 m of sediment, provide confidence in our interpretation of rapid deposition in a tide dominated setting. Physical and/or biological reworking is evident along the sequence, but in the section analysed here, is not intense enough to destroy the sedimentary structure. The possible importance of storm action on Romney Marsh has been mentioned elsewhere (Allen, 2004) and its impact on this sequence cannot be discounted (e.g. layers 271 and 281), but it has not been sufficient to disrupt the regularly sinusoidal tidal signal. Similarly, seasonal fluxes in sediment supply, if present, could only obscure the tidal signal if the availability of sediment was, at times, restricted such that distinct laminations could not form (e.g. Dark and Allen, 2005). Alternatively, such seasonal variations may simply enhance the effect of the winter equinox on rhythmite preservation.

The change from Unit 3 to 4 records a decline in energy conditions as water depths shallowed and salinity decreased. We suggest that these changes record land reclamation in the lower Brede that is documented in historical records from 1302 AD. Although the valley was subjected to repeated flooding during the 14th century, it was largely reclaimed from the sea by 1460 AD (Gardiner, 1995). The foraminifera suggest that open marine conditions persisted during the initial phase of lower energy conditions. Above 75 cm there is an increase in the frequencies of the brackish lagoon species, *Haynesina germanica* and *Elphidium williamsoni* (Figure 5), although low counts above 40 cm make palaeoenvironmental interpretations difficult.

7.2 Peat compaction and the provision of accommodation space at West Winchelsea

The West Winchelsea core preserves evidence for a rapid increase in water depth and the accumulation of 4.8 m of minerogenic sediments in at most a few hundred years. We can discount a rapid rise in relative sea level as the cause for this change, given what we know about regional and global trends in ocean volume and crustal motions during the late Holocene (Waller and Long, 2002). Erosion of the salt marsh sediments (Unit 2) from the sample site may have provided some accommodation space – we note, for example, that this unit is thin in core 7 (Fig. 3) and that the change in grain-size data between Unit 2 and 3 is quite abrupt. However, we also observe that the foraminiferal data show a continuous and not abrupt change in palaeoenvironment between Unit 2 and 3. Moreover, even if limited erosion had occurred at the boundary between Unit 2 and 3, this would not alter the main conclusion of this study that significant compaction of the peat bed at West Winchelsea occurred in a geologically short period of time and caused significant landscape change.

Analogues from the geological record, and from the coastal plain of northwest Europe, provide a working hypothesis to explain the West Winchelsea sequence. In a study of the tidal mudflat deposits that overlie the Pennsylvanian coal measures in the eastern part of the Illionois Basin, USA, Kvale and Mastalerz (1998) suggest that the transgression of the Lower Block Coal peat was initiated by the rapid collapse of the peat surface. They propose that these ancient wetlands were destroyed following initial saline flooding that killed the marsh plants. Subsequent penetration of tidal creeks into the former marshland and an associated increase in tidal prism was accompanied by autocompaction of the peat, the sudden creation of accommodation space and the rapid deposition of thick sequences of tidal rhythmites above the peat surface. Rapidly accumulating sediments buried upright stumps of pteridosperms, calamites and occasional *Lepidodendron wortheni* greater than 4 m tall.

Elements of this model have also been independently invoked to explain the late Holocene inundation of peat on the Belgium coastal plain. Thus, Baeteman et al. (2002) suggest that after c. 3400 cal. yr BP a peat bed began to be locally eroded by channels. Tidal water only partly flooded the peat at first, and a veneer of sediment accumulated on the peat surface. These channels lowered the surface by drainage and promoted peat collapse. Initially, the majority of sedimentation occurred in the main tidal channels but, once these channels were full of sediment, a more extensive phase of lateral sediment accretion occurred across the peat surface. This second phase saw widespread erosion of the peat surface and the recently deposited overlying salt marsh and mudflat sediments. Baeteman et al. (2002) and Baeteman (in press) suggest that compaction of the peat provided the increase in accommodation space required to drive channel activity during this phase.

Our West Winchelsea record suggests elements of each of these models. The litho-, bio- and chronostratigraphic data indicate that the initial inundation of the peat at the site of the sample core was gradual and accompanied by the development of salt marsh conditions. In contrast to the Baeteman et al. (2002) record, there appears to have been a reasonable supply of fine-grained sediment to form the salt marsh sediment that accumulated directly on the peat surface in the first few centuries following tidal inundation.

The increase in water depth over the sample site above 369 cm reflects enhanced provision of accommodation space and the lateral expansion of tidal channel conditions across the West Winchelsea study site. We hypothesise that this change corresponds to the well-documented breach of the Rye barrier in the 13th century. The associated increase in tidal range, caused as the back-barrier tidal prism enlarged further, de-watered the peat via creek drainage (c.f. Baeteman et al., 2002). Once initiated, a strong positive feedback cycle developed in which dewatering promoted compaction and lowering of the peat surface which, in turn, caused an increase in flooding frequency and accelerated loading and compaction by sediment and tidal water. The increase in accommodation space provided the ideal conditions for the accumulation of the tidal rhythmites observed in the West Winchelsea sample core. As the accumulation of sediment progressed, so the sediment fined upwards and preservation of higher resolution tidal cycles increased. Finally, a progressive decrease in flooding frequency was accompanied by a reduction in accommodation space and tidal energy as a prelude to reclamation.

There is independent dating evidence to support this model. At a site on the edge of Pett Level (Figure 1) the peat is overlain by a slope-wash deposit c. 50 cm thick, which in turn is buried by 3 m of partially laminated sands and silts. Deposition of the slope-wash deposit appears to have ceased towards the end of the Roman period, and radiocarbon dates on the humin and humic fraction from the top of this deposit date yield a pooled mean age of 1895 ± 51 (1947-1710 cal. yr BP) (Waller et al., in press). However, at some locations the slope wash deposit is highly heterogeneous and contains peaty pockets. Two pottery sherds were recovered *in situ* from this sediment in adjacent boreholes and date from the 12th to mid 13th century and mid 13th to 14th century (Barber, *pers. comm*.). The evidence for the disturbance of the peat, combined with the age discordance between the pottery and radiocarbon dates, strongly suggests that the peat surface was "worked", either for fuel or salt (c.f. Behre et al., 1979). With the slope-wash / peat deposits relatively accessible during the early medieval period, the overlying sands and silts must have accumulated rapidly, probably following the breach in the Rye barrier during the 13th century.

8. Discussion

The model outlined above envisages large scale, rapid, changes in palaeoenvironment in the lower Brede Valley that were driven by compaction of the main marsh peat. We now compare the West Winchelsea findings with other data from the surface of the main marsh peat from across the Rye area, and the Romney Marsh depositional complex more widely, to establish the magnitude of this compaction, and whether the trends observed here are reflected elsewhere.

8.1 The main marsh peat in the Rye area

As well as the detailed new investigations from 10 locations (Figure 1), lithostratigraphic information from the Rye area is available from previous palaeoenvironmental work (Long et al., 1996; Waller et al., 1988; Waller and Kirby,

2002) and commercial schemes. The resulting dataset provides us with over 300 borehole logs. Deep boreholes sunk in the Wainway channel and along the edge of the gravel deposits at Rye Harbour suggest peat is absent from the south-eastern part of the study area (Figure 8). In addition, peat is also absent from the post 13th century AD routes of the rivers Brede, Tillingham and Rother. As with the channel adjacent to West Winchelsea described above, post-depositional erosion of the peat seems probable at these sites.

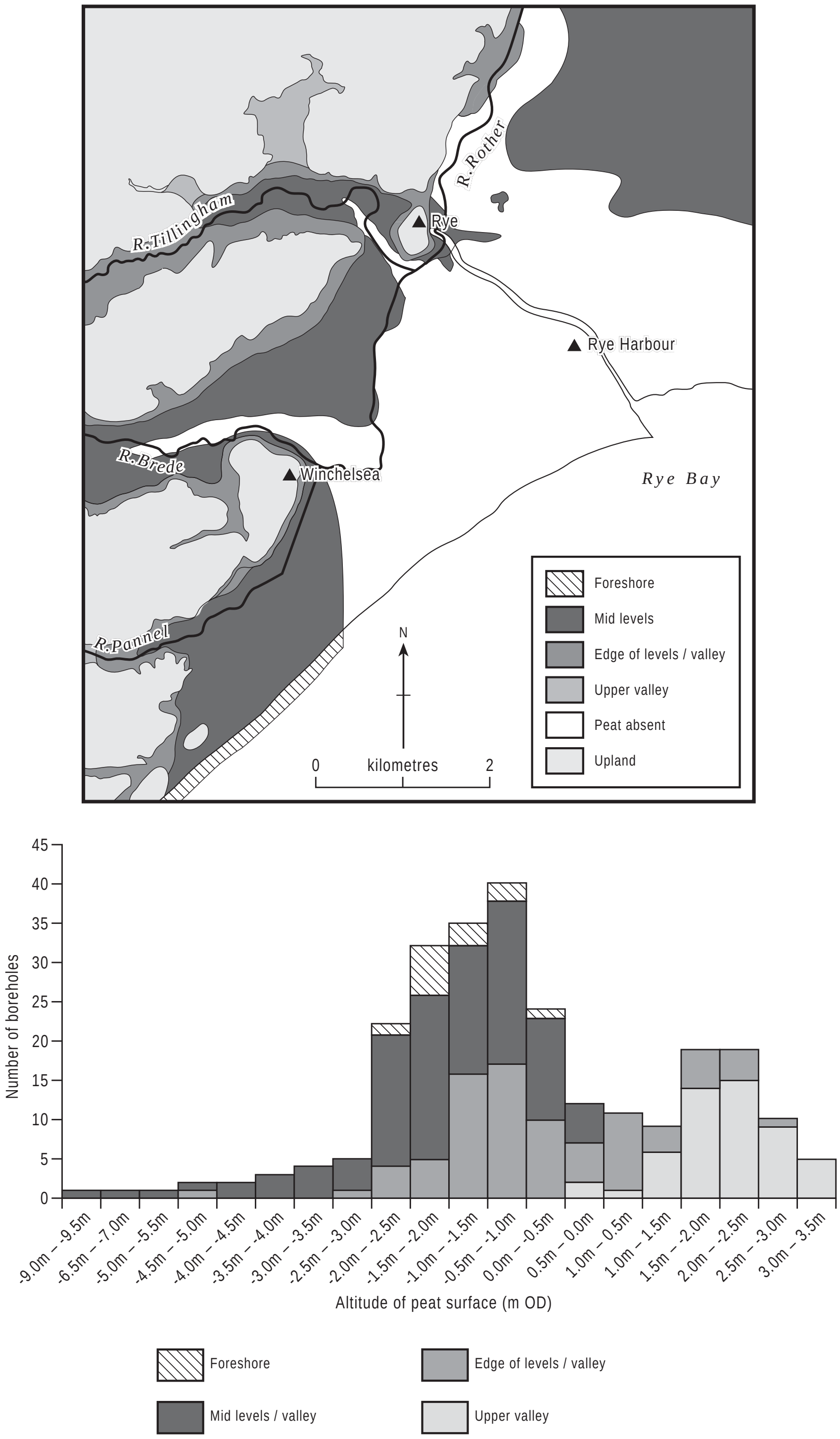


Fig. 8. Frequency histogram of the height of the upper contact (in meters OD) to the main marsh peat in the Rye area. Accompanying map shows areas of marshland from which the data have been extracted.

Peat is recorded in 259 boreholes. A frequency distribution of the altitude of the upper surface of the peat (Figure 8) shows a bimodal pattern with peaks at -1 m OD and 2 m OD. The highest altitudes (above 2 m OD) are recorded from upper valley locations; the Pannel valley where unusually peat outcrops at the modern surface (Waller, 1993) and at Lea Farm which similarly lies beyond the inland limits of marine / brackish sedimentation. Altitudes above 1 m OD are also recorded from sites that lie within 100 m of the edge of the valleys / Levels (such as Houghton Green and Pannel Farm). At such locations the peat bed directly overlies incompressible bedrock strata. In most boreholes, the peat is over and underlain by marine / brackish sediments and the altitude of the upper peat surface occurs between 0 and -2.5 m OD. The lowest contacts (below -2.5 m OD) are from sites where the peat is thin and (where data is available) the upper peat contact sharp, indicating that most of the peat has been eroded away, though the redeposition of eroded peat with tidal channels is also a possibility (Long et al., 1996).

Erosion and compaction can be separated at sites where detailed litho- and biostratigraphic data are available. Altitudes for sites where the upper contact of the peat appears gradational and there is no biostratigraphic evidence for erosion range from 2.21 m OD at Houghton Green to -1.99 m OD at West Winchelsea. If these contacts represent a former land surface which had a relatively even altitude (and at neither site is there evidence for raised bog formation) then West Winchelsea has been lowered by a minimum (as it is highly unlikely that the Houghton Green site experienced no compaction) of 4.2 m. With the current peat thickness at West Winchelsea of between 2 and 3 m (Waller et al., 1988; Long et al., 1996), this level of compaction equates to a reduction in peat thickness of approximately 50%.

8.2 The age of the main marsh peat surface in the Rye area

A chronology for peat formation in the Rye area is important if we are to establish that the un-eroded upper surface of the peat is a former land surface and so separate the effects of sediment compaction from those arising from other processes, such as relative sea-level rise. Radiocarbon dates obtained from the upper surface of the peat in the Rye area (Table 1) range from 3485 ± 28 BP at Pewis Marsh to 1240 ± 50 BP at East Guldeford. The simplest explanation for these age differences is that a progressive inundation of the main marsh peat resulted in the inundation of low-lying sites ahead of topographically higher sites. However, an age-depth plot of peat surface dates suggests that this is not the case (Figure 9), with same-aged index points differing in elevation by at least 3 m. For this reason, we do not believe that this age range reflects real diachroneity in wetland inundation. Moreover, pollen and multiple radiocarbon dates from several sites in the area suggest that the peat slowed or stopped accumulating during this interval. At some sites (e.g. Pewis Marsh), the slope-wash sediments occur above the peat, whilst elsewhere (e.g. Pett Level) the peat top appears to have been disturbed by peat cutting (see above). Only at West Winchlesea and East Guldeford do we find clear evidence for continuous sedimentation across the end of peat formation and into the establishment of salt marsh conditions. The radiocarbon dates from these sites (Table 1) suggest initial inundation of the peat sometime after c. AD 700-800, that is some 600 to 500 years before the 13th century storms that supposedly caused the initial breach of the Rye coastal barrier.

8.3 Implications of peat compaction for sea-level studies

Much effort in sea-level studies has focussed on reducing the height errors associated with reconstructing past RSL change. This has included the meticulous reconstruction of errors associated with, amongst others, the angle of borehole, levelling and benchmark uncertainties, as well as the indicative meaning and range of sea-level index points. Taken together, the root mean square error of these variables adds up to c. ±0.25 m to 0.50 m (e.g. Shennan, 1982; Long et al., 2000). However, most age/altitude plots of RSL data demonstrate a between-point scatter that, at any given point in time, far exceeds these carefully reconstructed levels of uncertainty. This is well-illustrated by the data from Romney Marsh described above (Figure 9), or in the 3 to 6 m-wide envelope that captures the scatter observed in the mid and late Holocene index points from the Fenland (e.g. Shennan, 1994). This range highlights the importance of peat compaction as a potential source of height uncertainty in late Holocene RSL reconstructions.

Allen (1999) suggests that the effects of sediment compaction are likely to be greater for transgressive contacts, especially where they overlie thick peat beds, compared to regressive contacts that lie above clastic sediment sequences. This pattern is certainly evident from the study area when we combine the Rye data with other previously published mid and early Holocene sea-level data from Romney Marsh (Figure 10). This analysis shows that the age/height scatter in the index points derived from the regressive contact to the main peat bed is much smaller compared with that from the transgressive contact to this peat bed. This comparison confirms the importance of avoiding the use of transgressive contacts for time/altitude sea-level reconstruction, especially where they occur from the upper part of thick peat beds. Although the exclusive use of basal peat as a means to minimise compaction is widespread in some areas of northwest Europe (e.g. Denys and Baeteman, 1995) and on the Atlantic seaboard of the U.S.A. (e.g. Gehrels et al., 1996), dates from the transgressive contact to intercalated peats remain an important component of U.K. sea-level research.

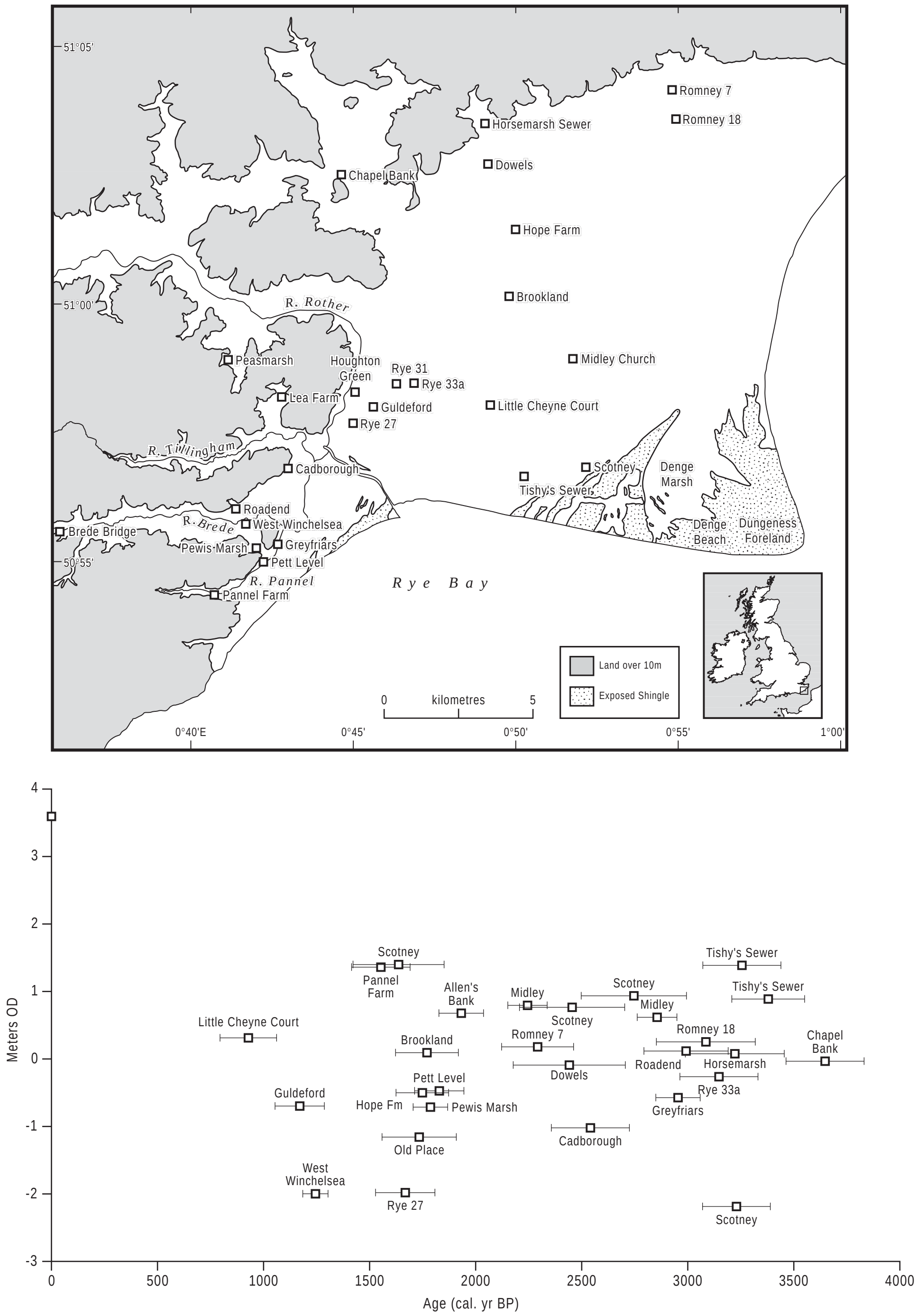


Fig. 9. Age/depth plot of radiocarbon dates from the upper surface of the main marsh peat. Site names locate individual data points shown on the accompanying map. Note that the highest index points tend to come from sites where the peats are thin or overlie relatively uncompressible sands or gravels (e.g. Scotney, Allen's Bank).

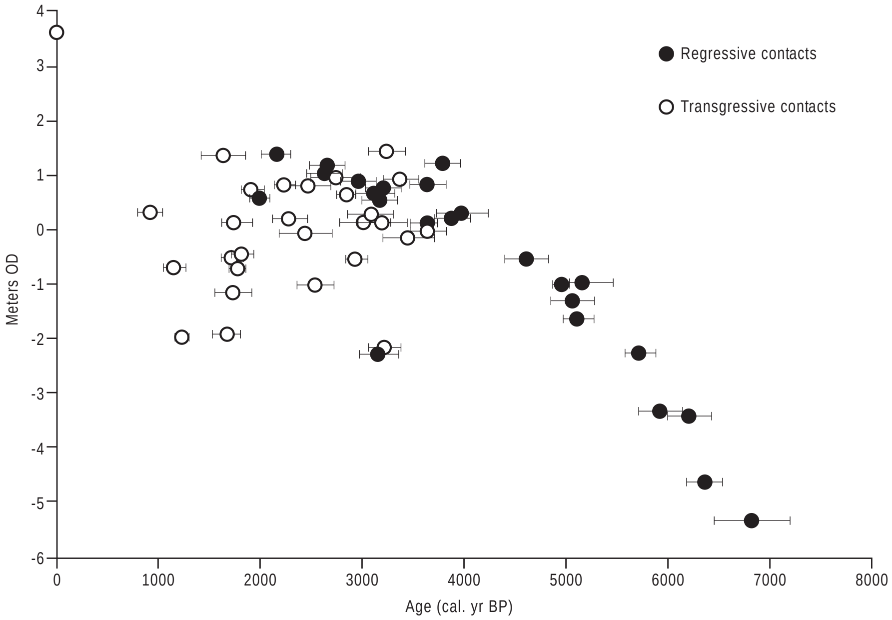


Fig. 10. Radiocarbon dates from regressive and transgressive contacts from the Romney Marsh depositional complex. Note that the scatter in the regressive contact dates, which lie directly above relatively incompressible silts, is much less than that for dates from the transgressive contacts which come from the surface of a thick bed of peat.

The Rye data show there is no doubt as to the significance of peat compaction as a driving mechanism behind coastal change and, in particular, as a process that contributed towards the late Holocene inundation of coastal wetlands. Indeed, although the exact timing of this event varies between places (Long et al., 2000), it seems likely that many of these former wetlands effectively "self-destructed" as a result of the compaction-related processes of dewatering and desiccation and loading by tidal water and clastic sediment.

When considered over Holocene timescales, the effects of peat compaction on landscape change are likely to have increased towards the present. This is because much of the early/mid Holocene stratigraphic record comprises minerogenic sediments, with only relatively thin and short-lived episodes of peat formation (e.g. Devoy, 1979; Long et al., 2000). Changes in RSL during this interval were strongly influenced by a combination of crustal motions and variations in ocean volume. During the mid Holocene, however, the shift to the extensive accumulation of peat beds, which today are still typically 1-3 m in thickness, meant that the coast was primed for major changes independent of any shifts in long-term crustal motions or eustatic sea-level change. It is ironic, therefore, that during the late Holocene, a time when the rate of sea-level rise was falling, the process of non-linear peat compaction meant that the potential for catastrophic coastal change was actually increasing.

9. Conclusions

In this paper we have explored the role of peat compaction in controlling landscape and sea-level change in the late Holocene on Romney Marsh, focussing attention on an extensive dataset from the area surrounding the town of Rye. Our main conclusions are as follows:

1. The surface of a laterally persistent late Holocene peat bed in the Rye area lies between c. -2.5 m OD and +3 m OD. This surface is lowest where the peat is thickest

and underlain by compressible minerogenic sediments. It is highest at the valley / Levels edges and beyond the inland limits of marine / brackish sedimentation.

2. Much of this variability is due to the effects of differential sediment (including peat) compaction. Same aged sea-level index points from the surface of this peat bed vary in height by up to 3 m.

3. A detailed analysis of pollen, foraminiferal and grain size data from West Winchelsea, provides new information on the magnitude and timing of peat compaction. Following an initial gradual inundation of this site, there was a significant increase in water depth and tidal energy that was accompanied by rapid deposition of tidally laminated sediments. We hypothesise that this increase in water depth was the result of historically documented events; the development of a large breach in the barrier and consequent flooding of the 13th century. Headward erosion of creeks, dewatering of the peat, and direct loading of the peat surface by sediment and water, combined in a positive feedback cycle to create new accommodation space and encourage rapid inter- and subtidal sedimentation.

4. Our work demonstrates the powerful influence that peat compaction had on the evolution of the late Holocene landscape at Rye and, we believe, at many other coastal lowlands in northwest Europe. Although the exact timing of peat burial varies between sites, this process is likely to have been a key driving mechanism behind rapid coastal change, far exceeding the effects of either eustatic change or crustal uplift/subsidence.

Acknowledgements

This work was funded by English Heritage as part of the Aggregate Levy Sustainability Fund. We thank our collaborators in this project for their assistance in the field, the laboratory and in the development of the ideas included in this paper, particularly Dr Andrew Plater, Dr Damien Laidler, Dr Jonathan Lageard, Dr Peter Wilson and Ms Kate Elmore. We thank Alex Bayliss and John Meadows of the English Heritage Scientific Dating Section for their contribution to the dating programme and discussions of the chronology. This paper benefited from stimulating discussions with Dr Cecile Baeteman, including during a very cold field visit to Romney Marsh in January 2004, and from helpful comments by Dr Roland Gehrels and an anonymous reviewer. Frank Davies, Eddie Million and Neil Tunstall assisted in the laboratory and the diagrams were drawn by Chris Orton and David Hume. This paper is a contribution to IGCP Project 495 "Quaternary Land-Ocean Interactions: Driving Mechanisms and Coastal Responses" and to the INQUA Sub-Commission on Coastal Processes and Sea-level Changes.

References

Allen, J.R.L., 1999. Geological impacts on coastal wetland landscapes: some general effects of sediment autocompaction in the Holocene of northwest Europe. Holocene 9, 1-12.

Allen, J.R.L., 2000. Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe. Quat. Sci. Rev. 19, 1155-1231.

Allen, J.R.L., 2004. Annual textual banding in Holocene estuarine silts, Severn Estuary Levels (SW Britain): patterns, cause and implications. Holocene 4, 536-552.

Archer, A.W., 1991. Modelling of tidal rhythmites using modern tidal periodicities and implications for short-term sedimentation rates. In: Franseen, E.K., Watney, W.L., Kendall, C.G. St. C., Ross, W. (Eds.), Sedimentary modelling, computer simulations and methods for improved parameter definition. Kansas Geol. Surv. Bul. 233, Lawrence, Kansas, USA, pp. 185-194.

Archer, A.W., 1994. Extraction of sedimentological information via computer-based image analysis of gray shales in Carboniferous coal-bearing sections of Indiana and Kansas. Math. Geol. 26, 47-65.

Archer, A.W., 1998. Hierarchy of controls on cyclic rhythmite deposition, Carboniferous basins of eastern and mid-continental U.S.A. In: Alexander, C.R., Davis, R.A., Henry, V.J. (Eds.), Tidalites: processes and products. SEPM Spec. Publ. 61, pp. 59-68.

Archer, A.W., Johnson, T.W., 1997. Modelling of cyclic tidal rhythmites (Carboniferous of Indiana and Kansas, Precambrian of Utah, USA) as a basis for reconstruction of intertidal positioning and palaeotidal regimes. Sedimentology 44, 991-1010.

Archer, A.W., Kuecher, G.J., Kvale, E.P. 1995. The role of tidal-velocity asymmetries in the deposition of silty tidal rhythmites (Carboniferous, eastern interior coal basin, USA). J. Sedimentary Res., A65, 408-416.

Baeteman, C., In press. How subsoil morphology and erodibility influence the origin and pattern of late Holocene tidal channels: case studies from the Belgian coastal lowlands. Quat. Sci. Rev.

Baeteman, C., Denys, L., 1995. Western coastal plain of Belgium. In: Schirmer, W. (Ed.), Quaternary Field Trips in Central Europe, vol. 2, North Sea Coasts, Verlag Dr. Friedrich Pfeil, Munich, pp. 1010-1014.

Baeteman, C., Scott, D.B., van Strydonck, M., 2002. Changes in coastal zone processes at a high sea-level stand: a late Holocene example from Belgium. J. Quat. Sci. 17, 547-559.

Beets, D.J., van der Valk, L., Stive, M.J.F., 1992. Holocene evolution of the coast of Holland. Mar. Geol. 103, 423-443.

Beets, D.J., van der Spek, A.J.F., van der Valk, L., 1994. Holocene ontwikkkeling van de Nederlandse kust. Rijks Geol. Dienst No. 40.0016, pp. 53.

Behre, K-E., Menke, B., Strief, H., 1979. The Quaternary geological development of the German part of the North Sea. In: Oele, E., Schüttenham, R.T.E., Wiggers, A.J. (Eds.), The Quaternary History of the North Sea. Acta. Univ. Ups. Symp. Univ. Ups. Annum Quingentesimum Celebrantis: 2, Uppsala, pp. 85-113.

Bell, M., Caseldine, A., Neumann. H., (Eds.), 1999. Prehistoric intertidal archaeology in the Welsh Severn Estuary, Council for British Archaeology Report 120, pp 440.

Bennema, J., Geue, E.C.W.A., Smits, H., Wiggers, A.J., 1954. Soil compaction in relation to Quaternary movements of sea-level and subsidence of the land, especially in The Netherlands. Geol. Mijnb. 16, 173-178.

Dalrymple, R.W., Makino, Y., Zaitlin, B.A., 1991. Temporal and spatial patterns of rhythmite deposition on mudflats in the macrotidal, Cobequid Bay – Salmon River estuary, Bay of Fundy. In: Smith, D.G., Reinson, G.E., Zaitlin, B.A., Rahamis, R.A. (Eds.), Clastic tidal sedimentology. Mem. Can. Soc. Pet. Geol. 16, 137-160.

Dark, P., Allen, J.R.L., 2005. Seasonal deposition of Holocene banded sediments in the Severn Estuary Levels (southwest Britain): palynological and sedimentological evidence. Quat. Sci. Rev. 24, 11-33.

Denys, L., Baeteman, C., 1995. Holocene evolution of relative sea-level and local mean high water spring tides in Belgium – a first assessment. Marine Geology 124, 1-19.

Devoy, R.J.N., 1979. Flandrian sea level changes and vegetation history of the lower Thames Estuary. Phil. Trans. R. Soc. Lond. B25, 355-407.

Eddison, J., 1998. Catastrophic changes: the evolution of the barrier beaches of Rye Bay. In: Eddison, J., Gardiner, M., Long, A.J. (Eds.), Romney Marsh: environmental change and human occupation in a coastal lowland. Oxford University Committee for Archaeology, Oxford No. 46, pp. 65-88.

Eddison, J., Draper, G., 1997. A landscape of medieval reclamation: Walland Marsh, Kent. Landscape History 19, 75-88.

Gardiner, M., 1995. Medieval farming and flooding in the Brede valley. In: Eddison, J. (Ed.), Romney Marsh: the debatable ground. Oxford University Committee for Archaeology, Oxford No. 41, pp. 127-137.

Gardiner, M., 2002. The late Medieval "Antediluvian" landscape of Walland Marsh. In: Long, A.J., Hipkin, S., Clarke, H. (Eds.), Romney Marsh: coastal and landscape change through the ages. Oxford University Committee for Archaeology, Oxford No. 56, pp.101-120.

Gehrels, W.R., Belknap, D.F., Kelley, J.T., 1996. Integrated high-precision analyses of Holocene relative sea-level changes: lessons from the coast of Maine. Geol. Soc. Am. Bull. 108, 1073-1088.

Grimm, E.C., 1987. CONISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Comp. Geosci. 13, 13-35.

Grimm, E.C., 1993. TILIA: a program for analysis and display. Illinois State Museum, Springfield.

Green, R.D., 1968. Soils of Romney Marsh. Soil Survey of Great Britain Bulletin 4, Harpenden.

Haslett, S.K., Davies, P., Curr, R.H.F., Davies, C.F.C., Kennington, K., King, C.P., Margets, A.J., 1998. Evaluating late-Holocene relative sea-level changes in the Somerset Levels, southwest Britain. Holocene 8, 197-207.

Hobbs, N., 1986. Mire morphology and the properties and behaviour of some British and foreign peats. Quarterly Journal of Engineering Geology 19, 7-80.

Kvale, E.P., Archer, A.W., 1991. Characteristics of two, Pennsylvanian age, semidiurnal tidal deposits in the Illinois Basin, USA. In: Smith, D.G., Reinson, G.E., Zaitlin, B.A., Rahmani, R.A. (Eds.), Clastic tidal sedimentology. Mem. Can. Soc. Petrol. Geol. 16, 179-188.

Kvale, E.P., Fraser, G.S., Archer, A.W., Zawistoski, A., Kemp, N., McGough, P., 1994. Evidence of seasonal precipitation in Pennsylvanian sediments of the Illinois Basin. Geology 22, 331-334.

Kvale, E.P., Masterlerz, M., 1998. Evidence of ancient fresh-water tidal deposits. In: Alexander, C.R., Davis, R.A., Henry, V.J. (Eds.), Tidalites, processes and products. SEPM Spec. Publ. 61, 95-107.

Kvale, E.P., Johnson, H.W., Sonett, C.P., Archer, A.W., Zawistoski, A., 1999. Calculating lunar retreat rates using tidal rhythmites. J. Sed. Res. 69, 1154-1168.

Loeblich, A.R., Jr., Tappan, H., 1988. Foraminiferal genera and their classification, Vol. 1, Van Nostrand Reinhold, New York, 970 pp.

Long, A.J., Hughes, P., 1995. Evolution of the Dungeness foreland during the last 4000 years. Mar. Geol. 124, 253-271.

Long, A.J., Innes, J.B. 1993. Holocene sea-level changes and coastal sedimentation in Romney marsh, southeast England, UK. Proc. Geol. Assoc. 104, 223-237.

Long, A.J., Innes, J.B., 1995. The back-barrier and barrier depositional history of Romney Marsh, Kent, UK. J. Quat. Sci. 10, 267-283.

Long, A. J., Plater, A. J., Waller, M.P., Innes, J.B., 1996. Holocene coastal sedimentation in the Eastern English Channel: new data from the Romney Marsh region, United Kingdom. Mar. Geol. 136, 97-120.

Long, A.J., Scaife, R.G., Edwards, R.J., 2000. Stratigraphic architecture, relative sea level, and models of estuary development in southern England: New data from Southampton Water. In: Pye, K., Allen, J.R.L. (Eds.), Coastal and estuarine environments: sedimentology, geomorphology and geoarchaeology. Spec. Pub. 175, Geological Society Publishing House, Bath, pp. 253-279.

Long, A. J., Waller, M.P., Hughes, P., Spencer, C., 1998. The Holocene depositional history of Romney Marsh proper. In: Eddison, J., Gardiner, M., Long, A.J., (Eds.), Romney Marsh: environmental change and human occupation in a coastal lowland. Oxford University Committee for Archaeology, Oxford, No. 46, pp. 45-63.

Long A.J., Plater A.J., Waller M.P., Roberts H., Laidler P.D., Stupples P., Schofield

E., 2004. The depositional and landscape histories of Dungeness Foreland and the Port of Rye: understanding past environments and coastal change. University of Durham, 24 pp.

Long, D., Waller, M.P., McCarthy, P., 1998. The vegetation history, stratigraphy and pollen data for the Shirley Moor region. In: Eddison, J., Gardiner, M., Long, A.J. (Eds.), Romney Marsh: environmental change and human occupation in a coastal lowland. Oxford University Committee for Archaeology, Oxford, No. 46, 31-44.

Martino, R.L., Sanderson, D.D., 1993. Fourier and autocorrelation analysis of estuarine tidal rhythmites, lower Breathitt formation (Pennsylvanian), eastern Kentucky, USA. J. Sed. Petrol. 63, 105-119.

Murray, J.W., 1971. An atlas of British recent Foraminiferids. London, Heinemann.

Murray, J.W., 1979. British nearshore foraminiferids. In: Kermack, D.M., Barnes, R.S.K. (Eds.), Synopses of the British fauna (new series). Academic Press, London, No. 16. pp 68.

Paul, M.A., Barras, B.F., 1998. A geotechnical correction for post-depositional sediment compression: examples from the Forth Valley, Scotland. J. Quat. Sci. 13, 171-176.

Pizzuto, J.E., Schwendt, A.E., 1997. Mathematical modelling of autocompaction of a Holocene transgressive valley-fill deposit, Wolfe Glade, Delaware. Geol. 25, 57-60.

Plater, A.J., Turner, S., 2002. Palaeoenvironmental investigations of Allen's Bank, Lydd. Unpublished report by the University of Liverpool for Brett Aggregates Ltd., pp. 76.

Plater, A.J., Long, A.J., Spencer, C.D., Delacour, R.A.P., 1999. The stratigraphic record of sea-level change and storms during the last 2000 years: Romney Marsh, south-east England. Quat. Int. 55, 17-27.

Roep, T.P., van Regteren Altena, J.F., 1988. Paleotidal levels in tidal sediments (3800-3635 BP) at Bovenkarspel, NW Netherlands. In: de Boer, P.L., van Gelder, A., Nio, S.D., (Eds.), Tide-influenced sedimentary environments and facies. Dordrecht, Reidel, pp. 215-231.

Shennan, I., 1982. Interpretation of Flandrian sea-level data from the Fenland, England. Proc. Geol. Ass. 93, 53-64.

Shennan, I., 1994. Data synthesis: altitundinal trends. In: Waller, M.P., (Ed.), The Fenland Project, Number 9: Flandrian environmental change in Fenland. East Anglian Archaeology 70, pp. 53-60.

Skempton, A.W., 1970. The consolidation of clays by gravitational compaction. Q. J. Geol. Soc. Lond. 125, 373-411.

Smyth, C., Jennings, S., 1988. Mid to late Holocene forest composition and the effects of clearances in the Combe Haven valleys, East Sussex. Sussex. Arch. Coll. 126, 1-20.

Spencer, C.D., Woodland, W., 2002. Palaeoenvironmental changes during the last 4000 years at Scotney Marsh, Romney Marsh, Kent: a multiproxy approach. In: Long, A.J., Hipkin, S., Clarke, H. (Eds.), Romney Marsh: coastal and landscape change through the ages. Oxford University Committee for Archaeology, Oxford, No. 56, pp. 58-74.

Spencer, C.D., Plater, A.J., Long, A.J., 1998. Rapid coastal change during the mid- to late-Holocene: the record of barrier estuary sedimentation in the Romney Marsh region, south-east England. Holocene 8, 143-163.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., van der Plicht, J., Spurk, M., 1998. INTCAL98 Radiocarbon age calibration, 24,000-0 cal BP. Radiocarbon 40, 1041-1083.

Streif, H., 1972. The results of stratigraphical and facial investigations in the coastal Holocene of Woltzeten/Ostfriesland, Germany. Geol. Fören. Stockh. Förh. 94, 281-299.

Stupples, P., 2002. Tidal cycles preserved in late Holocene tidal rhythmites, the Wainway Channel, Romney Marsh, southeast England. Mar. Geol. 182, 231-246.

Tessier, B., 1998. Tidal cycles, annual versus semi-lunar records. In: Alexander, C.R., Davis, R.A., Henry, V.J. (Eds.) Tidalites, processes and products, SEPM Spec. Publ. 61, pp. 69-74.

Tessier, B., Archer, A.W., Lanier, W.P., Feldman, H.R., 1995. Comparison of ancient tidal rhythmites (Carboniferous of Kansas and Indiana, USA) with modern analogues (the Bay of Mont-Saint-Michel, France). In: Flemming, B.W., Bartholoma, A. (Eds.), Tidal signatures in modern and ancient sediments. Int. Assoc. Sedimentol. Spec. Publ. 24, pp. 259-274.

Tooley, M.J., 1978. Sea-level changes in north-west England during the Flandrian Stage. Oxford, Clarendon Press.

Tooley, M.J., Switsur, R., 1988. Water level changes and sedimentation during the Flandrian Age in the Romney Marsh area. In: Eddison, J., Green, C. (Eds.), Romney Marsh: evolution, occupation, reclamation. Oxford University Committee for Archaeology, Oxford, No. 24, pp. 53-71.

Waller, M.P., 1993. Flandrian vegetational history of south-eastern England. Pollen data from Pannel Bridge, East Sussex. New Phytol. 124, 345-369.

Waller, M.P., 1994a. The Fenland Project, Number 9: Flandrian environmental change in Fenland. East Anglian Archaeology Report No. 70, pp. 353.

Waller, M.P., 1994b. Flandrian vegetation history of south-eastern England. Stratigraphy of the Brede valley and pollen data from Brede Bridge. New Phytol. 126, 369-392.

Waller, M.P., 1998. An investigation into the palynological properties of fen peat through multiple pollen profiles from south-eastern England. J. Arch. Sci. 25, 631-642.

Waller, M.P., 2002. The Holocene vegetation history of the Romney Marsh region. In: Long, A.J., Hipkin, S., Clarke, H. (Eds.), Romney Marsh: coastal and landscape change through the ages. Oxford University Committee for Archaeology, Oxford, No. 56, pp. 1-21.

Waller, M.P., Kirby, J., 2002. Late Pleistocene/early Holocene environmental change in the Romney Marsh region: new evidence from Tilling Green, Rye. In: Long, A.J., Hipkin, S., Clarke, H. (Eds.), Romney Marsh: coastal and landscape change through the ages. Oxford University Committee for Archaeology, Oxford, No. 56, pp. 22-39.

Waller, M.P., Long, A.J., 2002. Holocene coastal evolution and sea-level change on the southern coast of England: a review. J. Quat. Sci. 18, 251-359.

Waller, M.P., Burrin, P.J., Marlow, A., 1988. Flandrian sedimentation and palaeoenvironments in Pett Level, the Brede and Lower Rother valleys and Walland Marsh. In: Eddison, J., Green, C. (Eds.), Romney Marsh: evolution, occupation, reclamation. Oxford University Committee for Archaeology, Oxford, No. 24, pp. 3-30.

Waller, M.P., Long, A.J., Long, D., Innes, J.B., 1999. Patterns and processes in the development of coastal mire vegetation: Multi-site investigations from Walland Marsh, South-east England. Quat. Sci. Rev. 18, 1419-1444.

Waller, M.P., Schofield, J.E., In press. Mid to late Holocene vegetation and land use in the Weald of south-eastern England: multiple pollen profiles from the Rye Area. Veget. Hist. Archaeobot.

Waller, M.P., Long, A.J. Schofield, J.E., In press. The interpretation of radiocarbon dates from the upper surface of late Holocene peat layers in coastal lowlands. Holocene.

Table 1
Radiocarbon dates from transgressive and regressive contacts of mid and late Holocene age in the Rye area and the Romney Marsh depositional complex. Dates are calibrated using the intercept method and bi-decadal dataset of Stuiver et al. (1998). Where two laboratory codes are given, the humin and humic acid fractions were dated separately, the results presented here being the pooled mean.

Site	**Laboratory code**	**Radiocarbon age ± 1σ**	**Calibrated age range (2σ range)**	**Altitude (m OD)**	**Transgressive (T) or regressive (R) contact**	**Source**	**Dated material**
Broomhill Church	Q-2753	2160 ± 50	2003-2312	1.34	R	Tooley and Switsur (1988)	Sandy silty limus
Broomhill Church	Q-2752	2600 ± 50	2489-2845	1.14	R	Tooley and Switsur (1988)	Laminated silty limus
Horsemarsh Sewer	Q-2647	5500 ± 70	6003-6444	-3.42	R	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Brede Bridge	SRR-2646	5970 ± 150	6450-7208	-5.35	R	Waller (1994b)	Humified peat
Horsemarsh Sewer	Q-2648	5150 ± 70	5720-6168	-3.33	R	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Tishy's Sewer	Q-2649	3520 ± 60	3638-3964	1.2	R	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Tishy's Sewer	Q-2561	3410 ± 60	3478-3828	0.8	R	Tooley and Switsur (1988)	Limus with gravel
Midley Church	UB-3852	3673 ± 82	3726-4243	0.28	R	Long and Innes (1993)	Humified peat
Midley Church	UB-3854	3054 ± 58	3077-3382	0.73	R	Long and Innes (1993)	Humified peat

Brookland	UB-3730	4367 ± 39	4847-5041	-1.01	R	Long and Innes (1995)	Well humified peat
Rye 11	BETA-75451	5590 ± 70	6204-6532	-4.64	R	Long et al. (1996)	Humified peat with some *Phragmites*
Rye 31	BETA-65453	4550 ± 80	4883-5466	-0.98	R	Long et al. (1996)	Organic sand with some silt and detrital wood
Horsemarsh Sewer 2	BETA-87700	5890 ± 110	6413-6986	-2.92	R	Waller et al. (1999)	Dark brown detrital peat
The Dowels	SRR-5622	4970 ± 50	5598-5887	-2.29	R	Waller et al. (1999)	Detrital wood-rich peat
Hope Farm	SRR-5618	4485 ± 45	4972-5302	-1.65	R	Waller et al. (1999)	Dark brown detrital peat
Little Cheyne Court	SRR-5614	4410 ± 45	4860-5277	-1.3	R	Waller et al. (1999)	Black highly humified peat
Romney 7	BETA-109576	4070 ± 70	4415-4823	-0.55	R	Long, A. et al. (1998)	Humified peat with some clay
Romney 18	BETA-109579	3250 ± 100	3213-3715	-0.14	R	Long, A. et al. (1998)	Humified wood peat
Scotney	BETA-81363	3020 ± 70	2996-3376	-2.28	R	Spencer and Woodland (2002)	Humified peat
Scotney AY17	BETA-81365	3010 ± 60	3000-3355	0.57	R	Spencer and Woodland (2002)	Humified peat
Scotney AB27	BETA-81367	2610 ± 60	2471-3852	1.01	R	Spencer and Woodland (2002)	Humified peat
Scotney AW63	BETA-81368	3410 ± 40	3490-3825	0.05	R	Spencer and Woodland (2002)	Brown clayey peat
Scotney AW63	BETA-81369	2950 ± 60	2930-3323	0.66	R	Spencer and Woodland	Humified peat

						(2002)	
Scotney	BETA-81370	3580 ± 60	3694-4077	0.21	R	Spencer and Woodland (2002)	Humified peat
Scotney AW-AX67	BETA-81371	2850 ± 60	2787-3160	0.85	R	Spencer and Woodland (2002)	Humified peat
Allen's Bank, Lydd	BETA-170764	2040 ± 40	1898-2115	0.61	R	Plater and Turner (2002)	Humified peat
Brede Bridge	SRR-2645	3690 ± 70	3833-4236	0.4	T	Waller (1994b)	Clay-rich humified peat
Rye 33a	BETA-754354	2980 ± 60	2967-3335	-0.25	T	Long et al. (1996)	Humified peat with some roots and detrial wood
Rye 27	BETA-75452	1740 ± 60	1531-1816	-1.98	T	Long et al. (1996)	Humified peat
Chapel Bank	BETA-87707	3390 ± 70	3470-3827	-0.03	T	Long, D. et al. (1998)	Well humified peat
Tishy's Sewer	Q-2652	3160 ± 60	3211-3548	0.9	T	Tooley and Switsur (1988)	Silty limus with detrital plant remains
Tishy's Sewer	Q-2650	3060 ± 60	3077-3435	1.4	T	Tooley and Switsur (1988)	Silty limus with detetrital plant remains
Midley Church	UB-3851	2249 ± 48	2149-2346	0.8	T	Long and Innes (1993)	Humified peat
Midley Church	UB-3583	2762 ± 49	2762-2954	0.63	T	Long and Innes (1993)	Humified peat
Brookland	UB-3731	1846 ± 51	1627-1917	0.09	T	Long and Innes (1995)	Well humified peat with *Phragmites*
Horsemarsh Sewer 2	BETA-87704	3060 ± 80	3000-3348	0.09	T	Waller et al. (1999)	Dark brown detrital peat with wood.
The Dowels	SRR-5619	2355 ± 45	2183-2707	-0.09	T	Waller et al. (1999)	

Hope Farm	SRR-5615	1850 ± 45	1631-1883	-0.51	T	Waller et al. (1999)	Dark brown peat with silt inclusions
Little Cheyne Court	SRR-5611	1050 ± 45	799-1060	0.3	T	Waller et al. (1999)	Humified moss peat
Romney 7	BETA-109578	2290 ± 60	2123-2464	0.18	T	Long, A. et al. (1998)	Clay-rich humified peat
Romney 18	BETA-109581	2910 ± 70	2865-3316	0.27	T	Long, A. et al. (1998)	Well humified peat with roots
Scotney G60	BETA-81364	3050 ± 60	3074-3388	-2.185	T	Spencer and Woodland (2002)	Humified peat
Scotney AY17	BETA-81366	2380 ± 60	2212-2711	0.77	T	Spencer and Woodland (2002)	Humified peat
Scotney Q32	BETA-157460	1730 ± 70	1422-1856	1.39	T	Spencer and Woodland (2002)	Humified peat
Scotney AW-AX67	BETA-81372	2690 ± 80*	2498-2997	0.94	T	Spencer and Woodland	Humified peat
Allen's Bank, Lydd	BETA-170763	1990 ± 40	1828-2039	0.69	T	Plater and Turner (2002)	Well humified silty peat
Old Place	SRR-2893	1830 ± 80	1558-1926	-1.165	T	Waller (1998)	Humified peat
Pannel Farm	GrN-28586/ GrN-28587	1654 ± 45	1418-1691	1.365	T	This study	Organic-rich silt
Pewis Marsh	GrN-27875/ GrN-27910	1842 ± 30	1707-1867	-0.725	T	This study	Organic-rich silty clay
Greyfriars	GrN-28101/ GrA-24065	2837 ± 28	2853-3059	-0.57	T	This study	Well humified Peat
Pett Level	GrN-27875/ GrN-28108	1895 ± 51	1710-1947	-0.47	T	This study	Organic-rich silty Clay
Cadborough	GrN-28105	2480 ± 60	2360-2730	-1.02	T	This study	Well humified peat

East Guldeford	GrN-28104	1240 ± 50	1056-1283	-0.72	T	This study	Well humified peat
Roadend	GrN-28106	2860 ± 60	2793-3205	0.12	T	This study	Well humified peat
West Winchelsea	GrN-28734/ GrN-28735	1348 ± 27	1186-1307	-2.01	T	This study	Well humified Peat

Table 2. Pollen assemblage zones from West Winchelsea

Zone (core depth cm)	Characteristics
WW-3 (above 495 cm)	Herbaceous pollen forms >50% TLP, with Poaceae, Chenopodiaceae, Cyperaceae and *Spergula*-type the main taxa.
WW-2 (502-495 cm)	Herbaceous pollen (particularly Cyperaceae) dominates. Minor taxa include both freshwater (e.g. *Filipendula*, *Hydrocotyle vulgaris* and brackish (e.g. Chenopodiaceae, *Plantago maritima*) indicators.
WW-1 (512-502 cm)	A mixture of arboreal (notably *Alnus glutinosa*, *Betula* and *Salix*) and herbaceous pollen (Cyperaceae and Poaceae).

Table 3. Foraminiferal assemblage zones from West Winchelsea

Zone (core depth cm)	Characteristics
5 (85-0 cm)	Dominated by the brackish lagoon species *Haynesina germanica* and *Elphidium williamsoni*. Above 45 cm, only two species and a total of six foraminifera. Little palaeoenvironmental significance.
4 (185-85 cm)	*Gavelinopsis praegeri* is the dominant species, but the overall species diversity is much lower that in Zone 3. *Brizalina variabilis* occurs in higher numbers.
3 (365-185 cm)	A range of species dominated by nearshore shelf types,

	notably *Gavelinopsis praegeri*. The highest and most consistent number of total foraminifera found in the sample core occur in this zone.
2 (470-365 cm)	Brackish water lagoon taxa dominate, particularly *Haynesina germanica*, with low numbers of saltmarsh and nearshore shelf foraminifera.
1 (495-470 cm)	Low frequencies of the saltmarsh taxa *Trochammina inflata* and *Jadammina macrescens*.

Table 4. Grain size zones from West Winchelsea core

Zone (core depth cm)	**Characteristics**
Zone 3 (175-0 cm)	A sandy mud or mud, with a mean grain size comprising fine to medium silt. Typically sand (10%), silt (70%) and clay (20%). Very poorly sorted. Mean grain size 5-10µ.
Zone 2 (369-175 cm)	A sandy mud to muddy sand, with a mean grain size comprising medium to coarse silt. Typically sand (50%), silt (40%) and clay (10%). Poorly to very poorly sorted. Seven packages (A-G) of coarser and finer sediments (0.10 to 0.30 m thick). Mean grain size 10-60µ.
Zone 1 (519-369 cm)	A mud, with a mean grain size comprising fine to medium silt. Typically sand (10%), silt (70%) and clay (20%). Poorly sorted. Several of the lowermost samples are very clay-rich. Mean grain size 5-15µ.

List of Figures

Figure 7d Smoothed (seven point moving average) plot of sand layer thickness with estimated position of twice yearly equinoctial peaks marked from the West Winchelsea sample core

Figure 8 Frequency histogram of the height of the upper contact (in meters OD) to the main marsh peat in the Rye area. Accompanying map shows areas of marshland from which the data have been extracted.

Figure 9 Age/depth plot of radiocarbon dates from the upper surface of the main marsh peat. Site names locate individual data points shown on the accompanying map. Note that the highest index points tend to come from sites where the peats are thin or overlie relatively uncompressible sands or gravels (e.g. Scotney, Allen's Bank).

Figure 10 Radiocarbon dates from regressive and transgressive contacts from the Romney Marsh depositional complex. Note that the scatter in the regressive contact dates, which lie directly above relatively incompressible silts, is much less than that for dates from the transgressive contacts which come from the surface of a thick bed of peat.