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Evidence for Mediaeval soil erosion in the South Hams region of Devon, UK

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Abstract: A major theme of research into the causes of past and present soil erosion has been to determine the relative importance of climate and land-use change in influencing Holocene erosion rates. Previous work suggests that land-use change, especially the conversion of woodlands into agricultural land, is the main factor influencing long-term increases in soil erosion. A study of an extensive minerogenic sediment deposit in a wetland at Slapton Ley in Devon suggests that agricultural intensification occurred before the onset of sedimentation (a silty-clay layer *c.* 40 cm thick) in the valley-bottom wetland of the Slapton Sewage Works marsh. The base of the silty-clay layer lies at an altitude of between 2.2 and 2.6 m AOD and has been radiocarbon dated at two locations. Conventional radiocarbon ages ($\pm 2\ \sigma$) were 910 ± 160 yr and 960 ± 140 yr BP. Successful radiocarbon dating of the upper surface of this minerogenic layer at one location yielded a conventional radiocarbon age of 730 ± 120 yr BP. Within the errors associated with radiocarbon dating, the onset of sedimentation appears to be associated with a period of climatic deterioration towards the end of the Mediaeval Climatic Optimum. While agriculture plays an important role in exposing unprotected soil at certain times of the year, an increase in the magnitude and frequency of wet and severe winters may have led to a substantial increase in the risk of erosion. Contemporary analogues serve to illustrate the complex relationships which may exist between agricultural practices, climate and weather conditions and to explain why erosion is often localized and episodic in nature.

Key words: Soil erosion, weather, climate, agriculture, pollen analysis, mineral magnetism, Mediaeval period.

Introduction

A plethora of evidence now exists to suggest that periods of landscape instability played an important role in the geomorphological evolution of the British Isles in the late Holocene. In particular, research has focused on the formation of upland and lowland river systems and floodplains (e.g., Needham and Macklin, 1992; Brown, 1997) and the impact of land-use changes on alluvial and colluvial deposition (Boardman *et al.*, 1990; Boardman and Bell, 1992; Favis-Mortlock *et al.*, 1997). Possible causes of landscape instability in upland and lowland contexts have been a central theme of this research and basic climate-anthropogenic change models have been used to explain increased episodes of alluviation and colluviation (Tipping, 1992). The chronology of alluvial fans and debris cone sedimentation in upland environments in the British Isles show widespread evidence for phases of increased sedimentation rates in the late Holocene and particularly during the tenth to twelfth centuries and the sixteenth to nineteenth centuries (Harvey *et al.*, 1981; Innes, 1983; Harvey and Renwick, 1987; Brazier *et al.*, 1988; Brazier and Ballantyne, 1989; Tipping and Halliday, 1994; Anderson *et al.*, 2000). However, despite the apparent time synchroneity of these events, discerning the respective roles of climate and land-use change in controlling geomorphic activity remains a contentious issue (Ballantyne, 1991a; 1991b).

Agriculture and, to a lesser extent, mining, have been causally related to phases of geomorphic activity throughout the late Holocene, and soil erosion on agricultural land has had a significant impact on the British landscape since prehistoric times. Erosion of upland peat moors, for example, is often associated with grazing activity (Evans, 1992) and gully incision has been taking place for at least the last 250 years (Tallis, 1990). Alluvial and colluvial deposits in valley bottoms provide evidence for water erosion in the past and are often associated with woodland clearance and land-use change since Bronze Age times. For example, the onset of the deposition of alluvial soils around 3300 ± 90 BP, 1460 ± 80 BP and 290 ± 80 BP near Yeovil in Somerset has been used as evidence of increased human impact on hillslope erosion (Evans,

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1992). Industrial and agricultural activity during the Late Bronze Age and Iron Age correlate with minerogenic valley sedimentation in the Combe Haven valley in East Sussex (Smyth and Jennings, 1990) while woodland clearance and agricultural activity during the late prehistoric period has been linked with increased valley sedimentation rates (Brown and Barber, 1985; Tipping, 1992).

Macklin *et al.* (1992) suggest that patterns of Holocene river alluviation and river erosion in response to climate and cultural impacts can be viewed in terms of a continuum. At certain times each can control water and sediment yields but evidence from research in the Tyne basin (Macklin *et al.*, 1992) suggests that the fluvial regime, especially river erosion, is climatically driven. Human activity and climate change can therefore act individually or in combination to affect the soil and result in the same end-product, be it alluvium, colluvium, peat formation or erosion. Disentangling the role of human activity and climate change in forcing geomorphic activity has proved difficult (Bell, 1992). Advances in dating methods (e.g., Bailiff, 1992; Clark, 1992; Ellis and Brown, 1998) and the use of a variety of palaeoenvironmental techniques (pollen, charcoal, mineral magnetism, sediment chemistry) may partly address this problem by enabling researchers to explore major landscape forming events in more detail and by allowing them to ask more subtle questions about the causes, mechanisms and timing of landscape instability (cf. Jones, 1986; Tipping, 1992).

This paper attempts to address issues identified above in an exploratory analysis of a colluvially derived silty-clay layer found in a lowland valley infill adjacent to Slapton Lower Ley, South Hams, Devon. We present a range of field evidence and laboratory data (pollen, mineral magnetism, loss-on-ignition, sediment chemistry, particle size) in order to determine the most probable origins of this layer and to identify the timescale of deposition. Radiocarbon dating was employed to date the silty-clay layer, while pollen analysis, mineral magnetism, loss-on-ignition and particle size were used to reconstruct the cause of, and possible mechanisms controlling, its deposition in order to consider whether human activity, weather and climate may have interacted to initiate soil-erosion events in this area.

The Slapton village catchment

The research site is located in the South Hams region of South Devon (Figure 1, a and b; Ordnance Survey Grid Reference SX 8244). It forms part of the catchment of Slapton Lower Ley, a 77 ha shallow (max. depth 1.55 m) water body which developed as a result of the shoreward movement of sediment from the Skerries Bank as Holocene sea levels rose (Robinson, 1961; Hails, 1975). Radiocarbon dating suggests that the barrier was closed to the direct effect of marine processes at *c.* 2889 ± 100 radiocarbon years BP (Morey, 1976).

The Slapton village catchment (Figure 1c) trends NNW–SSE and comprises a minor component of the drainage area contributing to Slapton Lower Ley. It has a catchment area of 0.98 km^2, ranges in altitude from *c.* 129 m AOD in the north to *c.* 3 m AOD in the south and has an average valley-bottom gradient of 0.1024 m m^{-1}. Slapton village occupies the central section of the catchment and sewage effluent from the village is treated at a nearby treatment works and subsequently discharged to the Slapton Sewage Works marsh – a small wetland *c.* 80 m wide which extends upstream of the treatment plant for a distance of *c.* 300 m. The Slapton Stream joins the main valley of the Start Stream before discharging into Slapton Lower Ley (Figure 1c).

The catchment is underlain by slates, shales, siltstones and mudstones of Devonian age, although small areas of Permian sandstone outcrop within the Slapton village (Dineley, 1961; Brunsden, 1965). Soils of the Slapton catchment comprise typical brown earths of the Milford series. They are described as: 0–30 cm, dark reddish brown, moderately or slightly stony clay loam: 30–70 cm reddish brown, moderately stony clay loam; moderate fine subangular blocky structure; 70–85 cm extremely stony, with reddish brown stone coatings; single grain structure (Findlay *et al.*, 1984). The soils are well-drained and readily absorb winter

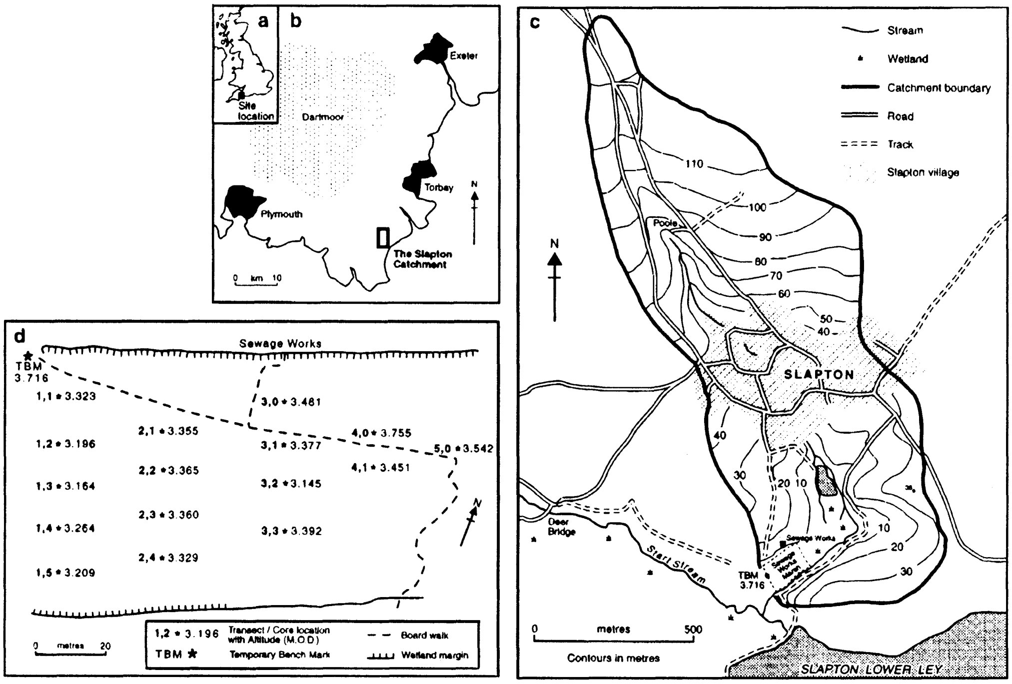

Figure 1 Location of the research area (a and b). Details of the Slapton village catchment (c) and details of the sampling area in the Slapton Sewage Works marsh (d).

rainfall. With their good structure they drain rapidly to field capacity and can be worked to a seedbed within one to two days of a wet period.

Mean annual precipitation for Slapton (1961–1993) is 1049 mm. Precipitation is highly variable, with monthly coefficients of variation exceeding 40% (Ratsey, 1975). Variability is greatest in spring and autumn. Most precipitation is associated with southwesterly and northwesterly airstreams from the Atlantic which account for 58% of the total precipitation and 57% of the rain days.

Field and laboratory methods

Stratigraphical descriptions, coring and sample collection has been undertaken within the Slapton Sewage Works marsh (Figure 1d). Cores for pollen analysis have been extracted using a 9 cm diameter Russian corer (Jowsey, 1966) at location 2,1 (Figure 1d). Since the Russian corer does not recover sufficient material for physical, geochemical and mineral magnetic analysis, additional samples were recovered by using 5 cm diameter plastic drainpipe hammered vertically into the sediments and retrieved using a tripod-mounted chain hoist. The use of drainpipe cores has resulted in some compaction and/or displacement of the silty-clay layer. The 33 cm of silty clay recovered by Russian coring for pollen analysis is equivalent to 25 cm recovered from drainpipe cores at an immediately adjacent site (within 1 m) following sampling. Two 1 cm thick peat samples were collected using a 9 cm diameter Russian corer at the upper and lower contacts of the clay layer for radiocarbon assay at coring locations 2,1 and 4,1 (Figure 1d). Samples were analysed at the Beta Analytic Laboratory, Miami.

Core samples for detailed laboratory analysis were collected at coring location 2,1 (Figure 1d). The Russian core was used to obtain subsamples for pollen analysis which were cut at 2 cm or 4 cm intervals while the plastic drainpipe core of *c.* 1.5 m length was split in the laboratory and sampled at 1 cm intervals. Each sample was weighed for the determination of wet bulk density and was subsequently oven-dried at 40°C overnight. Samples were reweighed for the determination of dry bulk density and subdivided for analysis of organic matter content by loss-on-ignition, particle size, mineral magnetic and geochemical properties.

Loss-on-ignition (LOI_{450}) was determined gravimetrically, following ignition at 450°C for 12 hours, in order to estimate organic matter content. The particle size distribution of each subsample was analysed using a Malvern Instruments laser granulometer. The diameter of the 10th, 50th and 90th percentiles and a measure of sorting (Span) were used to characterize the particle-size distribution (cf. Foster *et al.*, 1991). The total Mn content of sediment samples was determined by Flame Atomic Absorption Spectrophotometry following acid digestion (cf. Foster *et al.*, 1987).

All magnetic measurements were made on *c.* 10 ml soil and sediment samples. Low- and high-frequency susceptibility were measured using a Bartington MS2B dual-frequency sensor. ARM was measured on a Molspin fluxgate magnetometer after an anhysteretic remanence (ARM) was imparted by smoothly ramping down a mains frequency alternating field of 0.1 T while the samples were subjected to a steady field of 40 μT. Other remanence measurements were also made on a Molspin fluxgate magnetometer after subjecting samples to a forward magnetic field of 0.8 T and a reverse field of 0.1 T in a Molspin pulse magnetizer. These measurements allowed the derivation of IRM (0.8T and −0.1T), the S ratio and HIRM values (Table 1). Selected samples were subjected to a steadily increasing magnetic field at intervals between 0.025 and 0.8 T. IRM was measured immediately after magnetization and the remanence at each field was expressed as a percentage of saturation (assumed to be reached at a forward field of 0.8 T) in order to produce IRM acquisition curves. Measured and derived magnetic parameters, with their associated units, are given in Table 1.

Table 1 Measured and derived magnetic measurements

Property	Measured (M)/derived (D)	Instrument	Units
χ_{lf}	M	Bartington MS2B	10^{-6} m^3 kg^{-1}
χ_{hf}	M	Susceptibility Meter	10^{-6} m^3 kg^{-1}
χ_{fd}	D		10^{-9} m^3 kg^{-1}
$\chi_{fd\%}$	D		%
$ARM_{(40\mu T)}$	M	Molspin Variac	mAm^2 kg^{-1}
$IRM_{(0.025-0.8T)}$	M	Pulse Magnetizer	mAm^2 kg^{-1}
$IRM_{(-0.1T)}$	M	Molspin Fluxgate Magnetometer	mAm^2 kg^{-1}
S ratio	D	$(IRM_{(-0.1T)}/IRM_{(0.8T)}) \times -1$	dimensionless
HIRM	D	$(IRM_{(0.8T)} \times (1-S\ ratio))/2$	mAm^2 kg^{-1}

Subsamples of 0.5 cm thickness and 2 g wet weight were taken from the Russian corer and prepared for pollen analysis after Barber (1976). *Lycopodium clavatum* tablets were added to each subsample (Stockmarr, 1971) in order to calculate charcoal concentrations. At least 500 land pollen grains were counted for each sample, except for subsamples containing only a sparse amount of pollen, when the total land pollen count was restricted to 300. Pollen was identified with the keys of Faegri *et al.* (1989), Andrew (1984) and Moore *et al.* (1991) supported by comparison with photographs (Reille, 1992) and a modern type collection housed in the Geography Division at Coventry. Charcoal was analysed using the point-count estimation method described by Clark (1982).

Results

Stratigraphy and chronology of the Sewage Works marsh

A generalized stratigraphy for the marsh revealed over 6 m of sediment accumulation. A marked unconformity exists between inorganic silts and clays below 4.51 m depth and semi-fibrous peats above (Figure 2a). The inorganic silts and clays contain abundant marine and marine-brackish-water diatoms which are replaced by freshwater diatoms in samples collected in the clay layer just below the unconformity.

This unconformity probably occurred at the time of the final closure of the Slapton barrier beach and the isolation of the lagoon from marine influences. Independent radiocarbon dating has not been performed on overlying organic remains but it seems reasonable to suggest that the onset of organic accumulation began at *c.* 2889 ± 100 yr BP (2 σ) (Morey, 1976) (Figure 2a). While the overlying material is largely organic, occasional slate particles and thin silty-clay bands are encountered upcore to a depth of 1.2 m. At this point lies a second major unconformity comprising a 40 cm thick inorganic silty-clay layer with root fibres (Figure 2a). The extent and thickness of this silty-clay layer have been mapped and levelled using information from additional cores collected at locations given in Figure 1d. The levelled silty-clay layer surface is at a higher elevation and thickens slightly towards the southern boundary of the wetland (Figure 2, b and c).

The upper sample from core 2,1 (Beta-98113) gave a modern date, probably as a result of contamination from modern carbon

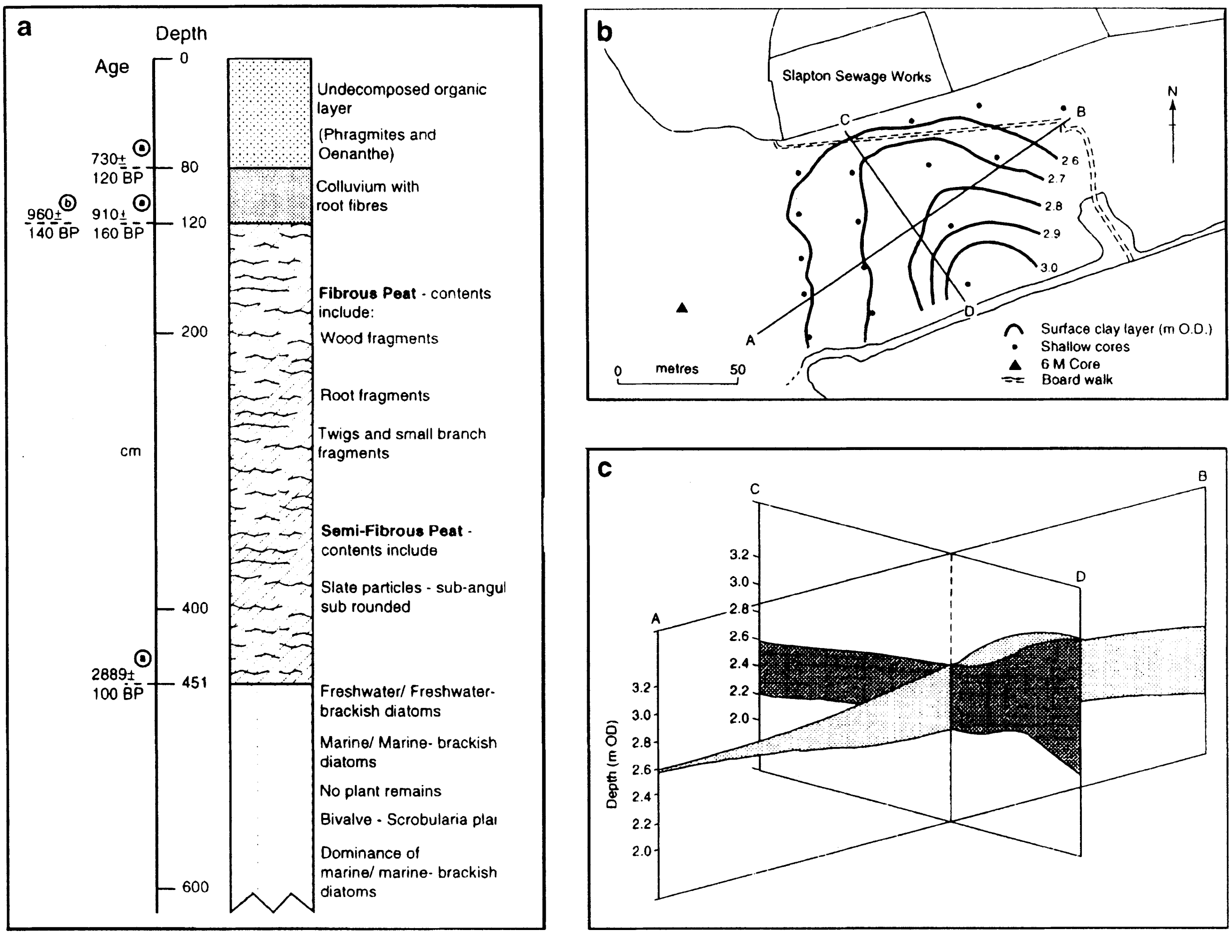

Figure 2 Stratigraphy of a 6 m long core retrieved from Slapton Sewage Works marsh (a) (coring location in b) (basal radiocarbon date from Morey, 1976; upper radiocarbon dates, this study ± 2σ: radiocarbon dates (i) from core 4,1 and (ii) from core 2,1, Figure 1d). Altitude of the surface of the silty-clay layer (b) and three-dimensional representation of the silty-clay layer (c).

from the sewage treatment works leaking into the wetland above the silty-clay layer. The basal sample (Beta-98114) gave a conventional radiocarbon age of 960 ± 140 BP (at 2 σ). The calibrated age of this sample, using the method of intercepts, is AD 1035 (between AD 1010 and 1175 at 2 σ). The upper sample from core 4,1, upstream of the sewage works and therefore unaffected by possible contamination (Beta-125171), gave a conventional radiocarbon age of 730 ± 120 BP (at 2 σ). The calibrated age of this sample is AD 1285 (between AD 1215 and 1325, and between AD 1340 and 1390 at 2 σ). The lower sample from the same core (Beta-125170) gave a conventional radiocarbon age of 910 ± 160 BP with a calibrated age of AD 1165 (between AD 990 and 1275 at 2 σ). Uncalibrated dates are given on the generalized stratigraphy of Figure 2a.

At two standard errors, the calibrated dates for the onset of deposition at the two coring locations are indistinguishable which suggests that, within dating errors, deposition was time synchronous and appears to have commenced at some time between AD 975 and 1275. The range of dates at 2 standard errors between the onset and cessation of deposition suggests that sedimentation could have occurred over timescales spanning as little as a few years to as much as *c.* 400 years.

Sedimentological and magnetic characteristics of the silty-clay layer

The dry sediment density averages 0.35 g cm^{-3} while the organic matter content of the clay layer averages *c.* 23%. The D50 particle size averages 15 μm while the 90th percentile of the cumulative particle-size distribution is of a medium to coarse silt (*c.* 45 μm). The sediments are relatively well sorted and Mn concentrations average 12 μg g^{-1}. Summary mineral magnetic characteristics are given in Table 2, which also includes comparative data for a range of topsoils and subsoils, screened through a 63 μm sieve and corrected for loss-on-ignition where appropriate, which were collected from the Slapton catchments.

Downcore trends in the dry:wet bulk density ratio and in LOI_{450} are given in Figure 3a. The two properties are inversely correlated. LOI_{450} approaches 50% in the upper 5 cm of the clay layer but averages less than 20% below 5 cm depth. Lower than average values are recorded between depths of 9 and 14 cm and 22 and 23 cm. Particle-size variations reflect both bulk density and organic matter trends (Figure 3b). Two fining-upwards sequences can be identified between 25 and 20 cm depth and between 18 and 12 cm depth. Upcore of 12 cm, particle size becomes coarser, with a distinctive peak at 6 cm depth. Mn concentrations (Figure 3c) decrease markedly from 25 cm depth to *c.* 18 cm depth, above which they show small fluctuations around a mean of *c.* 10 μg g^{-1}.

Downcore trends in mineral magnetic characteristics are given in Figure 4, a–d. χ_{lf} increases downcore to a peak at 5 cm depth, declines sharply to a minimum at 9 cm depth and decreases downcore below 11 cm depth. χ_{fd} and $\chi_{fd\%}$ show two distinct peaks, at 21 and 8 cm depth where $\chi_{fd\%}$ values exceed 4%. Between these peaks $\chi_{fd\%}$ values generally lie at *c.* 2%. ARM and the

Table 2 Summary statistics for soil samples collected in the Old Mill and Start catchments and for the silty-clay layer of the Slapton Sewage Works marsh (all samples corrected for loss-on-ignition)

	Slapton marsh silty-clay layer (n = 25)		Arable* topsoils (n = 20)		Grassland* topsoils (n = 16)		Woodland* topsoils (n = 9)		Subsoils* (n = 7)	
	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
X_{lf}	0.106	0.021	4.97	3.66	3.66	2.63	4.58	4.18	0.55	0.35
X_{fd}	2.121	1.644	458.61	192.58	366.34	289.12	459.85	439.58	61.1	21.43
$X_{fd\%}$	2.255	1.880	9.22	0.81	9.38	1.78	9.22	1.15	7.03	2.43
ARM	0.032	0.015	1.641	0.583	1.254	0.702	0.740	0.622	1.180	1.156
$IRM_{(0.8T)}$	2.124	1.078	32.99	13.46	24.35	14.33	19.37	14.13	7.69	3.29
$IRM_{(-0.1T)}$	−1.029	0.807	−29.76	12.43	−21.53	13.28	−17.55	13.46	−3.09	4.14
S ratio	0.537	0.273	−0.897	0.024	0.827	0.133	0.866	0.069	0.225	0.533
HIRM	0.305	0.147	1.43	0.56	1.18	0.54	0.70	0.30	2.30	0.624

*Data from Foster *et al.*, 1996; 1998.
Corrected for loss-on-ignition and based on analysis of the <63 μm fraction

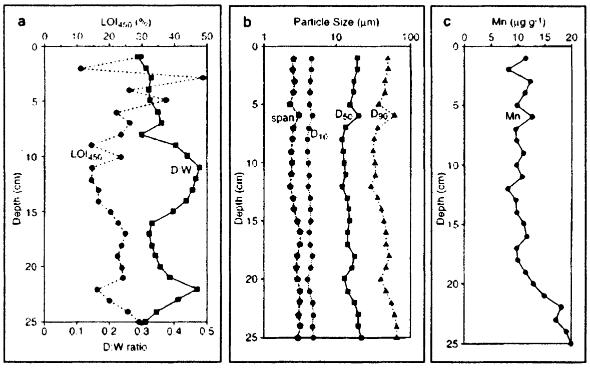

Figure 3 Loss-on-ignition, and the ratio of dry to wet bulk density (a), particle size (b) and the Mn concentration (c) for the silty-clay layer in the Slapton Sewage Works marsh. Depths relative to surface of silty-clay layer at coring location 2,1 (Figure 1d). Note that the coring method has resulted in some compaction of the layer when compared to depths presented in Figure 5.

S-ratio are plotted in Figure 4b and three minima are recorded in both parameters between 25 and 22 cm depth, at 9 cm depth and between 1 and 3 cm depth. Values of both ARM and the S-ratio are inversely related to X_{fd} and $X_{fd\%}$ (Figure 4a). $IRM_{0.8T}$ and HIRM are plotted in Figure 4c. Both parameters increase upcore and are positively correlated with ARM (Figure 4b). Trends in $IRM_{-0.1T}$ and the $IRM_{0.8T}$:X_{fd} ratio are plotted in Figure 4d. $IRM_{-0.1T}$ shows values close to zero at the onset and cessation of minerogenic deposition with more strongly negative values at *c.* 6, 13 and 18 cm depth. The $IRM_{0.8T}$:X_{fd} ratio shows major peaks at 24–21 and 8–9 cm depth. IRM acquisition curves for samples obtained from the silty-clay layer are plotted in Figure 4e, and Figure 4f plots envelope IRM acquisition curves for typical topsoils and subsoils, analysed on the <63 μm fraction, in the Slapton catchments (Foster *et al.*, 1998).

Pollen analysis

Pollen were counted and identified from a section of sediment between 50 and 150 cm depth to reconstruct the vegetational history before, during and after the deposition of the silty-clay layer. A pollen percentage diagram from the site is presented in Figure 5. The pollen diagram was drawn using the programme TILIA.GRAPH, version 2.0.b.5, designed by Grimm (1991). All pollen data are expressed as a percentage of total land pollen (TLP), excluding spores and aquatics. Spores and aquatic pollen taxa are expressed as percentages of total land pollen. A cross denotes a taxon representing one pollen grain. Plant nomenclature follows Stace (1991). The pollen diagram has been divided into four zones which are statistically defined using CONISS.

Interpretation

Causes of deposition of the silty-clay layer

Three possible explanations exist for the deposition of the silty-clay layer. First, it is conceivable that a change in the hydrological regime, or in the level of the outlet of the Ley to the sea, resulted in a temporary increase in water level which induced sedimentation higher up valley. Second, the sediment could have been deposited by a river meandering across the Slapton marsh valley. Third, the sediment could have been derived from within the catchment resulting from an increase in sediment delivery. Each of these explanations is evaluated below.

Temporary increases in water levels in Slapton Ley

Given that the base of the silty-clay layer ranges in altitude between *c.* 2.2 and 2.6 m AOD, its presence could conceivably be explained by the existence of a former high water level in the Ley inducing localized sedimentation. However, the detailed analysis of the stratigraphy of the freshwater lagoons provided by Morey (1976) suggests that freshwater peats accumulated in the Ley from −1.79 to −0.19 m AOD between 2889 ± 100 yr BP to 1813 ± 80 yr BP and contained no minerogenic sediments. This sequence was interrupted at the seaward margin by the deposition of a marine muddy sand which was subsequently overlain by a clay mud and diatom mud, the surface of the latter lying at *c.* 0.9 m AOD. The evidence provided by Morey (1976), and in a more recent review by O'Sullivan (1994), suggests that the early history of the site was associated with water levels much lower than the present day and that the Ley was shallow, clear and mildly productive. Indeed, it was not until 1856 that the outflow from the Ley was confined in a sluice and a weir was used to raise summer water levels. While this increase in water level has been used to explain the more recent sedimentation history in the Start valley (Foster *et al.*, 1996; Owens *et al.*, 1997) there is no evidence to suggest that the silty-clay layer discovered in the Slapton marsh was associated with a significant increase in the water level of the Ley and this explanation for the onset of deposition is subsequently rejected.

Deposition by a meandering river

The fine texture of the silty-clay layer and the field descriptions of this layer at 16 coring locations suggest that the sediments were not deposited within a meandering channel since contemporary

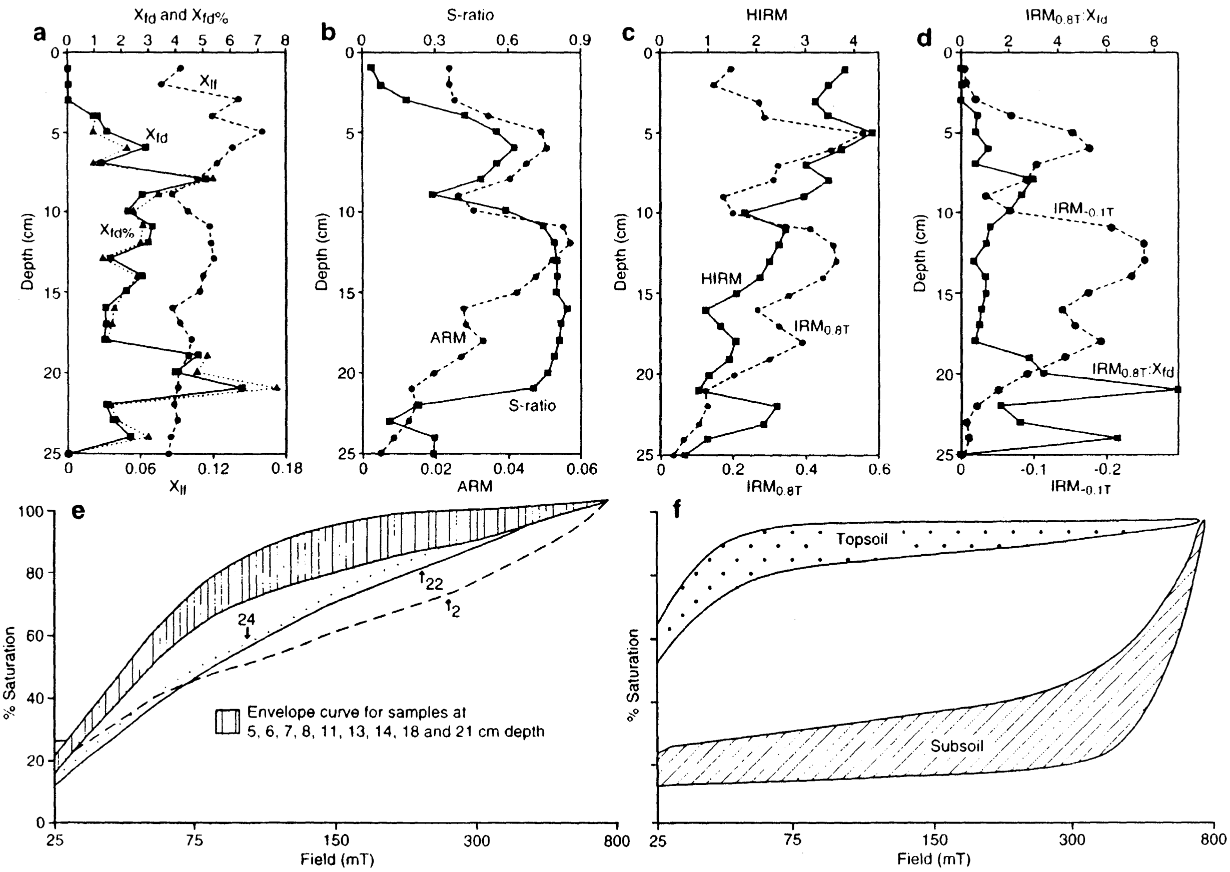

Figure 4 χ_{lf}, χ_{fd} and $\chi_{fd\%}$ (a), ARM and the S-ratio (b), IRM$_{0.8T}$ and HIRM (c), IRM$_{-0.1T}$ and the IRM$_{0.8T}$:χ_{fd} ratio (d) for the silty-clay layer in the Slapton Sewage Works marsh. Depths relative to surface of clay layer at coring location 2,1 (Figure 1d). IRM acquisition curves for 12 samples from the clay layer (envelope curve plotted for all samples except depths 2, 22 and 24 cm which are plotted as individual curves) (e) and characteristic IRM acquisition curves for topsoils and subsoils in the Slapton catchments (f) (after Foster *et al.*, 1996). Note that the coring method has resulted in some compaction of the layer when compared to depths presented in Figure 5.

in-stream deposits comprise substantial accumulations of coarse, platy and partly weathered slates. There is also no evidence, which might be provided by the preservation of sedimentary structures, to suggest that the deposit is associated with lateral accretion at the margin of a meandering river. The consistently fine-grained and structureless sediments are more typical of vertical (overbank) than lateral accretion deposits and it is unlikely that it was deposited by a river meandering across the marsh surface. This explanation for the deposition of the silty-clay layer is also rejected.

Derived from catchment sources

Since the evidence presented above provides little support for an increase in water level or deposition within, or at the margins, of a meandering river, it is suggested that the most likely explanation for the deposition of this silty-clay layer relates to an increase in the delivery of sediment from the contributing catchment. The following discussion evaluates the field and laboratory data in order to confirm this interpretation and attempts to identify the most likely source of the sediment within the catchment.

Contemporary cultivated topsoils in the Slapton catchments have a mean loss-on-ignition of *c.* 5.2% (range 2.3 to 10.7%, n = 62) while the organic matter content of the silty-clay layer generally lies between 10 and 30% (Figure 3a). Direct comparison of organic matter content between potential sources and the deposit is complicated by the likely effects of modern farming methods in reducing soil organic matter levels and by the preferential transport of organic matter due to its lower bulk density than mineral grains. Loss-on-ignition values are at a minimum at 2 cm depth, between 9 and 11 cm depth and at 22 cm depth suggesting periods when a major influx of minerogenic sediment occurred. The two fining-upwards sequences between 25 and 20 cm depth and 18 and 12 cm depth (Figure 3b) appear to end when LOI$_{450}$ values approach a minimum. Such a pattern might be commensurate with rapid influxes of minerogenic sediment over a relatively short period of time (single events to years) although the high organic matter content of the entire deposit might suggest slower sedimentation rates (decades to centuries).

The magnetic characteristics and pollen data provide evidence to support the hypothesis that the silty-clay layer can be traced to catchment soils. A Principal Component Analysis suggested that IRM$_{0.8T}$ and χ_{fd} provide unique and uncorrelated characterization of the magnetic 'remanence type' and 'susceptibility type' properties of the silty-clay sediments and the IRM$_{0.8T}$: χ_{fd} ratio is plotted in Figure 4d. Two distinct periods of high IRM$_{0.8T}$:χ_{fd} ratios are apparent. The first lies between a depth of 8 and 12 cm and the second between 19 and 24 cm. IRM acquisition curves for selected samples plotted in Figure 4e can be compared directly with envelope IRM acquisition curves for typical catchment topsoils and subsoils in Figure 4f. While the majority of samples demonstrate typical topsoil characteristics, samples at 2, 22 and 24 cm depth appear to contain a mixture of materials comprising both topsoils and subsoils which might indicate periods of subsoil/channel bank contributions.

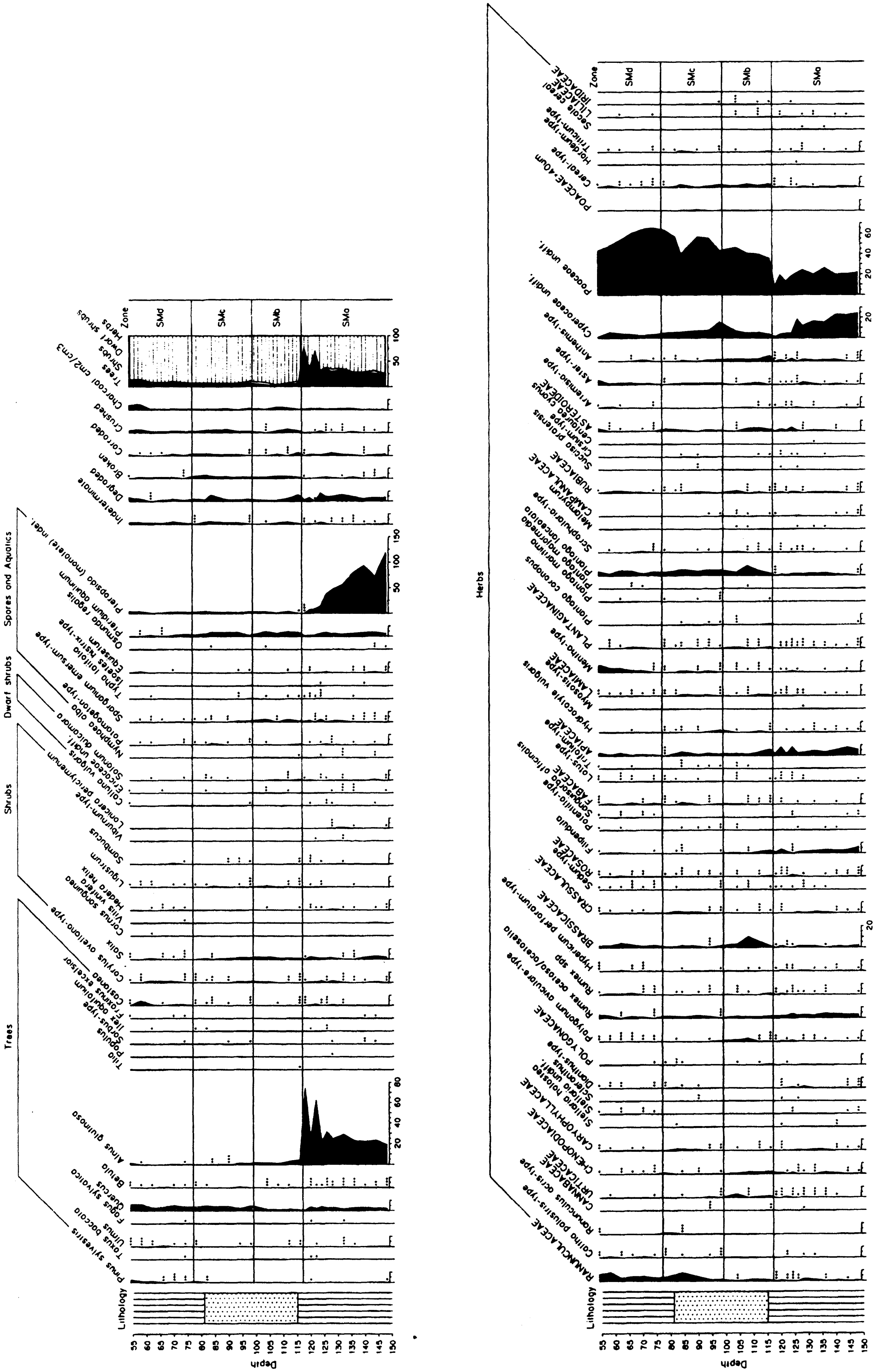

Figure 5 Percentage pollen diagram for Slapton marsh between 50 and 150 cm depth.

No attempt has been made to model sediment sources quantitatively since the data of Table 2 and Figure 4 provide evidence for poor preservation of the mineral magnetic record. In attempting to model sediment sources using mineral magnetic properties, a number of fundamental assumptions must be made regarding the post-depositional stability of the tracer. Recent research on the sediments of Slapton Ley and the Start valley floodplain in the catchment of Slapton Ley has suggested that the existence of strongly reducing conditions, coupled with the particle-size selectivity of tracer transport characteristics, makes quantitative source ascription problematic (Foster *et al.*, 1998). A similar problem can be identified in the Sewage Works marsh by examining the mineral magnetic concentration parameters of Table 2. Most magnetic concentration parameters in the silty-clay sediments of the Slapton Sewage Works marsh lie outside the range of values for typical catchment topsoils and subsoils, suggesting that both magnetite and hematite dissolution may occur in this waterlogged environment. Anderson and Rippey (1988) and Foster *et al.* (1998) have used sedimentary Mn concentrations to indicate the likely onset of reducing conditions and the possible dissolution of magnetic mineral assemblages. Manganese concentrations in the silty-clay layer were measured to assess the degree of dissolution (Figure 3c) and were compared with concentrations in other local sedimentary sinks. The results suggest that magnetic mineral dissolution has taken place, since Mn concentrations in the marsh sediments lie well below maximum concentrations recorded in the sediments of the nearby Old Mill reservoir and of Slapton Lower Ley (600 and 300 $\mu g\ g^{-1}$ respectively; cf. Foster *et al.*, 1998). While there remains the possibility that the sediments deposited in the Slapton marsh are derived from subsoil sources or channel-bank erosion, this seems unlikely given the evidence provided by the IRM acquisition curves which are independent of absolute concentration and may provide the strongest evidence for a topsoil origin of the deposited material.

A topsoil origin is also supported by the pollen data which appears to confirm the idea that agricultural sources provided the sediment deposited in the silty-clay layer. The preservation status of the pollen contained within this layer also shows evidence of reworking and/or transportation.

The pollen diagram provides evidence of the existence of a fern-rich fen/marsh which evolved into an alder carr. Throughout all four local pollen zones Poaceae and, to a lesser extent, Cyperaceae pollen are recorded in high values, while *Filipendula*, Rubiaceae and Apiaceae, and a suite of other non-arboreal pollen and spore taxa (e.g., *Hypericum*-type, *Hydrocotyle*, *Myosotis*-type, *Mentha*-type, *Caltha*-type, *Lythrium salicaria*, *Utricularia*, Iridaceae, *Chrysoplenium-type*, *Potamogeton*-type, *Nymphaea*, *Isoetes histrix*, *Nuphar*, *Sparganium emersum*-type and *Typha latifolia*), are regularly recorded in low percentages. Pterisopda (monolete) indet. (often referred to as Filicales) and *Alnus* are also well represented during zone SMa, suggesting that habitat conditions were favourable for the establishment of alder carr across a fern-rich fen/marsh in the damper parts of valley bottom (cf. Chambers and Elliott, 1989).

Of more interest here is the evidence for agricultural activity contained within the silty-clay layer. This layer contains a suite of non-arboreal pollen taxa normally associated with agriculture. Cereal-type and *Triticum* pollen are recorded in all zones, along with the occasional occurrence of *Secale cereale* and *Hordeum*-type, suggesting that cereal cultivation was practised in the catchment. Because of their large size, their tendency is to remain in their hulls as the dispersal of cereal pollen grains is limited and percentages of cereal pollen recorded in sediments can be low even when cultivation is taking place locally (Maguire, 1983). A number of taxa commonly associated with agricultural land also occur in the pollen record. Brassicaceae and *Polygonum aviculare* commonly occur in cereal fields and *Centaurea cyanus* is also an agricultural weed (Behre, 1981; 1986; Gaillard and Berglund, 1988).

Pronounced values for Poaceae, *Urtica*, Asteraceae, Ranunculaceae, *Plantago lanceolata*, *Rumex* and *Trifolium*-type suggest that some of the slopes surrounding Slapton marsh were also being grazed, although the latter three taxa are also common in wet meadows. Ruderal communities may well have occupied the zone between the field edge and the marsh. *Cirsium*-type, Chenopodiaceae, Urticaceae and *Plantago media/major* pollen, *Artemisia* and *Pteridium* spores are recorded and these taxa are common in ruderal communities (Gaillard and Berglund, 1988).

There is also evidence in the pollen record that values of taxa with agricultural affinities increase in the silty-clay layer compared with the lower and upper organic deposits. Pollen values for cereal and *Triticum* are higher in the silty-clay layer, and other taxa associated with agricultural activity also increase or peak in the basal part of this deposit, for example Brassicaceae, *Plantago lanceolata*, *Polygonum aviculare*-type, Fabaceae and *Aster*-type pollen. Poaceae undiff. values also increase. Thus the pollen record from the silty-clay layer supports the idea that it has been eroded from previously cultivated soils.

An analysis of the preservation of the pollen suggests that the silty-clay layer contains higher amounts of crushed and, to a lesser extent, corroded pollen (*sensu* Moore *et al.*, 1991). Crushed pollen is considered to be indicative of mechanical damage during transport. Although these grains represent a small proportion of the total pollen sum (<10% TLP in all zones), the data suggest that some of the pollen has been reworked, which supports the idea of soil erosion. Evidence of pollen grain corrosion is usually attributed to microbial activity 'in which fungi and bacteria are responsible for the local oxidation of the exine which occurs under conditions of at least periodic oxidation' (Moore *et al.*, 1991: 170) which is appropriate for pollen derived from an agriculturally worked soil rather than a waterlogged, organic substrate.

While some of the increases in non-arboreal pollen percentages might be explained by an intensification of agriculture which occurred immediately prior to deposition, which facilitated the movement of sediment from the catchment slopes, these changes might also be an artifact of decreasing *Alnus* values. *Alnus* pollen percentages decrease dramatically following the deposition of the silty-clay layer at the start of zone SMb. It is difficult to ascertain the abundance of woodland as *Alnus* is a prolific pollen producer and can be over-represented in the pollen record (Janssen, 1959) and therefore mask pollen derived from the rest of the catchment. The loss of this local pollen source will have resulted in a change in pollen input and this possibly created an apparent rise in non-arboreal pollen.

In contrast to previous work, woodland clearance cannot be implicated as a direct causal factor of soil erosion in this instance. The pollen evidence suggests that the Slapton catchment had lost most of its woodland cover during the prehistoric period as arboreal pollen values shown in this section of the core, with the exception of *Alnus*, are low, below 10% TLP. A small area of mixed oak woodland appears to have been present in zones SMa to d, probably on the slopes of the valley. *Quercus* pollen is recorded between 2 and 5% TLP accompanied by regular, low percentages of *Corylus*, *Betula* and *Ulmus* and occasionally *Castanea*, *Taxus*, *Fagus*, *Pinus*, *Fraxinus*, *Populus* and *Tilia*. Hazel may have formed part of the understorey of this woodland with *Hedera, Ligustrum*, *Sambucus*, *Sorbus*-type, *Viburnum*-type, *Cornus sanguinea*-type and *Lonicera periclymenum*-type, all of which are recorded in the pollen record in low values in one or more of the zones.

The majority of the evidence provided above appears to support the contention that the silty-clay layer was derived from an increase in the delivery of sediment from the upstream catchment and was most probably derived from topsoil erosion. The following section considers available evidence in order to identify the most likely causal mechanism.

Causes of increased soil erosion

Agriculture and agricultural change

While further research is required, documentary evidence supports the pollen evidence that agricultural activities were exposing the soil to erosion and that the landscape was largely cleared of woodland by 900 radiocarbon years BP. According to Stanes (1983) it seems likely that people have been living in the Slapton area for the past 3000 years and possibly since Mesolithic times (Riley, personal communication). Bronze Age burial sites exist within the present village and an Iron Age fortification (Slapton Castle) exists on a hilltop location in the Start catchment. However, there is a large gap in history (the Dark Ages) until the Domesday survey of 1086 which suggests that large-scale clearance had already taken place by the time of the Norman conquests. Enclosure did not occur in this area, however, until the fifteenth century. Domesday identifies the presence of a flourishing agricultural community farming traditional open-field systems, and the records suggest that the village supported a population of *c.* 240 (Stanes, 1983). The Domesday record also shows that the South Hams had more plough teams per 1000 acres than all the rest of Devon *c.* AD 925, with the exception of the Exe valley, suggesting that farming was principally arable (Stanes, 1983).

Under Norman occupation, traditional farming methods were superseded by new techniques which had an impact on soil erodibility. A two- and three-rotation system with one year of fallow evolved in the Middle Ages and was common practice by the thirteenth century when population pressure induced an increase in the area of cultivated land. Recent studies suggest that erosion is more prevalent as the land is sown for crops, especially if spring-sown, and when under fallow. Evans (1990a) suggests that spring-sown crops facilitate erosion as they take a long time to germinate at a time of year commonly threatened by heavy storms. Indeed, Vancouver (1808) reported that winter rains and snowmelt led to severely eroded soils in Devon. Land worked downslope and the introduction of Mediaeval ridge and furrow would also facilitate water erosion (Evans, 1990a).

The role of weather/climate

While the evidence to link the silty-clay layer to agricultural soils is the best-supported hypothesis, the data does not adequately explain the timing of the deposition of the silty-clay layer or determine what triggered this period of landscape instability. It has been argued so far that the most plausible explanation for the source of the silty-clay layer is agricultural and that sediment has been transported into the marsh from the upstream catchment by surface erosional processes. Historical climate data for the British Isles suggest that weather conditions, especially increased precipitation and runoff, were more favourable for soil erosion at the time of deposition. Figure 6 shows the relationship between the calibrated radiocarbon dates above and below the silty-clay layer in relation to the frequency of wet winters and severe winters per decade as reported for the Mediaeval period for the British Isles. This climatic data compilation was derived from historical documentary sources by Britton (1937). The data demonstrate the rapid increase in the frequency of wet and severe winters per decade towards the middle of the thirteenth century which marks the end of a period often referred to as the Little Climatic Optimum. This warm period was a short-lived episode believed to have occurred between *c.* AD 700 and 1300 (Bell and Walker, 1992). The detailed documentary descriptions provided by Britton (1937) testify to a number of extremely wet winters and violent storms occurring throughout the twelfth and thirteenth centuries which affected large areas of the British Isles. While a lack of precision in the radiocarbon chronology precludes the establishment of a

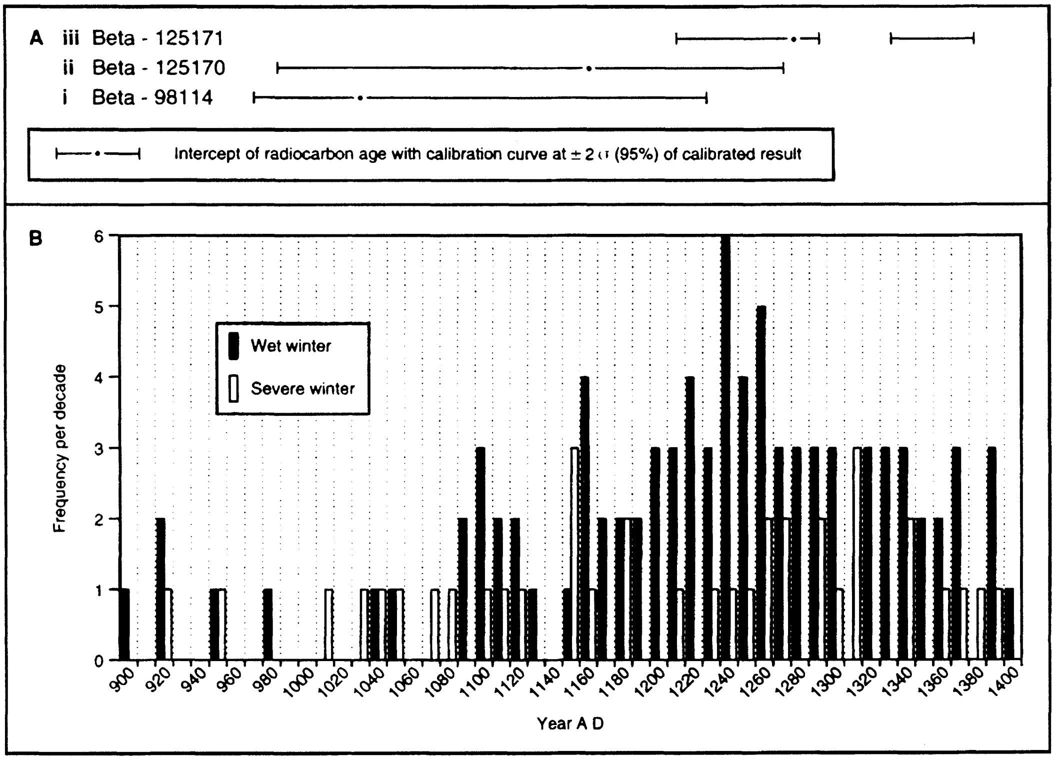

Figure 6 Calibrated radiocarbon ages (± 2σ) of peat underlying and overlying the silty-clay layer in the Slapton Sewage Works marsh (a) with the frequency of wet and severe winters per decade for the period AD 900 to 1400 (compiled from data in Britton, 1937).

precise link between a particular event and an erosional episode, it is not unreasonable to suggest that erosional events might have occurred in one or several of these years provided that soil tillage conditions (e.g., recently prepared seed bed) maximized the impact of rainfall (cf. Foster and Lees, 2000). If the erosion occurred towards the end of the Mediaeval Warm Period as climate deteriorated, it also seems reasonable to suggest that high-intensity or more frequent storms may have triggered localized erosional events including the Mediaeval minerogenic floodplain accumulation at Slapton marsh. Events of this type are well documented in contemporary soil-erosion studies and large amounts of eroded soil are often redistributed at slope-foot and/or in valley-bottom locations (cf. Evans, 1990b; Boardman, 1990; 1991; 1995; 1996; Evans, 1995; Boardman *et al.*, 1996; Foster *et al.*, 1997).

The occurrence of this depositional event towards the end of the Little Climatic Optimum also correlates with phases of known increases in rates of alluvial fan sedimentation in upland environments reviewed in the introduction. While time synchroneity is not proof of common causality, the apparent widespread distribution of geomorphic responses in a range of environments might provide circumstantial support for a climatic rather than an anthropogenic interpretation.

Conclusions

The silty-clay layer of Slapton Sewage Works marsh is the first known example of medieval soil erosion and valley sedimentation in the South Hams of Devon. The existence of this layer suggests that medieval cultivated open fields may have occasionally been subject to erosion and that the valley-bottom deposition recently identified in the Start catchment (cf. Foster *et al.*, 1996; Owens *et al.*, 1997) provides evidence to support the idea that this is not the first time that this region has witnessed phases of sedimentation associated with soil erosion on agricultural land. The regional significance of this event is unclear, although preliminary coring in the adjacent Start catchment has revealed the existence of an extensive, but as yet undated, silty-clay layer in a similar geomorphic and sedimentary environment.

The results from Slapton suggest that erosion occurred as a result of a combination of climate, weather patterns and human activity. Pollen data suggest that woodland clearance was not a direct causal factor initiating soil erosion and that agricultural activity was practised in the catchment for a considerable period before this layer was deposited. Antecedent conditions, especially pre-ripening by cultivation, followed by an increase in the magnitude and/or frequency of wet and severe winters may explain the timing of deposition. Consideration of climate, weather, socio-economic conditions, agricultural practices, soil type and topographical location are needed before the relationship between past soil erosion, human activity, weather and climate can be fully understood. In common with previous work (e.g., Favis-Mortlock *et al.*, 1997), this study is limited by inadequate information regarding socio-economic conditions and detailed evidence of past agricultural practices. Notwithstanding these deficiencies, additional errors imposed by the precision of the radiocarbon dating and the difficulties in reconstructing agricultural history solely from pollen records, we suggest that agricultural intensification is insufficient on its own to account for the presence of the silty-clay layer in the Slapton marsh. Preconditioning by agriculture may lead to a greater sensitivity of the landscape to climate change, and changes in the magnitude and/or frequency of more severe weather conditions may subsequently lead to an increase in sediment yield; a pattern which has been recently documented for a period of climate change in Midland England over the last 40 years (cf. Foster, 1995; Wilby *et al.*, 1997).

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