RECONSTRUCTING HOLOCENE SEA-LEVEL CHANGE IN THE SEVERN ESTUARY AND SOMERSET LEVELS: THE FORAMINIFERA CONNECTION.

Simon K. Haslett, Paul Davies, and Fiona Strawbridge

*Presently available Holocene relative sea-level curves for the Severn Estuary and Somerset Levels are inadequate as they are not based on sea-level index points (SLIPs) for which age, altitude, indicative meaning, and tendency are known. The Quaternary Research Unit at Bath Spa University College is currently engaged in establishing sea-level index points in the Severn Estuary and Somerset Levels in order to reconstruct a detailed Holocene relative sea-level history of the area. Assigning an indicative meaning to a SLIP requires bio-stratigraphic (*eg *foraminifera) analysis calibrated with reference to the modern environment. Here we report the first survey results of modern foraminiferal distribution in the Severn Estuary, demonstrating that certain species are restricted to particular levels within the tidal frame, and thus have great potential for establishing indicative meanings in local sea-level studies.*

Introduction

The construction of curves depicting Holocene sea-level change requires the identification of Sea-Level Index Points (SLIPs). These are points for which altitude, age, indicative meaning and range, and sea-level tendency are known (Shennan *et al* 1994). In the United Kingdom altitude is usually given in relation to Ordnance Datum at Newlyn (OD). Age may be determined in depositional SLIPs using the radiocarbon (^{14}C) method if sufficient carbonaceous matter (*eg* wood, peat, shells) is available; absolute dating is difficult for erosional SLIPs (*eg* 'wave-cut' rock platforms) where organic remains are rare. Indicative meaning refers to the tidal level that a SLIP represents (*eg* Mean High Water Spring Tides (MHWST) or Highest Astronomical Tides (HAT), *etc*), and indicative range encompasses any uncertainty present in assigning an indicative meaning (*eg* MHWST-HAT). Sea-level tendency indicates the sea-level trend at the SLIP, whether sea-level is falling (regression) or rising (transgression), and is expressed as negative or positive tendency respectively.

A number of sea-level curves have been constructed using Holocene sediments (mainly alternating marine clays and freshwater peats) in southwest Britain, including the Severn Estuary and Somerset Levels (*eg* Hawkins, 1971a, b; Heyworth and Kidson, 1982; Kidson and Heyworth, 1973, 1976, 1978; Figure 1). However, each of these models has been constructed using age and altitude data only, with no published details of indicative meaning or tendency of their age/altitude points, and thus they cannot be considered as SLIPs. A recent evaluation of these models (Haslett *et al* 1998), based on a study at Nyland Hill in the Axe Valley of the Somerset Levels (Figure 2), suggests that their accuracy is questionable for a number of reasons.

Firstly, Haslett *et al.* (1998) demonstrate that sediment compaction is severe in the Somerset Levels, showing that a layer of peat onlapping solid bedrock may consolidate to *c.*40% of its original thickness under a layer of clay to a depth of 3.61 m below the present-day surface. Heyworth and Kidson (1982) acknowledged that compaction may reduce the altitude of their points from the altitude at which they were originally deposited. Accordingly, they allowed a maximum correction of 1.3 m for a point at a depth >25 m below the present-day surface. It is likely that sediment compaction affected the sea-level curve of Heyworth and Kidson (1982), and indeed Haslett *et al* (1998) note that the steepness of that sea-level curve (Figure 1) during the early to middle Holocene may be artificial and the result of under-compensated compaction at depth.

Secondly, little information is given concerning the stratigraphy of Heyworth and Kidson's (1982) age/altitude points. Intuitively one may consider that some of their points originate from contacts between freshwater peat and marine clay, however, particularly in the Somerset Levels, many of their points come from the interior of freshwater peat sequences, including prehistoric trackways. This has implications for assigning an indicative meaning to their points because many of these peat deposits are considered to be of raised bog origin (Coles 1982), and may only have a tenuous relationship to the contemporary sea-level. Nevertheless, Heyworth and Kidson (1982) consider that all their points possess a MHWST indicative meaning, yet offer very little evidence to support this view. Modern sea-level studies (*eg* Shennan *et al* 1994; Haslett *et al* 1998) tend to employ a multi-proxy approach to establishing indicative meaning and range, such as sedimentological, micropaleontological, and palynological techniques.

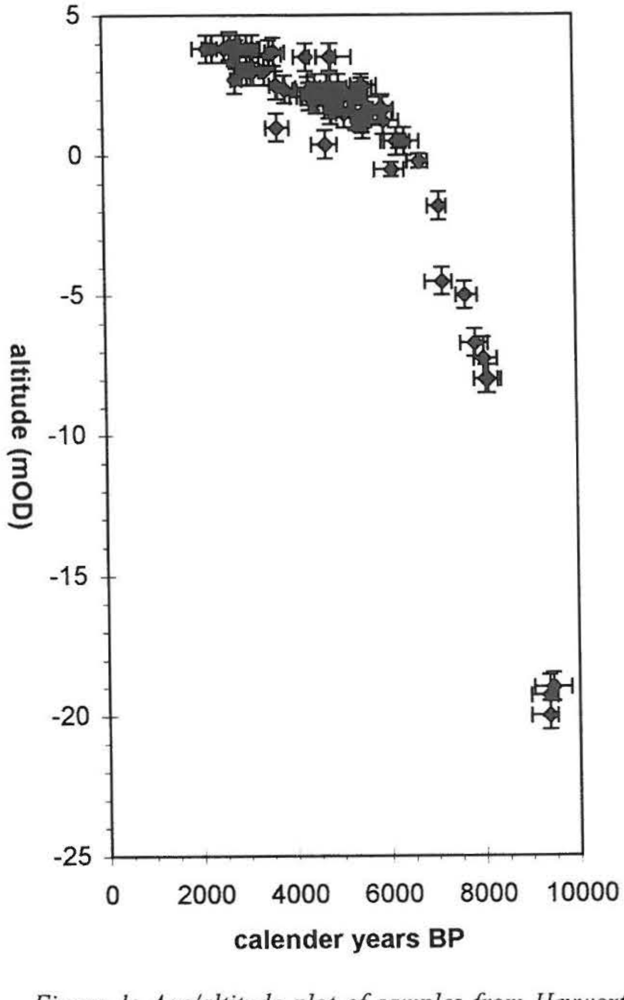

Figure 1: Age/altitude plot of samples from Heyworth and Kidson (1982). These data were taken from their Table 4, under headings 'Bridgwater Bay and Somerset Levels' and 'Somerset Levels-Wooden Trackways'. Dates are in years BP and have been calibrated from the original ^{14}C dates using the CALIB programme of Stuiver and Reimer (1993). Data points represent the intercept age, the x-axis error bars indicate the age range at 2 SD, and the y-axis error bars are altitudinal errors assigned by Heyworth and Kidson (1982)

Thirdly, Heyworth and Kidson (1982) provide no information on the tendency of sea-level throughout the Holocene, with their resulting curve (Figure 1), linking age/altitude points, implying a continuous rise in sea-level. Undeniably, the general rising trend is correct, but any minor oscillations in relative sea-level that may have occurred through the Holocene in the area are hidden within the general trend. Knowledge of any oscillations would be extremely useful in better understanding land-sea interactions in the region, such as crustal stability, and has far-reaching implications for archaeology and archaeological potential within the Holocene deposits.

From this evaluation, Haslett *et al.* (1998) conclude that a re-investigation of Holocene relative sea-level change in the Somerset Levels is warranted and suggest that a systematic approach be adopted by, firstly, studying sites where altitude errors associated with sediment compaction are demonstrably minimal (*ie* where sediments onlap underformable solid bedrock); secondly, employing lithostratigraphical, micropaleontological and palynological techniques for directly establishing indicative meaning and range; and thirdly, assigning sea-level tendencies.

A deficiency in this approach at present is the accuracy with which indicative meanings can be assigned to SLIPs from the Somerset Levels. A number of methods are employed by Haslett *et al* (1998) who use diatoms, foraminifera and pollen for establishing the indicative meaning of their SLIPs, which coincide with litho-stratigraphical contacts between a lower peat and an upper clay. Diatoms are found to be very poorly preserved and of little use. This may be due to the groundwater chemistry in the Axe Valley, which is heavily charged with calcium carbonate derived from Carboniferous Limestone of the Mendip catchment, which generally leads to poor preservation of siliceous diatom frustules (Barker *et al* 1994). Pollen is found to be useful in examining the integrity of the peat-clay contact, with the occurrence of saltmarsh pollen in peat adjacent to the contact indicating the peat surface is intact and unlikely to have been eroded prior to clay deposition. The integrity of the contact is important to establish if ^{14}C dating is to be performed on a sample from the top of the peat, as any erosion will increase the age of the SLIP. Foraminifera were found to be fairly common and

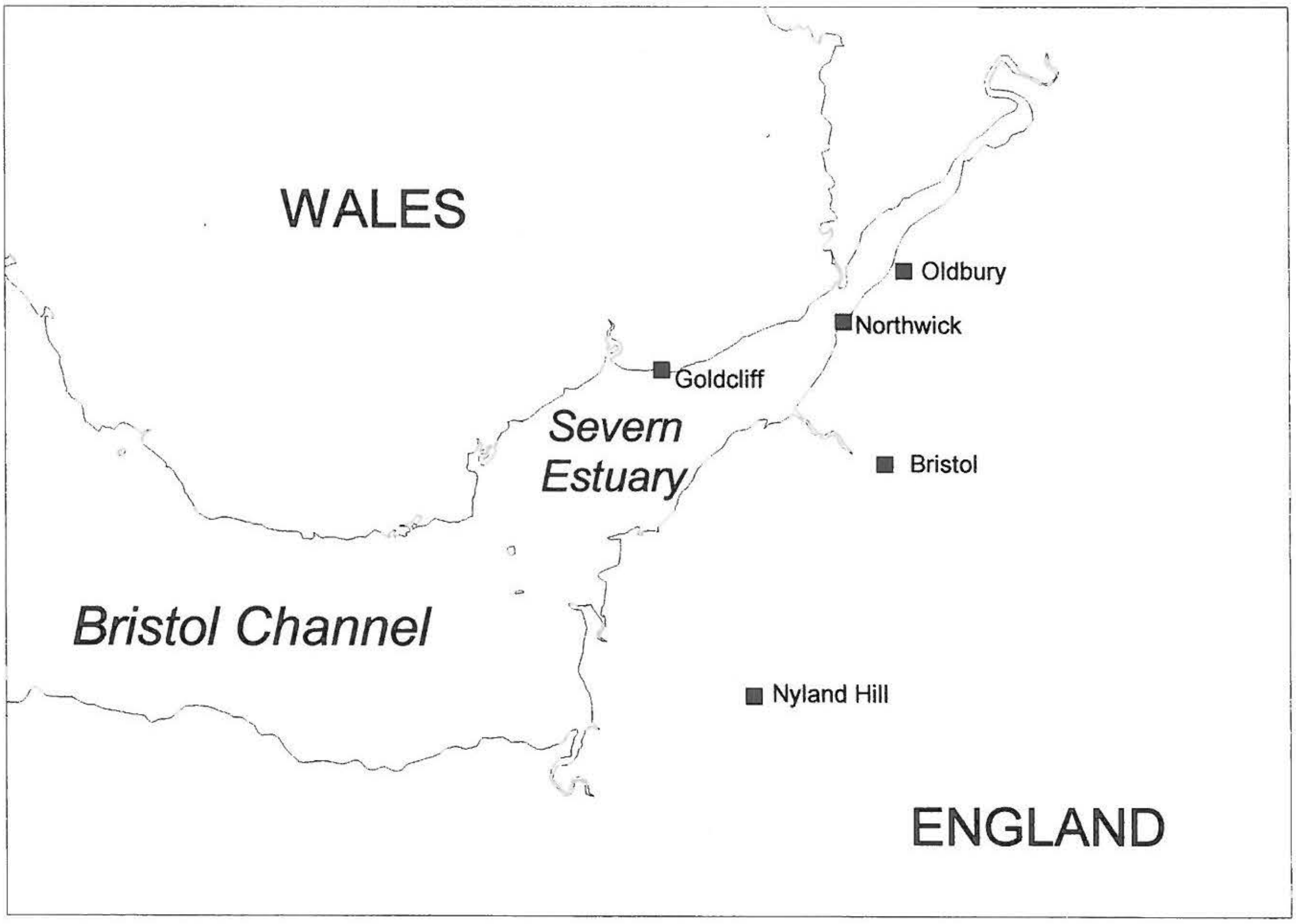

Figure 2: Location of sites mentioned in text

well preserved, both agglutinating and calcareous types (aided by groundwater chemistry), and were found to be the most useful tool for establishing indicative meanings. However, although foraminifera are known to be excellent sea-level indicators (Scott and Medioli 1978; 1986), knowledge of the relationship between foraminifera distribution and tidal levels in the modern Severn Estuary and Bristol Channel is very poorly understood. Therefore, Haslett *et al.* (1998) had to assign indicative meanings to their SLIPs based on extensive foraminifera studies on eastern North American coastlines. The aim of this paper is to report the first results of a study investigating the relationship between foraminifera and tidal levels in the Severn Estuary for use in Holocene sea-level studies of the region.

Foraminifera as sea-level indicators

Foraminifera are marine Sarcodine Protozoa that possess tests (shells) that are preservable in the fossil record. These tests may either be constructed using cemented detritus (agglutinating or arenaceous forms), or secreted using calcium carbonate (calcareous forms). Their life habits embrace planktonic and benthonic modes, although planktonic forms generally inhabitat the open ocean and seldom live in coastal waters in any abundance, whilst benthonic foraminifera exist on substrates from abyssal plains to high intertidal areas. There are many species of foraminifera which have narrowly defined niches, making them ideal for palaeoenvironmental analysis.

The application of foraminifera to sea-level studies is well-established (*eg* Scott and Medioli 1978; 1986). Saltmarsh foraminifera have been shown to occur within specific vertical zones on modern saltmarshes from eastern North America (*eg* Gehrels, 1994) which can be related to tide levels and accurately employed as tide level indicators in palaeo-saltmarsh sediments. Of greatest significance is the recognition that in micro- and meso-tidal saltmarshes of eastern North America, foraminifera extend up to Highest High Water (HHW *cf.* HAT), with the highest zone

(Zone 1A) characterised by a monospecific assemblage of *Jadammina macrescens*, which extends down to Mean Highest High Water (MHHW *cf.* MHWST). The recognition of Zone 1A in palaeo-saltmarsh sediments is thus a very useful indication of paleo-tidal level.

Through the transgressive contacts investigated by Haslett *et al* (1998) in the Somerset Levels, foraminifera were encountered in clay immediately overlying peat. However, Zone 1A was not recognised. Instead, the assemblage comprised *Jadammina macrescens* and *Trochammina inflata*, which equates to Zone 1B of the North American zonation, which indicates deposition around MHHW. Thus, the positive SLIPs established by Haslett *et al* (1998) were tentatively assigned an indicative meaning of MHWST. It was suggested that the absence of Zone 1A may be attributable to the sampling strategy, in that 2 cm thick blocks of sediment were analysed, which may have amalgamated Zone 1A and 1B.

Other studies of foraminifera in the Severn Estuary

Foraminifera inhabiting the modern Severn Estuary have received little attention. Murray and Hawkins (1976) reported on a limited study based on samples taken for undergraduate study from intertidal mudflats and saltmarshes at Brean, Clevedon and New Passage and found that the mudflats supported a calcareous fauna dominated by *Ammonia beccarii* and *Protoelphidium anglicum* (syn. *Haynesina germanica*), and that these species persisted onto the saltmarshes but with the important addition of *Elphidium articulatum* (syn. *E. williamsoni*). They go on to say that agglutinating forms common to other estuaries were not found living in the Severn Estuary *i.e. Jadammina macrescens*, *Trochammina inflata*, and *Miliammina fusca*, although dead specimens of *Jadammina macrescens* and *Trochammina inflata* had been found. Murray (1991) erected a number of ecologically defined foraminiferal associations (*eg* by temperature and salinity, but not tidal position) for marsh environments in the Severn Estuary based on Murray and Hawkins (1976), but does not do the same for tidal mudflats, and so are of limited use in sea-level investigations. Other studies involving foraminifera in the Severn Estuary and Levels have focussed on sediment transport (Culver 1980; Murray 1987), general palaeo-environmental analysis of Pleistocene interglacial and Holocene deposits (Locke 1970; Murray and Hawkins 1976; Culver and Banner 1978; Kidson *et al* 1978; Haslett 1997), and in archaeological studies (Aldhouse-Green *et al* 1993).

Study area and method

This study sets out to elucidate the distribution of foraminifera in relation to tidal levels and environments in the upper intertidal zone in the Severn Estuary. The Severn Estuary is severely macrotidal with a tidal range at Avonmouth of 14.5 m. Although the tidal range is envisaged to be slightly less than this in the palaeo-tidal Somerset Levels, it would undoubtedly still have been macrotidal. For instance, MHWST currently lies at 5.5 m OD at Weston-super-Mare at the mouth of the present Axe Estuary. Upstream in the palaeo-Axe Estuary the altitude of MHWST and the tidal range would increase, as occurs in the modern Severn Estuary.

The modern Severn Estuary commonly comprises saltmarshes and non-vegetated mudflats. The marshes often exhibit a descending suite of terraces which are surface expressions of three offlapping morphostratigraphic units (Allen and Rae 1987), referred to as low, intermediate (or middle) and high marsh on account of their relative height above OD. Intra-marsh clifflets and marsh-mudflat boundary cliffs interupt the seaward gradient of the intertidal zone. Two localities were chosen for analysis for different purposes.

A site at Oldbury-on-Severn (Figure 2) was selected because it exhibits a steep seaward sloping clifflet-less low-middle marsh surface (Figure 3) where it was anticipated that foraminifera distribution could be related to the tidal frame. Unfortunately, Oldbury is situated well away from a permanent tidal station (*ie* Avonmouth), but although not ideal, information about tidal levels has been collected using a temporary tidal station situated at Oldbury during the 1980's (Severn Tidal Power Group 1989) and this data is used here.

Northwick Oaze (Figure 2) has also been investigated because the low, middle and high marsh terraces are well-developed there (Figure 4), with extensive salt-pans in some areas. We reason that if different marsh surfaces with their

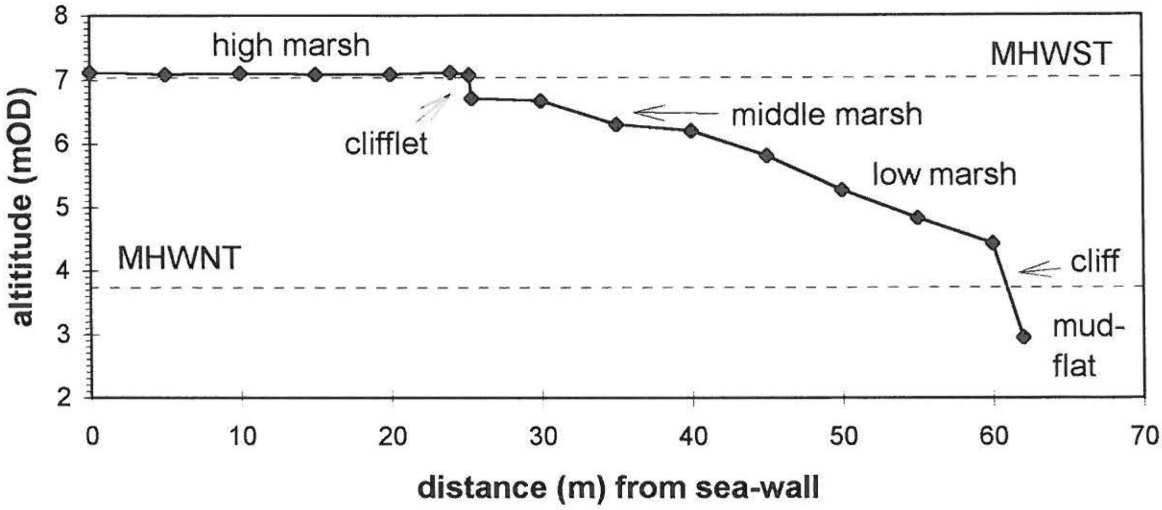

Figure 3: Geomorphology of the Oldbury-on-Severn saltmarsh/mudflat transect along which foraminifera samples were collected

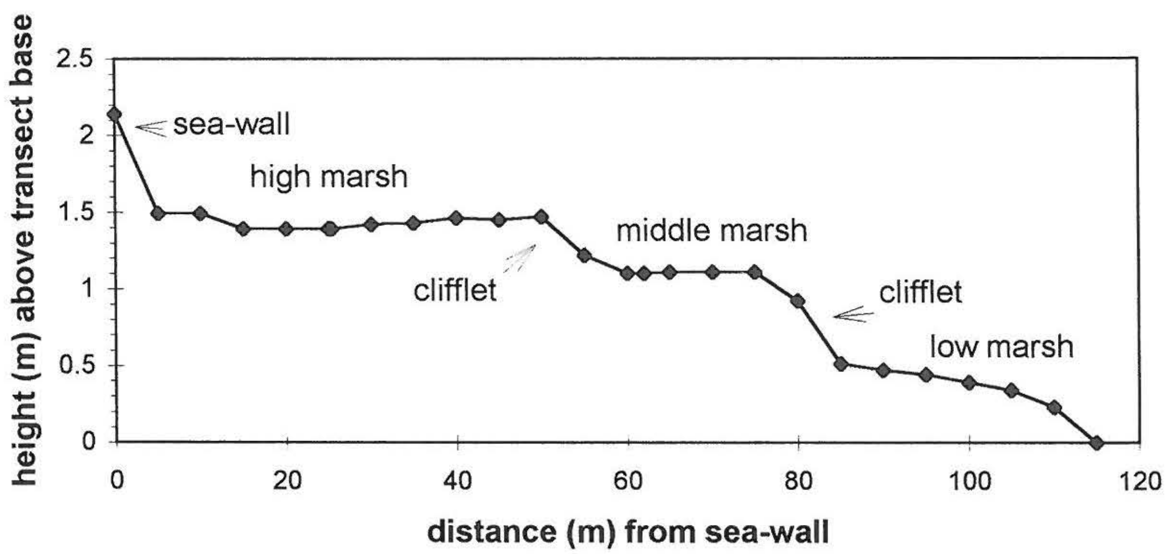

Figure 4: Geomorphology of the Northwick Oaze saltmarsh/mudflat. Foraminifera samples were collected along transects similar and perpendicular to this one, except the 1996 survey where the middle marsh abuts the sea-wall. Altitude (m OD) is not currently known for this site

distinct vegetation types support distinct foraminiferal assemblages, then they should be apparent on the well-developed terraces at Northwick. A sample from a salt-pan on the middle marsh surface was also collected and examined.

Surface samples for foraminiferal analysis were collected along shore-normal transects extending from the base of the seawall at each site. Each sample comprises 10x10x1 cm turf and/or sediment. Collecting took place in 1995 and 1996 during March-April at Northwick (as part of undergraduate projects) and May-June at Oldbury. At Oldbury, the altitude of each of the sample sites was surveyed in relation to OD. Samples were processed by wet-sieving at 63 μm and then air-dried before being examined under a reflected light microscope. All specimens encountered in a sample were identified and counted. Specimens that were living at the time of collection were not distinguished from dead specimens, and thus total foraminiferal assemblages are expressed, as recommended by Scott and Medioli (1980).

Results

The abundance of foraminifera in all saltmarsh samples examined was not great, with only the salt-pan sample at Northwick yielding >250 specimens, and thus very similar to the older Holocene sediments investigated by Haslett *et al.* (1998). Also, the lithology of all sediment examined was predominantly minerogenic clay. Thirteen species were represented in the assemblages recovered, but only five species (*Ammonia beccarii* (*non batavus*), *Elphidium williamsoni*, *Haynesina germanica*, *Jadammina macrescens* and *Trochammina inflata*) are considered in any detail here. These five are relatively large forms considered to be indigenous to the environments studied and are the forms most commonly recovered from the older Holocene sediments. The other species that were encountered (*Bolivina pseudoplicata*, *Bolivina marginata*, *Brizalina variabilis*, *Cibicides lobatulus*, *Gavelinopsis praegeri*, *Glabratella millettii*, *Globigerina* spp. and *Rosalina* spp.) are generally small forms that are uncommon and considered by Murray (1987) to represent post-mortem suspended transport of continental shelf material into the Severn Estuary, and so are exotic. These exotic forms occur mainly in mudflat and low marsh samples, which indicates that they rapidly settle out of suspension as the flood tide enters onto the saltmarsh. At Oldbury, where altitudinal control and information on tidal levels is available, the data are presented as percentage abundances combining both years (Figure 5), whereas for Northwick the data are presented semi-quantitatively for individual years (Table 1).

The most surprising result from the study is that, almost without exception, foraminifera do not occur on high marsh surfaces and so do not extend up to HAT. Indeed at Oldbury, foraminifera do not exceed MHWST, and so these saltmarshes are barren of foraminifera between MHWST and HAT (*cf.* high marsh), and yet the minerogenic lithology of the sediment is very similar throughout. At Oldbury, below MHWST there does appear to be a clear zonation of foraminifera occurrences (Table 2), with *Haynesina germanica* characterising assemblages around Mean High Water Neap Tides (MHWNT) (*cf.* mudflat and low marsh), *Ammonia beccarii* characterising assemblages mid-way between MHWNT and MHWST (*cf.* low to middle marsh), and *Jadammina macrescens* and *Trochammina inflata* dominating assemblages up to MHWST (*cf.* upper middle marsh). Therefore, the highest zone encountered is equivalent to Zone 1B and

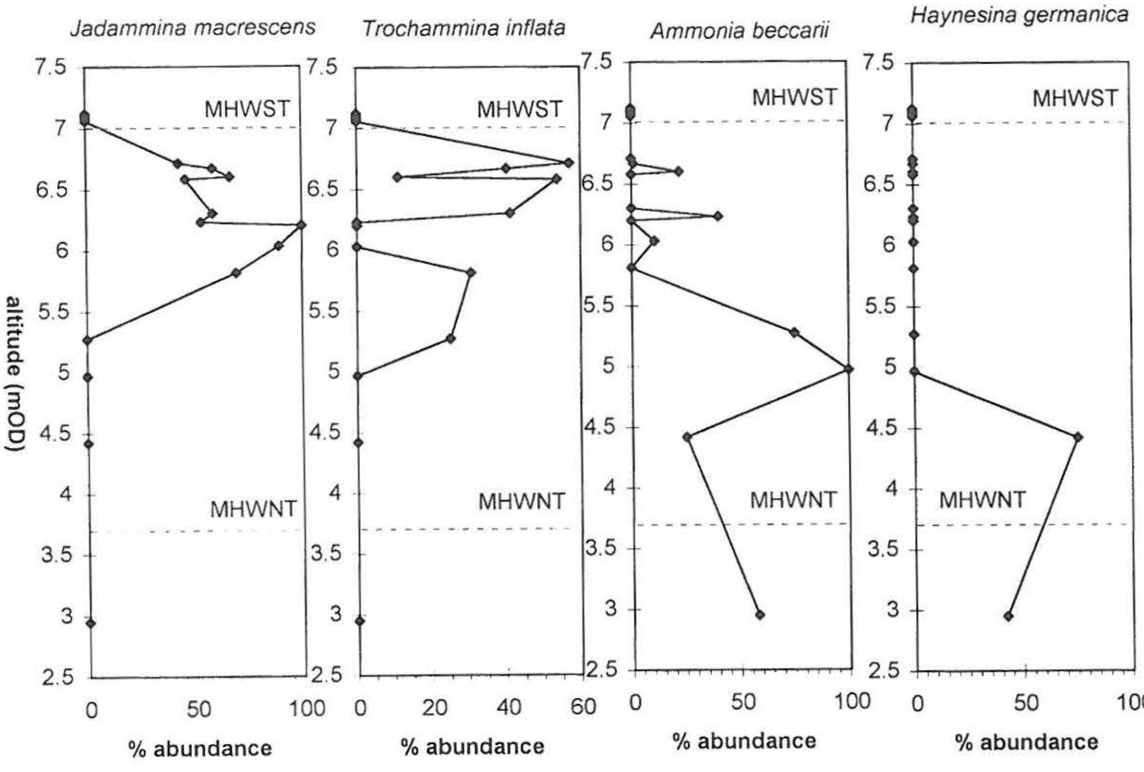

Figure 5: The percentage distribution of foraminifera species at Oldbury-on-Severn in relation to altitude (m OD) and tidal levels. MHWNT = Mean High Water Neap Tides, MHWST = Mean High Water Spring Tides

distance* (m)	marsh surface	abundance	*Ammonia beccarii*	*Brizalina variabilis*	*Elphidium williamsoni*	*Haynesina germanica*	*Jadammina macrescens*	*Rosalina spp.*	*Trochammina inflata*	*Globigerina spp.*
Northwick Oaze										
1995 surface transect										
17	high marsh	barren								
49	high marsh	few					F			
53	mid marsh	abundant	P		A		F	F	P	
80	mid marsh	common	C		C		P		F	
110	mid marsh	few					F			
142	mid marsh	common			P	F	C			
147	low marsh	abundant	A			F			P	
210	low marsh	abundant	C		F	P		F		
225	mudflat	common	P	F		P			P	
1996 surface transect										
0	foot of seawall	barren								
10	mid marsh	barren								
20	mid marsh	barren								
30	mid marsh	few							P	
40	mid marsh	barren								
50	mid marsh	common	C		C	P	F		F	
60	mid marsh	common	C		A	C	F		F	
70	mid marsh	few	P		F					P
80	mid marsh	common	F		A				C	
90	mid marsh	abundant	F		A	A	F		F	
130	low marsh	common	P		F	P	C			
140	low marsh	common	A		F					
150	low marsh	common	C							
160	low marsh	abundant	A		F	P				
170	low marsh	few	F			F				
180	low marsh	abundant	A		C					
200	low marsh	abundant	A		F					
210	low marsh	few	F		P					
220	low marsh	few				F				
230	low marsh	common	P			C				
Salt pan fauna (%)		very abundant	53		17	29				
Goldcliff mudflat sample		abundant	C			A				

*distance (m) from seawall, P = present, F = few, C = common, A = abundant.

Table 1: Semi-quantitative distribution of foraminifera across saltmarsh/mudflat transects (including salt-pan) at Northwick Oaze. The beginning of each transect starts at the foot of the sea-wall. The results of a mudflat sample from Goldcliff collected in April 1991 is also shown

approximates MHWST. Only in the 1995 Northwick transect (Table 1) does *Jadammina macrescens* comprise a monospecific assemblage on the seaward extremity of a high marsh surface, which may represent the only example of a Zone 1A assemblage encountered in this study.

Discussion

The absence of foraminifera between MHWST and HAT at Oldbury is surprising and contrary to the eastern North American studies where foraminifera extend up to HHW (*cf.* HAT) (Scott and Medioli 1978, 1986; Gehrels 1994). This may be due to the severely macrotidal nature of the Severn Estuary, and the fact that the highest predicted tide in any one year may not attain the level of HAT of the 18.6 year cycle (J. R. L. Allen, personal communication). Therefore, saltmarshes high within the tidal frame may be considered terrestrial in some years as far as predicted tidal ranges are concerned, and thus not sufficiently marine influenced to support foraminifera. Given the wetting and drying extremes experienced on the high marsh platforms, it is conceivable that taphonomic processes prevent foraminifera being preserved in the sediment. However, this study investigates total assemblages (*ie* living and dead specimens), and absence of foraminifera on the high marsh indicates actual absence of living specimens.

Such a relationship of minerogenic sediments that are barren of foraminifera is seen within the Holocene sedimentary record of the Somerset Levels. At a site in the Axe Valley (site NYH/1 of Haslett *et al* 1998; see their fig. 2 for location), a lower clay unit is overlain by a substantial peat, representing a phase of marine regression. Foraminifera investigation of the clay-peat contact (Figure 6), reported here for the first time, clearly shows a Zone 1B assemblage (comprising *Jadammina macrescens* and *Trochammina inflata*) within the lower clay which extends up to *c.*0.1 m below the clay-peat contact, although the sediment within this barren zone is lithologically similar to the underlying clay. Thus, based on the evidence presented here from Oldbury, this sequence may be interpreted as a regression with MHWST level at NYH/1 reached *c.*0.1 m below the clay-peat contact, with the contact itself presumably representing the level of HAT.

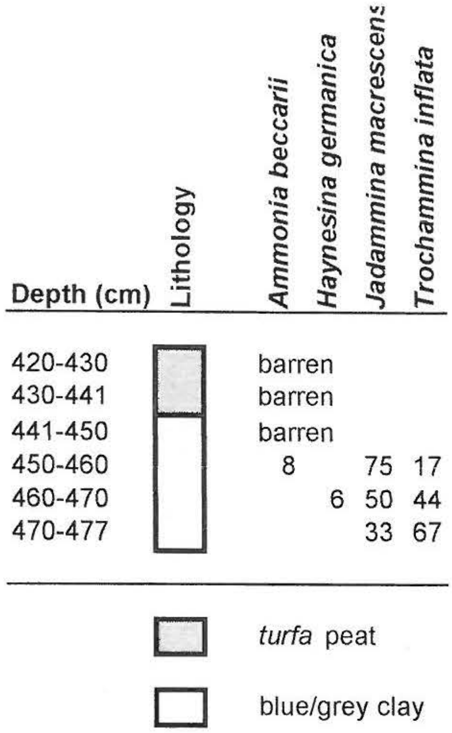

Figure 6: Distribution of foraminifera across aclay/ peat contact at site NYH/1 (Nyland Hill, Axe Valley, Somerset) (see Fig. 2 of Haslett et al *1998, for precise location). Abundance is shown as percentage (%) counts*

The same lithological and bio-stratigraphical relationship is not seen at transgressive contacts, where foraminifera occur in clay immediately overlying peat (*eg* at sites NYH/4 and NYH/12 of Haslett *et al* 1998). Foraminifera have even been found within the top 0.05 m of a Middle Wentlooge Formation peat at Goldcliff, Gwent (Fig. 2 (NGR ST 374 819); see Allen and Rae 1987, for stratigraphical explanation), suggesting saltmarsh peat development prior to the minerogenic clay deposition of the overlying Upper Wentlooge Formation. In this case at Goldcliff (previously unpublished), the foraminifera assemblage within the top 0.05 m of the peat is equivalent to Zone 1A, and the assemblage within the overlying clay is equivalent to Zone 1B. Thus, in these older Holocene examples from the Axe Valley and Goldcliff, the peat-clay contact represents an indicative meaning of MHWST, whilst the transition from HAT to MHWST occurs within the top of the peat.

These findings have significant and so far unique implications for sea-level studies in the

Severn Estuary and Somerset Levels in that it highlights the potential errors in using lithostratigraphy alone to establish indicative meaning, as it appears that during regression the clay-peat contact represents an indicative meaning of HAT, whilst transgressive peat-clay contacts indicate MHWST. A possible, and tentative, explanation for these observation is related to the minimal marine influence experienced high within the tidal frame in these severely macrotidal (palaeo)environments, and the resistence of the established depositional environment to sea-level change. Thus, in general terms, under a regressive regime, minerogenic saltmarsh may persist between MHWST and HAT, whilst peat would form above HAT, but during a transgression established peat may continue to accumulate below HAT, particularly if not experiencing marine inundation on an annual basis, until increasing marine influence and inundation become intolerable and minerogenic deposition begins.

The case of *Elphidium williamsoni* - a geomorphological indicator?

This species was largely absent from the Oldbury transects, but common on the Northwick low and midde saltmarsh terraces. It was also found to be abundant in non-vegetated salt-pans at Northwick, in association with *Ammonia beccarii* and *Haynesina germanica*. The topography of the Oldbury (Figure 3) and Northwick (Figure 4) marshes are fundamentally different, in that the Oldbury low-middle marsh surface slopes uninterrupted to the marsh-mudflat cliff, whereas at Northwick the marsh terraces are near-horizontal with a noticeable levée at the seaward end of the middle marsh terrace. Thus, surface drainage of ebb tidal waters at Northwick is impeded, resulting in prolonged wet surface conditions and salt-pan development. From this, it appears that the distribution of *Elphidium williamsoni* on Severn Estuary saltmarshes is related to marsh drainage and geomorphology. Its

Tide Levels	Altitude (mOD)	*Jadammina macrescens*	*Trochammina inflata*	*Ammonia beccarii*	*Haynesina germanica*	Local zonation (this paper)	Equivalent North American Zone*	Local Environment
	7.5					barren zone	High Marsh Zone 1A	High Marsh
MHWST	7							
	6.5					*J. macrescens* and *T. inflata* zone	High-Middle Marsh Zone 1B	Middle Marsh
	6							
	5.5							
	5					*A. beccarii* zone	no direct equivalent zones	
	4.5							
	4					*H. germanica* zone		Low Marsh
MHWNT	3.7							
	3.5							
	3							Mudflat
	2.5							

* North American zonation based on Scott and Medioli (1986)

Table 2: Summary of foraminifera altitudinal distribution and local foraminifera zones erected at Oldbury-on-Severn. Dashed line indicates the altitudinal range of species where they are uncommon

occurrence in association with other characteristic saltmarsh species, such as *Jadammina macrescens* and *Trochammina inflata*, appears to indicate near-horizontal middle saltmarsh development, whilst its association with *Ammonia beccarii* and/or *Haynesina germanica* may indicate either saltpan, marsh creek, or near-horizontal low marsh terrace deposition. Therefore, unlike the other species included in the Oldbury zonation (Table 2) which appear to have a tidal relationship, *Elphidium williamsoni* appears to be more influenced by geomorphology and drainage.

An example of the occurrence of *Elphidium williamsoni* in Holocene sediments from the Somerset Levels is available for site NYH/4 of Haslett *et al.* (1998; see their Fig. 2 for precise location) (Figure 7). At NYH/4 a transgressive peat-clay contact has an indicative meaning of MHWST (Zone 1B or *Jadammina macrescens/ Trochammnia inflata* zone of this paper). Relative sea-level continues to rise indicated by transition through the *Ammonia beccarii* and *Haynesina germanica* zones (of this paper), and deposition at approximately MHWNT. The position of the palaeo-marsh surface within the palaeo-tidal frame appears to stabilise around MHWNT allowing a near-horizontal palaeo-marsh surface to develop, as indicated by the rise in *Elphidium williamsoni* coincident with the persistence of *Haynesina germanica*.

Conclusions

Haslett *et al.* (1998) have demonstrated the need to re-investigate Holocene relative sea-level change in the Severn Estuary and Somerset Levels. The present study has highlighted the need to carry out biostratigraphical analysis of potential SLIPs so that accurate indicative meanings may be applied. Foraminifera appear to be extremely useful for this purpose in the Severn Estuary and Somerset Levels, and this study investigated modern assemblages for

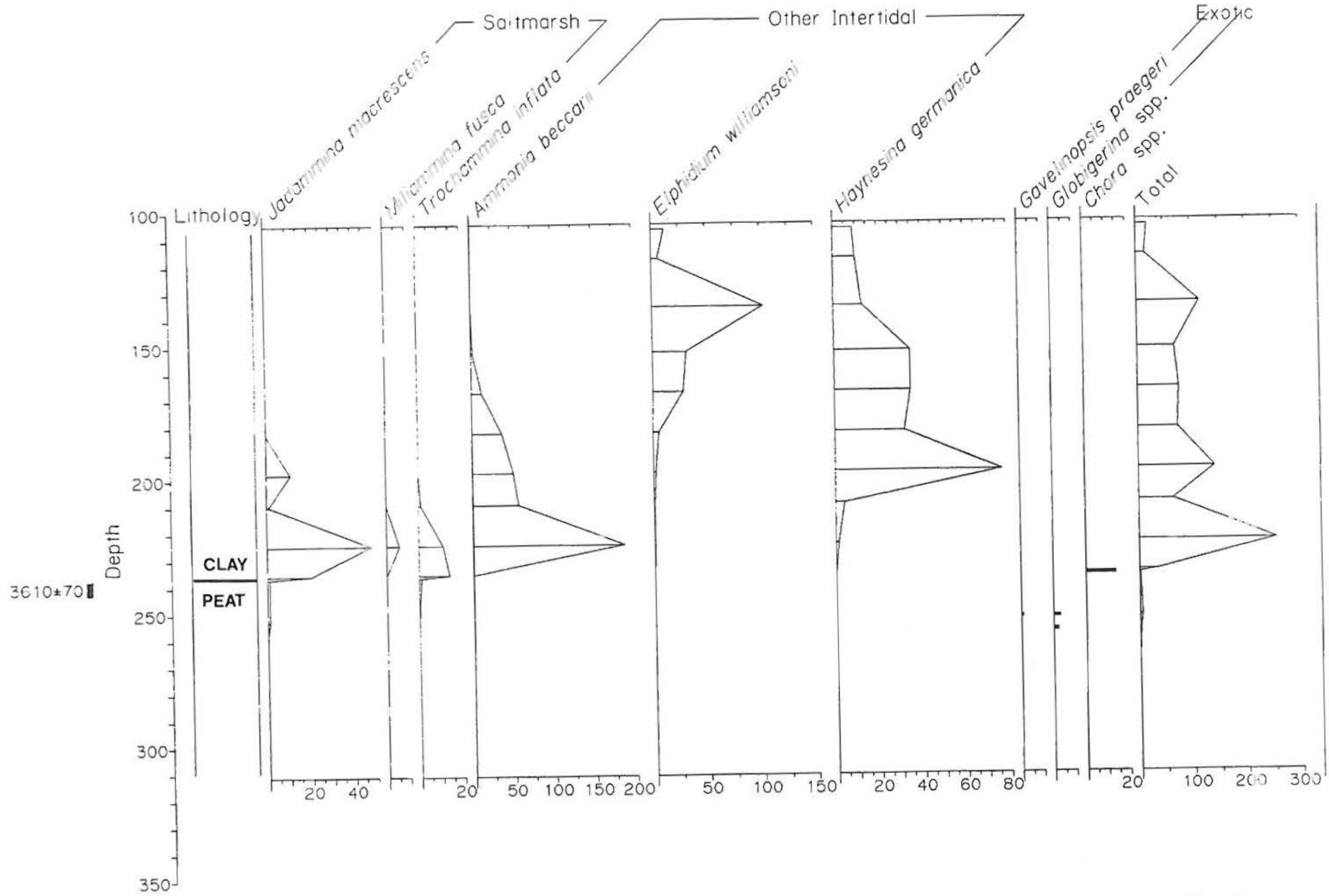

Figure 7: Distribution of foraminifera through core NYH/4 (Nyland Hill, Axe Valley, Somerset) (see Fig. 2 of Haslett et al *1998, for precise location) (from Haslett* et al.*, 1998). Abundance is shown as raw counts. Radiocarbon date is in years BP (laboratory code Beta - 101740)*

calibrating fossil assemblages. The principal conclusions from these studies are:

1. a modern foraminiferal zonation can be constructed for the Severn Estuary, relating foraminifera distribution to tidal levels;

2. in the modern Estuary foraminifera apparently do not commonly occur between MHWST and HAT, resulting in a zone barren of foraminifera;

3. the application of this zonation in older Holocene sediments at previously investigated sites suggests that the indicative meaning of regressive clay-peat contacts is HAT, whilst transgressive peat-clay contacts represent deposition at MHWST level, emphasising the inadequacy of lithological analysis and the need for biostratigraphical control in sea-level studies;

4. the distribution of *Elphidium williamsoni*, unlike other species investigated, does not appear to be strictly controlled by tidal levels. Although it appears to be restricted to saltmarsh environments, it only occurs with any abundance on surfaces with impeded drainage, such as mature near-horizontal marsh terraces, and so may be considered a geomorphological rather than sea-level indicator.

It is conceded that the modern sites investigated at Oldbury and Northwick were perhaps not ideal for this study in that intra- and extra-marsh cliffs interupt the profiles. However, the results from Oldbury are encouraging and further studies have already commenced at Bath Spa University College using sites where such interruption is lacking and for which tidal level information is more secure.

Acknowledgements

We would like to thank Bath Spa University College for funding all aspects of this work. We are also grateful to Pat Brunt for processing samples, Natasha Martin and *Coastal Science* undergraduate students (1995-1997) from Bath Spa University College for assistance in the field, and to Antony Long for calibrating Heyworth and Kidson's (1982) ^{14}C dates. Finally, we would like to thank Martin Bell for his helpful comments on an earlier draft of this paper.

References

Aldhouse-Green, S. H. R., Whittle, A. W. R., Allen, J. R. L., Caseldine, A. E., Culver, S. J., Day, M. H., Lundquist, J. and Upton, D. (1993) Prehistoric Human footprints from the Severn Estuary at Uskmouth and Magor Pill, Wales. *Archaeologica Cambrensis*, **CXLI**, 14-55.

Allen, J. R. L., and Rae, J. E. (1987) Late Flandrian shoreline oscillations in the Severn Estuary: a geomorphological and stratigraphical reconnaissance. *Philosophical Transactions of the Royal Society* **B315**, 185-230.

Barker, P., Fontes, J. -C., Gasse, F. and Druart, J. -C. (1994) Experimental dissolution of diatom silica in concentrated salt solutions and implications for palaeoenvironmental reconstruction. *Limnology and Oceanography*, **39**, 99-110.

Coles, J. (1982) Prehistory in the Somerset Levels 4000-100BC, in M. Aston and I. Burrow (eds.) *The archaeology of Somerset: a review to 1500AD*, 29-41. Somerset County Council.

Culver, S. J. (1980) Differential two-way sediment transport in the Bristol Channel and Severn Estuary, UK. *Marine Geology*, **34**, M39-M43.

Culver, S. J. and Banner, F. T. (1978) Foraminiferal assemblages as Flandrian palaeoenvironmental indicators. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **24**, 53-72.

Gehrels, W. R. (1994) Determining relative sea-level change from salt-marsh foraminifera and plant zones on the coast of Maine, U. S. A. *Journal of Coastal Research*, **10**, 990-1009.

Haslett, S. K. (1997) An Ipswichian foraminiferal assemblage from the Gwent Levels (Severn Estuary, UK). *Journal of Micropalaeontology*, **16**, p. 136.

Haslett, S. K., Davies, P., Curr, R. H. F., Davies, C. F. C., Kennington, K., King, C. P. and Margetts, A. J. (1998) Evaluating Late Holocene relative sea-level change in the Somerset Levels, southwest Britain. *The Holocene*, **8**, 197-207.

Hawkins, A. B. (1971a) The Late Weichselian and Flandrian transgression of South West Britain. *Quaternaria*, **14**, 115-130.

Hawkins, A. B. (1971b) Sea level changes around South-West England. *Colston Papers*, **23**, 67-87.

Heyworth, A. and Kidson, C. (1982) Sea-level changes in southwest England and Wales. *Proceedings of the Geologists' Association*, **93**, 91-111.

Kidson, C. and Heyworth, A. (1973) The Flandrian sea-level rise in the Bristol Channel. *Proceedings of the Ussher Society*, **2**, 565-584.

Kidson, C. and Heyworth, A. (1976) The Quaternary deposits of the Somerset Levels. *Quarterly Journal of Engineering Geology*, **9**, 217-235.

Kidson, C. and Heyworth, A. (1978) Holocene eustatic sea level change. *Nature*, **273**, 748-750.

Locke, S. (1970) The post glacial deposits of the Caldicot Level and some associated archaeological discoveries. *The Monmouthshire Antiquary*, **3**, 1-16.

Kidson, C., Gilbertson, D. D., Haynes, J. R., Heyworth, A., Hughes, C. E. and Whatley, R. C. (1978) Interglacial marine deposits of the Somerset Levels, south west England. *Boreas*, **7**, 215-228.

Murray, J. W. (1987) Biogenic indicators of suspended transport in marginal marine environments: quantitative examples from SW Britain. *Journal of the Geological Society, London*, **144**, 127-133.

Murray, J. W. (1991) *Ecology and Palaeoecology of Benthic Foraminifera*. Longmans, London.

Murray, J. W. and Hawkins, A. B. (1976) Sediment transport in the Severn Estuary during the past 8000-9000 years. *Journal of the Geological Society, London*, **132**, 385-398.

Scott, D. B. and Medioli, F. S. (1978) Vertical zonations of marsh foraminifera as accurate indicators of former sea-levels. *Nature*, **272**, 528-531.

Scott, D. B. and Medioli, F. S. (1980) Living vs. total foraminiferal populations: their relative usefulness in palaeoecology. *Journal of Paleontology*, **54**, 814-831.

Scott, D. B. and Medioli, F. S. (1986) Foraminifera as sea-level indicators, in O. van de Plassche (ed.) *Sea-level Research: A Manual for the Collection and Evaluation of Data*. Geo-Books, Norwich, 435-456.

Severn Tidal Power Group (1989) *Severn Barrage Project: detailed report (volumes 1-4)*. Department of Energy.

Shennan, I., Innes, J. B., Long, A. J. and Zong, Y. (1994) Late Devensian and Holocene relative sea-level at Loch nan Eala, near Arisaig, Scotland. *Journal of Quaternary Science*, **9**, 261-283.

Stuiver, M. and Reimer, P. J. (1993) Extended ^{14}C data base and revised CALIB. 3.0 ^{14}C age calibration program. *Radiocarbon*, **35**, 215-230.

Simon Haslett and Paul Davies
Quaternary Research Unit,
Faculty of Applied Sciences,
Bath Spa University College,
Newton Park,
Newton St. Loe,
Bath, BA2 9BN, UK.

Fiona Strawbridge,
RSGIS Unit,
Faculty of Applied Sciences,
Bath Spa University College,
Newton Park,
Newton St. Loe,
Bath, BA2 9BN, UK.