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Abstract

A Holocene sedimentary sequence at Marazion Marsh, Mount's Bay, west Cornwall, U.K. is examined with reference to coastal evolution and relative sea-level change. A sample core analyzed in this paper shows the base of the sedimentary sequence rests on weathered bedrock material. Basal organic-rich deposits are overlain by minerogenic materials dominated by sand. A sharp contact separates these two sedimentary units. Changing coastal conditions are reconstructed using lithostratigraphic, biostratigraphic and chronometric data from this sequence. The lower organic-rich unit accumulated between ca. 5420 ± 60 and 4380 ± 55 yrs B.P. Substantial changes in the marsh environment, involving vegetation succession from initial herb domination to mesophytic woodland and eventually to fen-carr/reed-marsh development, is indicated by pollen records from this unit. Diatom data show increased salinity within the basal sequence as arboreal pollen values decline and fen-carr/reed-marsh becomes established. Radiocarbon dates from this and other cores from west Cornwall are used to construct a local time/altitude plot of relative sea level (RSL). It is concluded that the sediment sequence at Marazion Marsh appears to have accumulated in an embayed environment. The sequence was both indirectly and directly affected by changes in relative sea-level position and the influence of protective/transgressive coastal morpho-sedimentary structures and associated processes of sedimentation during the mid-Holocene period.

1. Introduction

Marazion Marsh, west Cornwall (Grid Reference SW 506326) lies ca. 3.5 km east of Penzance on the shores of Mount's Bay. The bay lies between the Lizard Peninsula and Land's End Peninsula (Ordnance Survey Sheet No. 203 Scale 1:50 000). A fossilised sand and gravel barrier normally prevents marine access to the marsh in all but extreme weather conditions. A spatially discontinuous and degraded sand dune occurs on parts of the barrier surface. Landward of the barrier the *Phragmites* dominated marsh is drained

by a stream known as Marazion (or Red) River (Fig. 1).

Stratigraphic surveying reveals ca. 10 m of unconsolidated sedimentary materials within Marazion Marsh. At Borehole number 2 (BH2), Holocene deposits are found between -6.24 m and $+3.07$ m OD (Ordnance Datum). The stratigraphy of the BH2 deposits is similar to other sequences at this site from comparable altitude (Fig. 2). Discussion here concerns only the sequence between -6.24 m and -0.03 m OD (UK Ordnance Datum) at BH2, as modern artifacts identified within parts of the sequence

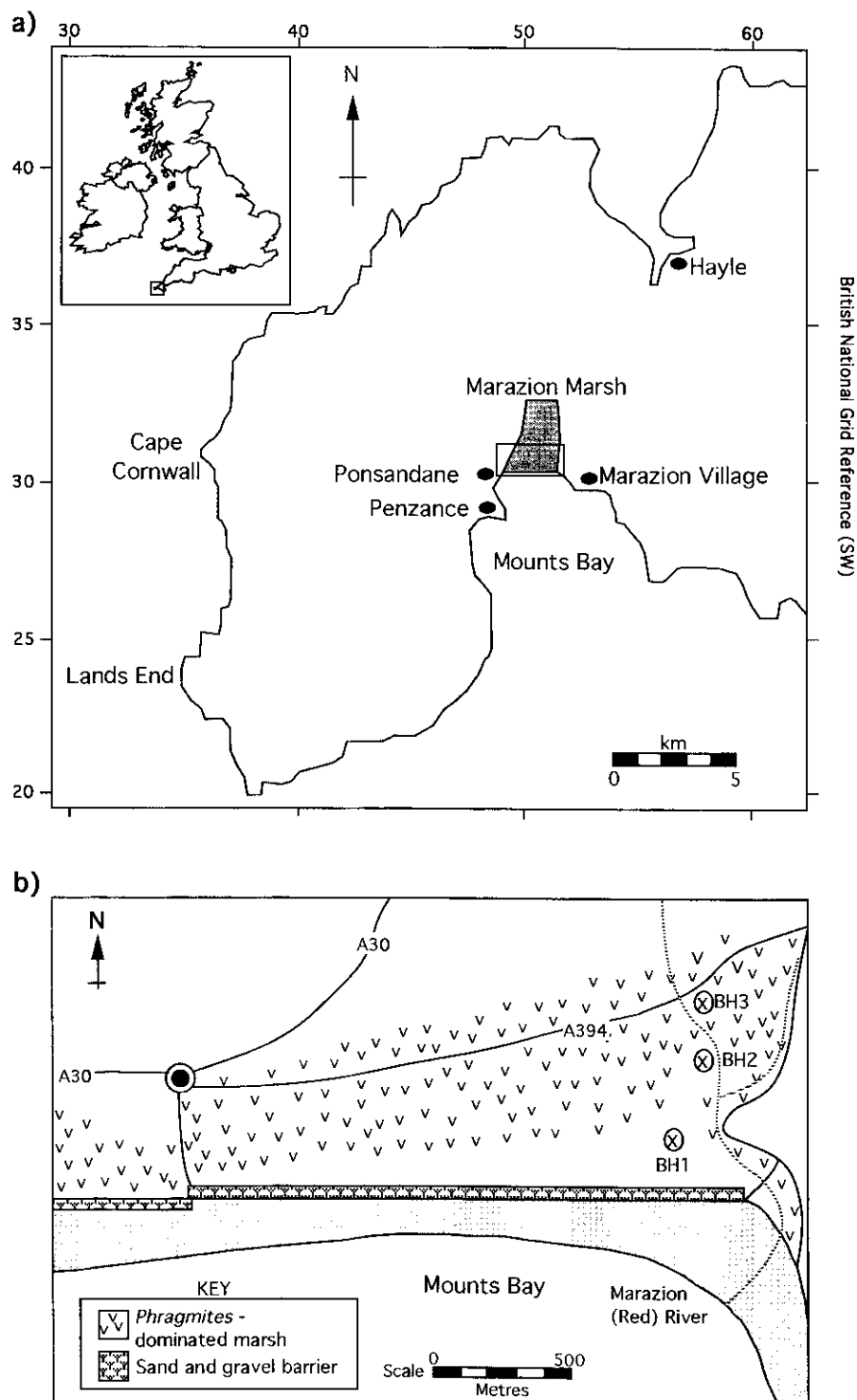


Fig. 1. (a) The location of Marazion Marsh, west Cornwall, U.K. The box indicates the portion of the marsh enlarged as Fig. 1b. (b) Marazion Marsh. Site features and borehole positions.

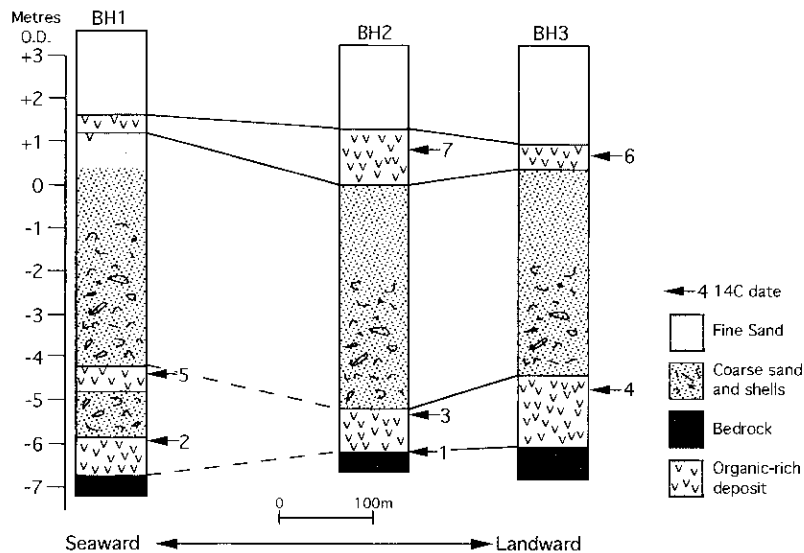


Fig. 2. Marazion Marsh stratigraphy: boreholes 1, 2 and 3 and radiocarbon dated horizons: 1 = 5420 ± 60 (Q2779); 2 = 5050 ± 80 (Q2777); 3 = 4395 ± 60 (Q2774); 4 = 4380 ± 65 (Q2780); 5 = 5100 ± 65 (Q2776); 6 = 1210 ± 40 (Q2775); and 7 = 1610 ± 40 (Q2778).

between -0.02 m and the present surface indicate disturbance caused by anthropogenic activities.

The objective of this paper is to examine palaeo-environmental information (stratigraphic, pollen, diatom and particle size data) from Marazion Marsh to interpret patterns of coastal evolution and relative sea-level movements on the adjacent coast. These data are evaluated in the context of previous research on local and regional scales. A temporal framework for this interpretation is provided by ^{14}C dating.

2. Previous research in southwest Cornwall

2.1. Organic-rich deposits

Buried organic-rich sediments have been recorded in several Cornish coastal localities (French, 1985), including nearshore (Boase, 1826), intertidal (Whiteley, 1877) and embayment lag (Reid, 1913) environments. The main characteristics of 'submerged forest' deposits include instances of fallen trunks, stumps and branches of various plant species (Ussher, 1880; Rogers, 1832). In addition, plant rooting systems embedded in these sediments have commonly been found (Robson,

1944). These organic-rich deposits are frequently, but according to the Marazion data inaccurately, referred to as 'submerged forests' in the literature (Reid, 1913; Heyworth, 1978, 1986). Pascoe (1970) presents an outline palynological report (without pollen diagrams) for an organic-rich deposit at Maenporth, Cornwall, which remains the only pollen record from a 'submerged forest' deposit in west Cornwall other than those compiled by Healy (1993). Heyworth (1978, 1986) has presented a methodological and conceptual model for the reconstruction of past coastal (particularly 'sea-level') behaviour on the evidence of such deposits from elsewhere on the U.K. coast. Heyworth (1986) concludes that the preservation of trees at particular elevations in 'submerged forest' deposits accurately reflects past sea-level positions. This conclusion is placed in perspective in the light of findings from Marazion Marsh.

2.2. Sand and gravel deposits

References to coastal sand and gravel deposition on the Cornish coast are plentiful (e.g. Boase, 1826; Rogers, 1832) and have been reviewed by Healy (1993), but little palaeoenvironmental interpretation has been based on their characteristics.

Healy (1993) has shown that long sequences of marine sand/fine gravel occur within Holocene coastal stratigraphies in west Cornwall. These minerogenic sequences are frequently positioned between layers of organic-rich material. This is in contrast to stratigraphic sequences common elsewhere in the U.K., where organic-rich deposits are intercalated with finer-grained sands, silts and clays (e.g. Devoy, 1979; Shennan, 1986).

2.3. Relative sea-level studies

The regional relative sea-level record for the southwest of England is based on diverse data, as shown in the work of Kidson and Heyworth (1973, 1976, 1978, 1979) and Heyworth and Kidson (1982). The influence of a wide continental shelf, an amphidromically complex situation (Hinton, 1992) with a large tidal range (Admiralty Tide Tables—Mean Spring Tide Range: Bristol (Avonmouth) 12.3 m; Ilfracombe 8.5 m; Land's End (Sennen Cove) 5.4 m; Penzance (Newlyn) 5.6 m) and an indented, crenellate coast with narrow valleys and numerous restricting sedimentary structures makes the observation of regional relative sea level a difficult objective. In the absence

of local relative sea-level studies in Cornwall until recently, the regional pattern of relative sea-level recovery proposed by Heyworth and Kidson (1982) has represented a best approximation for the area. A number of important points emerge from the latter work which are significant in interpreting the Marazion Marsh data.

The relative sea-level history of southwest England and Wales as presented by Heyworth and Kidson (1982) is based on five 'corrected' curves. These come from the Bristol Channel, the English Channel, Cardigan Bay, the Somerset Levels Trackways and north Wales (Fig. 3). Heyworth and Kidson argue that, with the exception of north Wales, no real difference exists among the curves. The apparent variations the authors ascribe to 'inherent uncertainties and the use of present-day MHWST (mean high water spring tide) as the common reference datum'. The authors draw upon a wide variety of radiocarbon data generated from several earlier studies to construct their time/altitude graphs. This introduces a number of problems. Firstly, there is little conceptual or methodological commonality among listed source studies which form the basis for their analysis. Secondly, Heyworth and Kidson adjust the height

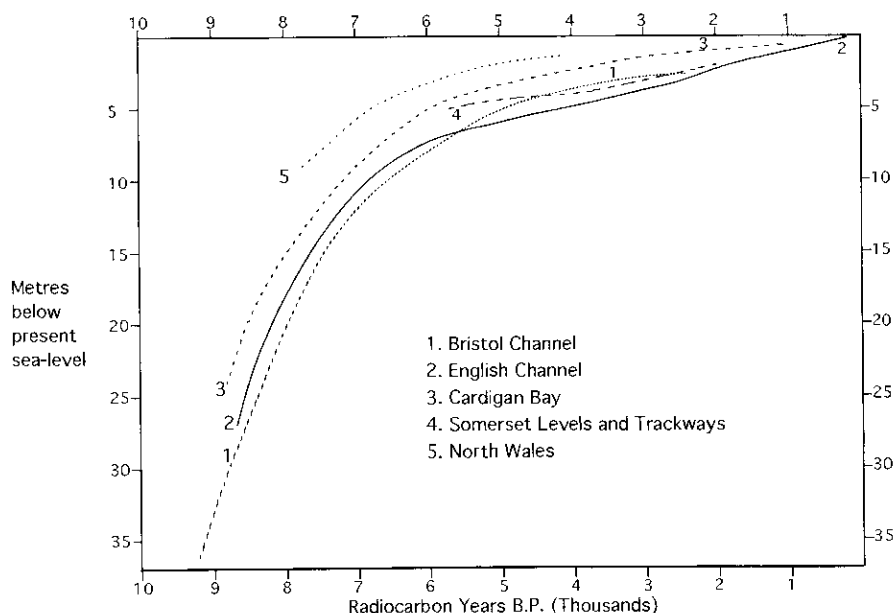


Fig. 3. Regional sea-level curves for southwest England, from Heyworth and Kidson (1982).

relationship between ^{14}C dated samples and tidal levels in an effort to create a common datum (MHWST). This is done using current tide tables to reconstruct Holocene tide cycles with which, as recognised by the authors, there is no directly measured correspondence. Thirdly, the authors point out that many of the radiocarbon dates generated by previous studies have, at best, a tenuous relationship to sea level. Several of the dates from the English Channel sites have no known stratigraphic context, though a relationship to OD is provided. Finally, some of the sea-level curves produced by Heyworth and Kidson are based on very limited numbers of dated samples (e.g. two in the case of the curve for north Wales).

Little specific attention has been paid to the influence of local or site-specific controls on litho-stratigraphic/biostratigraphic materials used in earlier coastal studies in southwest England. In this paper particular emphasis is placed on reconstructing local conditions which determined the nature of coastal stratigraphies and palaeoenvironmental records.

3. Field and laboratory methods

A series of boreholes was excavated within Marazion Marsh using a manually powered bucket bailer rig and a selection of sediment augers. Stratigraphic procedures and management of samples for analytical purposes was carried out according to established principles (Harland, 1972; Birks and Birks, 1980). Core locations were levelled to the U.K. Ordnance Datum (OD) using a standard engineer's level and altitudes are expressed in metres OD.

Biostratigraphic and lithostratigraphic characterisation of sediments from Marazion Marsh involved the use of particle size analysis and palaeoecological studies of pollen and diatom microfossils. The palaeoecological records presented here relate specifically to Marazion Marsh BH2, though ^{14}C dates from other locations within the marsh are also discussed.

Pollen evidence was used to reconstruct vegetation assemblages within the lower organic-rich horizons. Pollen and spores were identified using

the floras of Moore and Webb (1978), Faegri and Iversen (1975) and Beug (1961) as well as a pollen reference collection at the Geography Department, University College Cork. Pollen diagrams were constructed on the basis of pollen counts totalling at least 600 grains per level. Pollen frequencies are expressed as a percentage of total land pollen (TLP) counted at each level.

Diatom studies were carried out principally to distinguish changes in saline conditions within the sediment sequence, assisting palaeoenvironmental interpretation. Diatom valves were found to be plentiful in many horizons, particularly where minerogenic fines occurred. However, sequences of sediment dominated by marine sand (containing whole and fragmented adult and juvenile shell remains) were usually found to be barren of diatoms and other microfossils. However, close to the contact plane with the surface of the organic-rich sequence fossil diatom valves were recovered; these were often found to be broken and corroded. Floras used for fossil diatom identification were those of Hustedt (1930–1966), Cleve-Euler (1951–1955), Van der Werff and Huls (1957–1974), Hendey (1964), Molder and Tynni (1967–1973), Patrick and Reimer (1966–1975) and Barber and Haworth (1981). The counting sum was 600 valves per level examined. Taphonomic nomenclature follows Hustedt (1957) and Schrader and Schuette (1981). Diatom frequencies are expressed as a percentage of total diatom valves counted (TD) for each stratigraphic level.

Particle size determination involved the use of wet and dry sieving techniques for physical measurements. Laboratory and statistical methods, as well as nomenclature, follow McManus (1988).

Selected samples from key stratigraphic positions at Marazion Marsh (minerogenic–organic deposit boundaries; local pollen assemblage zone (LPAZ) boundaries) were submitted to the Godwin Laboratory, University of Cambridge, for ^{14}C dating. In all cases sample material consisted of amorphous organic-rich sediment. In one instance (Q-2774) the carbon content of the material at the key horizon (–5.18 m, BH2) was inadequate for ^{14}C assay. Here dateable material was of necessity drawn from an adjacent horizon within the core. This date is discussed in the text.

Sample measurements were performed on a Quantulus Liquid Scintillation Spectrometer. Radiocarbon ages are expressed in radiocarbon years before present (^{14}C yrs B.P.) and calibrated in yrs B.P. (Stuiver and Reimer, 1993).

4. Lithostratigraphic records

Many coastal sites in west Cornwall are underlain by rock platforms (Healy, 1993), and stratigraphic data from three locations within Marazion Marsh proved organic-rich sedimentary sequences occur directly above weathered bedrock (Fig. 2). The earliest organic-rich deposits appear no younger than ca. 5500 ^{14}C yrs B.P. The age of the majority of these deposits ranges from ca. 5420 ± 60 to 4380 ± 55 yrs B.P. (Table 2).

Above the basal organic-rich deposit a sequence of several metres (–5.18 m to –0.03 m OD) of sand-dominated sediment (with some gravel, silt and traces of organic material) occurs. Plentiful marine shells and shell fragments were found within the sand matrix. Shells are sometimes found in a well preserved condition with whole valves and bivalves of both adult and juvenile forms present. Additionally, substantial quantities of shell material are highly comminuted to a level where identification is not possible. In general the best preserved remains occur immediately above the basal organic-rich sediments (Fig. 2), with the highest proportion of whole shell remains found in this position (–5.00 m to –2.43 m OD). The shells identified were *Cerastoderma edule*, *Littorina littorea* and *Macoma balthica*. Whole and fragmented adult and juvenile remains of *Hydrobia ulvae* were also recognised. As the sand sequence progresses upwards the degree of maceration increases. Because of the difficulty of retrieving sand cores intact and undisturbed it is not possible to indicate whether shells recovered were in their growth position.

5. Biostratigraphic records

Studies of the palaeoecology of pollen and diatom microfossil assemblages found within the

sediment sequence at Marazion Marsh BH2 were directed toward assisting interpretation of changes in palaeoenvironment in the period when the sequence accumulated. For the purposes of this paper the primary function of these data is to indicate changes in watertable elevation and salinity levels within the marsh deposits. A brief discussion of the characteristic components of pollen and diatom assemblages and their relative frequency is provided and interpreted with reference to the evolution of the stratigraphy under discussion. Full palaeoecological reports on Marazion Marsh and several other coastal sites in west Cornwall are provided by Healy (1993).

5.1. Pollen analysis

A summary relative percentage frequency pollen diagram from the basal organic-rich sequence at Marazion Marsh BH2 is presented in Fig. 4. This has been divided into LPAZs using standard approaches detailed by Moore and Webb (1978) and Birks and Birks (1980). The purpose of this division is to delineate clearly distinct changes of affinity in vegetation assemblages through pollen data to assist palaeoenvironmental interpretation.

LPAZ-A (–5.96 m to –5.84 m OD) indicates high relative frequencies of herbaceous pollen (ca. 57% TLP). By far the most significant contributor is Cyperaceae (61% of herb pollen), though frequencies of Gramineae, Chenopodiaceae, Compositae tubuliflorae, Saxifragaceae and Umbelliferae are also significant.

In LPAZ-B (–5.83 m to –5.45 m OD) a very substantial and sustained expansion in the proportions of thermophilous trees and shrubs occurs. Arboreal pollen (AP) expands to reach ca. 60% of total pollen at –5.52 m OD *Alnus* (ca. 48% TLP) is the most significant contributor between –5.83 m and –5.73 m OD. In addition, *Quercus* (11% TLP) and *Pinus* (ca. 1% TLP) pollen, as well as much smaller quantities of *Ulmus* and *Fraxinus* pollen (both <1% TLP), contribute to the AP sum. Of the shrubs, *Salix* pollen are absent, but both *Ilex aquifolium* (ca. 1.5% TLP) and *Juniperus communis* (<1% TLP) are represented in LPAZ-B. Grass (ca. 6% TLP) sedge (ca. 6% TLP) and other

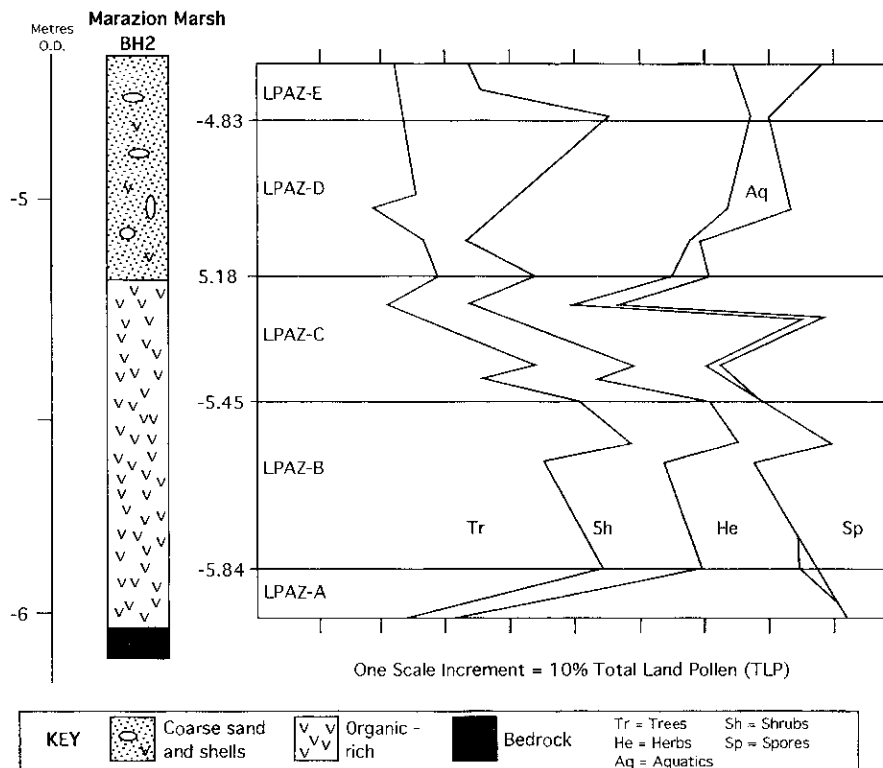


Fig. 4. Marazion Marsh BH2 summary pollen diagram.

herb pollen are present in the LPAZ, but do not achieve high values relative to the AP component.

In LPAZ-C (–5.44 m to –5.18 m OD), and particularly in LPAZ-D (–5.17 m to –4.83 m OD), herbaceous pollen proportions rise considerably (to average ca. 30% TLP), mainly at the expense of AP. Shrub pollen values are significant (ca. 25% TLP in LPAZ-D). *Salix* pollen first appears in LPAZ-C and increases in relative frequency to 6% TLP at –5.03 m OD in LPAZ-D. Along with *Corylus* (ca. 25% TLP) *Salix* appears a significant component of the vegetation from –5.44 m OD. Total values for herbaceous pollen exceed 30% TLP by –5.25 m OD. The frequency of both Cyperaceae (ca. 28% TLP at –5.13 m OD) and Gramineae (ca. 22% TLP at –5.03 m OD) pollen increases considerably through these LPAZs, along with that of a range of other herbs. Well-preserved macrofossils identified as *Phragmites* stems were present throughout this sequence. Chenopodiaceae pollen achieves its high-

est frequency (ca. 2% TLP) between –5.28 m and –5.08 m OD on the LPAZ C/D boundary. Aquatic plants are also represented, particularly *Myriophyllum spicatum* (ca. 5% TLP at –4.98 m OD). Pollen proportions described for LPAZ-C and LPAZ-D are further emphasised and maintained in LPAZ-E.

5.2. Interpretation of the pollen record

The vegetation transition from LPAZ A/B through LPAZ E indicates increasing site wetness as the lower organic-rich layer accumulated. Chenopodiaceae pollen may suggest a possible saline/brackish water influence within LPAZ C, D and E, though the presence of Chenopodiaceae pollen is not necessarily interpreted as a salt marsh indicator. Macrofossil remains in the sequence between –5.44 m and –4.83 m OD suggest that *Phragmites* became established along the coast during this accumulation phase and contributes to

grass pollen. Trees likely to be most susceptible to wet ground conditions diminish, leaving behind an *Alnus*-dominated fen-carr and reed-marsh environment.

5.3. Diatom studies

A summary relative percentage frequency diatom diagram from Marazion Marsh BH2 is presented in Fig. 5. The diagram is divided into five strata using LPAZ boundaries. Strata do not equate diatom assemblage zones. The purpose of this division is to provide a visual impression of the correspondance between vegetation change and saline conditions in the basal sediment sequence. Each stratum shows the relative proportion of Oligohalobian, Mesohalobian and Polyhalobian diatom groups.

In Stratum 1 and 2 *Pinnularia* (ca. 23% TD), *Eunotia* (ca. 31% TD) and *Navicula* (ca. 18% TD) groups are strongly represented. The most common species identified was *Eunotia minor* (ca. 7%), with *E. gracilis* (ca. 4%), *E. pectinalis* (ca. 4%), *E. diodon* (ca. 5%) and *E. pectinalis* var. *elongata* (ca. 3%) particularly prominent. *Pinnularia nobilis* (ca. 5.5% TD), *P. microstauron* (ca. 6% TD) and *P. gibba* (ca. 6.5% TD) were common within the *Pinnularia* group. *Navicula gastrum* (ca. 4.5% TD), *N. bacillum* (ca. 4% TD) and *N. dicephala* (ca. 5% TD) were encountered along with several variants of *Synedra* species (*Synedra ulna*, *S. acus* and *S. rumpens* ca. 8% TD in total). *Asterionella formosa* (fragmented) was also recognised in the basal sediments. Additionally, *Cymbella turgida* (ca. 1.5% TD), *Coscinodiscus lacustris* (ca. 0.9% TD) and

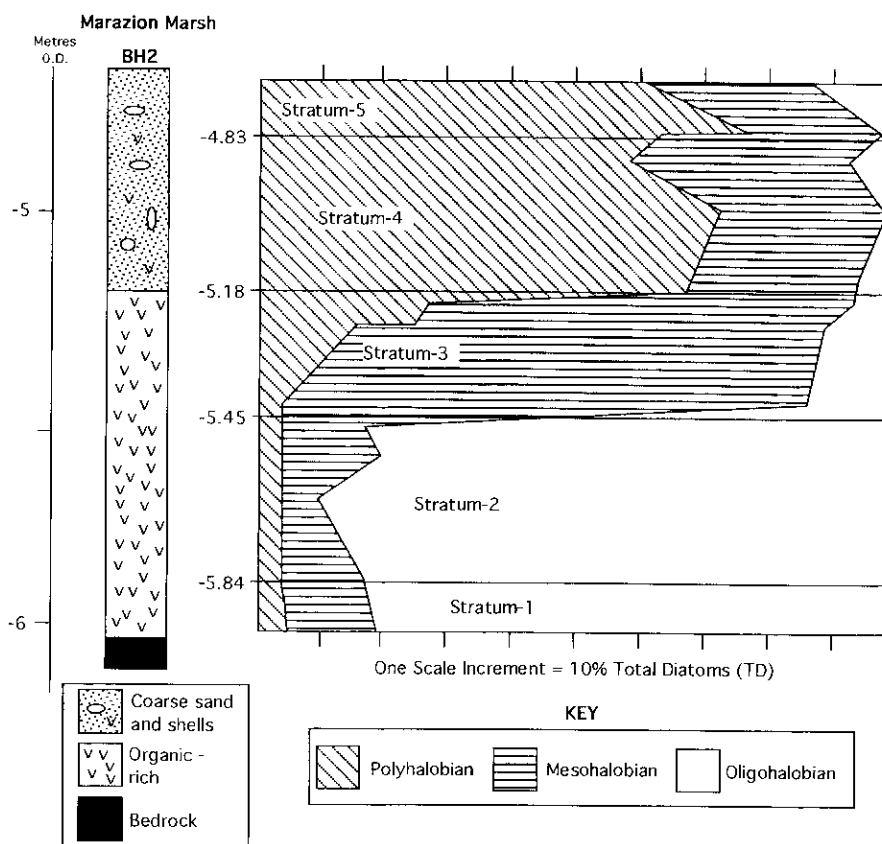


Fig. 5. Marazion Marsh BH2 summary diatom diagram.

Fragillaria intermedia (ca. 0.7% TD) were commonly found.

The frequency of brackish diatom species increases to ca. 75% TD in Stratum 3 (–5.48 to –5.25 m OD). *Rhopalodia gibberula* (ca. 16% TD), *Navicula expansa* var *expansa* (ca. 10.5% TD), *Surirella ovata* (ca. 8% TD), *Achnanthes hauckiana* (ca. 6.5% TD), *Amphora spectabilis* (ca. 7% TD) and *Nitzschia plana* (ca. 6.5% TD) are among the Mesohalobian species found in large numbers in Stratum 3 as Oligohalobian frequencies diminish. These are joined by increasing frequencies (ca. 25% TD) of Polyhalobian diatom species in Stratum 3 at –5.25 to –5.18 m OD, with marine species such as *Opephora pacifica* (ca. 5.5% TD), *Paralia sulcata* (ca. 4% TD), *Diploneis chersonensis* (ca. 6% TD), *Fragilaria schultzi* (ca. 5% TD) and *Podosira stelliger* (ca. 2.5% TD) present. The relative frequencies of these species continue to increase proportionally above –5.18 m OD. The taxonomic variety of the polyhalobian assemblage remains restricted through Strata 4 and 5, but polyhalobian frequencies are consistently greater than those of other diatom groups, reaching ca. 70% and 73% in Stratum 4 and 5, respectively.

5.4. Interpretation of the diatom record

The evidence provided by diatom records clearly shows that rising freshwater levels were not the sole factor controlling site ecology as organic-rich sediments accumulated. A significant transition from predominantly fresh water to marine/brackish water conditions occurs. It is concluded that deposits exhibiting these characteristics formed in isolation from direct marine influences, with pollen data suggesting a corresponding watertable rise (Fig. 4). Lanyon et al. (1982) demonstrate the complexity and rapidity of changes in back-barrier groundwater levels under changing tidal and sedimentary regimes, particularly within embayment environments. An undulating site surface (as currently evident at Marazion Marsh) may have been subject to local ponding and waterlogging while concurrently supporting vegetation suites of various salt tolerance levels at different elevations.

5.5. Particle-size analysis

Particle-size analysis was undertaken on twenty four samples within the sedimentary sequence between –4.83 m and +0.08 m OD (Table 1). Initially homogenous leptokurtic sands (–4.83 m to –4.07 m OD) give way to coarse, poorly sorted sediments (–4.06 to –2.61 m OD) coinciding with high proportions of carbonate materials. Next, a sequence of moderately sorted (but leptokurtic) finer sediments (–2.60 m to –2.22 m OD) occurs suggesting well sorted sub-populations within this matrix. This is succeeded by a coarsening upward progression (–2.21 m to +0.08 m OD) within which disparate skewness values occur and carbonate quantities are much reduced.

5.6. Interpretation of particle-size data

A generally fining upward sequence suggests lower energy controls replaced initially high energy

Table 1
Marazion Marsh BH2: particle-size data

Altitude OD (m)	Sorting value	Skewness value	Kurtosis value
+0.08–0.30	0.91	–0.28	1.01
–0.31–0.68	0.91	–0.32	1.02
–0.69–0.72	0.86	–0.26	1.09
–0.73–1.15	1.09	–0.49	1.03
–1.16–1.21	0.93	–0.30	1.04
–1.22–1.28	1.31	–0.54	1.02
–1.29–1.41	1.89	–0.70	1.03
–1.42–1.54	1.12	–0.49	1.18
–1.55–1.75	1.61	–0.53	1.03
–1.76–1.90	1.45	0.09	0.99
–1.92–2.01	1.44	–0.07	1.06
–2.02–2.13	1.35	–0.02	1.06
–2.14–2.21	1.37	0.00	1.02
–2.22–2.32	1.05	1.27	0.04
–2.33–2.41	0.94	0.07	1.32
–2.42–2.60	0.82	0.16	1.22
–2.61–2.80	1.00	0.09	1.03
–2.81–2.86	1.03	0.09	0.97
–2.87–3.02	1.07	0.02	1.17
–3.03–3.25	1.38	0.19	0.90
–3.26–3.47	1.61	–0.25	0.90
–3.48–3.76	1.52	–0.47	0.89
–3.77–3.91	1.33	–0.38	1.29
–3.92–4.06	1.77	–0.75	1.05
–4.07–4.83	0.80	0.04	1.15

flux conditions as the sand-dominated sequence accumulated at Marazion Marsh. However, additional evidence to support this is not provided by sediment sorting values. There appears to be no distinct modality within individual series, though there is some evidence for the presence of identifiable sub-populations within the overall matrix. These characteristics may indicate that the fining upward sequence is a function of the composition of the sediment supply providing the available particle population rather than of differentiation of coastal energy levels. The prevailing environment controlling marine sand deposition is difficult to determine from these data.

5.7. Discussion of the lithostratigraphic and biostratigraphic data

The transition from freshwater to marine/brackishwater conditions in organic-rich basal sediments at Marazion Marsh appears to have occurred gradually, according to palaeoecological data. There is no evidence on which to argue that the changing character of the deposits was due to large-scale marine water inundation. The marine/brackish influence evident in the microfossil record may have been caused by barrier overwash and temporary marine water pulses gaining access to Marazion Marsh through stream channels or temporary barrier breaches. The role of high magnitude meteorological events, possibly coinciding with high tidal movements, may have been important in facilitating such processes (Winkelmolen and Veenstra, 1980). Seepage through clastic barriers offers another mechanism by which such a process may operate, particularly where large clasts increase porosity within protective structures.

While the onshore movement of sand-dominated marine sediments in the form of landward moving barrier/beach-ridge structures appears likely according to the stratigraphy of Marazion Marsh, little can be said about their spatial or temporal stability. There is no substantive evidence in the present day for offshore barrier remnants congruent with drowned sedimentary structures within adjacent marine areas, and U.K. waters generally show a lack of free barrier forms. A number of factors may be responsible for this. For example,

there is an increasing recognition that sediment budgets have changed substantially through the Holocene (Carter et al., 1989), culminating in sediment starvation of many coastal areas in the present day (Psuty, 1992). Altered wave, tide and bathymetric controls (Woodworth, 1991) may have played a significant part in obscuring morpho-sedimentary patterns of the past (Orford, 1987). Individually and collectively, these factors make the identification of past offshore sedimentary pathways difficult to trace.

The barriers and barrier fragments of the kind currently active (e.g. Loe Bar) and relict (e.g. Marazion, Maenporth) in west Cornwall are considered to represent the final stage of allogenic (Dawson, 1980; Trenhaile, 1983) coastal change. Their protective function allowed back-barrier sedimentation to occur in an initially freshwater environment. As destruction thresholds for coastal barrier structures were approached an increased marine influence was brought to bear to their rear. This gained expression in a transition from freshwater to brackish-marine to marine-brackish sedimentation. Abrupt contacts between the surface layers of organic-rich deposits and overlying marine minerogenic sediments appear to have been linked with ultimate barrier breaching and subsequent marine sedimentation.

6. Relative sea-level studies in west Cornwall

6.1. The relative sea-level record in west Cornwall

On barrier-dominated coasts relative sea level possibly represents a passive factor in coastal development (Orford, 1987; cf. Devoy, 1987). It is clear that some coastal responses alter as nearshore and littoral processes vary spatially with sea-level movements. Changes in the degree, or kind, of coastal response appear related to the rate at which relative sea level varies and the effect that has on the major functions controlling coastal morphology (Orford, 1987). Central to this idea is the behaviour and function of sedimentary structures in initially determining, and subsequently reinforcing, coastal form (Dillon, 1970). The inherent nature of local relative sea-level change means

that shoreline position is constantly migrating, frequently over large distances, in relatively short time periods (Carter, 1982a,b; Leatherman, 1983a,b). In the majority of examples coastal stratigraphic sequences retain only a portion of sea-level history in a particular locality. This requires that information from a number of sites be integrated to reconstruct local, extra-local or regional relative sea-level change patterns. For this reason the relative sea-level history of Marazion Marsh is discussed in the context of time/altitude data from other sites in west Cornwall (Fig. 6; Table 2).

6.2. Time/altitude data

Fig. 6a shows radiocarbon ages derived from organic-rich sedimentary strata at a number of coastal sites in west Cornwall. Details of precise location, altitude (OD), laboratory reference labels and calibrations are provided in Table 2. The time/altitude plot indicates a curvilinear pattern of relative sea-level recovery, with the altitudinal spread of radiocarbon ages narrowing approaching the present day. There is no clear expression of onlap/offlap sediment sequences (*sensu* Devoy, 1982; Shennan, 1982), reflecting the absence of definable transgressive/regressive stratigraphic contacts in the west Cornwall stratigraphy, such as those described by Tooley (1978), Devoy (1982) and Shennan (1982) at other U.K. sites.

6.3. Chronometric data from Marazion Marsh

The earliest ^{14}C dated materials from Marazion Marsh occur at a depth of -6.21 m OD at BH1 with an age of 5420 ± 60 yrs B.P. [cal. yrs B.P. (95.4%) 6390 to 6030] (Q-2779). ^{14}C dates of 5050 ± 80 yrs B.P. [cal. yrs B.P. (95.4%) 6020 to 5620] (Q-2777) from BH3 at -5.71 m OD and 4395 ± 60 yrs B.P. (cal. yrs B.P. 5280 to 4840) (Q-2774) from BH2 at -5.28 m OD were obtained from the basal organic-rich deposit illustrated in Fig. 2. Additionally, Q2780 at -4.71 m OD at BH1 provides a date of 4380 ± 55 yrs B.P. [cal. yrs B.P. (95.4%) 5260 to 4840] approaching the top of the organic-rich stratum.

6.4. Interpretation of RSL data

According to palaeoecological data, between approximately 5500 yrs B.P. and 4500 yrs B.P. there is little direct evidence for RSL rise recorded at Marazion Marsh. There is, however, strong palaeoecological evidence for a rising water table and increasing salinity within the marsh in this time period, coinciding with organic-rich sedimentation. These in combination suggest an increased marine influence, linked to RSL position and/or elevation. The data suggest that the marine influence on sedimentation was indirect, concordant with the presence of protective sedimentary (barrier) structures which were liable to temporary overwash and/or penetration by sea water. The absence of biostratigraphic indicators linked to defined reference water levels (Van de Plassche, 1986) precludes an absolute determination of RSL elevation using a unitary time/altitude model based on these data. The indicative meaning of individual samples, linking their elevations to particular reference water levels, is obscured. There is a general absence of time/altitude studies focusing on the calculation of indicative (or vertical) ranges for sea-level indicators in embayment environments. However, it appears clear that the predominant direction of RSL movements at Marazion Marsh between 5500 yrs B.P. and 4500 yrs B.P. constituted a rise in RSL.

A substantial and apparently rapid deposition of marine sediments above basal organic-rich deposits is evident from the Marazion Marsh data. This depositional phase occurred after ca. 4400 yrs B.P. (Q2774, Q2780). The meaning of these ^{14}C dates in relation to the precise timing of marine sand deposition is equivocal for two reasons: first, to acquire a sample suitable for ^{14}C assay sample material was collected from between -5.28 m and -5.275 m OD (Q2774) rather than at the stratigraphic contact (-5.18 m OD); and secondly, the abrupt nature of the stratigraphic contact at -5.18 m OD may represent an erosion plane or non-sequence, thus indicating an unduly 'early' event. However, the latter is considered unlikely due to continuity in the palynological record.

The Cornish ^{14}C ages plot significantly lower on the altitudinal axis than do the 'regional' curves

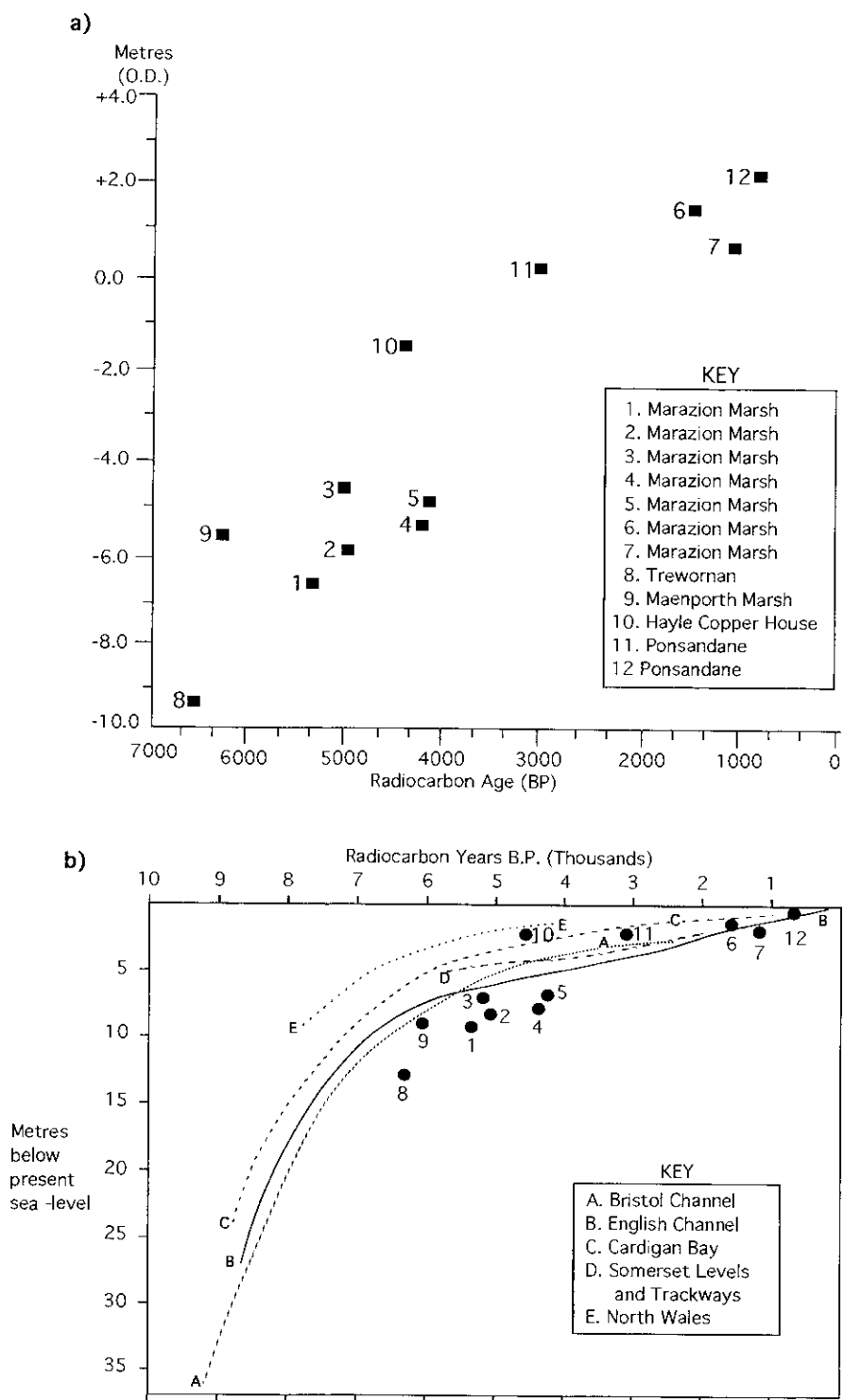


Fig. 6. (a) Time/altitude plot based on ^{14}C dates (Table 2) from west Cornwall, U.K. (b) The altitudinal relationship between the regional sea-level curves of Heyworth and Kidson (1982) and the Cornwall radiocarbon dates; the Cornwall data are adjusted to MHWST.

Table 2
¹⁴C dates from west Cornwall

Site Name	Grid reference	Laboratory reference	¹⁴ C Age ± B.P.	68.3% Probability (calibrated B.P.)	95.4% Probability (Calibrated BP)	OD (m)
Hayle	SW565380	Q-2773	4520 ± 50	5295–5050	5317–4987	–1.59
Marazion Marsh (3)	SW512313	Q-2774	4395 ± 60	5200–4870	5280–4840	–5.28
Marazion Marsh (6)	SW512313	Q-2775	1210 ± 40	1260–1010	1260–970	+0.80
Marazion Marsh (5)	SW513316	Q-2776	5100 ± 65	5950–5770	5985–5665	–4.46
Marazion Marsh (2)	SW513316	Q-2777	5050 ± 80	5890–5710	6020–5620	–5.71
Marazion Marsh (1)	SW511312	Q-2779	5420 ± 60	6200–6120	6390–6030	–6.21
Marazion Marsh (4)	SW511312	Q-2780	4380 ± 55	5030–5020	5260–4840	–4.71
Maenporth	SW791297	Q-2881	6110 ± 85	7160–6820	7210–6790	–5.53
Ponsandane	SW481311	Q-2882	680 ± 50	667–590	688–545	+2.21
Ponsandane	SW481311	Q-2883	3050 ± 65	3340–3080	3380–3030	+0.42
Marazion Marsh (7)	SW510312	Q-2778	1610 ± 40	1532–1415	1593–1389	+0.88
Trewornan, River Amble	SW96753	Q-2781	6460 ± 80	7420–7230	7520–7220	–9.40

described by Kidson and Heyworth (1982) prior to ca. 4000 yrs B.P., when adjusted to MHWST datum for comparison purposes (Fig. 6). As well as the fundamental problems affecting the reliability of the Heyworth and Kidson curves described above, additional factors may be suggested to explain this. The conditions governing organic-rich sedimentation are likely to have differed among the sites from which relative sea-level data has been collected. Most importantly on the basis of the Marazion Marsh data, it appears probable that processes of sedimentation produced morpho-sedimentary structures and embayments which fundamentally influenced the relationship between sedimentation and the prevailing RSL position in the mid Holocene period. Such effects are not likely to have been synchronised in time and space, thus introducing unique local variations in records of coastal evolution. Averaged 'regional' records may not closely resemble local or site-specific data.

7. Discussion

The effective control of coastal watertable elevation by tidal position is an important mechanism for the accumulation of organic-rich sediments landward of protective sedimentary structures. It appears that such sediments (or macrofossils contained within them) may not be directly related to

a particular relative sea-level position in either a temporal or spatial sense, as has been suggested by Heyworth (1986). They represent an indirect response of the embayed environment to sea-surface elevation through the agency of ground-water fluctuation. The palaeoecological record suggests that sedimentation within Marazion Marsh was closely linked to processes of coastal change associated with RSL rise and morpho-sedimentary configuration. A rising water table consequent on changing shoreline position or elevation appears to have been one part of the environmental change equation.

The morphology and angle of the slope over which changes in relative sea-level take place may have a considerable influence on morpho-sedimentary configuration of the shoreline (Kraft et al., 1979; Carter, 1988). These factors may function within at short timescales determined by a set of controls which are governed mainly by wave climate (Carter, 1982a, 1988) and meteorological effects, such as storminess (Bird, 1993). The influence of such controls, added to local factors such as headland-bay configuration and longshore sediment movement, can introduce the necessary conditions to allow unique local patterns of coastal evolution to develop (Howard and Frey, 1985). Lithostratigraphic, biostratigraphic and chronometric evidence from the lower organic-rich stratum suggest that these conditions produced an

embayed environment which prevailed during the course of organic sedimentation at Marazion Marsh.

The functioning of such a system appears reliant on sediment supply, as argued by Dillon (1970). Where the supply of suitable sedimentary materials (Orford, 1987) is favourable, the potential for the growth and migration of transgressive coastal structures producing embayed back-barrier environments is created. A mechanism for this process is proposed by Leatherman (1987), who suggests that the response of sandy shorelines to sea-level rise is erosion, unless offset by ample sediment supply. Data from Marazion Marsh shows that substantial marine sedimentation took place on the Cornish coast in the mid-Holocene period, suggesting that supply and movement of sediment was sufficient to fulfill the conditions required for the growth and functioning of morpho-sedimentary structures. The effect of such structures as that which created the Marazion Marsh embayment appear to have isolated landward sedimentary sequences from direct marine influences. Organic-rich sediments accumulated in response to increased watertable elevation consequent on RSL rise, while processes such as temporary breaching, overwash, the penetration of percolating seawater and saltwater access (e.g. through stream channels) raised salinity levels in the upper layers of organic-rich strata. The eventual destruction or collapse of protective/transgressive structures allowed rapid inundation of embayed environments by sand-dominated marine sediments, producing a sharp and/or erosive contact with the inundated marsh surface.

8. Conclusion

Chronometric data show that basal organic-rich deposits at Marazion Marsh accumulated in the period ca. 5500 yrs B.P. to 4500 yrs B.P. It is argued that organic-rich sedimentation occurred in an embayed environment, isolated from open marine conditions by the presence of morpho-sedimentary structures. Palaeoecological data shows that groundwater levels were high, initially encouraging accumulation of freshwater back-

barrier organic-rich sediments. As morpho-sedimentary structures around the Marazion Marsh embayment approached their stability thresholds under the influence of coastal processes and changing RSL position, the penetration of seawater introduced saline conditions as the upper levels of basal organic-rich horizons were deposited.

Stratigraphic and palaeoecological data from Marazion Marsh show that minerogenic sequences post date basal organic-rich deposits. The inundation of these organic-rich environments by sand-dominated marine sediments appears to have been rapid. The main transgressive phase at Marazion Marsh took place after ca. 4500 yrs B.P. Indeed, similar patterns of coastal behaviour have been recorded at adjacent sites. Willis (1961) records a marked marine transgressive episode in the Fenlands between 4680 yrs B.P. and 4285 yrs B.P., which is supported by data presented by Shennan (1982). Greensmith and Tucker (1976) also record evidence for marine transgression until at least 4000 yrs B.P. on the Essex coast. Data from Chesil Beach corresponds closely with the Marazion Marsh data, showing the initial inundation of basal organic-rich strata by shell rich marine sands around 4500 yrs B.P. (K. Coombe, pers. commun., 1993) bearing out the findings of Hails (1975a,b). In this context it is concluded that the evidence presented for Marazion Marsh throws significant new light on mechanisms for coastal evolution combining the influence of morpho-sedimentary structures and relative sea-level change.

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