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SEA LEVEL, SALT MARSH AND FEN: SHAPING THE SEVERN ESTUARY LEVELS IN THE LATER QUATERNARY (IPSWICHIAN-HOLOCENE)

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The Holocene sediments (c.8 km³) in the Severn Estuary Levels (c.840 km²) rest on a rockhead platform that was dissected by streams prior to the Ipswichian (last interglacial) high-stand of the sea (c.6 m OD). Ipswichian fluvial gravels plug these valleys and grade up into shelly, littoral deposits which also lie buried in places along the inner margin of the Holocene outcrop. The Devensian cold period saw widespread periglacial conditions, with ice entering the levels in the Carmarthen Bay, Swansea Bay and Cardiff Bay areas during the glacial maximum (19-23 ka cal BP) Sea level rose unevenly during the Holocene which followed, significant fluctuations being superimposed on the underlying upward trend, which was at first very rapid. The uneven rise created on the margins of the Severn Estuary a Holocene sequence, typically 10-15 m thick, of transgressive estuarine silts (salt marshes with creek networks, some mudflats) which alternate with regressive, high intertidal-terrestrial peats (chiefly reed swamp, fen carr, woodland, raised bog). These peats are very variable in development, both regionally and locally, but in response to environmental factors tend to become thicker with increasing distance from the sea and the rivers that cross the levels. Continuous sediment compaction strongly influenced the character of the local succession and ensured, together with the configuration of the underlying bedrock surface, that quasi-isochronous lithological contacts within the sequence now have a relief of up to several metres. The continuing rise of sea level, coupled with an increase in tidal range, is driving the estuary as a whole northeastward up the Severn Vale, together with the Holocene sequence on its margins.

Introduction

The archaeological monuments, sites, and materials of the Severn Estuary Levels, together with the human activities they reflect, lie in the context of a geologically and geomorphologically complex region, which embraces as its central feature the shallow depression which today is partly flooded by the Severn Estuary below Gloucester and the Bristol Channel west of Cardiff and Weston-super-Mare (Figure 1A). Here, as geological conditions changed, we see through human actions a shifting interplay between cold and warmth, hill and lowland, and dryland, wetland, and waterway. Many activity/ occupation sites survive in the modern landscape, but others, because of their original setting and subsequent geological changes, lie deeply buried on former land surfaces or within thick sequences of chiefly estuarine sediment. The area presents many concealed deposits of unknown archaeological potential.

In order to understand these various archaeological sites at any geographical scale, a sound appreciation of the geological and geomorphological development of the region is clearly essential. Long ago, North (1964) attempted just such a synthesis, but the time is now ripe for a new assessment of the Severn Estuary Levels. The aim here is briefly to review the last interglacial-glacial cycle in the area, and then consider the events of the Holocene 'interglacial' period, during which the Severn Estuary Levels proper arose. These are disconnected outcrops (total *c*.840 km²) of chiefly silts and peats (total *c*.8 km³) formed close to changing sea and tidal levels on the margins of the inner Bristol Channel and Severn Estuary (Figure 1B). Crossing the outcrops are numerous rivers and many smaller streams, some of which fade into the maze of drains dug across the coastal marshes after their embankment.

In discussing the deposits, Ipswichian, Devensian and some Holocene dates are quoted in terms of thousands of calendar years (ka BP); other Holocene dates are given using radiocarbon analyses (conventional ^{14}C years BP; calibrated years BP).

Topography of the rockhead surface

The partly drowned landscape associated with the Holocene Severn Estuary Levels had been shaped during the later Pleistocene by substantial shifts of climate and relative sea level (Edmonds 1972;

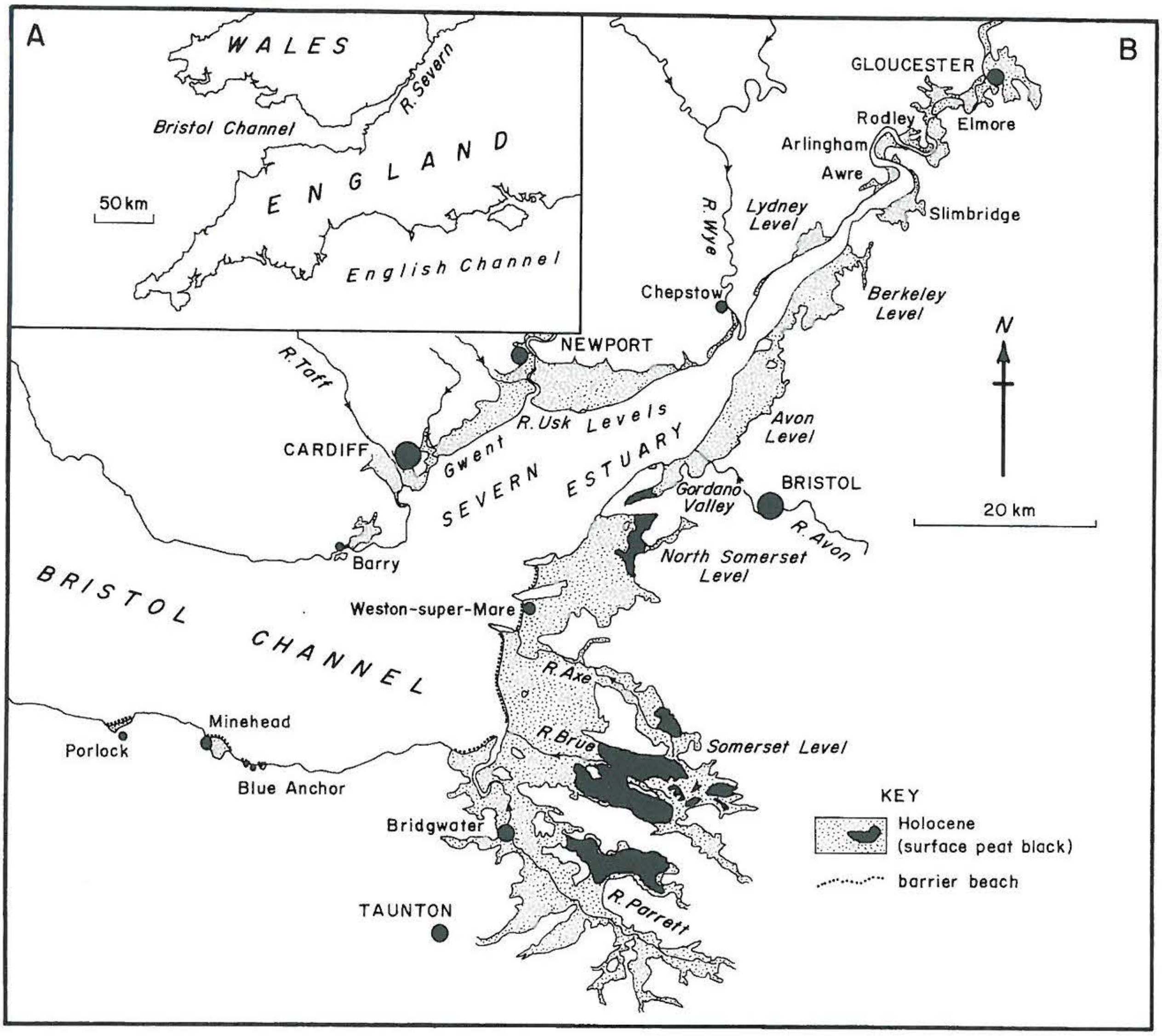

Figure 1: The Severn Estuary Levels. A - Setting in southwest Britain. B - The Holocene outcrops which form the Severn Estuary Levels.

Bowen 1974, 1977, 1999; Gilbertson and Hawkins 1978; Bowen *et al.* 1986) and by vertical crustal movements (Watts *et al.* 2000). In the Severn Vale and Bristol Channel the rockhead took the form, in the broadest terms, of 'valleys within a valley' (Figure 2). The hills of South Wales, Devon and Somerset, together with those of the Forest of Dean and Cotswolds, overlooked an area, mostly below Ordnance Datum, that shelved gently and comparatively smoothly to an inner valley 10-20 m deeper. Shaped primarily by rivers, this narrow, subaxial, slightly meandering feature descended gradually to the southwest and west. By means of hydrographic, geophysical and borehole evidence, the valley has been mapped from Gloucester to the central Bristol Channel (Anderson 1968; BGS 1983, 1986). Similar data show that it is the trunk of an even more extensive network, as yet incompletely known, of lesser drowned/buried valleys, many of which extend into features re-occupied by rivers and streams today (Codrington 1898; Jones 1942; McFarlane 1955; Leese and Vernon 1960; Hawkins 1962, 1990; Anderson and Blundell 1965; Anderson 1968, 1974; Williams 1968; Gilbertson and Hawkins 1978; Evans and Thompson 1979; Waters and Lawrence 1987; Brabham and McDonald 1992; Allen 2001a).

The last interglacial-glacial cycle

The last interglacial-glacial cycle is composed of the Ipswichian warm stage (*c.*110-135 ka BP) and the subsequent longer and more complex Devensian (glacial) cold period (110-10.5 ka BP). During the Ipswichian, global sea level quickly attained a brief highstand (121-128 ka BP) probably of about 6 m

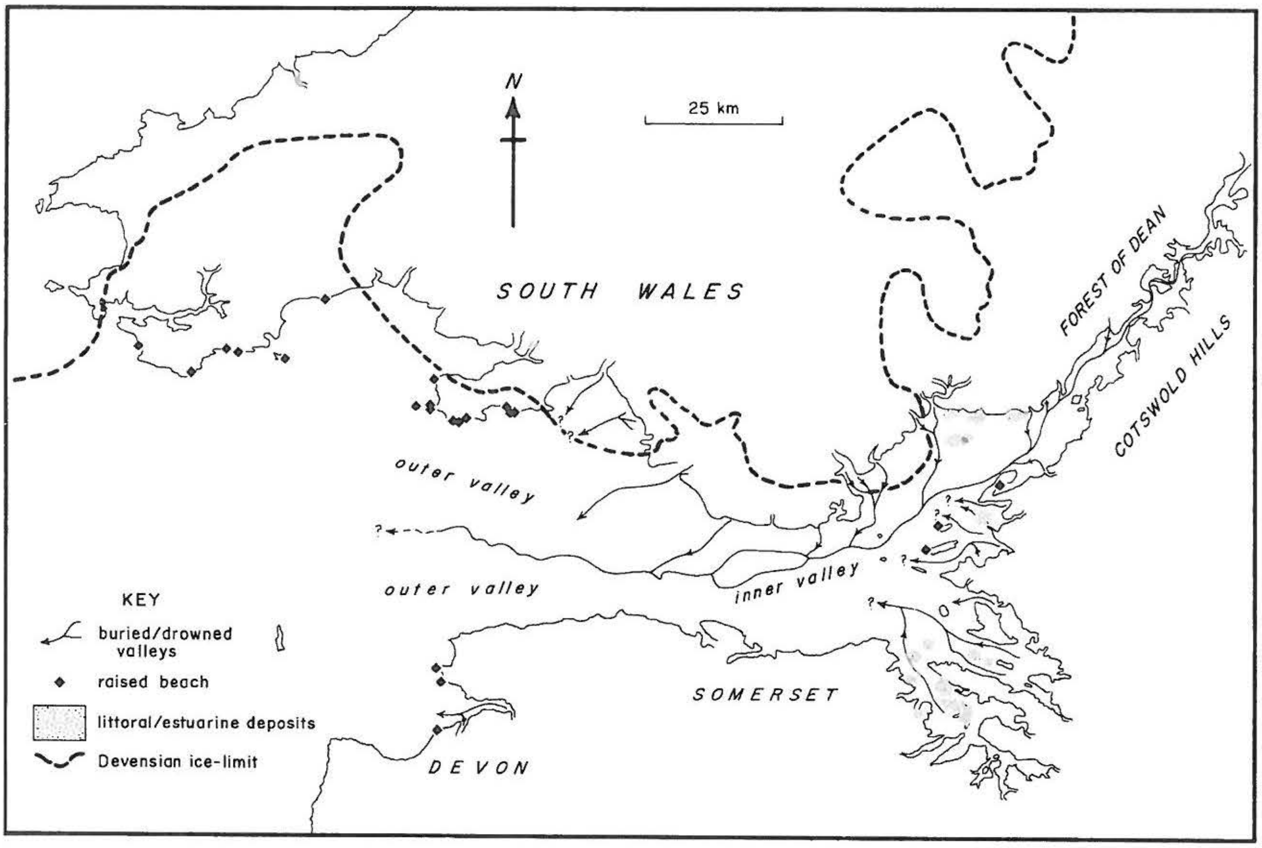

Figure 2: The Bristol Channel and Severn Estuary during the later Quaternary, showing pre-Ipswichian buried/ drowned valleys, approximate position of the coast (estimated mean high-water of spring tides) at the Ipswichian highstand, Ipswichian raised beaches and surviving littoral deposits, and the maximum extent of Devensian glaciers. The areas occupied by Ipswichian littoral deposits have been slightly exaggerated. See text for sources.

OD (Stirling *et al.* 1998; Vezina *et al.* 1999; Cuffey and Marshall 2000), a conclusion widely supported by evidence from the lower Severn Vale and Bristol Channel.

By the highstand (*c.*125 ka), the valleys within a valley lay deeply drowned (Figure 2). The seaway narrowed inland less rapidly and was more intricate than at present, however, and only where strong rocks (Devonian-Carboniferous) occurred do the Ipswichian and modern coastlines almost coincide. Cliffs formed of the less resistant Triassic and Jurassic beds appear to have retreated significantly from their Ipswichian positions, judging from the evident truncation of valleys and spurs and measured rates of erosion (Mackintosh 1868; Reynolds 1906; Williams and Davies 1987, 1989; Davies and Williams 1991; Allen 2000a). Water temperatures were similar to those of today, judging from the molluscs and foraminifera recovered from the Ipswichian deposits. These assemblages require more study, however, especially from the standpoint of age.

Much evidence survives from the northern coast of the Bristol Channel and outer Severn Estuary (Figure 2), chiefly as wave-cut platforms overlain by gravels – the raised beaches of the area – many with dateable molluscs, at altitudes of 5-15 m OD. These are known from Freshwater West, Broadhaven, Manorbier and Swanlake Bays, Caldy Island, Marros, and many sites on Gower (Strahan *et al.* 1909; Dixon 1921; George 1932; Leach 1934; Bowen 1973; Bowen *et al.* 1985; Sutcliffe *et al.* 1987). Further east, on the sub-Holocene surface beneath the Gwent Levels (Figures 2 and 3), there occur at about Ordnance Datum locally shelly sands and gravels representing inshore shoals (Andrews *et al.* 1984; Allen 2001a) and, at Gold Cliff (Haslett 1997; Allen 2000a), shelly shoreface/beach deposits. These littoral sediments take apparently depositional forms that are independent of the rockhead beneath (Figure 3B, C). Steers (1964) had identified the inner margin of these Levels as an abandoned shoreline. Shelly beds are also common toward the tops of the thick gravels and sands infilling the valleys that dissect the rockhead (Figure 3A), suggesting that, as proposed from the North Somerset Level

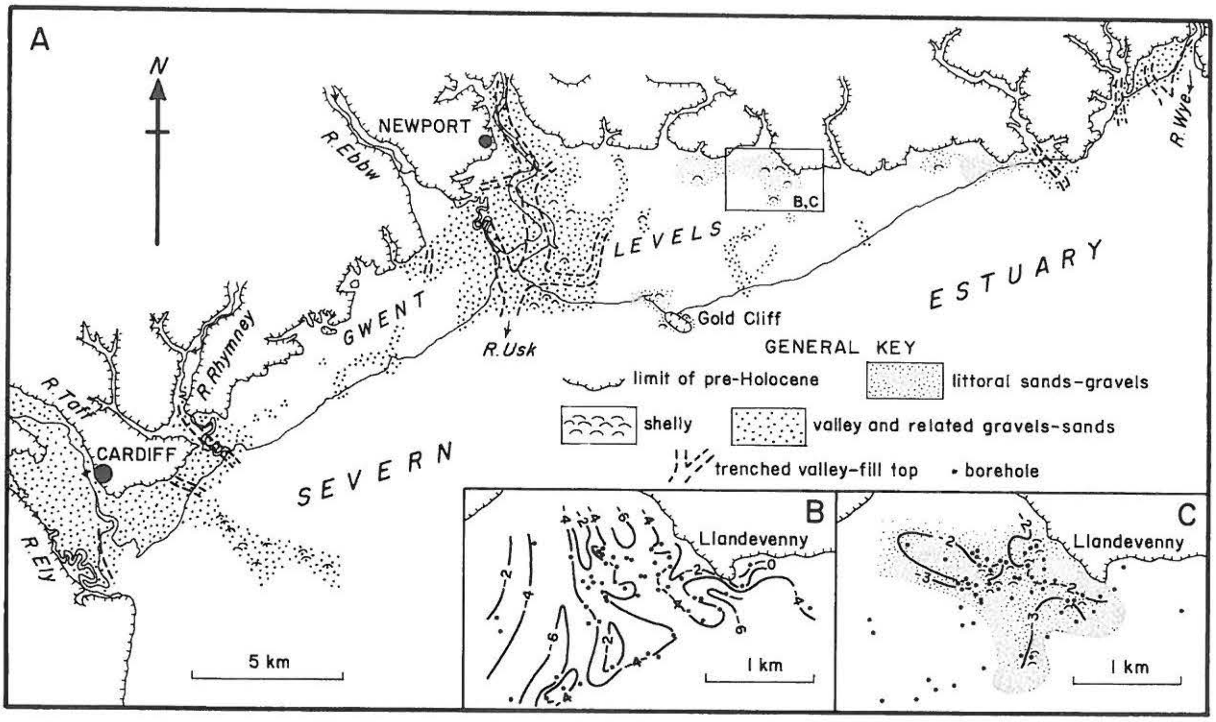

Figure 3: Buried pre-Holocene sands and gravels in the Gwent Levels as shown by about 1000 boreholes. After Allen (2001a) with additional data from Anderson and Blundell (1965) and Williams (1968). A - Known distribution of valley and littoral deposits (NB locally, valley gravels grade up into shelly sands-gravels of probable littoral origin, but these are not separately distinguished). B - Topography of the rockhead southwest of Llandevenny (contours in metres OD). C - Distribution of littoral sands-gravels southwest of Llandevenny (contours on the upper surface in metres OD)

(Gilbertson and Hawkins 1978), the infills date to the early Ipswichian marine transgression (Allen 2001a). These various marine deposits occur at too high an altitude to record the later, intra-Devensian brief highstand at about -15 m OD (Rodriguez *et al.* 2000). Evidence of the Ipswichian high sea level has not so far been recorded upstream of the Wye and Avon but, if shorelines were developed in this part of the area, they probably occupied much the same position as the inner margin of the Holocene outcrop, at a similar altitude.

Less stratigraphic evidence has survived from the Ipswichian southern coast of the outer Severn Estuary and Bristol Channel (Figure 2). Rock platforms and raised beaches are described from Westward Ho!, Baggy Point, Saunton, Weston-super-Mare, Woodspring and Weston-in-Gordano (ApSimon and Donovan 1956; Gilbertson and Hawkins 1977; Kidson and Wood 1974; Kidson 1977; Edmonds *et al.* 1979; Whittaker and Green 1983; Bowen *et al.* 1985; Briggs *et al.* 1991). A platform overlain by periglacial and aeolian deposits at Clevedon may also record an Ipswichian raised beach (Gilbertson and Hawkins 1974). The Ipswichian Burtle Sand Beds of the Somerset Level (Andrews *et al.* 1979) are the uppermost of a probably much more extensive set of deposits that once infilled the deep valleys of this area (Green and Welch 1965; Whittaker and Green 1983; Edmonds and Williams 1985). Typically rising to 6-8 m OD, their rich (albeit mixed and transported) fauna and varied sedimentological characteristics (Bulleid and Jackson 1937, 1941; Kidson 1970, 1971; Kidson *et al.* 1978, 1981; Hunt and Clark 1983) convincingly point to deposition as estuarine shoals and sand flats within the influence of rocky shores and rivers draining nearby lands. Especially convincing is the dominance of the estuarine bivalve *Macoma balthica,* and the presence of channel structures, mud-clast conglomerates and cross-bedding with mud draped foresets. The immediately underlying Burtle Clay Beds, known from a few localities, appear to be of mudflat-salt marsh origin, and could have formed on the margins of the expanding estuaries. Similar in character and altitude to the Burtle Sand Beds are plausibly Ipswichian shelly deposits at Kenn to the north (Gilbertson and Hawkins 1978). Finds made in the valley of the R. Cary suggest that rivers fed from the east into the Somerset estuaries (Hunt *et al.* 1984).

Many sources probably contributed sediment to the Ipswichian sea (Kidson 1977; Allen 2000a),

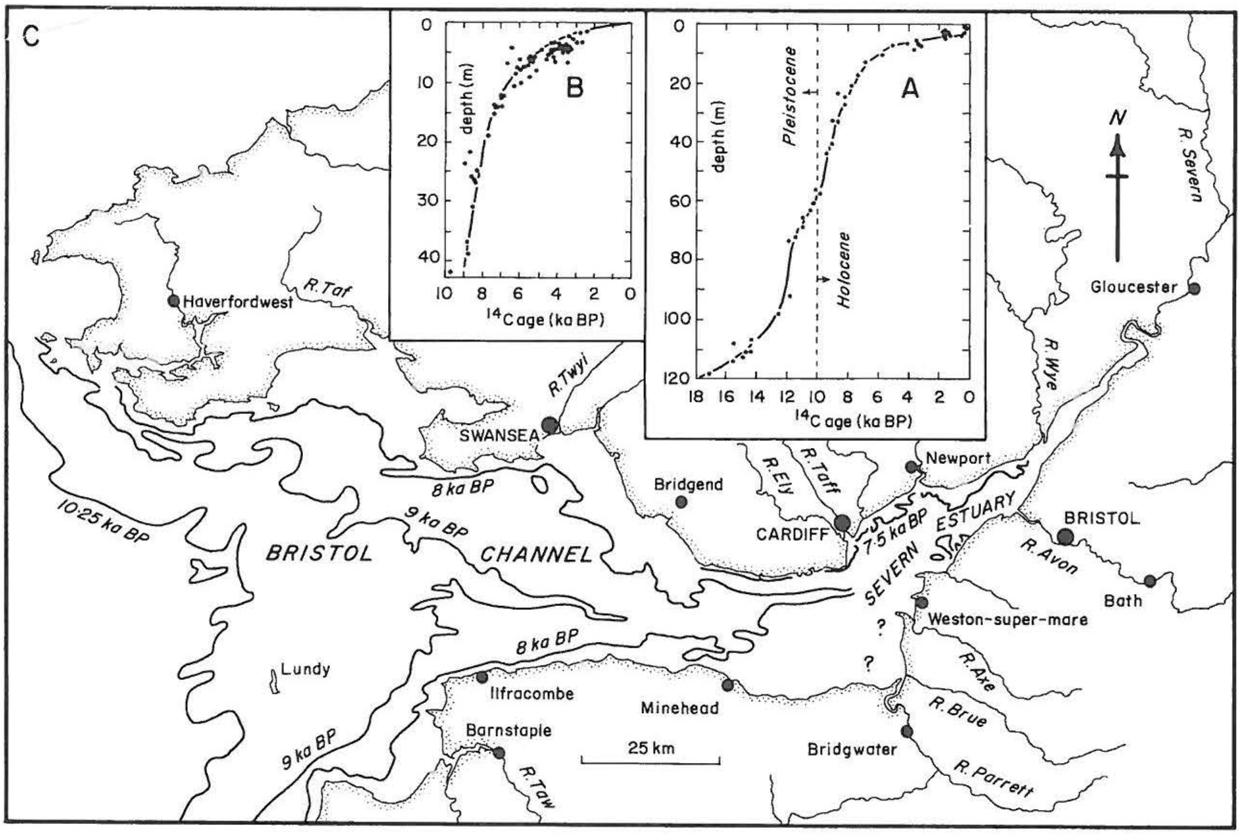

Figure 4: The later Quaternary marine transgression of the Bristol Channel and Severn Estuary. A - Global sea-level rise after the Devensian glacial maximum, as deduced from radiocarbon-dated coral reefs (chiefly Barbadian) in the Caribbean islands (after Fairbanks 1989). Depth is given relative to mean sea level and is corrected for crustal subsidence. B - Sea-level rise in Southwest England, based chiefly on radiocarbon-dated peats in the Bristol Channel-Severn Estuary (after Hawkins 1971). The plotted curve links samples from basal and near-basal peats, and depth is given relative to mean high-water of spring tides. Note the clustering of samples from intercalated peats, subject to compaction, below this curve. C - Approximate early Holocene shorelines in the area. Those from c. *10.25,* c. *9 and* c. *8 ka BP are taken from Hawkins (1971). That for 7.5 ka BP is based on Evans's (1982) geophysical survey establishing the concealed rockhead.*

including northerly-derived Pleistocene deposits, perhaps partly in the Celtic Sea to the west (Tappin *et al.* 1994), which became reworked. The surviving Ipswichian sediments are chiefly of gravel or sand grade, and many of the sands, notably in the Burtle Sand Beds, consist chiefly of finely comminuted shells. In contrast with today, estuary-margin mudflat and marsh deposits are extremely sparse, and recorded only from the Somerset Levels. Hence the Ipswichian sea either experienced a more severe wind-wave climate – plausible given its greater size and depth – or was supplied with less mud by rivers and as the result of the marine erosion of clay-rich deposits.

Late in the succeeding Devensian cold stage, when sea level had fallen by many tens of metres, glaciers encroached southward onto the northern edges of the outer valley (Figure 2), reaching a greatest extent at *c.*19-23 ka (Bowen 1974, 1999; Bowen *et al.* 1986; Eyles and McCabe 1989; Yokoyama *et al.* 2001). Ice lobes pushed into Carmarthen Bay, Swansea Bay and the Cardiff-Newport area. The Devensian deposits, in places overlying Ipswichian sand shoals and raised beaches, are a complex of tills and fluvioglacial sands and gravels (Strahan 1907; Strahan *et al.* 1909; Squirrell and Downing 1969; Waters and Lawrence 1987; Barclay 1989; Wilson *et al.* 1990; Harris and Donnelly 1991). Where ice was lacking, periglacial processes affected the rock floor of the outer valley. Ice-wedge casts and other periglacial structures are widely recorded from the rockhead in the Severn Estuary (Bradshaw and Smith 1963; Allen 1984, 1987a; Harris 1989). Much head formed around isolated hills within the outer valley (Allen 2000a) and along its extensive fringes (Welch and Trotter 1961; Green and Welch 1965; Squirrell and Downing 1969; Edmonds *et al.* 1979, 1985; Gilbertson and Hawkins 1983; Whittaker and Green 1983; Edmonds and Williams 1985; Waters and Lawrence 1987;

Kellaway and Welch 1993; Edwards 1999). Locally, wind-blown sediments have been recorded (e.g. Greenly 1922; ApSimon *et al.* 1961; Gilbertson and Hawkins 1974, 1978). Of particular archaeological importance are mid and late Devensian cave deposits associated with the Carboniferous Limestone of the South Welsh littoral, with their rich mammalian faunas and evidence of sporadic human activities (e.g. Stuart 1982; Sutcliffe *et al.* 1987; Ford 1989; Aldhouse-Green *et al.* 1995; Aldhouse-Green and Pettitt 1998; Lynch *et al.* 2000). A brief intra-Devensian warming led to a marine highstand at *c.* -15 m (Rodriguez *et al.* 2000), but stratigraphic or geomorphological evidence of this event has not yet been recognised in the area of the Bristol Channel and Severn Estuary.

The Holocene

Sea-level rise and other environmental factors

Mean annual temperature in the area of the Severn Estuary Levels rose by approximately 15°C between the Devensian glacial maximum (*c.*19-23 ka) and the start of the Holocene at 10.5 ka BP (Bell and Walker 1992). Interglacial conditions replaced full glacial ones during the last 3 ka of this interval, with abrupt temperature increases occurring on a decadal time-scale. The chief effect of the amelioration was the release of meltwater from glaciers and a global eustatic sea-level rise of as much as 130-135 m (Fairbanks 1989; Yokoyama *et al.* 2000, 2001), at first gradual, then swift and then, over the last 5-6 ka, again more gradual (Figure 4A). This rise (Hawkins 1971) was experienced in the Bristol Channel and Severn Estuary area (Figure 4B), which was rapidly transgressed by the sea after about 11 ka (Figure 4C), a peat cored *c.*25 km south of Swansea confirming the 9 ka shoreline (Evans and Thompson 1979). A number of prehistoric activity/ occupation sites on the floor of the outer valley are known to have been drowned during the transgression, for example, at Porlock (Boyd-Dawkins 1870) and Gold Cliff (Gwent Levels) (Bell *et al.* 2000) during the Mesolithic, and at Oldbury Flats (middle Severn Estuary) in the Neolithic and Bronze Age (Allen 1998). They are probably just a few of the many sites likely to have been established on the valley floor. Simultaneously, the transgression created accommodation space able to receive the estuarine deposits which constitute the Holocene sequence underlying the Levels. Globally, sea level continues to rise, at 1-2 mm a^{-1} (e.g. Gornitz 1995), and at an apparently accelerating rate (Woodworth *et al.* 1999). Mean annual temperature has continued to fluctuate in the area by the order of 1°C, giving rise to the mid Holocene warm episode, and to shorter warm periods in Roman, high-medieval and modern times (Bell and Walker 1992).

Sea-level behaviour in the area (Figure 4B) depended not just on global change but also on regional and local factors, especially the glacio-hydro-isostatic adjustment of the Earth's crust (Shennan 1989; Lambeck 1993a, 1993b). The behaviour of relative sea level has been established largely by radiocarbon-dating peats and other organic materials which occur at measured altitudes at the base of or within the Holocene sequence (Hawkins 1971; Heyworth and Kidson 1982; Bell 1990; Haslett *et al.* 1998; Scaife and Long 1995). In the context of this method, 'sea level' should be understood to mean a variable water level very high in or at the top of the tidal frame, for it is this tidal level that constrains the upward growth of salt marshes and the development of organic marshes in coastal settings. Tidal levels are affected as much by secular and longer-term changes in tidal range as by the movement of mean sea level itself (e.g. Austin 1991; Woodworth *et al.* 1991). At the same time, they also change spatially, especially within estuaries (e.g. Allen 1990; van der Molen 1997). Other methods for the determination of sea levels have been devised for the last two millennia (Allen 1991), when generally no peats arose, but the behaviour of sea and tidal levels in this interval remains poorly constrained. At least one of the peat-based curves (Heyworth and Kidson 1982) may, however, be too low by as much as a few metres, on account of the neglect of sediment compaction (Haslett *et al.* 1998; Allen 1999; Shennan *et al.* 2000a), and the plots as a whole depict only the underlying behaviour of sea level. The fact that peats, recording highest intertidal-supratidal organic marshes, appear at several levels in the Holocene sequence means that higher-frequency fluctuations of sea level were superimposed on the underlying upward trend (e.g. Shennan 1995; Allen 1995). These fluctuations had a time-scale of hundreds of years but probable amplitudes of no more than a few decimetres to one or two metres or so (Allen 1995, 1997a). What remains uncertain about these fluctuations, or sea-level tendencies (Shennan 1982; Tooley 1982), is their synchroneity and areal extent. One such event, it is clear, was concluded 2500-3000 years ago, and is widely registered in the Northwest European coastal zone (van Geel *et al.* 1996; Long *et al.* 2000). Other events, however, appear to have been of more

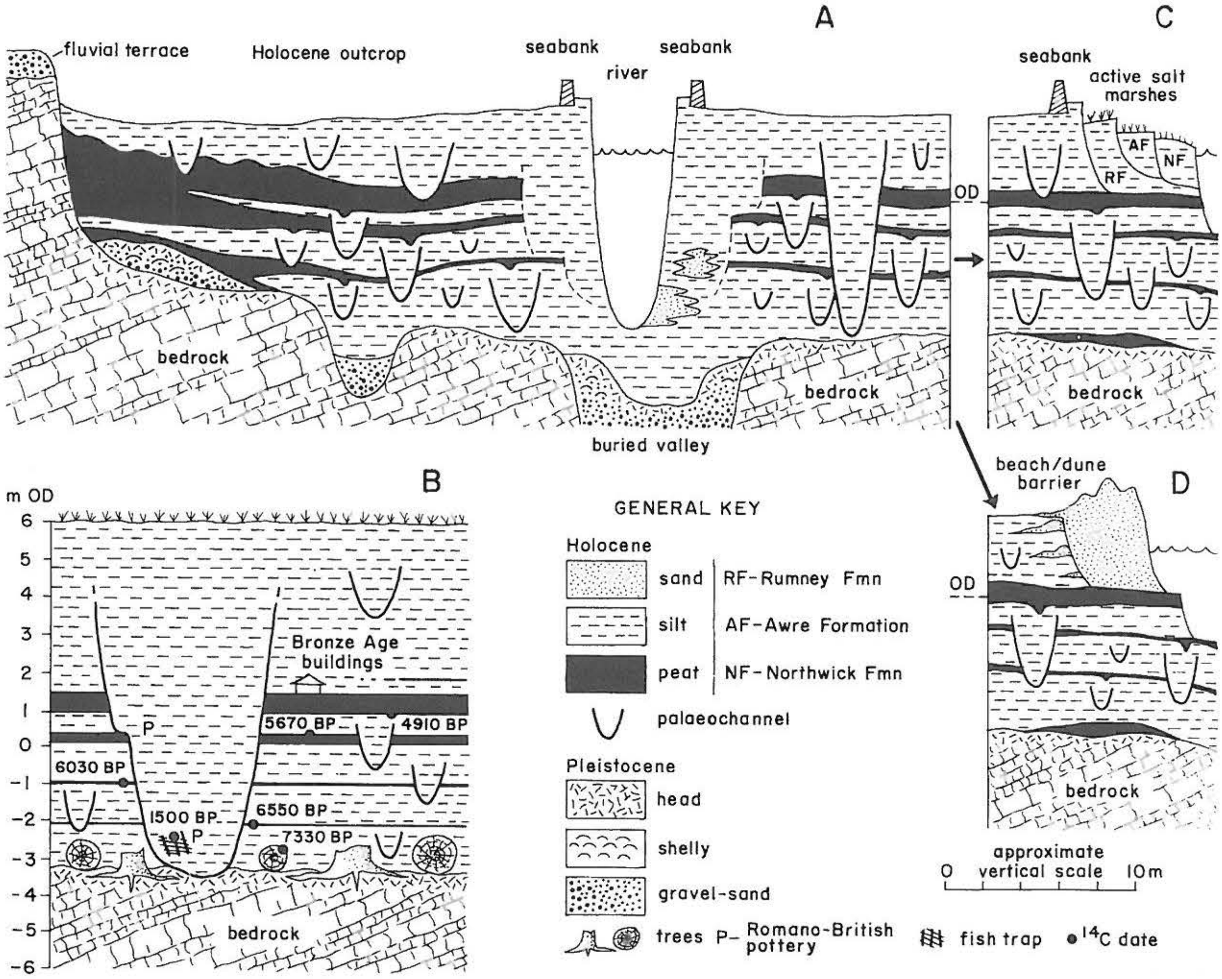

Figure 5: The later Quaternary sequence in the Severn Estuary Levels. A - Schematic representation illustrating the buried rockhead with incised valleys (pre-Ipswichian), trenched Ipswichian fluvial-littoral valley-fills, Ipswichian inshore sands, and Holocene estuarine deposits divided between silt-dominated facies close to rivers and mixed silt-peat facies further away. B - composite measured and dated Holocene sequence in the Redwick area, Gwent (see also Table 1). C - Terraced marsh developed on a sheltered, tide-dominated shore (e.g. middle Severn Estuary). D - Barrier sequence developed on an exposed, wave-dominated shore (e.g. Bridgwater Bay).

local significance. For example, between Burnham-on-Sea (Druce 1998, fig. 2) and Redwick (Allen and Bell 1999, fig. 1), about 35 km apart across the inner Bristol Channel, there is little agreement between the dates of especially the earlier of the recorded peat beds.

As modelled by Hawkins (1971) and Austin (1991), the Holocene marine transgression of the valleys in a valley was swift (Figure 4C), as in many parts of the Northwest European continental shelf (Lambeck 1995; Shennan *et al.* 2000b), and accompanied by significant changes in the tidal and sediment regimes. The transgression during its earlier stages was perhaps too rapid to have either permitted much sediment accumulation along the fringes of the sea or allowed what did accumulate to survive, for the known marine-estuarine deposits in the Levels date from after 7-9 ka. As the sea-level rise slowed, however, sediment began to accumulate extensively at the edges of the sea. Typically, the Holocene sediments of the Severn Estuary Levels mantle the rockhead, and a variety of Pleistocene glacial, fluvial and littoral deposits, to a thickness seldom more than 10-15 m. They are chiefly silts, representing intertidal mudflats and mineralogenic salt marshes, which alternate with peats recording various types of coastal organic marsh. Some sands and occasional gravels occur in association with tidal reaches of the larger rivers in the area. Along the Somerset coast, barrier beaches of gravel or sand with cappings of aeolian dunes shelter the marshes of the hinterland (e.g. Kidson 1960; Bell 1990). Many of these coarse littoral deposits are found on shores which had been or continue to be in retreat, as shown by the survival offshore of older Holocene marsh deposits. The breaches in these barriers where the rivers escaped to the sea also gave the tide access to the sheltered marshes, until artificial earth banks began to be built along the edges of the channels (Williams 1970; Rippon 1997).

General character of the sequence

Stratigraphic knowledge of the Holocene in the Severn Estuary Levels is very uneven, but it is already clear that, while the successions in different parts of the area are broadly similar, great lateral variation occurs on geographical scales of metres to kilometres. The Gwent Levels reveal that several factors combine to create the variability (Allen 2001a).

Figure 5A depicts the chief kinds of succession. The tidal rivers are associated with a facies typified by fining-upward sequences of fine-medium sands and silts. These may begin with a basal peat, but more commonly directly overlie either the rockhead or Pleistocene deposits (tills/sands-gravels/head). Intercalated peats are uncommon and, when present, generally low-lying. The most abundant and widespread facies, formed away from river influence, is an alternation of silts and peats on a scale of decimetres to metres. Up to five peats, and occasionally more, of which one may be basal, are present in the longer sections, tending to thicken upward, as in a composite profile (Allen and Bell 1999) measured and dated at Redwick, Gwent Levels (Figure 5B, Table 1). Here the Holocene estuarine sediments smother an oak forest that grew on a sandy-pebbly head with periglacial structures and frost-shattered clasts of Welsh origin.

Lateral variability is especially marked in the intercalated silt-peat facies (Figure 5A). Intrinsic environmental factors operating on scales of hundreds of metres to kilometres cause the silts to thin and the peats to thicken away from coasts and rivers (Allen 1995; Woolnough *et al.* 1995). Shifts in the coastline on similar scales gave rise to concealed stratigraphic discontinuities within the sequence, for example, in the Wentlooge Level (Allen 2001a), where the erosional followed by depositional events that created buried mid and late Holocene shorelines find a post-medieval parallel (Allen 1987b). Variations in rockhead altitude induced differential sediment compaction and stratigraphic distortion throughout the period of sediment deposition (Allen 1999, 2000b). The response to burial also depended strongly on lithology (Hawkins 1984), ranging from highly susceptible peats, through moderately responsive

Table 1: Radiocarbon ages of peats and other organic materials, Redwick composite sequence (see also Figure 5B).

Materials and laboratory number	*Conventional radiocarbon age (years BP)*	*Calibrated radiocarbon age (years BC/AD)*[1]
fish trap in palaeochannel (Beta 134642)	1500±60	AD425-655
timbers, Bronze Age buildings (Swan 225-228)	2930±70 2940±70 3060±70 2950±70	1390-930 BC 1390-940 BC 1510-1100 BC 1400-990 BC
base fourth peat (Beta 113004)	4910±70	3805-3620 BC
top third peat (Beta 128779)	5670±90	4725-4340 BC
second peat[2] (Beta 134641)	6030±80	5205-5170 BC
first peat[2] (Beta 134640)	6550±70	5625-5635 BC
oak in basal bed (outer tissues) (Beta 134641)	7330±70	6375-6030 BC

1 - Stuiver *et al.* (1998), two standard-deviation range
2 - Whole-bed samples

organic-rich silts and silts, to weakly affected sands. Consequently, peat beds, which are especially compressible, tend to thicken and dip away from concealed hills and ridges, as described by Bell (1995), Haslett *et al.* (1998) and Shaw and Ceman (1999), and as can be seen in the intertidal zone at Grange Pill, Ley Pill and Oldbury Pill in the middle Severn Estuary. Considerable lateral complexity is locally evident in some peats (e.g. Bell *et al.* 2000). Where the rockhead lies deep, compaction gradually lowered beds by as much as 3-4 m below their altitude at deposition. An ubiquitous and common cause of lateral variation is the erosional expansion and subsequent infilling of tidal creeks in association with the deposition of silt beds (Allen 2000c). These palaeochannels ranged from gullies a few decimetres deep and wide to large waterways tens of metres across at the rim with beds many metres below. Even modest-sized ones cut deeply into older strata, breaking their lateral continuity. The final infill of the creeks tends to be a ribbon-like plug of thickened peat, to the top of which subsequent differential compaction imparts the false appearance of a channel (Allen 1999).

The Holocene sediments are referred to the Wentlooge Formation (Allen and Rae 1987), which may be divided informally into lower (thick silts with no or only few and thin peats), middle (thick peats alternating with silts), and upper (thick silts typically with no peats) divisions. Typically, the silts are pale greyish to bluish green in colour, but in the upper division are commonly mottled pale brown. They vary from structureless to delicately laminated, and at some horizons display what appears to be an annual banding, pointing to rapid deposition over a short period, up to a few centimetres annually. Silts infilling the younger palaeochannels are pale olive-green. These sediments too are commonly laminated, but their bedding is irregular and moderately dipping, as the result of deposition on inclined, uneven surfaces, and commonly shows signs of disturbance as the result of slumping down the channel sides (Allen 1985, 2000c; Allen and Rippon 1997).

Embanking of the Severn Estuary Levels began in the Roman period (Allen and Fulford 1986, 1987) and continued into modern times (Rippon 1996, 1997). Consequently, the Wentlooge Formation is incomplete over large areas, lacking the highest strata to a degree set by the date of land-claim and any post-embanking siltation (e.g. Rippon 1996, 1997). Because of coastal erosion, the formation is also widely exposed intertidally. Exclusive to active salt marshes in sheltered areas are other silt formations, commonly up to several metres thick, which record episodes of shoreline retreat and advance during the last millennium. These are the Rumney, Awre and Northwick Formations (Allen and Rae 1987; Allen 1987b, 1997b), encountered throughout the Severn Estuary. They can be mapped across the surfaces of the surviving marshes by the low clifflets, recording past shorelines, that divide one terrace-like unit from another. The Rumney Formation, divisible between lower (medieval) and upper (early modern-modern) parts, consists of pale brown grading up to grey silts, and underlies the highest salt marshes. Both the lower and upper parts are erosively-based. Salt marshes at an intermediate level, dating from the late 19th century, conceal erosively-based grey silts of the Awre Formation. The youngest deposit, initiated during the middle decades of the last century, is the Northwick Formation, a set of grey silts lying on an erosion surface beneath the lowest-lying marsh. These morphostratigraphic units afford an alternative coastal facies (Figure 5C) to the gravel-sand barriers of the more exposed inner Bristol Channel (Figure 5D). It is implied with little justification that such barriers existed over most of the Holocene (Kidson and Heyworth 1976; Jennings *et al.* 1998), but they may have appeared on the Somerset coast only within the last few millennia as shores retreated, rock cliffs became accessible, and wave fetches and energies increased under the impact of continuing sea-level rise which widened and deepened the seaway (and see Rippon this volume).

The rising sea level continues to influence the area, destroying and redistributing the Holocene deposits (Allen 1990b). Higher-frequency shoreline instability is recorded by the concealed stratigraphic discontinuities of mid-late Holocene date within the sequence (Allen 2001a), as well as by the Rumney, Awre and Northwick Formations (Allen and Rae 1987), and many examples of set-back embankments (Allen 2000d). The events which created these shorter-term changes are superimposed on an underlying tendency toward coastal retreat, expressed by the widespread, intertidal exposure and erosion of Holocene sediments, and the creation of Holocene outliers (e.g. Kerney 1976; Gilbertson *et al.* 1990; Allen and Fulford 1992; Druce 1998). Essentially, as the older Holocene deposits become removed and the surviving salt marshes build higher, a process of 'stratigraphic roll-over' pushes the entire estuary system further up the Severn Vale (Allen 1990b).

Introduction to the outcrops

The older Holocene in the small Elmore-Longney, Rodley, Arlingham, Awre and Slimbridge Levels (Figure 1B) consists of a generally thick, mainly woodland peat with intertidal silts above and below (Prevost *et al.* 1901; Allen 1990c; Hewlett and Birnie 1996; Crooks 1999). The peat top, at roughly 5 m OD, dates to 2360±60 ^{14}C years BP (800-200 cal BC) (Beta 81686) at Elmore, 2340±60 ^{14}C yrs BP (800-200 cal BC) (Beta 80693) at Longney, and 3110±50 ^{14}C years BP (1500-1210 cal BC) (Beta 80696) at Slimbridge. Considerable channel instability and early embanking are recorded by a variety of younger, locally sandy Holocene deposits and features (Allen 1986, 1990b; Allen and Fulford 1990a, 1990b; Hewlett and Birnie 1996). The nature and cause of the instability remain poorly understood.

Of the Lydney Level (Figure 1B) little is known. Holocene estuarine silts with a basal peat over gravel are recorded from the inner harbour at Lydney (Lucy 1877). Coastal instability was rife, as in the Tidenham area downstream (Allen and Rae 1987), and at least half of the surviving outcrop arose in the last two millennia (Allen 2001b). On and near the coast of the Berkeley Level opposite, interbedded peats and estuarine silts with palaeochannels rest locally on gravel, but chiefly on a mildly dissected, periglaciated, forested bedrock that supported Neolithic-Bronze Age activity/occupation sites (Lucy 1877; Welch and Trotter 1961; Murray and Hawkins 1976; Allen 1984, 1992, 1998; Allen and Fulford 1987, 1992, 1996; Allen and Rippon 1997a; Riley 1998; Crooks 1999). The embanking dates from Roman times but the coast, with its terraced active marshes, has not proved stable (Allen and Rae 1987; Allen and Fulford 1996; Allen 2000d). The susceptibility of both banks of the estuary to erosion is further demonstrated by the discovery of medieval landing places now detached from shore but originally apparently within tidal creeks (Fulford *et al.* 1992; Allen and Fulford 1996).

In the Vale of Gordano, at the southwestern end of the Avon Level (Figure 1B), a perhaps Devensian buried sand bar (Gilbertson *et al.* 1990) divides a peat-dominated Holocene sequence inland from a mainly silty one to seaward (Jefferies *et al.* 1968). In the main part of the Level (Welch and Trotter 1961; Kellaway and Welch 1993), the Holocene is of the order of 12 m thick, consisting of estuarine silts with probably at least four, subordinate peats resting on either gravel or bedrock (Jones 1881-82; Leese and Vernon 1960; Seddon 1964; Hawkins 1968, 1990; Murray and Hawkins 1976; Insole 1997; Riley 1998). Radiocarbon dates from these peats have been collected by Insole (1997). After Roman times tidal siltation was for a period resumed in parts of the area (Rippon 1997). An analysis of borehole records connected with the extensive industrial developments and road-building should yield a better understanding of the evolution of the Avon Level.

The Gwent Levels (Figure 1B) are perhaps the best known of the Holocene outcrops (Welch and Trotter 1961; Squirrell and Downing 1969; Waters and Lawrence 1987), on account of dock excavations (Strahan 1896; Strahan and Cantrill 1912; Hyde 1936), intensive borehole studies (Locke 1970-71; Allen 2001a), recording of the superb coastal exposures (Allen 1987b; Allen and Rae 1987; Allen 2000b; Bell *et al.* 2000), and wide-ranging archaeological and environmental work (Locke 1970-71; Allen and Fulford 1986; Smith and Morgan 1989; Whittle *et al.* 1989; Aldhouse-Green *et al.* 1993; Fulford *et al.* 1994; Allen 1996a; Allen and Rippon 1997b; Bell and Neumann 1997; Nayling and Caseldine 1997; Locock 1998, 1999; Locock and Walker 1998; Walker *et al.* 1998; Allen and Bell 1999; Bell *et al.* 2000). Typically 10-15 m thick, and resting on a locally forested land surface, the sequence except near the rivers is of estuarine silts that alternate with numerous peats tending to thicken landward away from sources of tidal silt. The so-called 'main' peat bed has a strongly diachronous top dating over several hundreds of years (Table 2). Over small areas along the inner margin of the Levels its top is at or near the ground surface. Near rivers, however, mainly estuarine sands grading up into silts are seen (e.g. Hawkins *et al.* 1989). Embanking began in the Roman period (Allen and Fulford 1986) and continued into modern times (Rippon 1996). Much erratic coastal retreat occurred over the last two millennia or so (Allen 1987b, 2000c), leading to deep seabank repositioning (Allen and Fulford 1986; Allen 1988, 1996b, 2000d; Allen and Rippon 1997b).

The Holocene sequence of the North Somerset Level (Figure 1B) is poorly known (Whittaker and Green 1983; Hawkins *et al.* 1989; Kellaway and Welch 1993; Allen and Rae 1987; Butler 1987). A peat-dominated facies inland apparently grades seaward into estuarine silts with subordinate peats, in Woodspring Bay erosively overlain, after deep dissection preceding deposition by the local Rumney Formation. North and south of Weston-super-Mare, however, beach-dune sand barriers guard the shore, but their history, aside from a presence in the Bronze

Table 2: Selected radiocarbon dates defining the age of the top of the 'main' peat in the Gwent Levels.

Locality and laboratory number	*Conventional radiocarbon age in years BP (calibrated age)*	*Authority*
Goldcliff[1] (Car 644)	3130±70 (1610-1210 BC)	Smith and Morgan, (1989)
Rumney Great Wharf[2] (Beta 46951)	3080±50 (1510-1210 BC)	Allen (1996a)
Redwick[2] (Swan 225)	2930±70 (1320-920 BC)	Bell and Neumann, (1997)
Barlands Farm[1] (Beta 72506)	2900±60 (1300-920 BC)	Walker *et al.*, (1998)
Cold Harbour[2] (Car 991)	2900±60 (1300-920BC)	Whittle *et al.*, (1989)
Llanwern-Bishton[1] (Q 691)	2660±110 (1100-410 BC)	Godwin and Willis, (1964)
Vurlong Reen[1] (Beta 63590)	<2470±60 (810-410 BC)	Walker *et al.*, (1998)
Magor Pill[1] (Beta 73058)	2430±70 (770-400 BC)	Allen and Rippon, (1997b)
Llandevenny[1] (Beta 133531)	2310±70 (800-150 BC)	Locock (1999)
Goldcliff[1] (GrN 24145)	2160±40 (370-110 BC)	Bell *et al.* (2000)

1 - peat samples
2 - wooden buildings/hearths associated with peat top

Age (Bell 1990), is at still obscure. The area is extensively embanked, beginning in Roman times in the north (Williams 1970; Boon 1980; Rippon 1997, 2000; Allen 2000c). In the south, the stratigraphy reveals over the last few millennia a complex interaction between human and natural forces (Rippon 2000).

The largest and most intricate Holocene outcrop is provided by the main Somerset Level (Figure 1B), watered by the Axe, Brue and Parrett (Williams 1970; Green and Welch 1965; Whittaker and Green 1983; Edmonds and Williams 1985; Rippon 1997). In the interior, which is the better known, thick, variable peats over estuarine-freshwater silts lie at or close to the surface over considerable areas, having gone on forming as late as the fourth century AD (Godwin 1941, 1948, 1955, 1981; Clapham and Godwin 1948; Beckett 1978; Beckett and Hibbert 1979; Alderton 1983; Caseldine 1986; Coles and Coles 1986; Housley 1988; Coles and Dobson 1989; Housley *et al.* 1999). This development passes toward the rivers and the sea into chiefly estuarine silts, commonly with a single mid-Holocene peat, that overlie early Holocene peaty sands infilling deep river valleys (Horner 1816; Godwin 1941; Kidson and Heyworth 1976; Hawkins *et al.* 1989; Aalbersberg 1996; Druce 1998; Haslett *et al.* 1998). Along the high ground that bounds the Level, as at Brean Down (Bell 1990; Allen and Ritchie 2000), these facies interfinger with colluvial deposits. Thus the later sequence differs from that in the Gwent Levels (e.g. Figure 5B), where there

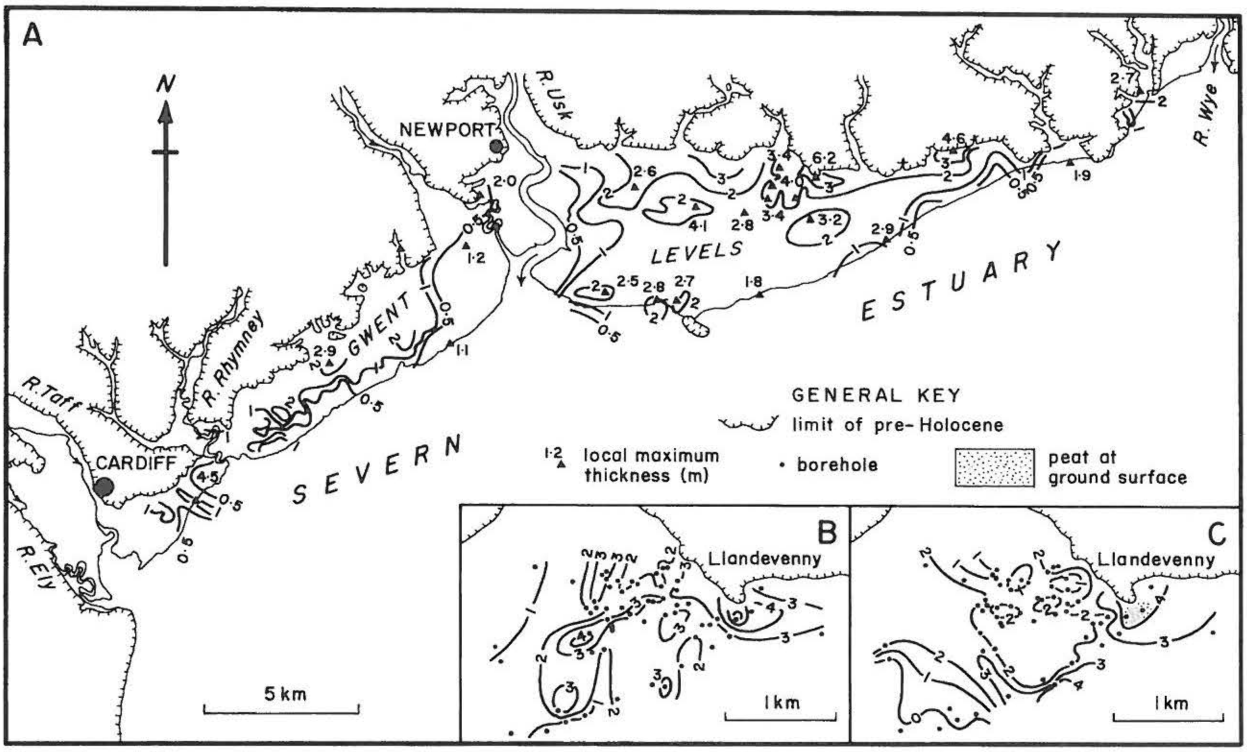

Figure 6: Development of Holocene peats in the Severn Estuary Levels, as shown by 882 boreholes. A - Contours (in metres) of limiting values of total peat thickness (simplified after Allen 2001a). B - Contours showing the total thickness of peat (in metres) southwest of Llandevenny (after Allen 2001a). Except locally where a thin basal peat is developed, only a single ('main') bed is present. C - Contours showing the altitude (m OD) of the top of the 'main' peat southwest of Llandevenny (after Allen 2001a).

are more and longer-lasting peats, possibly because in Somerset peat-formation was suppressed in favour of mineral sedimentation, perhaps due to high compaction rates favoured by the deep rockhead present beneath much of the area. Further work is particularly needed on the evolution of the coastal barriers in Somerset (Kidson 1960; Bell 2000), and on the age of the earliest marine sediments in the buried valleys, as there is apparent disagreement on the timing of their transgression (Hawkins 1971; Kidson and Heyworth 1976).

Finally, isolated outcrops (Figure 1B) of Holocene estuarine silts and peats occur on the north coast at Barry (Strahan 1896) and in the south at Blue Anchor, Minehead and Porlock (Godwin-Austen 1865; Kerney 1976; BGS 1997; Jennings *et al.* 1998; Edwards 1999). Transgressive beach barriers have invaded the last three locations, at Blue Anchor to the accompaniment of severe erosion of the local cliffs of soft Mesozoic rocks.

Salt marshes

The silts which dominate the Holocene deposits of the Levels represent chiefly salt marshes and other tidally influenced wetlands, together with some intertidal mudflats. Firstly, these environments are implicated when foraminifera from the silts (Strahan 1896; Prevost *et al.* 1901; Godwin 1941, 1955; Murray and Hawkins 1976; Green 1989; Aldhouse-Green *et al.* 1993; Druce 1998) are compared to contemporary assemblages (Murray and Hawkins 1976; Haslett *et al* 1997; King and Haslett 1998). Supporting evidence comes from the pollen (e.g. Smith and Morgan 1998; Bell *et al.* 2000). Secondly, distinctive and ubiquitous stratigraphic and sedimentological features (Allen and Fulford 1992, 1996; Allen and Rippon 1997a, 1997b; Allen 1999, 2000c, Allen and Bell 1999; Bell *et al.* 2000) show that, as in contemporary British salt marshes (Pethick 1992), the accumulation of the silt beds proceeded simultaneously with the initiation, erosional expansion and eventual infilling of extensive networks of tidal creeks and gullies on the silt marshes (e.g. Figure 5A). These networks are of proven archaeological potential, yielding artefacts pertaining to fishing, communication and trade (e.g. Allen and Fulford 1996; Nayling 1998; Allen and Bell 1999; Bell *et al.* 2000), and the movement, at low tide within the marsh, of herbivorous mammals. It is almost certainly through a large creek belonging to the late Holocene cycle of networks (Allen 2000c) – perhaps either that at Redwick or at Elver Pill – that the Romano-Celtic boat (Nayling *et al.* 1994) reached its final resting place at Barland's Farm near the inner edge of the Caldicot Level.

Hydraulic modelling suggests that sea-level fluctuations (see above) drove the evolution of these networks (Allen 1995, 1997c, 2000c). As sea level began to rise, salt marsh replaced peat marsh within decades as increasingly deep, silt-laden tidal waters regularly flooded onto and off the coastal lowlands. The networks grew as the most mechanically efficient response to this demand, much of the tidally advected mud being left behind, but at rates and grain sizes that declined away from the open coast, tidal rivers and larger creeks (Woolnough *et al.* 1995; Reed *et al.* 1999). As the rate of rise declined, less water covered the marsh during each tidal cycle and the response of the creeks was to infill and contract. They had largely or wholly disappeared by the time sea level became stable again and a fresh peat blanket arose. Only watercourses draining the hinterland survived peat-forming episodes.

Peat marshes

The ubiquitous peat beds arose from the tissues – leaves, stems and roots – of the plants growing on the marshes, but at times when relative sea level was roughly stable or falling, so that tidal silt contributed little or nothing to the total sediment supply. Replacing the preceding salt-marsh silts within decades (Allen 1995), the beds record a considerable range of highest intertidal to supratidal (terrestrial) wetland environments (Wheeler and Proctor 2000). They tend to thicken inland (Figure 6A), developing diachronous lower and upper contacts (e.g. Table 2), for silt declined in availability away from the coast and chief watercourses. Generally speaking, lower contacts are not markedly diachronous and can be almost isochronous, but upper contacts can range in age by several centuries.

Northwest Europe affords only a few, very incomplete, contemporary models for these vanished organic wetlands, but it is clear that sedge/reed swamp, fen carrs, coastal woodland, raised bog and detritus-gathering open waters are all represented in the Severn Estuary Levels (Godwin 1981; Smith and Morgan 1989; Walker *et al.* 1998; Bell *et al.* 2000). Alder, oak, birch and willow dominated the woodland and carr peat facies (Prevost *et al.* 1901; Allen 1992; Bell *et al.* 2000), the trees now appearing as upright stumps and either windsnapped, windtilted or windthrown trunks (Allen 1992). The longer-lasting marshes became raised bogs (Godwin 1981; Smith and Morgan 1989; Walker *et al.* 1998; Bell *et al.* 2000). Clustered mounds 5-10 m across developed on the bog in the Somerset Level (Clapham and Godwin 1948; Coles and Coles 1986), and possibly elsewhere (Bell *et al.* 2000), and peat domes some metres high (Godwin 1981; Hobbs 1986) of a larger geographical scale may have also have been present. Of the various peat facies, the raised bogs found in the wider Holocene outcrops, and especially the upper surfaces of the bogs, have the highest archaeological potential (Coles and Coles 1986; Bell and Neumann 1997; Locock 1999; Bell *et al.* 2000). Prehistoric trackways abound, and locally, in addition to the famous Somerset lake villages, there are groups of buildings, some sheltering livestock grazed, probably seasonally, on salt marshes then encroaching on the bog. In the Gwent Levels, for example, at least six sites have revealed single or clusters of buildings. Geo-archaeologists are, however, far from understanding the complex circumstances – including climate, differential peat deposition, differential sediment compaction, and the flow and chemistry of shallow groundwaters – that allowed local features of relief exploitable by humans to arise and survive for a time on these bogs.

Low mechanical strength and susceptibility to oxidation and bacterial-fungal decay make peat a readily compacted sediment (MacFarlane 1969; Hobbs 1986), as may be judged from the widely reported collapse of peatlands after drainage (Hutchinson 1980; Nieuwenhuis and Schokking 1997; Brew *et al.* 2000). The thicker peats of the Severn Estuary Levels display much local variability on account of this factor combined with depositional relief, lithological variations in the sequences containing them, and an uneven rockhead below (Figure 6B, C). Bed thicknesses vary rapidly and, as Kidson and Heyworth (1976) and Curran (1979) early noted, the altitudes of the bottoms and tops of the same lithostratigraphic units can range, with a strong inversion of the depositional relief, by as much as 3-4 m (Allen 1999, 2001a). It is not just these buried landscapes which have been strongly affected by compaction. Embanking and draining accelerate the compaction of sediments of all kinds in the affected area (e.g. de Glopper 1973; Hutchinson 1980; Nieuwenhuis and Schokking 1997), and this is largely the explanation in such coastal lowlands as the Wentlooge and Caldicot Levels (Rippon 1996) for the overall dished form of the ground.

Conclusions

Many environmental changes, including an increasing level of human activity and engagement, are registered in the Bristol Channel and Severn Estuary area and in the sediments and landscapes of the Holocene Severn Estuary Levels, as follows.

(1) Shaped prior to the Ipswichian, the rockhead is a network of valleys within a valley.

(2) During the Ipswichian transgression the valleys were infilled with fluvial gravels and sands.

(3) Raised beaches and a littoral-estuarine sediments were deposited during the Ipswichian highstand on the rockhead and in the drowned valleys.

(4) During the Ipswichian regression, the valley gravels became trenched.

(5) Ice entered from the north during the Devensian glacial maximum; head and aeolian deposits and periglacial structures arose in unglaciated areas.

(6) The latest Devensian-Holocene sea-level rise caused the area to be rapidly transgressed from the west. A forested land surface with scattered human habitations was drowned.

(7) The slowing but unsteady sea-level rise allowed interbedded estuarine silts (salt marshes) and peats (highest intertidal-supratidal marshes) to form at the margins of the sea. Humans exploited these extensive wetlands and their tidal waterways from prehistoric times onward, eventually embanking them in the Roman and later periods.

(8) The continuing rise of sea level is causing stratigraphic 'roll-over', the estuary system as a whole, together with the Holocene sequence on its margin, advancing northeastward up the Severn Vale.

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