Palaeoenvironmental Reconstruction in the Breydon Formation, Holocene of East Anglia

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ABSTRACT

The foraminiferal and ostracod faunas from two East Anglian, Holocene cores are described. Together they add further environmental evidence to the lithological alternation between peat and alluvial mud sedimentation observed in these sections resulting from local changes in sea-level. Sedimentological and microfaunal differences between the two sections reflect their relative positions in the estuary with respect to the local palaeogeography. Foraminifera are abundant, the Ostracoda less so, nevertheless a comprehensive environmental interpretation is given and a foraminiferal ecological zonation proposed. Palaeoenvironmental reconstructions are based upon both microfossil groups which complement each other. *J. Micropalaeontol.*, **12** (1): 35-46, August 1993.

INTRODUCTION

Recent investigations into the Holocene sediments of Central Broadland, west of Great Yarmouth, East Anglia, have provided a number of cores for sedimentological and palaeontological analysis. The cores were distributed over a wide area with a view to reconstructing local sea-level and palaeogeographical changes in the, post-glacial, marginal marine deposits of East Anglia. The sedimentary sequences recovered are dominated by estuarine and marine, fine grained, calcareous sediments, mainly clays and muds. In some areas coarser grained sands occur as localised channel fill deposits. Periods of regressive overlap during times of relatively low sea-level resulted in the deposition of peat.

Microfossils particularly the Foraminifera are generally abundant, the Ostracoda less so. An initial palaeoenvironmental reconstruction of these sediments, based upon their microfossil assemblages has been undertaken at the University of East Anglia (Coles, 1977). The present work details ostracod faunal change (I.B.) in two of these cores and combines that information with a foraminiferal ecological zonation based upon a comprehensive study of foraminiferal assemblages from a large numbers of Holocene sequences in this area (M.G.). These results have been used to refine the interpretation of sedimentological changes. The stratigraphical interval studied covers approximately the last six to seven thousand years.

East Anglia possesses a great number of modern, fresh and brackish water environments whose calcareous
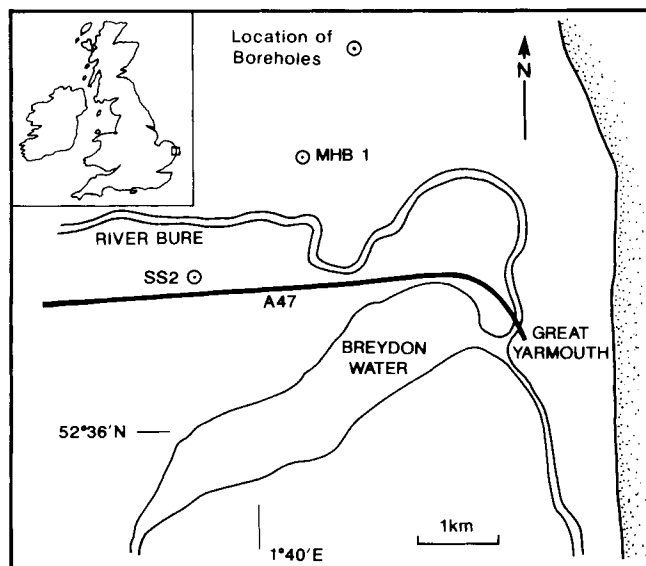

Fig 1. Location of Cores MHB1 and SS2.

invertebrate microfauna has not been studied in detail since the last century (Brady & Robertson, 1870). All ostracod species recovered from the Holocene sediments still live in British waters, including the East Anglian region, today. Their preferred ecological niches are, generally, well known (Athersuch et al., 1989) and many of the ostracods have

been collected by one of us (I.B.) as living specimens from the present day East Anglian estuaries during the course of this research. By combining this modern ecological information with the faunal composition of each assemblage it has been possible to provide a more detailed record of environmental changes within the sequence than could be afforded through the study of one microfossil group alone. No previous work has appeared on the Ostracoda of the Holocene deposits in this area.

BACKGROUND

The present work is a result of two separate research programmes undertaken at the University of East Anglia. The first, in association with the British Geological Survey, during remapping of the Yarmouth Geological Sheet recovered a number of cores through the Holocene sequence, thus providing a large sample base. The second project concerns the use of ostracod shell chemistry as a means of estimating salinity levels in a modern East Anglian estuary with a view to applying the technique to Holocene faunas, and in so doing, attempting to reconstruct past sea-level changes through the study of fossil shell chemistry. The results of that work, intended to supplement standard micropalaeontological results, appear elsewhere (Boomer, in press).

The Holocene deposits in this area are represented by a 10 to 25 metre thick sequence comprising three peat layers separated by two much thicker clay strata. The transgressive/regressive nature of the sedimentary succession means that the most complete sequences are found in the East of the study area. Agricultural methods have also led to the disturbance and/or removal of the youngest sediments in certain areas. This alternation in sediment type appears to reflect changes in effective sea-level in the area. Previous micropalaeontological and sedimentological investigations into these deposits were undertaken by Alderton (1983), Coles (1977), Coles & Funnell (1981) and Funnell (1979). The interpretation of peat and clay alternations is thought to be a complex story involving changes in relative sea-level and development/destruction of spits and barriers across the estuary mouth. The average subsidence rate for the lower Yare Valley is estimated as averaging 1.5 metres every 1000 years since 9000 years B.P. The Holocene evolution of the

Suffolk estuaries has recently been studied (Brew, 1990; Brew et al. 1992) and their interpretation compared with the Yare Valley sequence to the north.

In their studies of the Holocene sediments underlying the lower Yare Valley and Halvergate Marshes Coles & Funnell (1981) and Funnell (1979) described the occurrence of Lower, Middle and Upper Peats separated by a lower and an upper estuarine clay deposit. Their chronological interpretation of this sequence is given below in 14C years before present;

post c. 1500Upper Peat
c. 2000 to c. 1500Upper Clay
c. 4500 to c. 2000Middle Peat
c. 7500 to c. 4500Lower Clay
pre 7500Lower Peat

The Upper and the Lower Peats were not encountered in the present study. The lowermost sediments in both sequences are represented by low intertidal Foraminifera and littoral to sub-littoral, phytal, marine Ostracoda. Thus, the transgressive transition from the 'non-marine' basal peat into 'littoral' conditions is missing. The layer of peat development encountered in both cores (i.e. the middle peat) was thought, by Coles and Funnell (1981), to have formed while the estuary mouth was effectively sealed by a coastal barrier, from about 4500 years ago. The second transgressive phase which, resulted in the deposition of the upper clay, was thought to have been initiated about 2000 years B.P. with its maximum influence at about 1600 years ago. The abrupt cessation of clay deposition at about 1500 years B.P. has been postulated as indicating the southward extension of the Great Yarmouth Spit across the mouth of the Bure-Yare-Waveney estuary system (Brew, 1990).

SAMPLING

The two sections currently under investigation were taken using a "Minuteman" power- driven rotary auger. Cores were retrieved using a block and tackle system, this coring and retrieval method leads to sediment disturbance so that no sedimentary structures were recorded. Sediment samples were taken off the corer in 20 centimetre intervals. Small sub- samples were taken for foraminiferal analysis (10g for MHB1, 5g for SS2) while somewhat larger samples (approximately 75g) were, generally, used for the ostracod studies. All samples were broken down using hydrogen

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Explanation of Plate 1

All figured ostracod specimens and comparative Foraminifera specimens deposited at the British Museum (Natural History).

Fig 1. *Cyprideis torosa* (Jones) x44 (OS14160). **Fig 2.** *Leptocythere castanea* (Sars) x71 (OS14157). **Fig 3.** *Hemicythere villosa* (Sars) x70 (OS14153). **Fig 4.** *Cytherois fisheri* (Sars) x70 (OS14154). **Fig 5.** *Hirschmannia viridis* (O.F. Muller) x69 (OS14155). **Fig 6.** *Palmoconcha laevata* (Norman) x71 (OS14158). **Fig 7.** *Palmoconcha guttata* (Norman) x71 (OS14156). **Fig 8.** *Loxoconcha rhomboidea* (Fischer) x71 (OS14159). **Fig 9.** *Trochammina inflata* (Montagu) x91 (P52844). **Fig 10.** *Jadammina macrescens* (Brady) x101 (P52845). **Fig 11.** *Miliammina fusca* (Brady) x113 (P52846). **Fig 12.** *Elphidium williamsoni* Haynes x64 (P52847). **Fig 13.** *Elphidium excavatum* (Terquem) forma *lidoensis* Cushman x107 (P52848). **Fig 14.** *Haynesina germanica* (Ehrenberg) x112 P 52849. **Fig 15.** *Ammonia beccarii* (Linne) var *batavus* Hofker (Marsh creek specimen). x118 (P52857). **Fig 16.** *Elphidium earlandi* Cushman x137 (P52855). **Fig 17.** *Elphidium magellanicum* Heron-Allen and Earland x105 (P52854). **Fig 18.** *Haynesina depressula* (Walker & Jacob) x124 (P52850). **Fig 19.** *Elphidium macellum* (Fichtel & Moll) x64 (P52859). **Fig 20.** *Elphidium excavatum* (Terquem) forma *clavata* Cushman x110 (P52858). **Fig 21.** *Ammonia beccarii* (Linne) var *batavus* (Sub-tidal channel specimen). x65 (P52856). **Fig 22.** *Elphidium margaritaceum* Cushman x128 (P52853). **Fig 23.** *Elphidium oceanensis* (d'Orbigny) x151 (P52852). **Fig 24.** *Elphidium excavatum* (Terquem) forma *magna* Miller, Scott & Medioli. x101. (P52851).
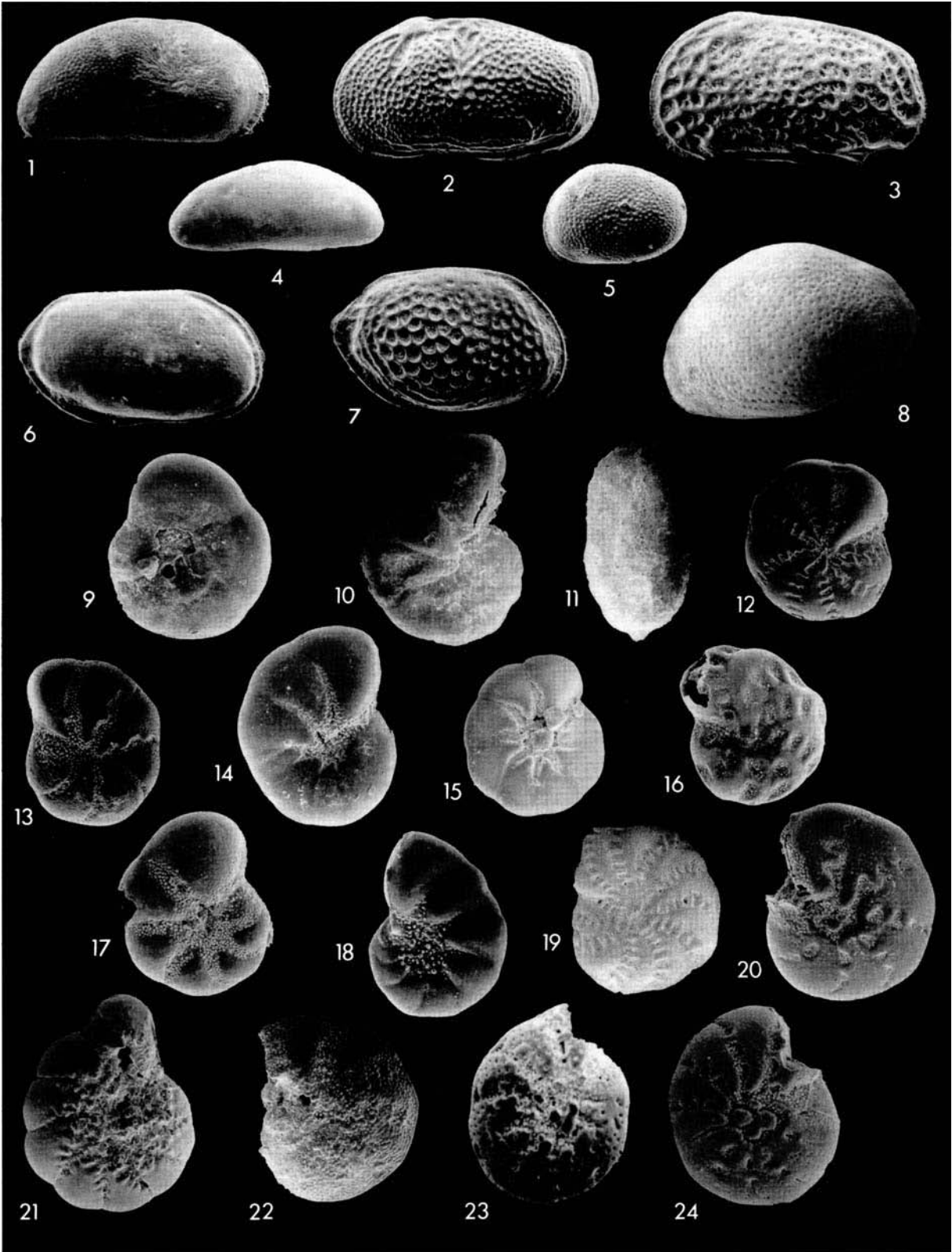
peroxide at room temperature for 24 hours. The resulting sediment was then washed to remove the mud (less than 635m) fraction, the final residue was often very small compared with the original sample size. These small samples, in some cases, yielded diverse ostracod faunas but low numbers of individuals which hampers the recognition of in situ and reworked/transported assemblages (this is particularly true for the upper part of core SS2 where only small samples were available). The palaeoenvironmental interpretation of a given sample is based, therefore, on the total aspect of the ostracod and foraminiferal fauna rather than the occurrence of one or two species unless they appear to be numerically important (i.e. relatively dominant) and in situ. In some cases assemblages were abundant but composed of one or two dominant species. Foraminifera are generally abundant in all samples recovered except where peats were encountered.

Core MHB1.
Core MHB1 was drilled on Mautby Marshes (Nat. Grid Ref. TG 4954 1054; Fig 1) and penetrated to a depth of just over 18 metres, twenty seven samples were taken altogether (figure 2). The base of the Breydon Formation was not reached in this core but adjacent boreholes show it to be 21-22 metres below ground level in this area with a 1-2 metre thick oyster bed lying directly on the Pleistocene basement. These sediments are sub-tidal and are believed to have been deposited following a rapid transgression.
Table 1. Lithological description of core MHB1.

Core SS2
Core SS2 was drilled on Acle Marshes (Nat Grid Ref. TG 4815 0910; figure 3) to a depth of 17.8 metres, twenty seven samples were taken (figure 3). Core SS2 was much less varied in its lithology than MHB1. This is probably due to its palaeogeographical position, being in a more open part of the estuary and, therefore, less likely to have been subject to minor "sea-level" fluctuations than the marginally situated MHB1. The base of the Holocene sequence was not reached in this core and the nature of the basement in this area is not known. Some cores in this area exhibit crude laminations in intertidal flat and sub-tidal flat muds.
Table 2. Lithological description of core SS2.

FORAMINIFERAL BIOZONES AND BIOFACIES OF THE BREYDON FORMATION
In all, some 23 boreholes from the Holocene Breydon Formation of East Anglia have been studied for their foraminiferal content. An environmental zonation scheme has been established where the presence of both individual species and species assemblages are used to determine the relative tidal position of mean sea-level at the time of deposition.

Foraminiferal Biozones
Introduction. The present scheme is based upon the previous work in this region (Coles, 1977; Coles & Funnell, 1981) and is expanded with new data from the present

study. A complete revision of these studies is currently in preparation (Godwin, in prep. a,b) following the approach introduced by Scott & Medioli (1978, 1986). Interpretation of the samples does not rely solely on the foraminiferal evidence. Average sediment grain size, plant remains, shell debris and Ostracoda are considered together with the size, condition and probable provenance of the foraminiferal tests with a view to assigning a sample to a given Zone. The Biozones refer to the depth of the environment relative to local, mean sea-level.

The definitions of Murray (1979) and Miller et al. (1982) are used for the identification of the ecomorphotypes of *Ammonia beccarii* and *Elphidium excavatum* respectively. The recognition of the variants of these two species is important in the scheme. The scheme can be summarised as follows:-

ZONATION INDEX SPECIES.
Upper Saltmarsh.
Zone IaT. inflata
Zone IbT. inflata, J. macrescens
Lower Saltmarsh
Zone IIa *T. inflata, J. macrescens, A. beccarii* vars *limnetes/tepida, H. germanica, E. williamsoni.*
Zone IIb*A. beccarii* vars *limnetes/tepida, H. germanica, E. williamsoni, E. excavatum* forma *lidoensis.*
Zone IIcLarge *A. beccarii* together with some (Marsh Creeks) Miliolids and a mixture of mainly saltmarsh and some sub-tidal morphospecies.
High Intertidal Flat
Zone IIIa*A. beccarii, H. germanica, E. excavatum* formas *excavata/selseyensis* plus a small percent of small, size sorted *E. earlandi, E. gerthi, E. magellanicum* and other shelf species.
Transition zone
Zone IIIb A mixture of IIIa and IVa assemblages sub-tidal species becoming more important.
Tidal Flat Channel
Zone IIIc As for IIc but saltmarsh species are rarer, and small, size-sorted, transported shelf material more common.
Low Intertidal Flat
Zone IVa *A. beccarii, H. germanica,* 4-10% *E. oceanensis* and/or *E. excavatum* forma *clavata.*
Sub-tidal Flats, (b) and Channels (c)
Zone IVb/c *A. beccarii, H. germanica,* 11-50% *E. oceanensis* and/or *E. excavatum* forma *clavata.* Miliolids *H. depressula & E. incertum* more common here than elsewhere.

The present study recognises only the Lower Saltmarsh through to Low Intertidal Zones.

The lower saltmarsh (0.8 to 0.6m above mean sea-level). Zone IIa, the upper part of this Zone, is typically dominated by *Phragmites* reed stands. Assemblages contain 20-50% textularids with *Trochammina inflata* and *Jadammina macrescens* being the most important species. Calcareous taxa constitute the remainder of the assemblage in Zone IIa but represent at least 90% of the, lower, Zone IIb. Diagnostic species are *Haynesina germanica, Elphidium williamsoni, E. excavatum* forma *lidoensis,* and *A. beccarii* vars *limnetes* and *tepida.* The ostracod *C. torosa* often reaches great abundance
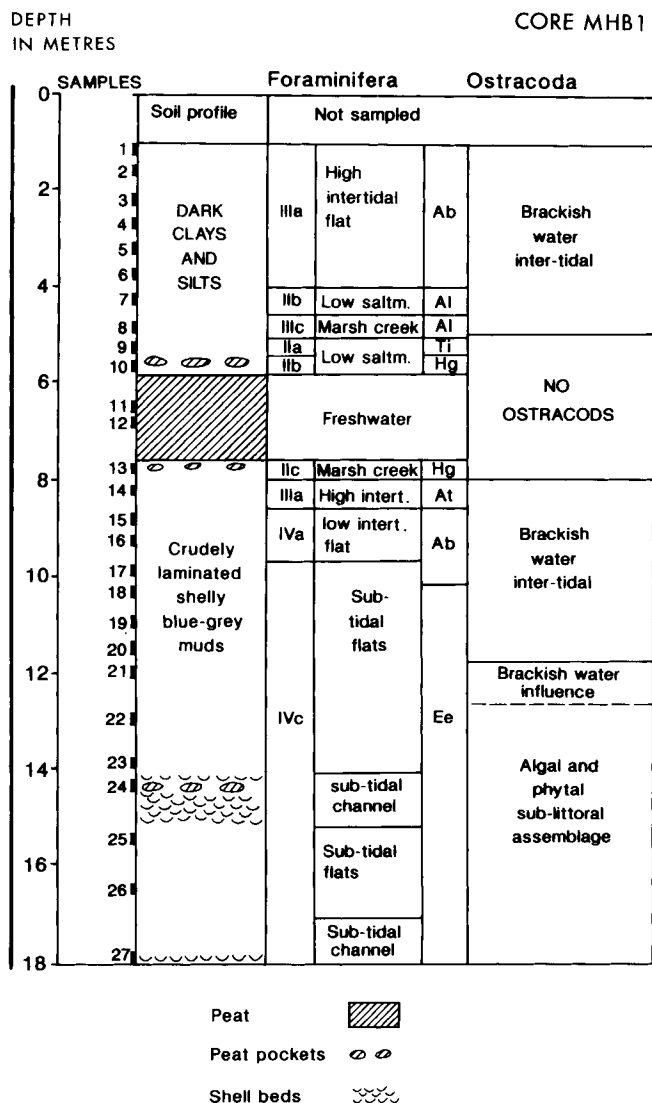
Fig 2. Lithological description and palaeoenvironmental interpretation of core MHB1.
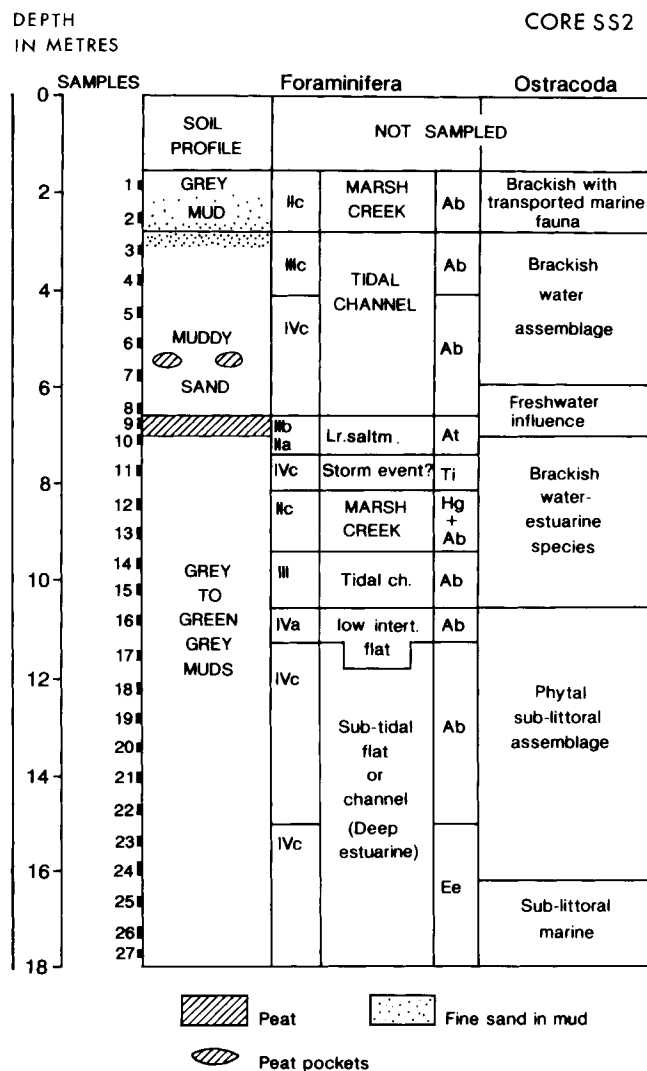
Fig 3. Lithological description and palaeoenvironmental interpretation of core SS2.

TABLE 1
Lithological description of Core MHB1

Depth (cm)	SEDIMENT DESCRIPTION
0-97	Soil profile.
98-190	Dark grey silty mud
191-380	Very dark grey to black mud
381-530	Dark grey silty mud
531-534	Brown silty mud with sharp upper contact
535-583	Brown silty mud with peaty pockets
584-760	Amorphous brown peat, sulphurous smell, sharp upper contact, lower contact not observed.
761-770	Blue grey silty *Phragmites* mud with patches of peat.
771-1805	Shelly, blue grey silty mud with *Scrobicularia plana* and *Cerastoderma lamarcki*. Shell beds occur at depths of 1425, 1446-1520 and 1795-1805cm. Patchy peat packets are recorded at 1426-1445cm.

SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T.inflata/J.macrescens/M.fusca	0	1.6	0	1.5	2.8	1.8	2.6	0.5	45	4.3	0	0	0	1.8	1	0.3	0.5	0	0	0	0	0	0	0.5	0	0	0
A.becarii var limnetes	0.4	0	0	0	1.4	0	55.1	28.5	20.8	4.3	0	0	0	3.6	0	3.2	0.8	0.6	0.6	0.8	1	1.6	0.3	0.5	1	1.3	2.5
E.williamsoni/E.excavatum forma lidoensis	2.4	3.1	0	1.5	1.4	2.6	8.9	2	2.1	10.6	0	0	0	4.4	1.5	4.2	2.7	0	0	0	1	0.8	0	0	0	0	0.3
P.germanicum	27.3	23.4	25.4	22.7	24.2	26.3	17.7	28.3	19.8	48.9	0	0	50	43.2	28	35.7	35.8	29.8	22.5	23.6	22.2	22.3	18.1	14.6	9.7	18.7	11.8
A.beccarii var tepida	0	0	0	0	1.1	0	6.3	8.3	5.4	21.3	0	0	28.6	23.8	25	21.3	17.5	19.7	19	18.4	23.8	29.7	31.3	33.3	46.8	27.3	36
A.becarii var batavus	44.9	53.1	48.3	53.2	49.8	51.8	0	19.7	3.3	6.4	0	0	14.3	16.2	32	25.8	22.6	26.2	27.6	27.3	19.8	19.6	27	19.3	15.3	24.2	20.9
E.gerthi/E.earlandi/E.magellanicum E.excavatum formas excavatum/selseyensis	22	17.6	18	15.3	14.7	15.9	9	11.1	3.3	4.2	0	0	7.1	5.1	1	1.2	0.2	0.6	0	0	0	0	0	0	0	0	0.3
E.oceanensis/E.excavatum forma clavata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.5	6	17.4	21.9	30.2	29.6	29.4	24.3	22	29.3	26.2	25.3	25.2
E.margaritaceum/E.crispum/macellum E.excavatum forma magna	1.2	1.6	3.3	2	1.1	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H.depressula/E.incertum	0.8	0	3.4	1.5	1	0.6	0.7	0.5	0	0	0	0	0	1.1	2	2.3	1.1	0	0.9	0.3	0.7	0.9	0.6	2.5	0	0	0.3
SHELF ROTALIDS	0	1.6	1.6	3.4	1.8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MILIOLIDS	0.8	0	0	0	0.7	0.6	0.6	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0.8	0.6	1	0.9	3.2	2.7
Planktonics/Cretaceous fossils	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total specimens in 10g	245	128	122	203	281	170	158	207	91	47	0	0	14	279	202	342	360	1500	1000	1300	600	224	650	1800	950	500	2200
Total number of morphospecies	11	9	9	13	20	10	10	12	8	7	0	0	4	10	10	12	11	10	7	7	8	9	10	11	7	7	15

Fig 4. Foraminiferal biostratigraphy of core MHB1 (per cent abundance).

TABLE 2

Lithological description of Core SS2

Depth (cm)	SEDIMENT DESCRIPTION
0-156	Soil profile.
156-280	Light grey very soft mud, grading down into sand.
280-658	Grey, fine sand at top becoming muddy sand down-core. Peat patches at 540cm.
658-693	Brown compact peat.
693-1794	Light grey/blue soft mud, grades downwards into grey, then dark grey and finally a green grey mud at 1758cm.

TABLE 3

Summary of Biofacies Scheme

Biofacies	Marker species	Environment
Ti	(T. inflata)	Ur to Lr Saltmarsh.
Hg/Al	(H. germanica/A.beccarii Al - var limnetes)	Lr Saltmarsh
Hg - Lr	H. germanica	Saltmarsh to Tidal flat
At/Ab	(A. beccarii var tepida A. beccarii var batavus)	Lr Saltmarsh to Sub-tidal channels

in this zone.

Marsh creeks (Zone IIc) and intertidal channels (IIIc), which are largely sub-tidal, display a mixture of saltmarsh and deeper water Foraminifera. Large specimens of *A. beccarii* var *batavus*, miliolids and the ostracod *C. torosa* are diagnostic of these zones. A rare ecomorphotype of *A. beccarii* var *limnetes* which has an umbilical boss also occurs in these environments. The sediments here tend to be sandier and the population density may be low.

Intertidal flats (0.4m above to 1.7m below mean sea-level). Zone IIIa (High Intertidal Flat) assemblages are mainly composed of *H. germanica* and *A. beccarii*. Small, size-sorted specimens of *E. earlandi, E. gerthi, E. magellanicum, E. margaritaceum* and various exotic shelf species constitute a small but consistent faunal element in most assemblages. Forma *excavata* and *selseyensis* dominate the ecomorphotypes of *E. excavatum* in this Zone. Molluscan debris and *Phragmites* remains are rare in this environment but mineral grains of coal, muscovite mica and framboidal pyrite are generally common in these crudely laminated muds.

Zone IVa (Low Intertidal Flat) is diagnosed by the presence of 4-10% *E. oceanensis* and/or *E. excavatum* forma *clavata*. Assemblages are otherwise similar to zone IIIa except that shelf species are less important but, where they are recorded, tend to be larger than average. Typically, sub-assemblages of *E. gerthi, E. crispum-macellum, E. margaritaceum* and the rare *E. excavatum* forma *magna* dominate the transported element of the assemblage and range down into Zone IVc. Ostracoda, where abundant, are dominated by *Loxoconcha* spp. and/or *Hemicythere villosa*.

Sub-tidal flats and channels (more than 1.7m below mean sea-level). Zone IVc assemblages (as defined by Banner & Culver, 1978) constitute a range of test sizes, from juvenile to adult, of the sub-tidal species *E. oceanensis, E. excavatum* forma *clavata* and *A. beccarii* or *H. germanica* still dominate most populations, and sediments are generally quite shelly. Sub-tidal channels contain the large specimens referred to above in Zones IIc-IIIc and many assemblages consist of up to 100% *A. beccarii. H. germanica* and miliolids are the most common accessory species in this environment.

Foraminiferal Biofacies
Four distinct Biofacies have been identified which are much wider ranging zones than the depth controlled Zones referred to above. The biofacies reflect not only depth but also salinity, energy of the environment, substrate type and temperature. This scheme follows the 'associations' of Murray (1991). The Biofacies are named after the dominant or diagnostic species in each assemblage.

Additional ecological information for the key taxa is derived from Coles (1977), Coles & Funnell (1981), Culver & Banner (1978), Murray (1971, 1973, 1979), Murray & Hawkins (1976), Miller et al. (1982) and Banner & Culver (1978). Much of the information regarding salinity and temperature tolerance is summarised in Murray (1991). The present Biofacies scheme is summarised in table 3.

Biofacies identified in the present study.

Trochammina inflata Biofacies (Ti). Range: Upper to Lower Saltmarsh. Salinity: 0-35 ppt (generally brackish). Energy of environment: Low. Sediment type: Phragmites mud. Temperature: 0-30°C.

Haynesina germanica/Ammonia beccarii var limnetes **Biofacies (Hg/Al)**. Range: Al - Lower saltmarsh; Hg - Lower Saltmarsh to Sub-tidal Flat. Salinity: 0-15 ppt (brackish). Energy of environment: Low. Sediment type: Phragmites or estuarine muds. Temperature: 0-20°C.

C Ammonia beccarii var tepida/Ammonia beccarii var *batavus* **Biofacies (At/Ab)**. Range: Lower Saltmarsh to sub-tidal channels. Salinity: At - brackish, Ab - brackish to marine. Energy of environment: Medium to high. Sediment: Muds and sands. Temperature: 0-20°C.

C. Elphidium excavatum - Elphidium oceanensis **Biofacies (Ee)**. Range: Sub-tidal. Salinity: Brackish. Energy of environment: Medium to high. Sediment: Shelly estuarine muds. temperature: 0-20°C.

Microfossil assemblages from core MHB1.
The sediments at the base of the core (17- 27) are characterised by foraminiferal assemblages belonging to the 'Ee' Biofacies and, therefore, to the IVc sub-tidal Biozone (Fig 2). The dominant species is *A. beccarii* (50- 60%) with roughly equal proportions of marine and brackish water morphotypes present. Few tests show evidence of transportation from inner estuarine areas or from the estuary mouth although miliolids become relatively common towards the base of the core. The assemblages suggest medium energy levels and brackish salinity prevailing at this time. Water temperatures may have been lower than at later times suggested by the abundance of *E. excavatum* forma *clavata* (Murray, 1991). Further cores in this area suggest that the estuary was of the 'drowned valley' type in Lower Clay times (Godwin, in prep a). The foraminiferal and ostracod biostratigraphy of this core is given in figures 4 and 5, The most abundant and/or environmentally significant taxa are figured in plate 1.

The lowermost samples (27-25) are dominated by assemblages of the ostracods *H. villosa* and *L. rhomboidea*. These are essentially algal and phytal feeders respectively. The former species decreases markedly at sample 25 with the subsequent samples (24-21) dominated by *L. rhomboidea*. Another loxoconchid, the marine species *P. guttata*, is common in the lower part of core SS2 but is only represented by a few specimens in the Lower Clay of core MHB1. Samples 21-20 see a decrease in *L. rhomboidea* with an increase in the importance of the brackish water species *C. torosa* and *L. castanea*. This clearly represents an increased freshwater influence. This pattern continues from sample 19 through to 14 with these two species eventually representing the only Ostracoda at the top of the Lower Clay as diversity decreases.

Samples 16-14 indicate a rapidly shallowing environment. Silting up of the estuary was probably aided by the barring of the estuary mouth by a sand spit (Coles & Funnell, 1981). Samples 15-16 have 6-9.5% *E. oceanensis* and are interpreted as low intertidal flat, Zone IVa. By sample 14 this component is absent and shallow water species have

increased importance suggesting a high intertidal flat Zone IIIa assemblage. This regressive sequence belongs to the 'Ab' Biofacies.

At the level of samples 13-14 there is a major change in the sediment type with shell debris replaced by *Phragmites* red material. There is a fall in diversity and abundance which is indicative of saltmarsh and marsh creek environments. The assemblages are placed in the marsh creek Zone IIc due to the presence of large specimens of *A. beccarii* var *batavus*, typical of channel faunas. It is inferred that the channel has cut into the intertidal flat sediments below. Samples 11-12 are barren peats witnessing the culmination of the regressive phase of deposition. The interval covered by samples 13-9 represents the Middle Peat and no Ostracoda are recorded from these levels. The two samples immediately above the peat, 6 and 8 (sample 7 was not investigated for ostracods) possess specimens of *H. rubida*, *Xestoleberis* sp. and *L. castanea*. There does not appear to be any evidence of a gradual increase in salinity in the ostracod faunas immediately following the peat development. This would support the suggestion that the top of the peat is an erosion layer (Godwin in prep a) marking the sharp onset of a transgressive phase in the Upper Clay. Samples 7-10 belong to the Lower saltmarsh Zones although channel migration has led to the presence of erosive surfaces adding further complexities to this part of the sequence. These samples are assigned to the 'Hg' foraminiferal Biofacies. Sample 10 has 10% *E. williamsoni*, diagnostic of the Lower saltmarsh Zone IIb. This environment shallowed further in sample 9 with 45% *T. inflata* and *J. macrescens* indicating a IIa level in the 'Ti' Biofacies. The sediments were then cut by a channel (seen in sample 8), with Zone IIc faunas containing 19% *A. beccarii* var *batavus* and accessory, transported, shelf material. This feature had silted up by sample 7 represented by Zone IIb faunas in the 'Al' Biofacies.

Samples 1-7 show the transgression regaining momentum and the entire sequence is interpreted as a high intertidal flat Zone IIIa lying in the 'At' Biofacies. Assemblages contain a small percentage of *Elphidium* species and small, size sorted, shelf taxa. Samples 5-2 are dominated by the brackish water ostracod *L. castanea* with a few specimens of phytal estuarine Ostracoda as accessory species. The uppermost sample (MHB1-1) contains assemblages of *L. castanea*, *L. lacertosa* and *C. fisheri* the latter two species are tolerant of fluctuating salinity levels and therefore represent a marginal setting within the estuary. The final evidence of silting up is lost in the soil profile.
Table 3. Summary of Biofacies Scheme.

Microfossil assemblages from core SS2
The initial transgressive phase (samples 17-27) is similar to the basal part of core MHB1 and is interpreted as sub-tidal mudflats (Zone IVc). The 'Ee' Biofacies is not as fully developed as in MHB1 and there are higher numbers of exotic Foraminifera. *A. beccarii* var *batavus* is the dominant species and suggests higher salinities here than at the more marginally positioned MHB1 site. The foraminiferal and ostracod biostratigraphy for this core is given in Figs 6 and 7.

The lowermost samples of this core (27-25) are dominated by two species of *Palmoconcha*, *P. guttata* and *P. laevata*, only a few of the former species and none of the latter were recorded in the other core. These represent sub-littoral marine assemblages. samples 24 through to 16 are dominated by the phytal *L. rhomboidea* a common shallow sub-littoral species with secondary species such as *H. villosa*, *H. viridis*, *C. torosa* and *L. castanea* important at certain levels. The latter two species are recorded in many samples throughout the two cores. Although they may constitute a large percentage of some samples, analysis of their population structure would suggest that they are often transported from the shallower water, brackish regions of the estuary.

The regressive phase with abrupt shallowing and low intertidal flat taxa (sample 16) gives way to channel faunas with relatively high numbers of sub-tidal species. These assemblages are still within the 'Ab' Biofacies indicating higher salinity levels persisting. Textularids are common in some of the marsh creek (Zone IIc) material. Sample 11, a thin sand, has a IVc sub-tidal fauna and is thought to represent a storm event. The sequence ends with a *Phragmites* mud in the 'Ti' Biofacies and IIa lower saltmarsh Zone capped by a much eroded remnant of the Middle Peat. Ostracod assemblages from samples 15 to 9 indicate decreasing salinity conditions and increasing euryhalinity with the predominance of *C. torosa* and a decrease in diversity. The peat horizon in this borehole (SS2-9) contains Ostracoda. Sample 8 contains five freshwater taxa in addition to the brackish water species.

The succeeding transgressive phase which began the Upper Clay deposition is characterised in this area by a series of channel sands in the 'Ab' Biofacies (samples 8-5). Here, the presence of the inner estuarine *Haplophragmoides* spp. indicates a nearby freshwater source. The environment is sub-tidal with typical channel faunas.

By sample 5 the final regression is seen starting with shallow water species becoming increasingly important. The final phase (samples 3-1) marks a return to mud deposition with increasing quantities of *Phragmites* debris added to the sediment. The channel here becomes a marsh channel before finally silting up. The five samples succeeding the peat horizon (7-3) are dominated by the two ostracod species most commonly observed in the estuary today (*C. torosa* and *L. elliptica*). The two uppermost samples, however, possess few specimens of *C. torosa* but other species such as *Sclerochilus* and a number of more marine taxa are recorded. Indeed, samples 5 through to 1 contain a number of instars of sub-littoral, open marine species e.g. *Cytheropteron sp.*, *Robertsonites tuberculatus*, and *Pontocythere elongata*. These are interpreted as either reworked specimens from the surrounding estuarine sediments as the estuary silted up and/or the result of storm surges bringing in these small specimens.

The two boreholes described above, although taken

within two kilometres of each other, show differences in the ostracod assemblages recovered. They both display the same peat/silty-mud alternations reflecting local sea-level and/or palaeogeographical changes. Both cores are dominated by brackish water mud dwellers, estuarine phytal species or shallow marine taxa. Core MHB1 has yielded moderately rich ostracod assemblages of low diversity, the majority representing in-situ populations. Core SS2, however, has a more diverse fauna. Many samples in the latter core contain species which are represented by only one or two specimens. These clearly represent an allochthonous element. It is assumed, therefore, that SS2 represents an environment where mixing of in situ and transported valves occurs. The faunal dichotomy between the two cores reflects the environmental differences which can occur within short distances in the estuarine setting.

ENVIRONMENTAL INTERPRETATION OF CORES MHB1 AND SS2

A complete study of the many boreholes from this area have afforded a detailed reconstruction of the palaeogeographic history of this estuary. The Breydon Formation in the study area occupies a flat bottomed valley with relatively steep sides. MHB1 is sited approximately 300 metres due south of the northern margin of the valley which is marked by a palaeo-shoreline which is clearly visible today. Core SS2 is sited south of the River Bure, and towards the centre of the estuary.

In the early part of the Lower Clay the MHB1 site lay close to the shore. The estuary is interpreted as a drowned river valley, with a sub-tidal channel sweeping close to the shoreline at this point. Immediately to the south the estuary shallowed to low intertidal sand flats before deepening again in the area of core SS2.

At the end of Lower Clay times the main channel had moved further south to the position of the present River Bure. During the regressive phase the SS2 area shallowed first and has a deeper sequence of saltmarsh sediments (mainly channel infills). The MHB1 site was transformed into intertidal flats before shallowing into the fresh and brackish water peats of Middle Peat times.

The Middle Peat occupied the whole width of the valley at this point. The transgression which resulted in the deposition of the Upper Clay is presumed to have been initiated by the destruction of a sand barrier which lay across the mouth of the estuary (Coles & Funnell, 1981). In the Upper Clay tidal flats are, once again, found on the northern margin of the valley (MHB1) although at a higher position in the section than seen in SS2. South of the River Bure the sedimentary sequence is dominated by somewhat deeper situated channel deposits. This is a reverse of the interpretation given for the Lower Clay in these two boreholes. With the formation of a new sand bar from the 10th century onwards, both sites gradually silt up.

ACKNOWLEDGEMENTS

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	1	2	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
C. torosa	0	0	0	0	0	0	0	0	0	0	0	100	96	88	86	63	95	63	23	5	4.7	14	36	2	8.8
L. castanea	46	86	75	75	71	11	0	0	0	0	0	0	4.3	12	9.1	23	0	10	54	25	3.1	10	9.1	4	6.9
L. elliptica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.5	0	0	0	0	0	4.1	0	0	0
C. fisheri	12	14	6.3	0	0	0	0	0	0	0	0	0	0	0	2.3	5.3	0	0	0	0	0	0	0	0	0
L. lacertosa	40	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.1	0	0	0
L. rhomboidea	0	0	0	13	0	0	0	0	0	0	0	0	0	0	2.3	3.5	5.3	27	23	70	91	49	36	44	61
H. viridis	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H. villosa	0	0	13	0	14	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.1	18	42	15
Xestoleberis sp.	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H. albomaculata	0	0	6.3	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.6	0	0	5.9	5.9
L. psammophila	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
S. striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.8	0	0	0	0	0	0	0	0	0
P. guttata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	2.9
Total number of specimens	114	29	16	8	7	9	0	0	0	0	0	9	23	17	44	57	19	30	13	20	64	49	11	101	102
Number of species	4	2	4	3	3	3	0	0	0	0	0	1	2	2	4	6	2	3	3	3	4	7	4	6	6

Fig 5. Ostracod biostratigraphy of core MHB1 (per cent abundance).

SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
T.inflata/J.macrescens/M.fusca	0	0	0	1	2.9	2	1	0	0	35.7	4.2	0	9.4	1.8	0	0	0	0	1.4	0	1	0	0	0.6	1	0	0
A.becarii var limnetes	1.5	0	1.9	13.7	1.9	1	0	2.8	0	0	0	4	5.1	6.4	0	0	0	0	0.9	0.7	0	5.2	6.2	5.7	7.3	8.5	1
E.williamsoni/E.excavatum forma lidoensis	3.1	0	0	0	0	1	0	3.7	0	0	0	0	0	0	0	0	0.5	0	1	0	0	0	0	0	0	0	0
H.germanicum	13.1	21.1	12.4	25.5	9.2	5.8	2	24.1	50	28.6	14.4	56	27.6	13.6	17.5	11.9	10.4	11.7	12.2	10.3	16.7	14.4	34.7	6.9	28.4	0	4
A.becarii var tepida	2.3	0.7	0	5.9	1	1	0	5.6	0	28.6	0	0	0	0	1.1	0.4	0.9	0	0.4	0	0	2.9	0.6	3.1	2	0	0
A.becarii var batavus	34.1	34.7	49.5	36.3	37	61.1	73	57.4	50	0	38.1	16	37.9	54.1	71.9	71.1	57.1	65	64.7	64.7	62	59.2	26.3	50.3	44.1	67	55
E.gerthi/E.earlandi/E.magellanicum E.excavatum formas excavatum/selseyensis	4.7	8.2	5.7	5.9	11.1	6.8	8	1.9	0	0	7.5	16	1.7	18.3	2.7	3.6	4.7	1.9	2.2	1.4	0.7	2.3	1.8	0.6	1.5	0.9	1
E.oceanensis/E.excavatum forma clavata	14.7	10.2	5.7	0	12	5.8	1	0	0	0	16.9	0	7.8	0	3.1	6.5	13.3	11.7	14.9	17.6	12.7	12.6	24	28.9	12.2	21.7	33
E.margaritaceum/E.crispum/macellum E.excavatum forma magna	2.3	6.1	4.8	0	2.8	4.9	2	1	0	0	5.1	0	2.6	0.9	1.1	0.7	3.8	0	0	0	0	0.6	1.8	0.6	0	0	1
H.depressula/E.incertum	8.5	6.1	6.7	8.8	6.5	5.8	5	1	0	0	2.5	8	6	6.4	1.6	4	5.7	6.9	1.3	2.2	1.3	0.6	1.2	0	2	1.8	1
SHELF ROTALIDS	5.4	5.4	7.5	2	9.3	2.9	4	2.8	0	7.1	7.6	0	0.9	0	0	0	0	0	0.9	1.5	1.3	1.1	0	1.3	1.5	0	3
MILIOLIDS	7.8	5.4	6.6	1	5.6	3.8	4	0	0	0	3.3	0	1.7	0.9	0.5	1.8	3.8	1	0.4	1.3	3.3	0.6	4.2	0	0	0	1
Planktonics/Cretaceous fossils	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total specimens in 10g	119	147	105	102	108	103	100	108	2	14	118	25	116	109	189	277	105	103	300	136	150	174	167	150	200	106	100
Total number of morphospecies	25	20	19	12	24	22	18	11	2	5	19	6	13	10	12	13	9	7	14	10	12	12	12	11	10	5	11

Fig 6. Foraminiferal biostratigraphy of core SS2 (per cent abundance).

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SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
C. compressa	0	0	0	0	0	0	0	5.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Candona sp.	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Darwinula sp.	0	0	0	0	0	0	0	5.9	0	0	0	0	0	0	0	0	0	2.1	0	0	0	0	0	0	0	0	0
L. inopinata	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. euplectella	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C. fuscata	14	0	7.1	11	0	0	0	18	0	0	0	0	10	18	0	0	0.7	0	1.4	2.1	0	0	0	0	0	0	0
C. torosa	9.1	0	11	56	7.7	55	33	41	60	100	18	50	30	27	14	19	7.3	20	1.4	0	0	4.3	0	0	0	0	0
L. elliptica	4.5	43	0	0	31	10	22	5.9	0	0	0	0	10	18	9.5	2.4	0.7	1	5.7	0	0	0	0	0	0	0	0
L. castanea	9.1	0	7.1	0	0	0	0	0	0	0	0	0	40	18	19	7.2	6.6	5.2	5.7	8.3	6.3	13	0	42	11	13	13
L. lacertosa	0	7.1	7.1	0	7.7	0	0	0	0	0	0	50	5	0	9.5	2.4	7.3	3.1	0	0	13	2.1	9.8	0	3.5	2.1	0
C. fisheri	0	0	7.1	0	0	0	0	0	0	0	0	0	0	9.1	0	0.8	0	2.1	0	0	0	2.1	0	0	3.5	0	2.4
Semicytherura sp	4.5	0	7.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cytheropteron sp	9.1	0	0	11	7.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H. albomaculata	4.5	0	3.6	0	7.7	0	0	0	0	0	9.1	0	0	0	0	0	0	0	8.6	0	0	6.4	4.9	0	1.8	2.1	0
A. convexa	4.5	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	3.8	0	0	0
H. viridis	4.5	0	0	11	0	5	0	0	0	0	0	0	0	0	14	10	7.3	11	10	0	25	21	11	5.7	8.8	2.1	4.9
P. elongata	14	7.1	7.1	0	7.7	0	0	0	0	0	9.1	0	0	9.1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sclerochilus sp	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0
H. villosa	0	0	7.1	0	15	0	0	0	0	0	9.1	0	0	0	0	0	0	0	0	0	0	6.4	28	0	0	0	0
R. tuberculatus	0	0	3.6	0	7.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L. rhomboidea	0	0	0	0	0	10	0	0	0	0	0	0	0	0	9.5	32	35	33	56	73	34	21	28	17	14	0	8.5
Leptocythere sp.	4.5	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.4
X. nitida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	19	8	11	5.7	4.2	3.1	2.1	0	0	0	0	0
C. littoralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.4	1	0	4.2	3.1	2.1	11	1.9	0	6.4	2.4
U. britannica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1	0	0	0	0	0	0	0	0	0
S. cornuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
H. cellulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.8	0	0	0
S. sella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2
P. variabile	9.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2.1	0	0	0	0	0	0	0
L. psammophila	0	7.1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S. nigrescens	0	0	7.1	0	0	0	0	0	0	0	9.1	0	0	0	9.5	6.4	21	6.2	1.4	2.1	3.1	0	0	0	3.5	2.1	0
S. striata	0	0	11	0	0	0	0	0	0	0	9.1	0	5	0	0	0	0.7	0	0	0	0	0	0	0	0	0	2.4
C. lutea	0	0	0	0	7.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L. baltica	0	0	0	0	0	5	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C. whitei	0	0	0	0	0	0	0	0	0	0	9.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. guttata	4.5	0	0	0	0	10	0	0	0	0	9.1	0	0	0	0	0	0	0	2.9	0	6.3	6.4	0	1.9	35	28	43
Eucythere sp.	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S. acuticostata	0	7.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L. pellucida	0	0	0	0	0	5	22	0	0	0	0	0	0	0	0	0	0	0	0	4.2	3.1	8.5	0	11	18	17	4.9
P. laevata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.1	0	6.1	17	0	28	15
P. cuneiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.3	0	0	0	0	0
S. angulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0
Total number of specimens	22	14	28	9	13	20	9	17	5	5	11	2	20	11	21	125	137	97	70	48	32	47	82	53	57	94	82
Diversity	14	6	13	5	9	7	4	7	2	1	9	2	6	6	8	9	12	14	11	8	10	13	8	8	10	9	11

Fig 7. Ostracod biostratigraphy of core SS2 (per cent abundance).