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THE CHANGING ESTUARINE ENVIRONMENT IN RELATION TO HOLOCENE SEA-LEVEL AND THE ARCHAEOLOGICAL IMPLICATIONS

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Estuarine development has been previously modelled in relation to the rate of relative sea-level rise, suggesting intertidal surfaces attain different vertical positions within the tidal frame according the rate of sea-level rise. These model results are significant in the context of Holocene sea-level rise, which experienced a continuum of very rapid to low sea-level rise rates, in that the estuarine palaeoenvironment and its resource potential for prehistoric populations is suggested to have changed through time. The present study empirically investigates the palaeoenvironmental development of the Somerset Levels (UK), an extensive coastal wetland (palaeo-estuarine system) that is of international archaeological importance. A composite sequence of Holocene sediments is analysed using foraminiferal and molluscan-based palaeoenvironmental techniques, and dated through radiocarbon and chemostratigraphic methods. The results indicate that during the Early Holocene (Mesolithic) the estuary was dominated by low saltmarsh and mudflat palaeoenvironments dictated by the rapid rate of post-glacial sea-level rise. This intertidal surface, low within the contempory tidal frame, would have been characterised by soft mud and sparse vegetation due to frequent tidal indundation, and would have possessed a high hydraulic duty (cf. the amount of tidal water accommodated by the surface) with associated large tidal creeks/channels. Towards the Middle Holocene (Neolithic) a transition to palaeoenvironments higher within the tidal frame is evident, so that mid and then high saltmarsh dominate the estuary. This transition was in response to a progressively decreasing sea-level rise rate, allowing the intertidal surface to elevate through the tidal frame. These intertidal surfaces are likely to have become progressively drier and more richly vegetated due to increasingly infrequent tidal inundation, with a corresponding reduction in hydraulic duty and creek/channel size, culminating in emergence and supratidal peat growth. The results also suggest that this sequence is reversed through the Late Holocene (late Neolithic, Bronze Age, Iron Age) so that Roman reclamation of the Somerset Levels took place against a rising sea-level. These data support previous theoretical models, and have significant implications for the resource potential of these changing estuarine palaeoenvironments for prehistoric populations.

Introduction

The modern European estuarine environment comprises a range of depositional settings from coarse-grade (e.g. gravel) deposits low within the intertidal zone, to fine-grade (e.g. silt) deposits high in the tidal frame, and supratidal organic (e.g. peat) deposits (Dalrymple *et al.*, 1992; Allen, 2000a; Haslett, 2000). Holocene estuarine evolution is recorded in numerous sedimentary archives, many of which now form extensive reclaimed coastal lowlands that fringe remaining active estuarine systems. These sediment archives commonly comprise a combination of minerogenic and organogenic lithologies, often as silty-clays and localised sands, and peat deposits respectively. The deposition of these sediments has been influenced by a number of factors, including minerogenic/organogenic sedimentation, sea-level behaviour, and compaction of the accumulating sediment body (Allen, 1990). A 'standard' Holocene lithostratigraphic sequence has been suggested by Allen (2000a), accreting in relation to post-glacial rise in sea-level, consisting of (1) a basal peat resting on pre-Holocene basement and deposited prior to marine inundation, (2) silts and sands deposited during the early Holocene phase of rapidly rising sea-level, (3) an interval of intercalated silts and peats approximately spanning 6000-2500 BP and reflecting the mid-Holocene slowing of the sea-level rise rate, and ultimately (4) a late-Holocene period of further silt deposition. The depositional environments that these lithologies represent, include both tidal flat/saltmarsh (intertidal) silts and freshwater/terrestrial (supratidal) peats, but also occasionally saltmarsh peats.

The archaeological potential of these sediments is being realised, but most archaeology, however, has been forthcoming from deposits dating from the mid-Holocene onwards, and especially in peat (e.g. Coles and Coles, 1986; Allen and Rippon, 1997; Bell and Neumann, 1997; Bell *et al.*, 2000). These supratidal peat marshes would have 'afforded many favourable occupation sites from which the associated terrain and waters could be exploited' (Allen, 2000a, 1210) and it is, therefore, unsurprising that they are relatively rich in artefacts. Minerogenic saltmarshes, however, are more frequently flooded, making permanent settlement unlikely, but not impossible (Rippon, 2000b), although these 'unsettled marshes could still be used seasonally for grazing and, on an occasional/seasonal basis for salt-making, hunting, wild-fowling, fishing and reed-cutting' (Allen, 2000a, 1211). The exploitation of resources from these estuarine environments by human communities is, therefore, highly dependent upon the position of the surface relative to the tidal

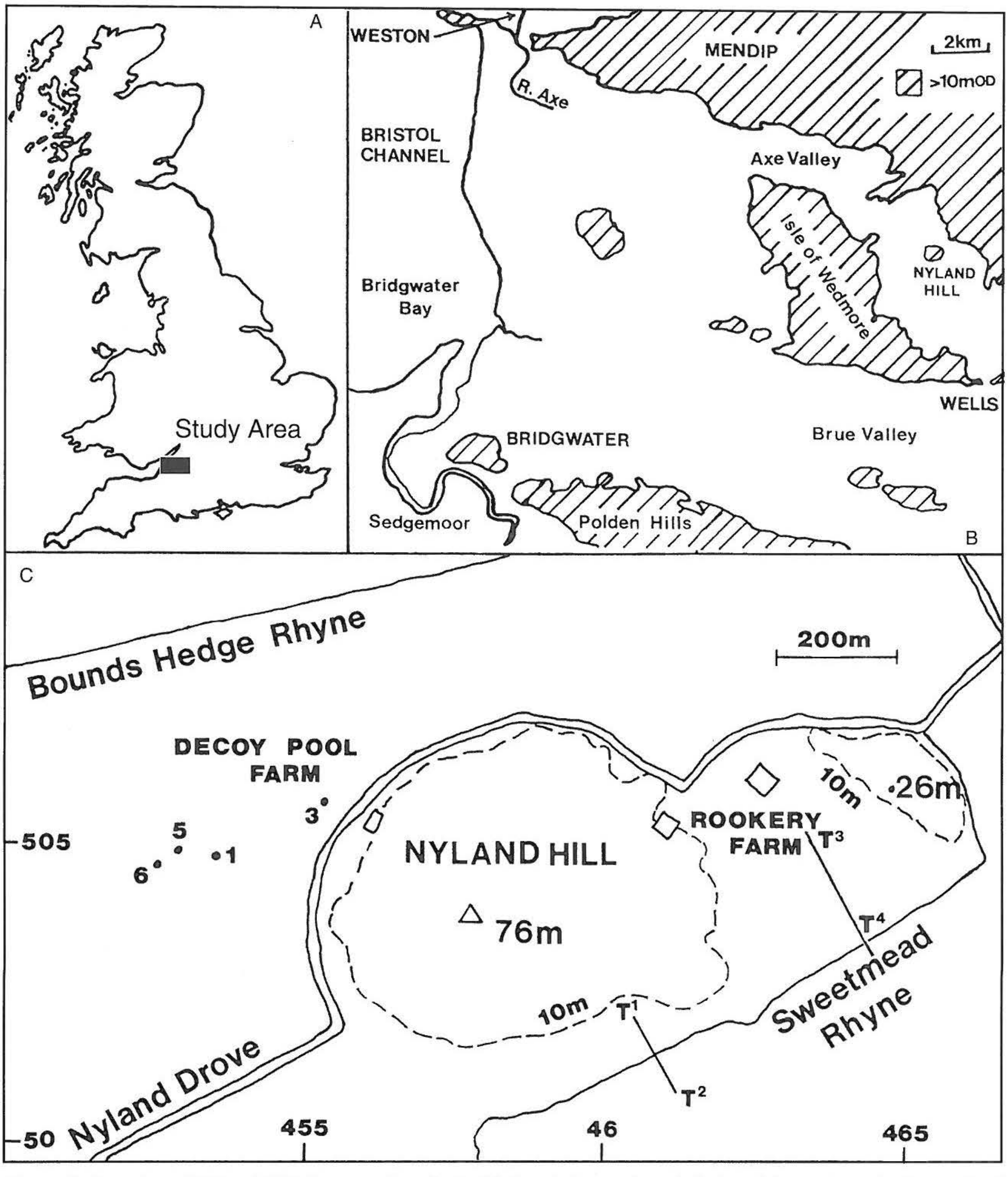

Figure 1: Location of Nyland Hill, Somerset Levels. In (c), borehole numbers 1, 3, 5 and 6 constitute the Decoy Pool Farm site (Figure 3), T1-T2 indicates the Rookery Farm transect position (Figure 4), and T3-T4 indicates the Big Basin transect position (Figure 5). Ordnance Survey grid references are prefixed ST.

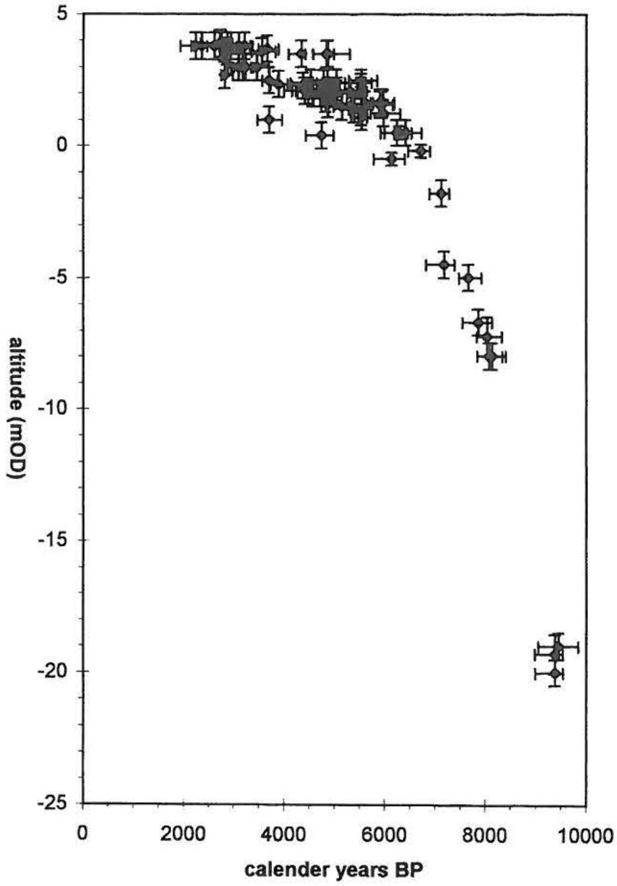

Figure 2: Age/altitude plot of samples from Heyworth and Kidson (1982). These data were taken from their Table 4, under headings 'Bridgwater Bay and Somerset Levels' and 'Somerset Levels-Wooden Trackways'. Dates are in calendar years BP and have been calibrated from the original 14C dates using the CALIB programme of Stuiver and Reimer (1993). Data points represent the intercept age, the x-axis error bars indicate the 2s age range, and the y-axis error bars are altitudinal errors assigned by Heyworth and Kidson (1982) (from Haslett et al., *1998a,b).*

frame. Indeed, even within a saltmarsh environment, particularly in a macrotidal estuary, there is distinct resource variation between low and high saltmarsh settings, principally influenced by the position of the saltmarsh surface relative to the tidal frame, which determines frequency and duration of tidal inundation, and the resultant altitudinal zonation of halophytic vegetation.

In order to begin to appreciate the resource potential of Holocene estuarine environments for prehistoric communities, and to evaluate the potential of sediments from the various environments to yield artefactual evidence, it is essential that the depositional environment of these sediments be established, especially in relation to sea-level and the prevailing tidal frame. Using theoretical numerical models, Allen (1990, 1995) and French (1993) investigate the development of saltmarshes in relation to (amongst other factors) the rate of sea-level rise. They conclude that a saltmarsh developing alongside a stable rate of sea-level rise is predicted to attain, and then remain constant (relative to the tidal frame) at, an elevation that is lower than the highest tide level. However, the elevation is predicted to be relatively lower within the tidal frame under a rapid rate of rising sea-level, and conversely higher within the tidal frame when the rate of sea-level rise is slower. Allen (1990) provides some supportive tests for his model, but these tests are performed on historic saltmarsh sediments and therefore, do not span the range of Holocene time and, of secondary importance, may not provide entirely analogous scenario's for prehistoric Holocene environments, that probably did not experience the level of human interference experienced by saltmarshes during historical times. French (1993) also suggests that variation in the sediment concentration of tidal waters may also influence the position attained by the surface within the tidal frame.

The present paper aims to empirically investigate Holocene estuarine depositional environments in relation to the rate of sea-level rise, to evaluate resources available for use at a given time by prehistoric communities, and to assess the archaeological potential of these sediments. The area chosen for this study is the Somerset Levels in southwest Britain (Figure 1). The Somerset Levels are a major coastal lowland system, now largely reclaimed, comprising a series of east-west trending valleys (Axe, Brue, and Sedgemoor valleys) buried by a substantial infill of Quaternary deposits (Kidson and Heyworth, 1976). The Holocene sequence is >20 m thick and is generally equivalent to the 'standard' sequence of Allen (2000a) described above, except that in the inner Brue Valley, the final phase of silt deposition is not present, and archaeologically-rich peat extends up to the ground surface (Coles and Coles, 1986). Holocene sea-level change in the Somerset Levels has been investigated by Hawkins (1971a, b), Kidson and Heyworth (1973, 1978), Heyworth and Kidson (1982), and Haslett *et al.* (1998a), and a sea-level curve for the region is given in Figure 2. This sea-level curve, notwithstanding concerns expressed by Haslett *et al.* (1998a), is employed for comparison with depositional environments established in this study for Holocene sediments recovered in the field using manual borehole techniques. Depositional environments are established here mainly through the application of foraminifera microfossils (Haslett *et al.*, 1998b), but also molluscs where they occur. Dating of the investigated Holocene sequence is performed through radiocarbon analysis of lithological contacts between minerogenic silty-clay and organic peat deposits, and also through chemostratigraphy related to Roman and post-Roman lead mining on the nearby upland area of Mendip (Figure 1). This geochemical connection between the Somerset Levels and the Mendip Hills, serves to highlight the close relationship between adjacent wetland and upland areas in terms of human activity and palaeoenvironmental records (cf. Louwe Kooijmans, 1993). This relationship is currently being examined, in part stimulated by recent appreciation of the archaeological and palaeoenvironmental potential of Mendip Holocene calcareous tufa deposits (Davies *et al.*, 2001).

Methods and Results

Study area and lithostratigraphy

The study area is centred around Nyland Hill (National Grid Reference ST461 503) situated in the Axe Valley, part of the Somerset Levels (Figure 1). Nyland Hill rises abruptly on all sides from the Levels at *c.* 6 m OD (Ordnance Datum, Newlyn) to its summit at *c.* 76 m OD. The site is *c.* 18 km from the present Axe Estuary at Weston-super-Mare on the Bristol Channel, a macrotidal coast with a maximum tidal range of 14.5 m at Avonmouth (Bristol). The solid geology of Nyland Hill comprises Carboniferous Limestone and Permo-Trias deposits (Green and Welch, 1965). The Holocene sequence around Nyland Hill has been described by Haslett *et al.* (1998a) from two borehole transects, at Decoy Pool Farm (boreholes 1, 3, 5 and 6) and Rookery Farm (T1-T2) (Figure 1). A new transect (T3-T4) is reported here, referred to as the 'Big Basin' transect, as it is situated within a significant embayment that separates Nyland Hill from a small outlying hill to the north-east with a summit altitude of *c.* 26 m OD (Figure 1).

The Decoy Pool Farm transect (Figure 3) is situated towards the centre of the Axe Valley and records a *c.*10 m portion of Allen's (2000a) 'standard' sequence, comprising a lower silt, middle peat and upper silt. This tripartite lithostratigraphic subdivision of Holocene sediments was correlated by Haslett *et al.* (1998a) with the Lower, Middle and Upper Wentlooge Formation of Allen and Rae (1987) from the Severn Estuary. Bowen (1999) has erected the Somerset Levels Formation (SLF) for the Holocene sediments of the Somerset Levels, which

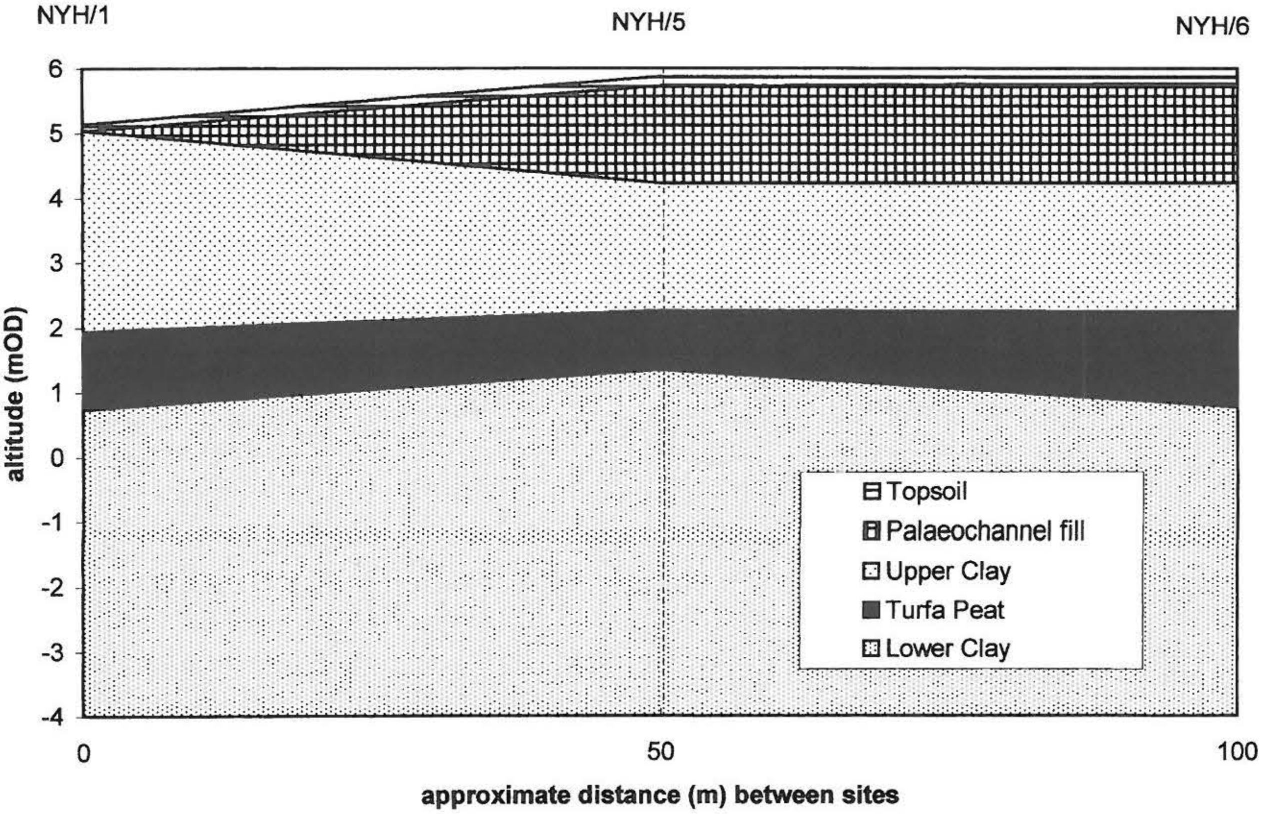

Figure 3: Lithostratigraphy of selected sites from Decoy Pool Farm, Nyland Hill, Somerset Levels (updated from Haslett et al., 1998a). Turfa peat = terrestrial peat.

Haslett *et al.* (2001a) have subsequently subdivided into the Lower, Middle and Upper SLF. Haslett *et al's* (1998a) borehole objective at Decoy Pool Farm was to maximise depth penetration, therefore, these borehole sites were located either in extant drainage ditches (NYH/1 and 3) or in a palaeochannel (NYH/5 and 6). This was unreported by Haslett *et al.* (1998a) and has two important implications regarding the upper silt; first, the uppermost upper silt is missing in all Decoy Pool Farm boreholes, and second, the top *c.* 1.5 m of deposits recovered from sites NYH/5 and 6 represent palaeochannel infill (discussed below), and there is likely to be an erosional contact between this fill and the underlying Upper SLF silt.

The Rookery Farm transect is situated on the southern flank of Nyland Hill (Figure 4) and was sited in order to investigate the relationship of Holocene sediments onlapping basement. Haslett *et al.* (1998a) record the Middle SLF peat dipping away from Nyland Hill, mirroring the basement slope. The Upper SLF silty-clay overlies this and attains a quasi-horizontal surface at *c.* 5.5-6 m OD. It was in this transect that peat compaction of 2.22 m was proven with a 3.16 m overburden of silty-clay, an observation which has highlighted the severe problem of compaction in coastal Holocene sequences (Allen, 1999, 2000b; Crooks, 1999). Figure 4 includes two borehole sites (NYH/17 and 18) and other data added subsequent to Haslett *et al.* (1998a), but shown in Haslett (2000, 146), which help to further resolve general lithostratigraphy, basement topography and maximum altitude of the Upper SLF surface.

The lithostratigraphy of the new 'Big Basin' transect is shown in Figure 5. This transect was surveyed in 1997 using an Eijkelkamp gouge, and sediment samples for laboratory analysis were collected using a Russian-type corer. The altitude of the ground surface at each borehole site was established relative to OD using a Leica Total Station TC400. Boreholes are numbered 1-12 and prefixed NYH/97. The aim is to investigate a long transect that incorporates the Holocene sediment and basement interactions on the flank of Nyland Hill, and also extends far enough away from the hill so as to link up with the tripartite sequence observed at Decoy Pool Farm. The lithostratigraphy recorded in Figure 5 fulfils this aim, with the Lower, Middle and Upper SLF present. The Lower SLF is >3 m thick at sites NYH/97-1 and 2, where basement was not reached. The upper surface is horizontal at 0 m OD from NYH/97-1 northwards to NYH/97-7. Further north from NYH/97-9, it wedges out to NYH/97-7, but then extends up basement slope to the north end of the transect, as a relatively thin (<0.5 m) layer that obtains a minimum altitude for its upper surface of 3.64 m OD at NYH/97-11. The Middle SLF is represented in the main by a thick

Figure 4: Lithostratigraphy along the Rookery Farm transect, Nyland Hill, Somerset Levels. T1-T2 refers to transect line shown on Figure 1 (based on Haslett et al., 1998a, and Haslett, 2000). Turfa peat = terrestrial peat.

dark-brown terrestrial peat (with occasional wood and *Phragmites*), as at both the Decoy Pool Farm and Rookery Farm transects. However, an isolated thin pale-brown limnic peat (deposited in open water) is recorded at the base of the Middle SLF at NYH/97-1, and a more substantial layer is observed over 60 m of the transect, extending up basement slope from NYH/97-8 to the NE end, where at both NYH/97-3 and 11 this limnic peat is directly overlain by silty-clay of the Upper SLF. The Upper SLF blankets the upper surface of the terrestrial and limnic peat deposits, increasing in thickness to the southeast as bedrock descends to increasing depths allowing maximum compaction of the peat. A modern soil occurs on the sub-horizontal upper surface of the Upper SLF, comprising a thin organic-rich (autochthonous) brown soil.

Dating

Four radiocarbon (^{14}C) dates are employed here to provide chronologic constraint for the onset and termination of Middle SLF peat (Table 1). The Middle to Upper SLF contact along the Rookery Farm transect (Figure 4) is dated by Haslett *et al.* (1998a) at 3640-3330, 3715-3460, and 3725-3465 calendar years before present (cal. yrs BP) (1950). The Lower to Middle SLF contact is dated at NYH/97-7 along the 'Big Basin'transect (Figure 5) through a new Accelerator Mass Spectrometry (AMS) ^{14}C date of 6855-6490 cal. yrs BP. In addition to ^{14}C dating of peats, Haslett *et al.* (1998a) were able to assign a date to the reclaimed surface that is close to the present landsurface. This was achieved through chemostratigraphic techniques utilizing the onset of Roman Lead mining on the nearby Mendip Hills. A reclamation date of AD 130-221 was obtained using this technique, which overlaps an independent artefactually-derived date of AD 138-296. The same technique is applied here to date sediment infilling the palaeochannel at Decoy Pool Farm, into which boreholes NYH/5 and 6 were cored. Borehole NYH/5 is geochemically analysed for Lead (Pb), Zinc (Zn), Copper (Cu) and Nickel (Ni) using flame atomic absorption spectrophotometry. All samples were air-dried, sieved to obtain <200 mm fraction, and dissolved for spectroscopic analysis using concentrated HCl and HNO_3 (3:1) (Forstner and Wittmann, 1979). The results are shown in Figure 6

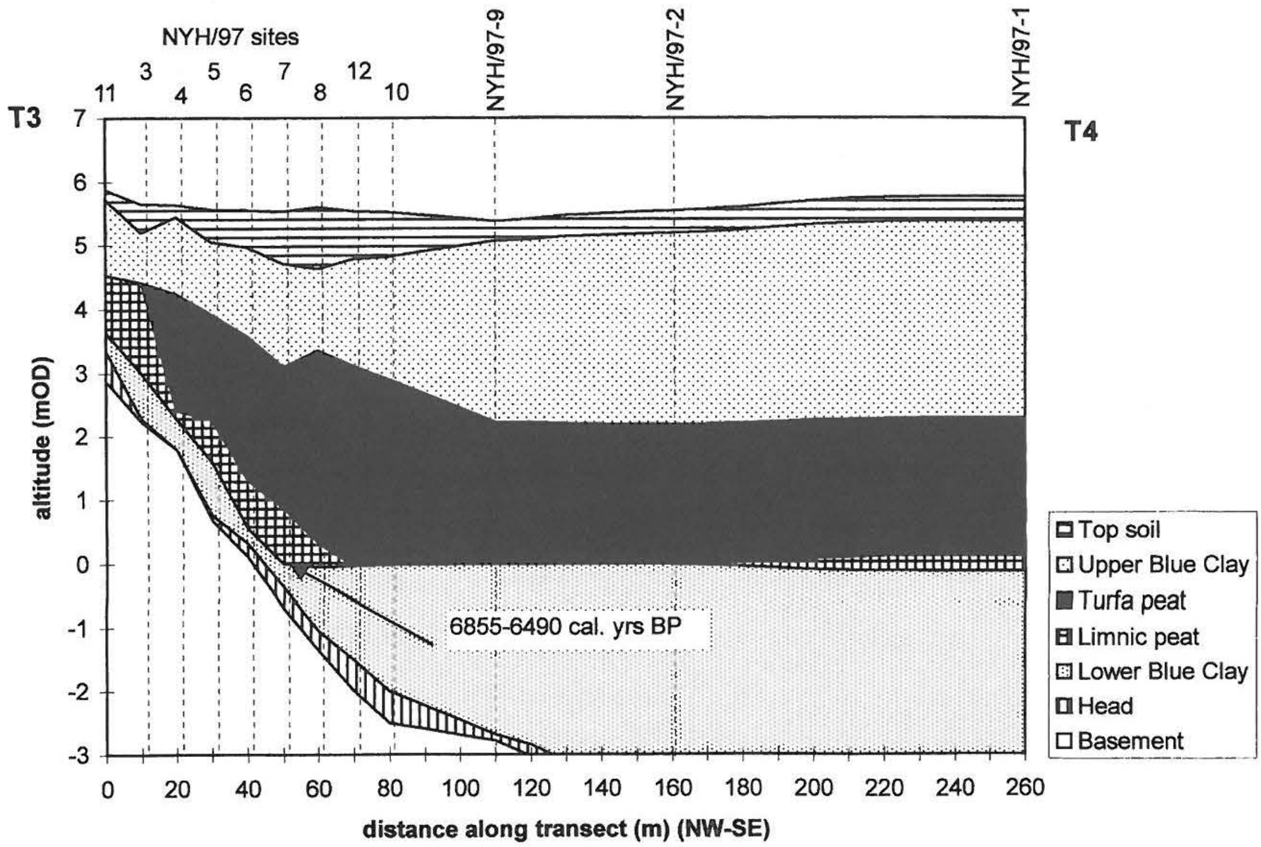

Figure 5: Lithostratigraphy along the 'Big Basin' transect, Nyland Hill, Somerset Levels. T3-T4 refers to transect line shown on Figure 1. Turfa peat = terrestrial peat.

Table 1: Details of radiocarbon dates obtained from Nyland Hill, Somerset Levels, calibrated using the CALIB 3.0 programme of Stuiver and Reimer (1993).

Core	*Depth (m)*	*Laboratory code*	*Radiocarbon age BP (1X)*	*Calibrated Intercept age cal. yrs BP*	*Calibrated age cal. yrs BP (1X)*	*Calibrated age cal. yrs BP (2X)*	*Altitude (m OD)*	*Corrected altitude*	*Indicative Meaning*	*Tendency*
NYH/4	2.37-2.42	Beta-101740	3370±60	3610	3680-3540	3715-3480	3.88	4.64	MHWST	positive
NYH/11	3.3-3.35	Beta-101741	3380±60	3620	3685-3555	3725-3465	2.42	4.64	MHWST	positive
NYH/12	2.12-2.17	Beta-101742	3250±80	3460	3565-3375	3640-3330	3.18	4.64	MHWST	positive
NYH/97-7	5.07-5.12	Beta-114969	5860±70	6700	6755-6630	6855-6490	0	0	HAT	negative

and indicate similar metal concentrations below and above the lithological contact (at *c.* 1.66 m depth) between the Upper SLF and palaeochannel fill respectively. However, an abrupt increase in metal concentrations occurs *c.* 1.2 m depth which is interpreted as representing the onset of Roman Lead mining on the Mendip Hills between AD 43-49 (Leech and Leach, 1982). Therefore, the palaeochannel was in existence prior to the Roman occupation of the region, and persisted for some time afterwards.

Palaeoenvironmental Analysis

Palaeoenvironmental analysis of Holocene sediments in the Somerset Levels has been undertaken using a range of proxies. Peat of the Middle SLF has been investigated through a number of tech-niques, including palynological (e.g. Beckett and Hibbert, 1979; Haslett *et al.*, 1998a) and plant macrofossil (e.g. Caseldine, 1984) analyses. Records derived from these studies have established a detailed palaeoenvironmental history throughout Middle SLF peat deposition. However, these methods are not well-suited to the study of the mostly minerogenic marine sediments of the Lower and Upper SLF. In these deposits, Haslett *et al.* (1998a, b) applied diatom and foraminifera analysis, and found that foraminifera are well-preserved, moderately abundant and yield useful information regarding depositional environment, including the relationship of depositional surfaces and tidal levels (see also Haslett *et al.*, 2001b). Foraminifera are marine Sarcodine Protozoa that have been employed in palaeoecological studies for some time (Murray, 1991), and in relation to the present study they have been found to be especially signficant in reconstructing changes in sea-level (Scott and Medioli, 1978, 1986; Gehrels, 1994, 1999, 2000; Haslett *et al.*, 1998a, b; Horton *et al.*, 1999; Horton and Edwards, this volume; Haslett, 2000) and palaeodepositional environments (Boomer and Godwin, 1993; Boomer, 1998; Haslett, 2001), as well being indicators of sediment transport (Haslett *et al.*, 2000a) and coastal pollution (Alve, 1995). Modern intertidal foraminiferal species ranges are altitudinally restricted within the tidal frame (see Haslett *et al.*, 1998b for a local example) and are, therefore, able to provide information regarding the indicative meaning of a sample. Indicative meaning refers to the position of a depositional surface within the contemporary tidal frame so that, for example, a sample may be assigned an indicative meaning of Mean High Water Neap Tide (MHWNT), Mean High Water (MHW), Mean High Water Spring Tide (MHWST), or Highest Astronomical Tide (HAT) depending on the constituent foraminiferal species within a sample. Any uncertainty in assigning an indicative meaning may be expressed as an indicative range, for example, MHWNT-MHWST.

Foraminifera analysis has previously been performed on material from three borehole sites at Nyland Hill, across the regressive contact between silts of the Lower SLF and peat of the Middle SLF at NYH/1 (Haslett *et al.,* 1998b), and across the transgressive contact between Middle SLF peat and Upper SLF silts at NYH/12, which is continued through part (<1.5 m) of the Upper SLF silts at NYH/4 (Haslett *et al.,* 1998a). These studies indicated the potential of foraminifera analysis in Holocene deposits of the Somerset Levels, but were stratigraphically limited, primarily focused on establishing indicative meaning at dated lithological contacts. The aim of the present study, however, is the reconstruction of depositional palaeoenvironments throughout as much of the SLF as possible using manual hand-coring field techniques. In the light of previous research, emphasis is placed here on investigating marine sediments of the Lower and Upper SLF, and also the sedimentary fill of the palaeochannel at Decoy Pool Farm. The Lower SLF is investigated using cores collected at sites NYH/97-2 and NYH/97-7 along the Big Basin Transect, the Upper SLF is investigated using cores collected at sites NYH/8 and NYH/11 along the Rookery Farm

Table 2: Foraminifera results given as raw counts for Decoy Pool Farm (Somerset Levels) borehole sites. See Figs 1 and 3 for location.

Sample	**[1]Lithology**	*Ammonia beccarii*	*Bolivina pseudoplicata*	*Brizalina variabilis*	*Bucella frigida*	*Cyclogyra involvens*	*Elphidium gerthi*	*Elphidium williamsoni*	*Gavelinopsis praegeri*	*Globigerina* spp.	*Haynesina germanica*	*Jadammina macrescens*	*Quinqueloculina seminulum*	*Rosalina williamsoni*	*Spiralis* spp.	*Trochammina inflata*	**Total**	**Dry >63um weight (g)**	**[2]Indicative Meaning**	**Palaeoenvironment**	**[3]Sea-level Tendency**
Decoy Pool Farm (composite record)																					
NYH/5:55-57cm	▦	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3		tidal influence	marine influence	+ve
NYH/5:59-61cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:63-65cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:65-67cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.9	non-tidal	non-marine	-ve
NYH/5:69-71cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:73-75cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:77-79cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:81-83cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:85-87cm	▦	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		non-tidal	non-marine	-ve
NYH/5:89-91cm	▦	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1		tidal influence	marine influence	unknown
NYH/5:99-101cm	▦	23	8	2	3	0	0	14	11	7	48	3	1	1	0	0	121	0.6	unknown	storm event	unknown
NYH/5:105-107cm	▦	0	0	3	0	1	0	0	0	0	5	0	0	0	0	0	9		MHWNT	mudflat/low marsh	ss
NYH/5:109-111cm	▦	1	0	0	0	1	0	0	0	0	4	0	0	0	0	0	6		MHWNT	mudflat/low marsh	ss
NYH/5:113-115cm	▦	0	0	0	1	0	0	0	0	0	10	0	1	0	2	0	14		MHWNT	mudflat/low marsh	ss
NYH/5:117-119cm	▦	0	0	0	1	0	0	1	0	0	20	1	0	0	0	0	23		MHWNT	mudflat/low marsh	ss
NYH/5:139-141cm	▦	7	3	0	0	0	0	1	0	0	6	0	0	0	0	0	17	0.71	MHW-MHWNT	mudflat/low marsh	ss
NYH/5:170-172cm	░	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	6	0.86	MHWNT	mudflat/low marsh	ss
NYH/5:200-202cm	░	0	0	0	0	0	0	1	0	0	3	0	0	0	0	0	4	0.8	MHWNT	mudflat/low marsh	ss
NYH/5:230-232cm	░	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	3	2.92	MHWNT	mudflat/low marsh	ss
NYH/5:260-262cm	░	4	0	0	0	0	0	1	0	0	5	0	0	0	0	0	10	0.65	MHWNT	mudflat/low marsh	ss
NYH/5:275-277cm	░	3	0	0	0	0	1	2	0	0	7	0	0	0	0	0	13	1.09	MHWNT	mudflat/low marsh	ss
NYH/5:283-285cm	░	3	1	2	0	0	1	2	0	0	7	0	0	0	0	0	16	0.82	MHWNT	mudflat/low marsh	ss/+ve
NYH/5:287-289cm	░	4	0	0	0	0	0	8	0	0	7	1	0	0	0	0	20	0.98	MHW-MHWNT	low marsh	ss
NYH/5:290-292cm	░	5	0	0	0	0	0	30	0	0	19	0	0	0	0	11	65	1.1	MHW-MHWNT	low marsh	ss/+ve
NYH/5:305-307cm	░	20	0	0	0	0	0	8	0	0	31	10	0	0	0	7	76	0.7	MHWST-MHWNT	low-mid marsh	-ve/ss
NYH/5:314-316cm	░	3	0	0	0	0	0	1	0	0	7	0	0	0	0	0	11		MHW-MHWNT	low marsh	ss
NYH/5:321-323cm	░	14	0	0	0	0	0	8	0	0	42	1	0	0	0	0	65	1.02	MHW-MHWNT	low marsh	ss/+ve
NYH/5:335-337cm	░	407	0	0	0	0	0	14	0	0	19	2	0	0	0	0	442	0.93	MHW	low-mid marsh	-ve
NYH/5:351-353cm	░	79	0	0	0	0	0	132	0	0	153	0	0	0	0	0	364	0.96	MHWNT	mudflat/low marsh	+ve
NYH/5:354-356cm	░	35	0	0	0	0	0	2	0	0	5	0	0	0	0	0	42		MHW	low-mid marsh	ss
NYH/5:356-358cm	░	25	0	0	0	0	0	8	0	0	5	0	0	0	0	0	38		MHW	low-mid marsh	ss
NYH/5:358-360cm	░	147	0	0	0	0	0	23	0	0	21	0	0	0	0	0	191		MHW	low-mid marsh	ss
NYH/5:360-362cm	░	230	0	0	0	0	0	14	0	0	21	1	0	0	0	0	266		MHW	low-mid marsh	+ve
NYH/5:362-363cm	░	0	0	0	0	0	0	0	0	0	0	116	0	0	0	0	116		MHWST-HAT	high marsh	+ve
NYH/5:363cm	■	top of peat (unsampled)																			
NYH/1:50-100cm	░	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		MHWST	mid marsh	ss
NYH/1:100-130cm	░	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	5		MHWST	mid marsh	-ve
NYH/1:135-185cm	░	0	0	0	0	0	0	0	0	0	1	1	0	0	0	8	10		MHW	low-mid marsh	-ve
NYH/1:185-225cm	░	3	0	0	0	0	0	26	0	0	47	0	0	0	0	0	76		MHWNT	mudflat/low marsh	ss/+ve
NYH/1:225-250cm	░	4	0	0	0	0	0	6	0	0	76	1	0	0	0	2	89		MHW-MHWNT	low marsh	ss/+ve
NYH/1:250-275cm	░	4	0	0	0	0	0	13	0	0	20	9	0	0	0	13	59		MHW	low-mid marsh	ss
NYH/1:275-300cm	░	27	0	0	0	0	0	2	0	0	65	58	0	0	0	6	158		MHW	low-mid marsh	-ve/ss
NYH/1:300-315cm	░	94	0	0	0	0	17	74	0	0	97	0	2	0	0	0	284		MHW-MHWNT	low marsh	-ve/ss
NYH/1:315-320cm	░	51	0	0	0	0	5	37	0	0	105	0	0	0	0	0	198		MHWNT	mudflat/low marsh	+ve
NYH/1:420-430cm	■	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		>HAT	non-marine	ss
NYH/1:430-441cm	■	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		>HAT	non-marine	-ve
NYH/1:441-450cm	▒	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		HAT-MHWST	high marsh	-ve
NYH/1:450-460cm	▒	2	0	0	0	0	0	0	0	0	0	18	0	0	0	4	24		MHWST	mid marsh	ss
NYH/1:460-470cm	▒	0	0	0	0	0	0	0	0	0	1	9	0	0	0	8	18		MHWST	mid marsh	ss
NYH/1:470-477cm	▒	0	0	0	0	0	0	0	0	0	1	6	0	0	0	12	19		MHWST	mid marsh	
NYH/3:245-255cm	░	5	0	0	0	0	0	0	0	0	0	0	0	0	0	4	9		MHW-MHWNT	low marsh	-ve
NYH/3:255-265cm	░	2	0	0	0	0	0	0	0	0	3	0	0	0	0	3	8		MHW-MHWNT	low marsh	-ve
NYH/3:265-275cm	░	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	5		MHWNT	mudflat/low marsh	+ve
NYH/3:275-285cm	░	0	0	0	0	0	0	1	0	0	6	1	0	0	0	2	10		MHWST-MHWNT	low-mid marsh	ss
NYH/3:285-295cm	░	2	0	0	0	0	0	0	0	0	3	2	0	0	0	2	9		MHWST-MHWNT	low-mid marsh	

[1]Lithology key ▦ palaeochannel fill ░ blue/grey silty-clay (Upper SLF) ■ peat (Middle SLF) ▒ blue/grey silty-clay (Lower SLF)

[2]Indicative Meaning HAT=Highest Astronomical Tide; MHWST=Mean High Water Spring Tide
MHW=Mean High Water; MHWNT=Mean High Water Neap Tide

[3]Sea-level Tendency Refers to relative sea-level change in relation to the underlying sample.
+ve=sea-level rise; -ve=sea-level fall; ss=sea-level stillstand

Table 3: Foraminifera results given as raw counts for Rookery Farm (Somerset Levels) transect borehole sites. See Figs 1 and 4 for location.

Sample	[1]Lithology	*Ammonia beccarii*	*Elphidium williamsoni*	*Haynesina germanica*	*Jadammina macrescens*	*Spiralis* spp.	*Trochammina inflata*	Total	Dry bulk weight (g)	Dry >63um weight (g)	[2]Indicative Meaning	Palaeoenvironment	[3]Sea-level Tendency
Rookery Farm Transect													
NYH/8:50-60cm	░	26	76	5	0	0	0	107	62.89	3.89	MHW-MHWNT	low marsh	ss
NYH/8:70-80cm		11	64	2	0	0	0	77	41.36	4.28	MHW-MHWNT	low marsh	ss
NYH/8:90-100cm		3	26	4	0	0	0	33	55.71	3.56	MHW-MHWNT	low marsh	+ve
NYH/8:110-120cm		56	3	0	0	0	0	59	69.02	6.01	MHW	low-mid marsh	ss
NYH/8:130-140cm		56	0	1	0	0	0	57	57.46	3.16	MHW	low-mid marsh	+ve
NYH/8:150-160cm		27	1	0	26	0	14	68	66.21	9.27	MHWST	mid marsh	+ve
	sequence overlies thin layer of peat and bedrock												
NYH/11:30-40cm	░	0	1	1	0	0	0	2	78.81	11.16	MHWNT	mudflat/low marsh	ss/+ve
NYH/11:60-70cm		1	0	0	0	0	0	1	62.41	5.27	MHW	low-mid marsh	-ve/ss
NYH/11:90-100cm		5	0	2	0	0	0	7	85.9	2.02	MHW-MHWNT	low marsh	ss/+ve
NYH/11:120-130cm		5	0	0	0	0	0	5	62.07	1.4	MHW	low-mid marsh	-ve/ss
NYH/11:160-170cm		0	0	0	0	0	1	1	67.95	2.68	MHW-MHWNT	low marsh	ss
NYH/11:190-200cm		15	3	0	0	0	1	19	44.93	1.22	MHW-MHWNT	low marsh	ss
NYH/11:220-230cm		0	0	2	1	0	2	5	48.94	0.77	MHW-MHWNT	low marsh	ss
NYH/11:250-260cm		19	3	10	3	2	2	39	56.67	0.81	MHW-MHWNT	low marsh	ss
NYH/11:280-290cm		3	1	2	1	0	2	9	54.02	1.15	MHW-MHWNT	low marsh	ss
NYH/11:310-320cm		16	1	10	9	2	2	40	54.87	1.31	MHW-MHWNT	low marsh	ss
NYH/11:340-350cm		11	6	35	3	0	5	60	50.95	1.76	MHW-MHWNT	low marsh	+ve
NYH/11:370-373cm		16	2	0	0	0	2	20	14.74	1.22	MHWST-MHW	mid marsh	+ve
	sequence rests directly on peat												

[1]Lithology key	░ blue/grey silty-clay (Upper SLF)
[2]Indicative Meaning	HAT=Highest Astronomical Tide; MHWST=Mean High Water Spring Tide MHW=Mean High Water; MHWNT=Mean High Water Neap Tide
[3]Sea-level Tendency	Refers to relative sea-level change in relation to the underlying sample. +ve=sea-level rise; -ve=sea-level fall; ss=sea-level stillstand

Transect, and at site NYH/5 at Decoy Pool Farm, where the overlying palaeochannel fill is also examined. Sediment is processed for foraminifera by wet sieving at 63 μm and then being air-dried. The >63 μm fraction is examined in its entirety for foraminifera under reflected light, which are identified according to Murray (1979, 2000). Foraminifera encountered are well-preserved, of variable abundance and diversity. Raw counts are given in Tables 2-4, accompanied with information on indicative meaning, depositional environment, and sea-level tendency for each sample.

In the field, molluscan remains are visible in the brown sediment of the palaeochannel fill at NYH/5, Decoy Pool Farm. These were analysed in the laboratory by wet sieving sediment at 500 μm, air-drying, and picking specimens from the entire >500μm fraction under reflected light. Molluscs recovered were often thin-shelled species, and thus broken and fragmentary. Assemblages are low in abundance, but of low-moderate diversity. Raw counts are given in Table 5, with assigned depositional environments.

Discussion

This study, for the first time, presents long sequence palaeoenvironmental data for Holocene marine sediments underlying the Somerset Levels. In conjunction with non-marine records from terrestrial/freshwater peat deposits of the Middle SLF, these data present an opportunity to achieve a significant advance in our understanding of the Holocene development and further archaeological potential of this important coastal lowland. An attempt at realising this opportunity is systematically explored here, within the established lithological framework, and according to the aims stated in the Introduction. Although explicitly developed for the Somerset

Table 4: Foraminifera results given as raw counts for Big Basin (Somerset Levels) transect borehole sites. See Figs 1 and 5 for location.

Sample	[1]Lithology	*Ammonia beccarii*	*Elphidium williamsoni*	*Haynesina germanica*	*Jadammina macrescens*	*Trochammina inflata*	*Trochammina ochracea*	Total	[2]Indicative Meaning	Palaeoenvironment	[3]Sea-level Tendency
Big Basin Transect (composite record)											
NYH/97-7:510-512cm	■	0	0	0	0	0	0	0	>HAT	non-marine	-ve
NYH/97-7:512-514cm	░	0	0	0	0	0	6	6	HAT-MHWST	high marsh	ss
NYH/97-7:514-516cm	░	0	0	0	4	0	0	4	HAT-MHWST	high marsh	ss
NYH/97-7:516-518cm	░	0	0	0	13	0	0	13	HAT-MHWST	high marsh	-ve
NYH/97-7:518-520cm	░	0	0	0	28	5	0	33	MHWST	mid marsh	ss
NYH/97-7:526-528cm	░	0	0	0	9	2	0	11	MHWST	mid marsh	-ve
NYH/97-2:550-560cm	░	2	0	0	0	0	0	2	MHW	low-mid marsh	ss
NYH/97-2:560-570cm	░	7	1	2	0	0	0	10	MHW	low-mid marsh	ss
NYH/97-2:570-580cm	░	7	0	1	0	0	0	8	MHW	low-mid marsh	ss
NYH/97-2:600-610cm	░	3	0	0	0	0	0	3	MHW	low-mid marsh	-ve
NYH/97-2:630-640cm	░	6	4	2	0	0	0	12	MHW-MHWNT	low marsh	ss
NYH/97-2:640-650cm	░	4	3	1	0	0	0	8	MHW-MHWNT	low marsh	ss
NYH/97-2:670-680cm	░	2	1	2	0	0	0	5	MHW-MHWNT	low marsh	-ve
NYH/97-2:700-710cm	░	0	4	2	0	0	0	6	MHWNT	mudflat/low marsh	ss
NYH/97-2:720-730cm	░	2	11	42	0	0	0	55	MHWNT	mudflat/low marsh	

[1]Lithology key ■ peat (Middle SLF) ░ blue/grey silty-clay (Lower SLF)

[2]Indicative Meaning HAT=Highest Astronomical Tide; MHWST=Mean High Water Spring Tide; MHW=Mean High Water; MHWNT=Mean High Water Neap Tide

[3]Sea-level Tendency Refers to relative sea-level change in relation to the underlying sample. +ve=sea-level rise; -ve=sea-level fall; ss=sea-level stillstand

Levels, the following is also applicable to a number of other coastal lowlands in non-glaciated regions of NW Europe.

Early Holocene
(Lower Somerset Levels Formation)

The Lower SLF comprises minerogenic silts and clays of marine origin and predates 6855-6490 cal. yrs BP. The foraminifera record obtained from boreholes along the 'Big Basin' Transect (Table 4) indicates that a general regressive sequence is present from mudflat/low marsh depositional environments up to high marsh, with an indicative range of MHWNT to HAT at the silt-peat contact between the Lower and Middle SLF. However, of the *c.* 2.4 m sediment sequence examined here, the lower *c.* 2 m yields an indicative range of MHWNT-MHW, a position relatively low within the contemporary tidal frame. Only the top 0.4 m, directly underlying the silt-peat contact, suggest indicative meanings of MHWST or higher. These data are very similar to other borehole sites (ie East Brent (North), ST350 528, and North Yeo Farm, ST358 546) examined by Haslett *et al.* (2001a) on the coastal plain of the Somerset Levels. Together, these data suggest that throughout most of the Lower SLF depositional period, the depositional surface was relatively low within the tidal frame, and that according to Allen's (1990) model relative sea-level must have been rising at a high rate. The sea-level curve for the Somerset Levels (Figure 2) agrees with this interpretation, as relative sea-level is apparently rising rapidly between 10,000 and 7,000 cal. yrs BP at a rate of *c.* 5-6 mm yr^{-1}. These results are therefore, very supportive of Allen's (1990) model. The depositional surface elevates through the tidal frame only as the rate of sea-level rise decreases, and this is observed in the foraminifera record in samples directly underlying the silt-peat contact, which corresponds well with sea-level deceleration to *c.* 2 mm yr^{-1} between 7,000

Table 5: Mollusc results given as raw counts for the palaeochannel fill at borehole site NYH/5 at Decoy Pool Farm (Somerset Levels). See Figs 1 and 3 for location.

sample	*Anisus leucostoma*	*Armiger crista*	*Bathyomphalus contortus*	*Bithynia* operculae	*Bithynia tentaculata*	*Lymnaea peregra*	*Lymnaea truncatula*	*Physa fontinalis*	*Pisidium nitidum*	*Pisidium obtusale*	*Pisidium personatum*	*Pisidium subtruncatum*	*Planorbis planorbis*	Succineidae	*Vertigo pygmaea*	Total	Interpretation
NYH/5:55-57cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	barren of molluscs
NYH/5:57-59cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NYH/5:59-61cm	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	poorly vegetated freshwater mudflat
NYH/5:61-63cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NYH/5:63-65cm	0	0	1	2	0	0	0	0	0	0	0	0	1	0	0	4	
NYH/5:65-67cm	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	2	
NYH/5:67-69cm	0	0	0	4	0	0	2	0	0	0	1	1	0	1	0	9	
NYH/5:69-71cm	1	0	2	2	2	0	1	1	0	0	1	0	0	1	0	11	possible freshwater flood
NYH/5:71-73cm	0	0	0	2	3	0	0	0	0	1	0	1	0	1	1	9	
NYH/5:73-75cm	1	1	1	5	3	1	0	0	0	0	0	1	0	1	0	14	
NYH/5:75-77cm	2	0	2	0	2	1	0	0	1	0	0	1	1	0	0	10	
NYH/5:77-79cm	0	0	0	1	2	0	0	0	1	0	1	0	0	0	0	5	
NYH/5:79-81cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	poorly vegetated freshwater mudflat
NYH/5:81-83cm	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	
NYH/5:83-85cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
NYH/5:85-87cm	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	3	
NYH/5:87-89cm	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	3	

and 5,000 cal. yrs BP (Figure 2).

The implications of these observations for reconstructing Early Holocene palaeoenvironments of the Somerset Levels are significant. Most of the estuarine surface would initially have been positioned within the contemporary tidal frame at *c.* MHWNT. A mudflat/low marsh palaeoenvironment would have spatially-dominated the intertidal zone, and because of its low tidal position would possess a high hydraulic duty (Allen, 1997a, 2000c), that is the amount of tidal water to be transferred on and off the surface during flood and ebb tides respectively. A high hydraulic duty requires relatively large (wide and deep) tidal creeks in a relatively dense creek network. The low tidal position also dictates that subaerial exposure of the surface would be relatively short, and the surface itself would be almost permanently saturated and muddy, as drying times between tides would be minimal. Higher marsh environments would occur as relatively steeply-inclined and narrow zones around the estuarine perimeter, on the footslopes of the upland flanks. Figure 7 schematically models this scenario as t1 (10-8ka); although this model has been informed by the results obtained for the Somerset Levels presented herein, the details given in Figure 7 are intended for illustrative purposes only, and it is hoped that it may prove to be applicable to other areas in southern Britain, The Netherlands, Belgium and northern France, where similar Early Holocene relative sea-level histories have been documented (Pirazzoli, 1991). However, it is worth noting that the Somerset Levels apparently differ, in terms of palaeoenvironmental development and stratigraphic

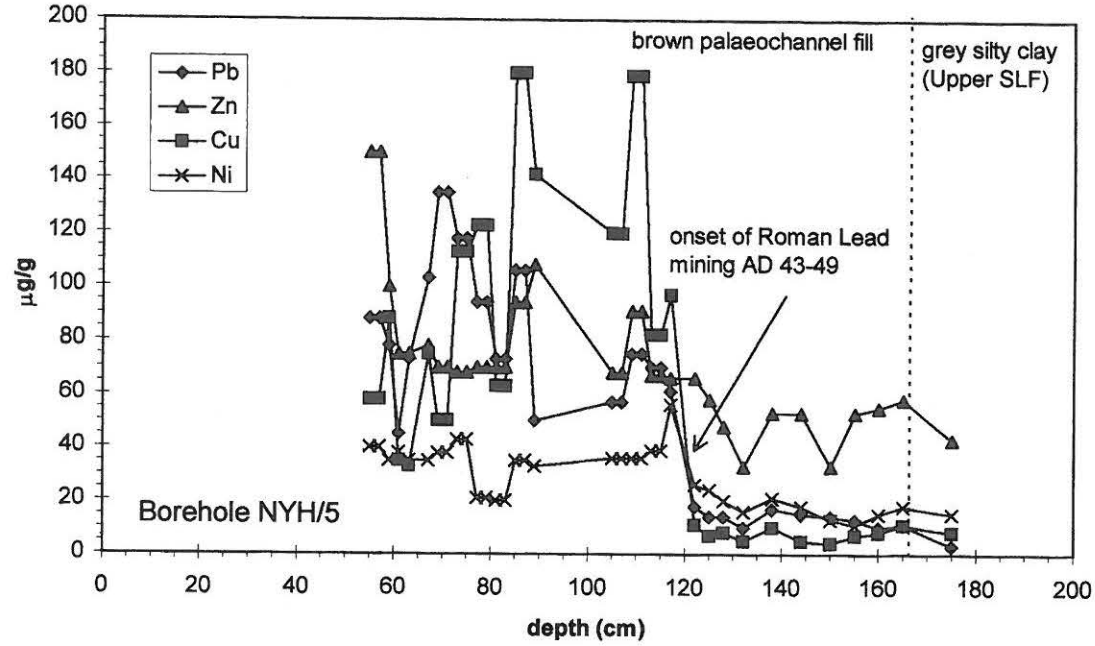

Figure 6: Chemostratigraphy of borehole NYH/5 situated in a palaeochannel at Decoy Pool Farm (Nyland Hill, Somerset Levels, UK).

architecture, from a model proposed by Long *et al.* (2000) based on work in Southampton Water.

Decelaration in the rate of relative sea-level rise towards the mid-Holocene in the Somerset Levels is expressed in foraminifera-derived indicative meanings as a transition to higher tidal levels as the silt-peat contact is approached. This transition would have manifested itself firstly (t2, Figure 7) through an expansion of mid marsh palaeoenvironments, with associated decreases in tidal flooding frequency, hydraulic duty and tidal creek size. With continued deceleration of the relative sea-level rise rate (t3, Figure 7) high marsh would dominate the estuarine palaeoenvironment, with infrequent tidal flooding, a low hydraulic duty, and small creeks. Throughout this transition, drying times would increase, resulting in a drier intertidal surface. Vegetation succession would also occur through t1-t3, responding to increased exposure, lower salinity, and drier conditions, from a low-diversity low marsh flora, such as (by modern analogy) *Salicornia* spp., through to more diverse higher marsh communities, such as (again by modern analogy) *Aster tripolium*, *Plantago maritima*, *Limonium vulgare*, *Cochlearia officinalis*, *Halimione portlacoides* and *Puccinellia maritima* (Haslett, 2000).

Middle Holocene (Middle Somerset Levels Formation)

The rate of sea-level rise ultimately falls to a level that is outpaced by organic sedimentation (Allen, 1990), leading to mire emergence and peat deposition (t4, Figure 7). Haslett *et al.* (1998b) suggest the indicative meaning of the regressive silt-peat contact between the Lower and Middle SLF is equivalent to HAT, a view that is supported by the new foraminifera results presented here. The age of the Middle SLF peat at Nyland Hill lies between 6855-6490 cal. yrs BP and 3640-3330 cal. yrs BP (Table 1), and its general development in the Somerset Levels has been the subject of a number of previous studies (Godwin, 1941, 1943, 1948, 1955; Clapham and Godwin, 1948a, b; Beckett, 1978; Beckett and Hibbert, 1979; Curran, 1979; Caseldine, 1986; Housley, 1988; Aalbersberg, 1996; Druce, 1998; Housley *et al.*, 2000; Wilkinson, 1999; Coles and Coles, 1999). From these studies, the general mire development has been established, comprising an initial *Phragmites*-dominated swamp, the subsequent establishment of fen-wood, then superceded by raised bog formation. Local development of *Cladium* peat, humified layers within raised bog peat, and the localised occurrence of detrital muds, add to the

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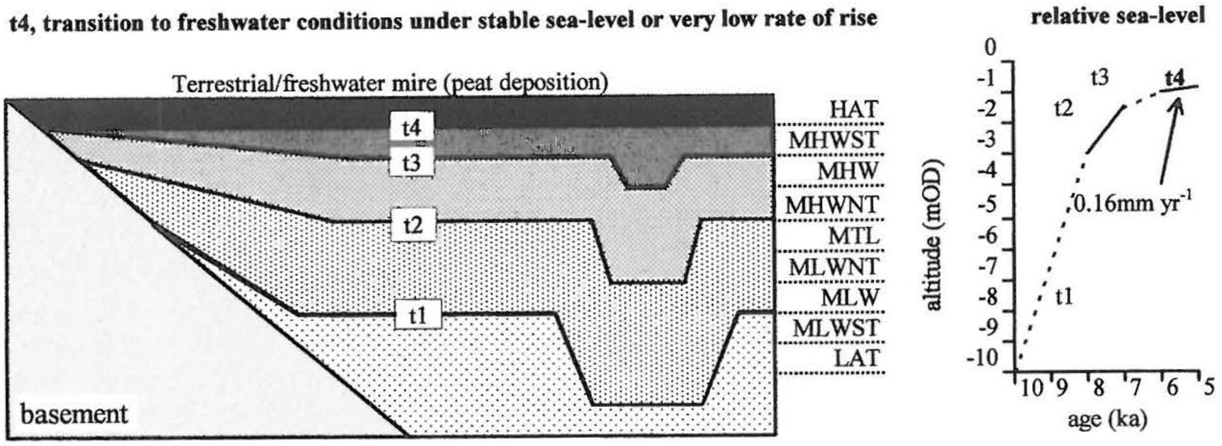
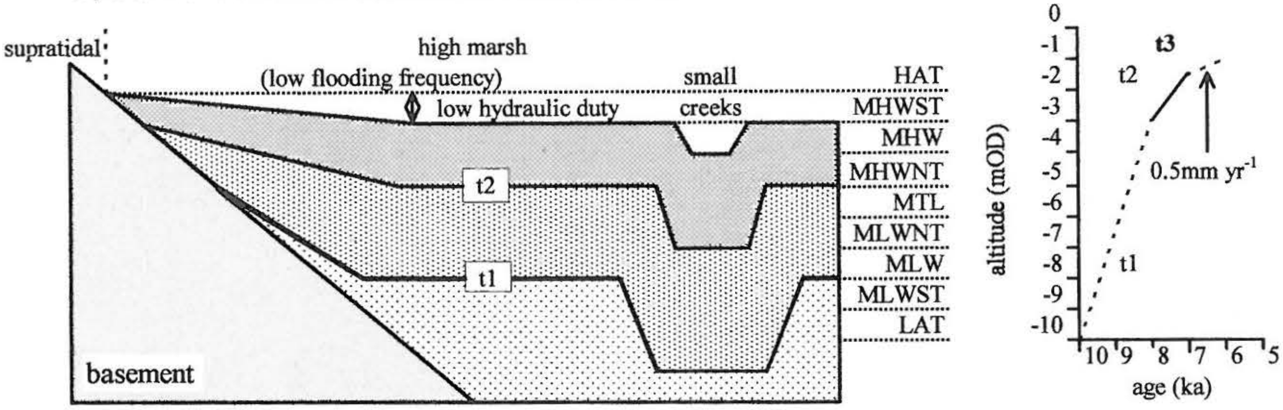
Figure 7: (Opposite) Model of Early-Middle Holocene (timeplanes t1-t4) estuarine development, where depositional environments are related to the prevailing rate of sea-level rise. Although this model has been informed by the present study of the Somerset Levels, the details given are for illustrative purposes only. See text for explanation of tide level abbreviations.

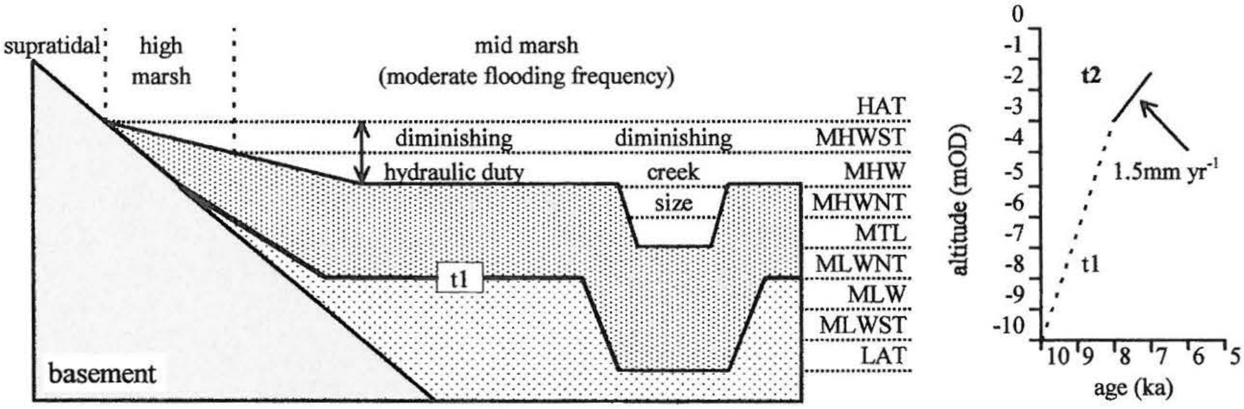
t4, transition to freshwater conditions under stable sea-level or very low rate of rise



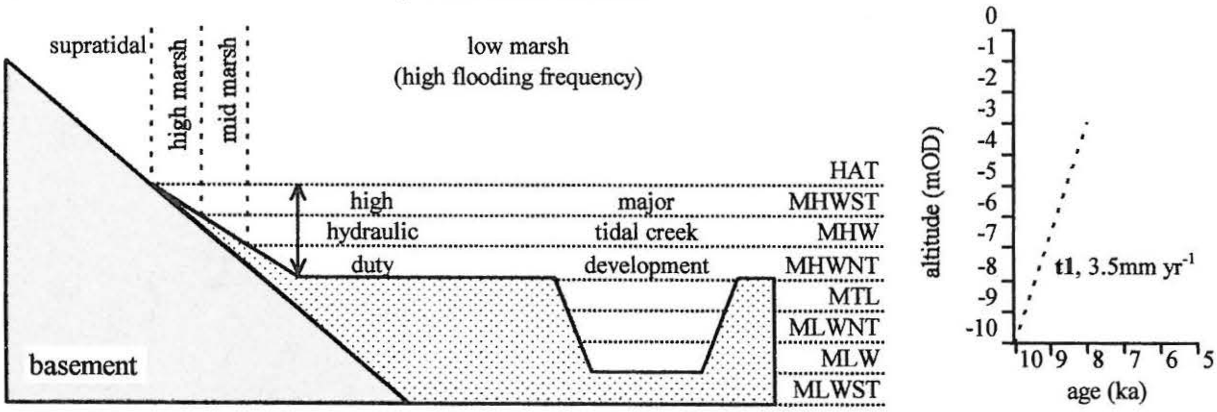
t3, saltmarsh environment under low rate of sea-level rise



t2, saltmarsh environment under moderate rate of sea-level rise



t1, saltmarsh environment under a rapid rate of sea-level rise



lithostratigraphic complexity of the Middle SLF in the region.

At Nyland Hill, the new 'Big Basin' Transect indicates that the mire palaeoenvironment consisted of a swamp-fen-bog succession, lithostratigraphically referred to here collectively as terrestrial peat. At the base of the slope adjacent to Nyland Hill, however, a limnic peat is mapped that is interpreted as being deposited under relatively open-water conditions. This lagg environment was probably a marginal environment only, being positioned between the extensive *terrestrial* peat accummulation of the open Somerset Levels, and the flanks of Nyland Hill, which undoubtedly supplied this lagg with freshwater as surface runoff. Such mid-Holocene lagg deposits have been described from the Brue Valley (Coles *et al.*, 1980; Orme *et al.*, 1982), but this is the first occurrence noted in the Axe Valley, suggesting that laggs occurred widely throughout the region. At Nyland Hill, the lagg persisted until transgression and deposition of the Upper SLF, however, during its deposition the environment migrated upslope as the vertical growth and lateral expansion of terrestrial peat progressed. This situation is similar to that recorded in the Brue Valley by Coles *et al.* (1980) who suggest that an initial wide expanse of lagg contracted as adjacent bog developed, but wet fringing pools were maintained at the bog margin throughout. The occurrence of open-water laggs between the surrounding upland and the raised bogs may have been a significant influence in the development of trackway construction in the region. Indeed, a number of trackways in the Brue Valley, at the Neolithic Baker Site (Coles *et al.*, 1980) and Garvin's Track at Walton's Heath (Orme *et al.*, 1982), are seen to cross lagg environments.

Late Holocene
(Upper Somerset Levels Formation)

The Upper SLF consists of minerogenic silty-clays of marine origin that overly the Middle SLF, with the peat-silt contact dated in the Rookery Farm Transect at 3640-3330 cal. yrs BP (Table 1). Foraminifera analysis of the Upper SLF (Tables 2 and 3) demonstrate a transgressive sequence, with an indicative meaning of the peat-silt contact of MHWST, supporting a previous observation of Haslett *et al.* (1998b). However, positive sea-level tendency continues throughout the Upper SLF at all sites analysed, with indicative meanings representing progressively lower tidal levels being evident upsequence. In the North Somerset Levels, Haslett *et al.* (2000b) analyse foraminifera collected in a monolith from an exposed section through the Upper SLF directly underlying the reclaimed Roman landsurface, and these data also suggest positive sea-level tendency up to the point of reclamation. According to Allen's (1990) model, these data suggest that through the Late Holocene, the rate of relative sea-level rise progressively increased. In terms of palaeoenvironmental development, the reverse of the sequence shown in Figure 7 is applicable, so that the sequence progresses from t4 towards t1.

These findings are opposite to the relative sea-level curve given in Figure 2, which indicates that sea-level is stable during the Late Holocene, showing no appreciable rise. The discrepancy between foraminifera-derived indicative meanings and the sea-level curve given in Figure 2 may be due errors inherent in the sea-level curve used here (Heyworth and Kidson, 1982), as Haslett *et al.* (1998a) have demonstrated that compaction severely affects the altitude of the peat-silt contact between the Middle and Upper SLF. Therefore, this study suggests for the first time, that relative sea-level continued to rise, and indeed the rate of rise continued to increase, at least up until Roman reclamation of the Somerset Levels. These data challenge the view that Roman colonists reclaimed a coastal wetland, comprising mainly higher marsh environments, aided by a relative sea-level fall (e.g. Rippon, 2000a). Indeed, it appears that the Somerset Levels may have been dominated by mid to low marsh environments at the time of reclamation, with a moderate to high hydraulic duty and associated large tidal creeks. Aerial surveys of the Axe Valley reveal large palaeochannels still visible on the surface (McDonnell, 1979), and Allen (2000c) documents 83 contemporary palaeochannels on the Gwent Levels of up to 230 m wide, some of which have yielded Roman artefacts indicating that these palaeochannels were open at least during part of the Roman period (AD 43-410).

Late Holocene palaeochannel development

The previous section suggests that at the time the Somerset Levels were reclaimed, which at Nyland Hill has been dated chemostratigraphically to AD 130-221 (Haslett *et al.*, 1998a), the estuarine environment was dominated by mid to low marsh, with a relatively high hydraulic duty, associated with many large tidal creeks to drain the tidal waters off the marshes. The palaeochannel fill from borehole

NYH/5 was biostratigraphically (foraminifera and mollusca) and chemostratigraphically analysed as discussed earlier. The lithostratigraphic contact between the Upper SLF and the palaeochannel fill occurs at *c.* 1.66 m depth, and metal pollution derived from the onset of Roman lead mining on the Mendip Hills appears at *c.* 1.2 m (Figure 6). Biostratigraphy indicates that the palaeochannel was under marine tidal influence up to sample NYH/5: 89-91 cm, as foraminifera occur in all samples from this level downwards (Table 2). The relatively high abundance/diversity assemblage encountered in sample NYH/5: 99-101 cm may represent storm surge activity. Foraminifera are absent from sample NYH/5: 87-89 cm, which is the lowest sample to yield freshwater molluscs in a sequence extending up to sample NYH/5: 59-61 cm (Table 3). Foraminifera return in sample NYH/5: 55-57 cm indicating the return of a marine influence. It is possible that this observed marine-freshwater transition at *c.* 0.89 m depth in borehole NYH/5 represents the beginning of the Roman control of tides entering onto the Somerset Levels and, therefore, it may not be unreasonable, in an exploratory sense, to assign the reclamation date of AD 130-221 to this level. It is then possible to calculate a sedimentation rate of 1.74-3.83 mm yr^{-1} for this interval, which if extrapolated from the onset of mining to the reappearance of foraminifera at a depth of 0.57 m, gives an age of AD 207-411 for the return of a marine influence in the palaeochannel. This date spans the demise of Roman control in the region, and consequently the return of foraminifera at 0.57 m may indicate a abandonment of tidal defences coincident with Roman withdrawal. The abandonment phase may be regional in extent, as it is also seen in the North Somerset Levels where Roman settlements are sealed by <0.2 m of intertidal sediment (Rippon, 2000a), also suggesting continued sea-level rise through the Roman Period.

Archaeological implications

The model of estuarine development (Figure 7) has clear archaeological implications, particularly in terms of resource availability, whether actually exploited or not. Some of these have already been alluded to, but are worthy of more explicit consideration.

At t1, archaeologically the earlier Mesolithic, it is evident that above MHWNT the intertidal resources are compressed laterally against the basement slopes, resulting in narrow, spatially restricted mid and high marsh resources (well-vegetated saltmarsh). The most extensive intertidal zone comprises either mudflat or low marsh vegetation which remains more or less permanently saturated due to the high hydraulic duty and limited sub-aerial exposure. Clearly, this type of early Holocene landscape would not have offered the extensive intertidal hunting and fowling opportunities often assumed for the Mesolithic as a whole, the well vegetated mid to high marsh simply not being spatially extensive at that time and overall a minor landscape component. The most extensive intertidal areas at this time would have been dangerous, unconsolidated mudflat. It is worth noting, however, that the major tidal creek systems at this time would have facilitated movement (by boat) around the inner estuary areas and served as ideal locations for fish traps.

Through t2 (8-7ka) and t3 (7-6 ka), archaeologically the middle to later Mesolithic, the slope-coastal relationship steadily changed as a result of sediment accumulation and a slowing down of relative sea-level rise. Gradually the mid and then high marsh areas expanded seawards and became spatially extensive, distinctive components of the landscape. In particular, large areas of relatively dry, infrequently flooded herbaceous saltmarsh communities would have provided plentiful and stable grazing opportunities for ungulates, a situation that may contribute to explain the presence of fossil footprints in this mid-Holocene depositional setting at other sites within the region (Aldhouse-Green *et al.*, 1992; Allen, 1997b). Given the general presumption for more or less continuously wooded dry-ground vegetation at this time, such extensive ecotonal areas at the land-sea interface would have been regionally distinctive. Although evidence is as yet lacking for the adjacent high ground of Mendip, it seems unlikely on general ecological grounds that the region had the 'upland' woodland edge ecotonal areas assumed for other British upland areas. Indeed preliminary molluscan analysis from extensive tufa deposits on Mendip has confirmed the presence of woodland on the eastern Mendip plateau during the Mesolithic period (Davies *et al.*, 2001). Note that communication possibilities by boat have correspondingly decreased through time.

By t4 (6-5 ka), archaeologically around the Mesolithic-Neolithic transition into the Neolithic, the rate of sea-level rise had dramatically slowed, allowing the establishment of extensive organic (peat) deposits around HAT. Seaward, extensive higher and middle marsh communities would still have persisted. In total, landscape diversity is continuing to increase but, as outlined earlier, lagg deposits forming around the slope margins may have made access to the peat and intertidal areas problematic. Trackways crossing the lagg areas was one possible response (see earlier). The lithological transition from peat to silt possesses an indicative meaning of MHWST, which differs from the HAT indicative meaning of the silt-peat contact at the base of the Middle SLF. Archaeological implications of the differing relationship between lithological change and tidal levels have been explored by Davies *et al.* (1998). During the deposition of the Upper SLF silts, it appears that a reversal of the Early Holocene sequence (Figure 7) occurred during the later Neolithic and Bronze Age, with a progressive lowering of the intertidal surface, increasing hydraulic duty and palaeochannel enlargement, concomitant with changing intertidal resources, terminated by Romano-British reclamation.

Conclusions

This study, for the first time, provides a long sequence palaeoenvironmental record for the estuarine Holocene deposits of the Somerset Levels. A number of conclusions may be drawn that are also applicable to Holocene estuarine environments beyond the Somerset Levels.

The position of the intertidal surface relative to the contemporary tidal frame is demonstrated to vary in relation to the rate of sea-level rise, so that during the Early Holocene, rapid sea-level rise dictates a surface low within the tidal frame, approximately equivalent to MHWNT-MHW. The surface is shown to rise through the tidal frame as the rate of sea-level rise decreases towards the Middle Holocene, ultimately rising above HAT, a transition marked by a silt-peat lithological change. This sequence is reversed during the Middle to Late Holocene, as the rate of sea-level rise is interpreted to progressively increase up to, during and following Roman reclamation of the coastal wetland. These data support the model of Allen (1990).

Surface position within the tidal frame determines the depositional environment. During the Early Holocene low saltmarsh or mudflats dominated the estuarine environment, with frequent tidal inundation, limited subaerial exposure, a high hydraulic duty, large palaeochannels, and muddy and sparsely vegetated surfaces. Expansion of mid and then high marsh environments accompanied the decrease in the sea-level rise rate towards the Middle Holocene. These environments are characterised by infrequent tidal inundation, increased subaerial exposure, a lower hydraulic duty, smaller palaeochannels, drier and more diversely vegetated surfaces. The Middle Holocene peat-forming mire environments may be related to stable or negative sea-level tendencies. The progressively increasing rate of Late Holocene sea-level rise is reflected in a transition from high to low marsh dominance within the estuarine environment,

As regards prehistoric human populations, it is evident that the nature of the coastal margin changed dramatically through the early-mid Holocene period. Both the extent of, and access to, intertidal resources varied according to the rate of relative sea-level rise and sediment accumulation. Communication possibilities varied too. Consideration of the opportunities available for the exploitation of coastal resources by human populations during this period must not assume constancy of resource base. Intertidal resources varied both spatially and temporally and for any given period of time need to be demonstrated rather than assumed.

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