PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

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Phil. Trans. R. Soc. Lond. B 1988 **322**, 221-272
doi: 10.1098/rstb.1988.0125

Phil. Trans. R. Soc. Lond. B 322, 221–272 (1988) [221]
Printed in Great Britain

STRATIGRAPHY AND PALAEOENVIRONMENTS OF THE RED CRAG AND NORWICH CRAG FORMATIONS BETWEEN ALDEBURGH AND SIZEWELL, SUFFOLK, ENGLAND

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WITH AN APPENDIX ON THE NON-MARINE MOLLUSCA FROM THE NORWICH CRAG FORMATION AT SIZEWELL

BY R. C. PREECE

(*Communicated by R. G. West, F.R.S. – Received 16 September 1987*)

[Plates 1 and 2]

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[Published 19 December 1988

This study uses a variety of criteria to examine short-range correlation within the Crag deposits in order to assess the validity of longer-range correlations within the British Pleistocene stage system. To this end, six rotary cored boreholes spaced at 0.5–1.0 km intervals were drilled along a north–south-aligned traverse between Aldeburgh and Sizewell, Suffolk. These show that the thick Red/Norwich Crag sequence is confined to a deep, sharply bounded basin, which is of probable erosional rather than tectonic origin.

The undisturbed borehole core material enabled an assessment of the limits of stratigraphic resolution within these dominantly high-energy, shallow marine sediments to be made. Subdivision of the sequence was done on the basis of lithostratigraphical and biostratigraphical (foraminifera, pollen and spores, dinoflagellate cysts, and molluscs) criteria; chronostratigraphical methods (palaeomagnetism and amino acid chronology) were also applied. The various subdivisions indicated by each of these disciplines were in large part consistent, demonstrating that valid stratigraphic units had been identified. Only amino acid chronology did not indicate any obvious subdivision of the sequence.

Three lithostratigraphical units were recognized within the thick Crag sequence. The lowest unit (AS-Lith 1) consists of coarse shelly sands interbedded with thinly laminated muds and fine sands. The middle unit (AS-Lith 2) consists of fine- to coarse-grained shelly sands arranged in two coarsening-upwards cycles. Units AS-Lith 1 and AS-Lith 2 are correlated on a lithostratigraphical basis with the Red Crag Formation of the adjacent Aldeburgh–Orford area to the south and are named the Sizewell Member and the Thorpeness Member respectively. The uppermost unit (AS-Lith 3) comprises fine- to medium-grained, well-sorted sands; it correlates with the Chillesford Sand Member of the Norwich Crag Formation of the adjacent Aldeburgh–Orford area.

The Sizewell Member of the Red Crag Formation is normally magnetized and palaeontologically distinctive. The pollen, foraminifera and dinoflagellate assemblages firmly establish it as Pre-Ludhamian in age, and probably equivalent to an interval within the Reuverian C to Praetiglian Stages of the Netherlands.

The Thorpeness Member of the Red Crag Formation is less easy to place within the British Pleistocene stage system. It is reverse magnetized, at least in part, and foraminifera assemblages suggest possible correlation with the Ludhamian Stage. No identifiable pollen or dinoflagellate assemblages were obtained.

The Chillesford Sand Member of the Norwich Crag Formation is largely unfossiliferous but the borehole material has yielded a single pollen spectrum that suggests correlation with the Bramertonian Stage.

1. Introduction

The Red Crag and Norwich Crag formations of East Anglia (figure 1) are shallow marine deposits which are the only well-developed suite of Upper Pliocene to Lower Pleistocene sediments in Britain. Consequently, they contain the type sections for the currently accepted British stratigraphic stages over this time interval.

The distinction between the Red Crag (iron-stained shelly sands in Essex and Suffolk) and the Norwich Crag (more variable sands, shelly sands and clays cropping out in Norfolk) was made in 1835 by Charlesworth. The complexity and variability of the sediments made the exact definition of these units, and of their proposed subdivisions, a subject of much debate in subsequent years. Classifications involving correlations of sedimentary units and molluscan faunas were suggested (Wood, Jr 1864; Wood, Sr 1866; Prestwich 1871). The weight of opinion subsequently turned away from a lithostratigraphical approach to rely largely upon studies of the abundant and well-preserved molluscan faunas, with the work of Harmer (1900,

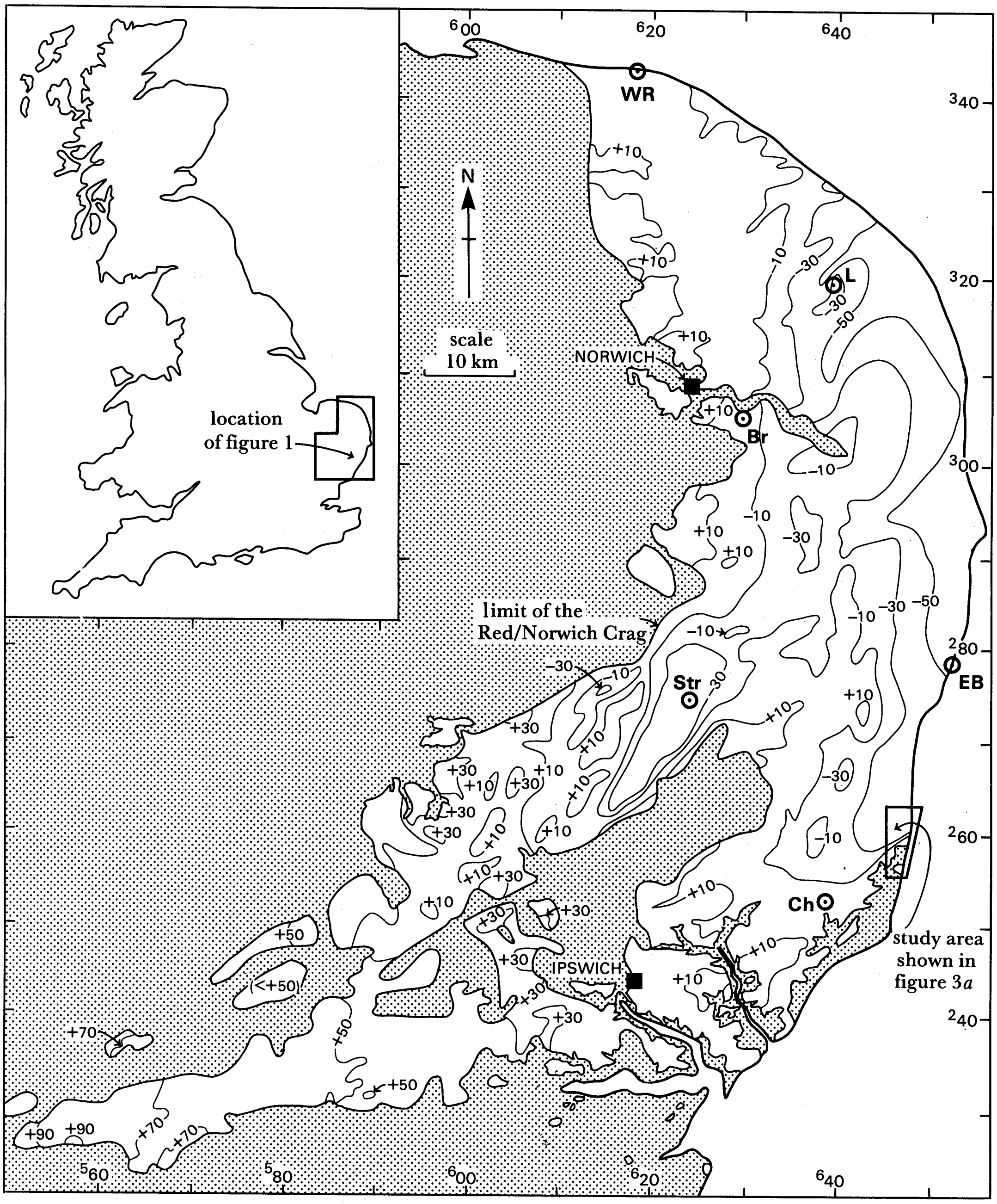


FIGURE 1. Distribution of the Red Crag and Norwich Crag formations in East Anglia, with contours on the base at 20 m intervals. Data adapted from Institute of Geological Sciences (1976, 1981), Bristow (1983), Ambrose (1974), Booth & Merritt (1982), Clarke & Ambrose (1975), Hopson (1981*a*,*b*, 1982), Marks (1982*a*,*b*), Marks & Merritt (1981), Marks & Murray (1981) and Thomas (1982). WR, West Runton; L, Ludham; Br, Bramerton; Str, Stradbroke; EB, Easton Bavents; Ch, Chillesford.

1902) being pre-eminent. He firmly established the belief that, traced northwards, the Crags successively became younger and contained progressively colder water faunas.

This concept of a single cooling trend within the Crag deposits was superseded by the detailed micropalaeontological studies of the Ludham borehole sequence, from Norfolk (West 1961; Funnell 1961) (figures 1 and 2). Alternating episodes of warm and cool climate were

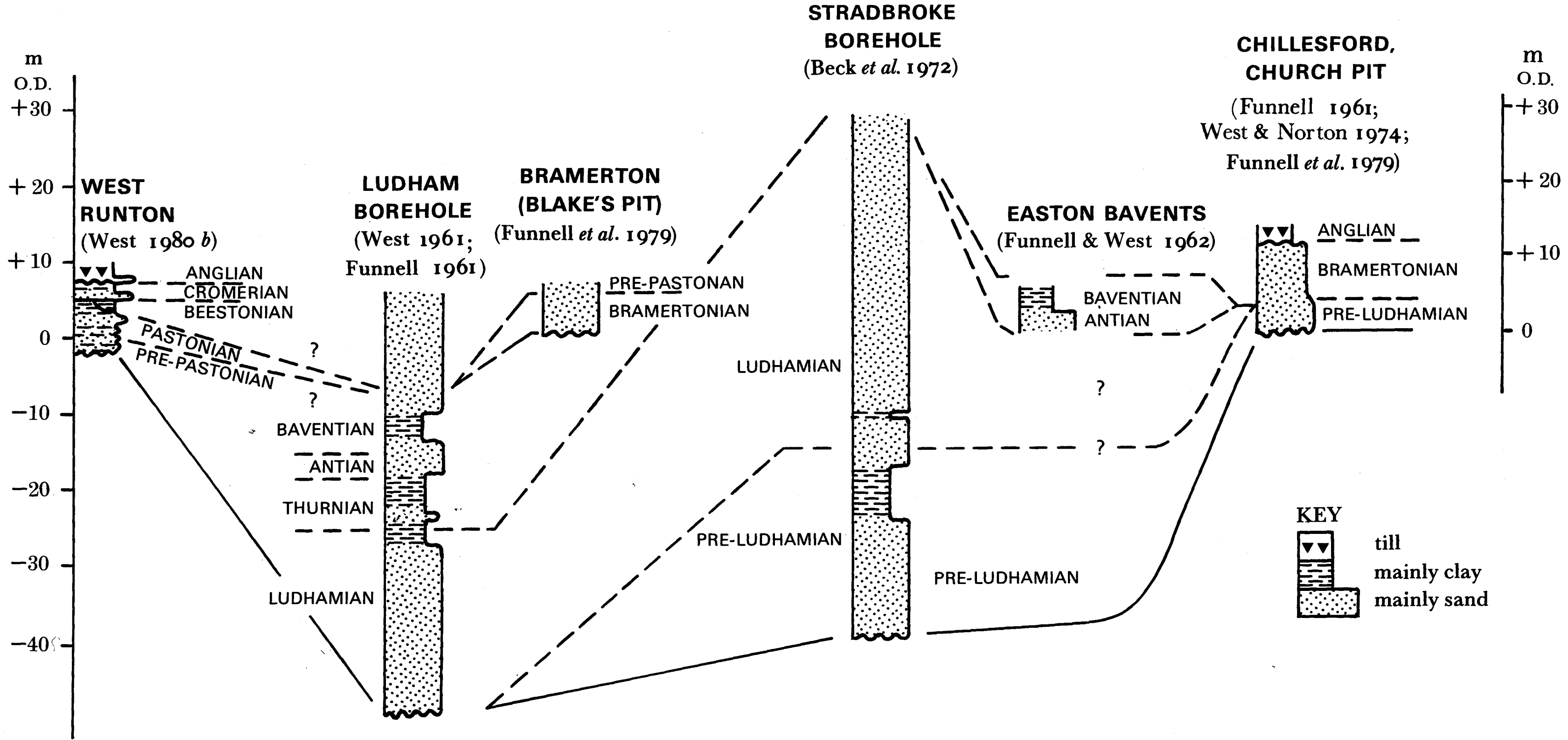


FIGURE 2. Stratigraphically important sections and boreholes in East Anglia. Stage nomenclature after Mitchell *et al.* (1973), modified after Funnell *et al.* (1979).

recognized, and these were subsequently correlated with those recognized in other borehole sequences and in sections (Funnell & West 1962; Beck *et al.* 1972; West & Norton 1974; Funnell *et al.* 1979; Funnell 1983). Formal stages have been established on the basis of these climatic episodes (Mitchell *et al.* 1973), and these constitute the standard stratigraphy for the lower part of the British Quaternary.

The correlation of some of the most important sections in East Anglia is shown in figure 2. The stratigraphy shown comprises a realistic framework for future research in East Anglia, but the sequence of climatic changes is believed to be incomplete by comparison with both the well-preserved oceanic record and the Netherlands sequence (Zagwijn 1975, 1985). Correlation of onshore sequences with the oceanic record remains a major challenge in late Tertiary–Quaternary studies. Chronostratigraphic studies are hampered by a dearth of reliable dating methods. The magnetic polarity of some East Anglian sedimentary sequences has been used in correlation (van Montfrans 1971; Beck *et al.* 1972) and amino acid dating, successfully applied to younger Quaternary sediments, has also been attempted (Miller *et al.* 1979; Davies *et al.* 1982).

Lithostratigraphical studies have failed to keep pace with developments in biostratigraphy, although a formal lithostratigraphical nomenclature has been proposed for the Crags of East Anglia (Funnell & West 1977). In practice, the recognition and delineation of lithostratigraphical units and the integration of these with the biostratigraphical data have been achieved only over part of southeast Suffolk, where the Red Crag and Norwich Crag sequence is relatively thin (Zalasiewicz & Mathers 1985). Elsewhere, palaeontologically described sections are correlated over long distances, with little knowledge of the sedimentary sequences in the intervening ground. In particular, only biostratigraphical methods have been used to correlate the thicker (more than 50 m) Crag sequences. This is partly because of the complexity of the sediments, and partly because the few well-documented boreholes are widely spaced.

The present study was therefore conceived as a multidisciplinary exercise in detailed short-range correlation within a thick Crag sequence. The aims were, firstly, to integrate biostratigraphical and chronostratigraphical data within a rigorous lithostratigraphical and sedimentological framework. Secondly, to assess the variation within microfossil assemblages at comparable levels within the sequence; in this way some idea might be gained of the degree of precision of, and the amount of confidence that can be placed in, the correlation of assemblages within such relatively high-energy, shallow-water sediments. Thirdly, to examine the nature of the transition from a relatively thin and simple Crag sequence (largely accessible at outcrop) to a more complicated, relatively thick Crag sequence of the type that has provided the basis for Lower Pleistocene stratigraphy (examinable only by borehole). The following methods were employed in the examination of the borehole core: lithostratigraphy (detailed lithological logging and granulometric analysis), biostratigraphy (examination of foraminifera, pollen spectra, dinoflagellate cysts and molluscs) and chronostratigraphy (measuring of magnetic polarity and amino acid analysis). These investigations are described and synthesized below.

2. GEOLOGICAL FRAMEWORK

The Red Crag and Norwich Crag underlie much of central and eastern East Anglia (figure 1). The deposits are up to 70 m thick around parts of the eastern coastline, and generally thin westwards. They rest on an irregular surface cut into Cretaceous and Tertiary strata. This surface includes several elongate depressions within which thick Crag sequences are preserved. The largest of these, the Stradbroke Trough (Funnell 1972), extends southwestwards from the Stradbroke borehole (figure 1).

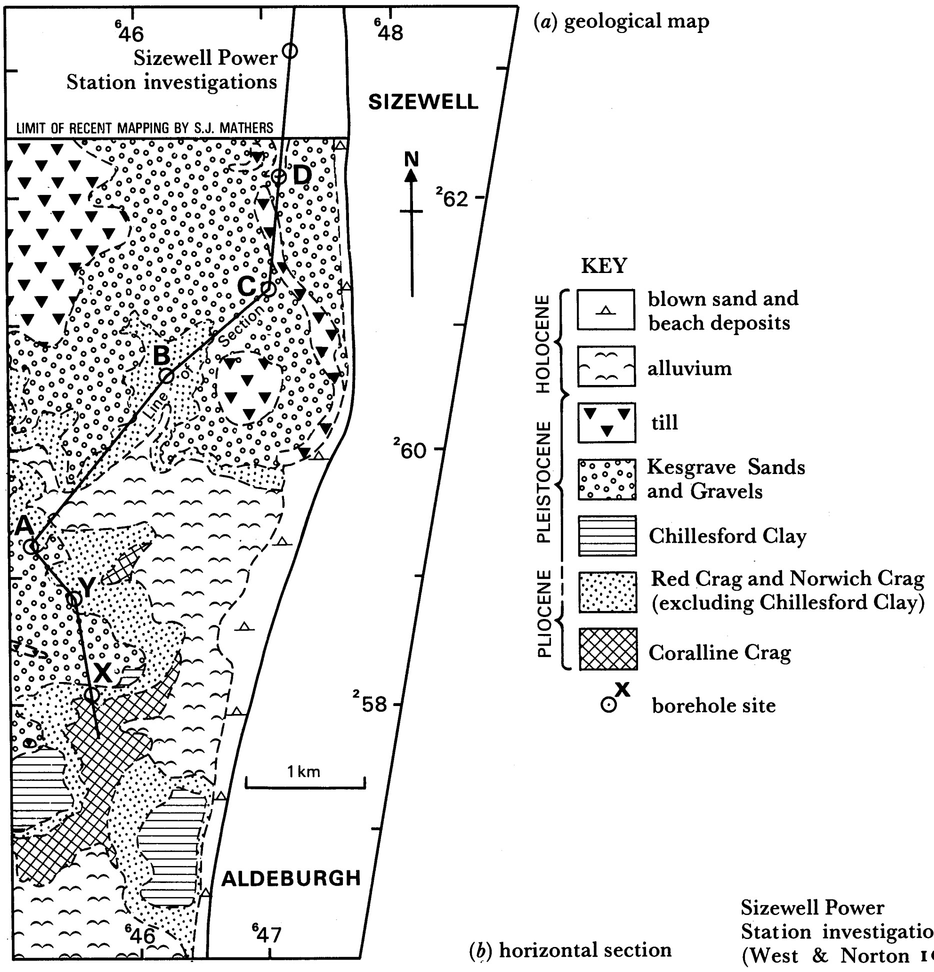
Bristow (1983) inferred that the Stradbroke Trough is fault-bounded and that Quaternary movements along these postulated faults controlled sedimentation. However, continuous sparker profiles have shown no evidence of comparable faulting affecting the Quaternary sediments within the adjacent North Sea Basin (Balson & Cameron 1985; Balson & Humphreys 1986), and it has been suggested that the depressions may have been formed by tidal scour (Funnell 1972) or by fluvial erosion (Carr 1967).

The study area lies near to the southern edge of the deep part of the Crag basin (figure 1). This edge coincides with the northern limit of the Lower Pliocene Coralline Crag, which for the purposes of this study can be regarded as part of the underlying bedrock. The surface geology is shown in figure 3*a*. Before this study, published syntheses of borehole records (see, for example, Institute of Geological Sciences 1981) had shown that the Plio-Pleistocene Crag sequence gradually increases in thickness northwards in this area, from *ca*. 20 m at Aldeburgh to *ca*. 60 m at Sizewell.

Fossiliferous surface exposures of Crag in the vicinity of Sizewell were initially assigned to the Pastonian (West & Norton 1974) and subsequently to the Bramertonian (Funnell *et al*. 1979). Stratigraphically important microtine rodent (vole) remains have recently been described from sites at and north of Sizewell (Mayhew 1985; Mayhew & Stuart 1986). In addition, micropalaeontological study of borehole material obtained during site investigations for the Sizewell 'A' and 'B' power stations led to the identification of the ?Baventian, ?Thurnian, ?Antian and Pre-Ludhamian stages beneath the Bramertonian (West & Norton 1974; Funnell 1983). No lithostratigraphical subdivision of these borehole sequences was made.

In this study six rotary cored boreholes (figure 3*b*) were drilled between Aldeburgh and Sizewell. The southernmost two boreholes (X and Y) proved thin Norwich Crag deposits unconformably overlying Coralline Crag, which in turn rested on London Clay at ca. −15 m O.D. The Coralline Crag was not encountered in the northernmost four boreholes (A, B, C and D), which proved a Red Crag and Norwich Crag sequence about 50 m thick resting on London Clay at between −40 and −50 m O.D. The deeper part of the Red/Norwich Crag basin is thus sharply bounded between boreholes Y and A (figure 3*b*).

The two boreholes (Y and A) that straddle the edge of the deep Red/Norwich Crag basin are 540 m apart. Over this distance the vertical difference in the height of the London Clay surface is 25 m. The corresponding difference on the base of the Red/Norwich Crag sequence is 43 m. These height differences prove northwards-inclined palaeoslopes of at least 3° and 5° respectively. Although these steeper segments might imply displacement by Quaternary faulting, available borehole data indicates no movement of the underlying Tertiary and Cretaceous strata. In particular, no Coralline Crag has been found flooring the basin, which would be expected if faulting had occurred. This, together with the observed lack of Quaternary faulting offshore (Balson & Cameron 1985; Balson & Humphreys 1986) leads us to interpret these steeper slopes as erosional.


(*a*) geological map

(*b*) horizontal section

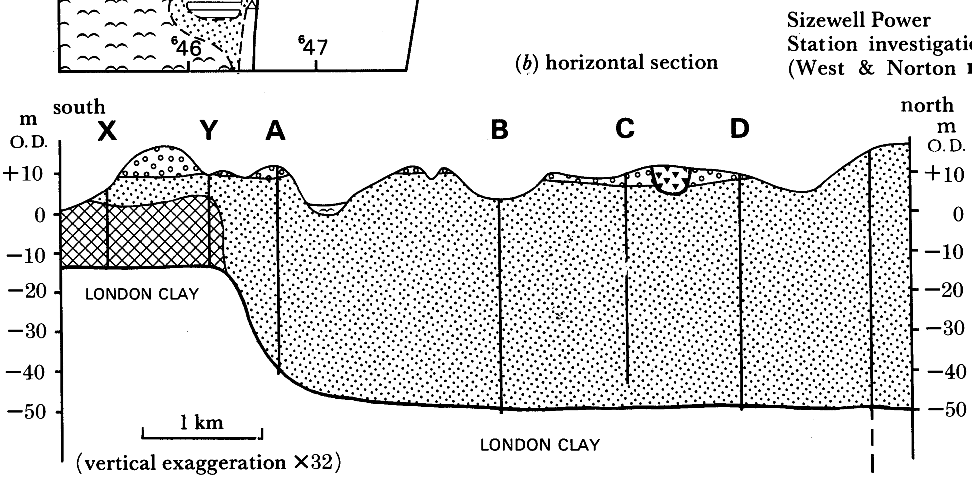


FIGURE 3. (*a*) Geological map of, and (*b*) horizontal section through, the Aldeburgh–Sizewell area, showing the locations of boreholes A [TM 4517 5925], B [TM 4627 6060], C [TM 4705 6128], D [TM 4712 6220], X [TM 4565 5806] and Y [TM 4553 5883].

3. Lithostratigraphy

(*a*) *Methodology*

The core recovered from the boreholes was 71 mm in diameter, and was sliced longitudinally to enable detailed lithological logs to be prepared (figure 4). Granulometric studies were carried out on samples taken every 1–4 m. The samples were graded at $\frac{1}{2}\phi$ intervals, the ϕ scale being the commonly used logarithmic expression of the Udden–Wentworth scale of grain size (see Leeder 1982, pp. 35–39), both with any shell material present, and with the shell material dissolved out using acid. Histograms showing grain size distribution, and plots of mean grain size and standard deviation (parameters after Folk & Ward (1957)) are shown in figure 5.

(*b*) *Description*

Three divisions of the Red/Norwich Crag sequence have been recognized in the cores from boreholes A, B, C and D (figure 3) on the basis of particle size data (figure 4); these divisions were made apparent by the gradings; lithological logging by visual inspection did not adequately demonstrate the subtle, gradual grain-size trends that are present in parts of the sequence. The subdivisions are summarized as follows.

AS-Lith 3: uniform fine and medium well-sorted sands.

AS-Lith 2: fine to medium and coarse, poorly sorted, shelly sands in coarsening upward cycles 5–20 m thick. Two cycles (sub-units) were recognized in each borehole.

AS-Lith 1: medium and coarse, poorly sorted, shelly sands with little or no discernable grain-size trend, interbedded with layers of clay with fine sand laminae.

Detailed descriptions of these units are given below. Grain size parameters, where quoted, refer to shell-free or artificially leached sediment.

(i) *AS-Lith* 1

This unit is a near-horizontal sheet of sediment up to 13 m thick that occurs at the base of the Red/Norwich Crag sequence. It was proved in the northernmost three boreholes (B, C and D) where its upper surface lies at about −35 m O.D.; no core was recovered from the corresponding levels of borehole A.

The unit comprises medium and coarse, greyish-green (unoxidized), shelly sands interbedded with clays that contain numerous fine sand/silt laminae (figure 6, plate 1). In boreholes B and D clays are present in the upper half of the unit, as layers less than 1 m thick separated by beds of coarse, shelly sand. In borehole C, only one substantial (3 m thick) clay layer was proved, overlain by 5 m of coarse shelly sand.

The non-carbonate fraction is dominated by medium and coarse quartz sand with the mean grain size generally between 1.5 and 2ϕ. The sorting is moderate to poor, with a standard deviation of between 0.6 and 1 ϕ. Coloured minerals (largely glauconite) are abundant. The shell material is ubiquitous and comprises comminuted to broken, and rarely subentire, mollusc valves. The shelly sands commonly appear to be structureless. Bedding lamination, where present, takes the form of slight variations in grain size, sorting and shell content of layers 10–40 mm in thickness. These laminations mainly show a low depositional dip, usually of less then 10°.

The clay layers are dark grey, with abundant laminae of fine and very fine sand and silt which are usually shell-free (figure 6). These laminae are irregularly distributed and vary in

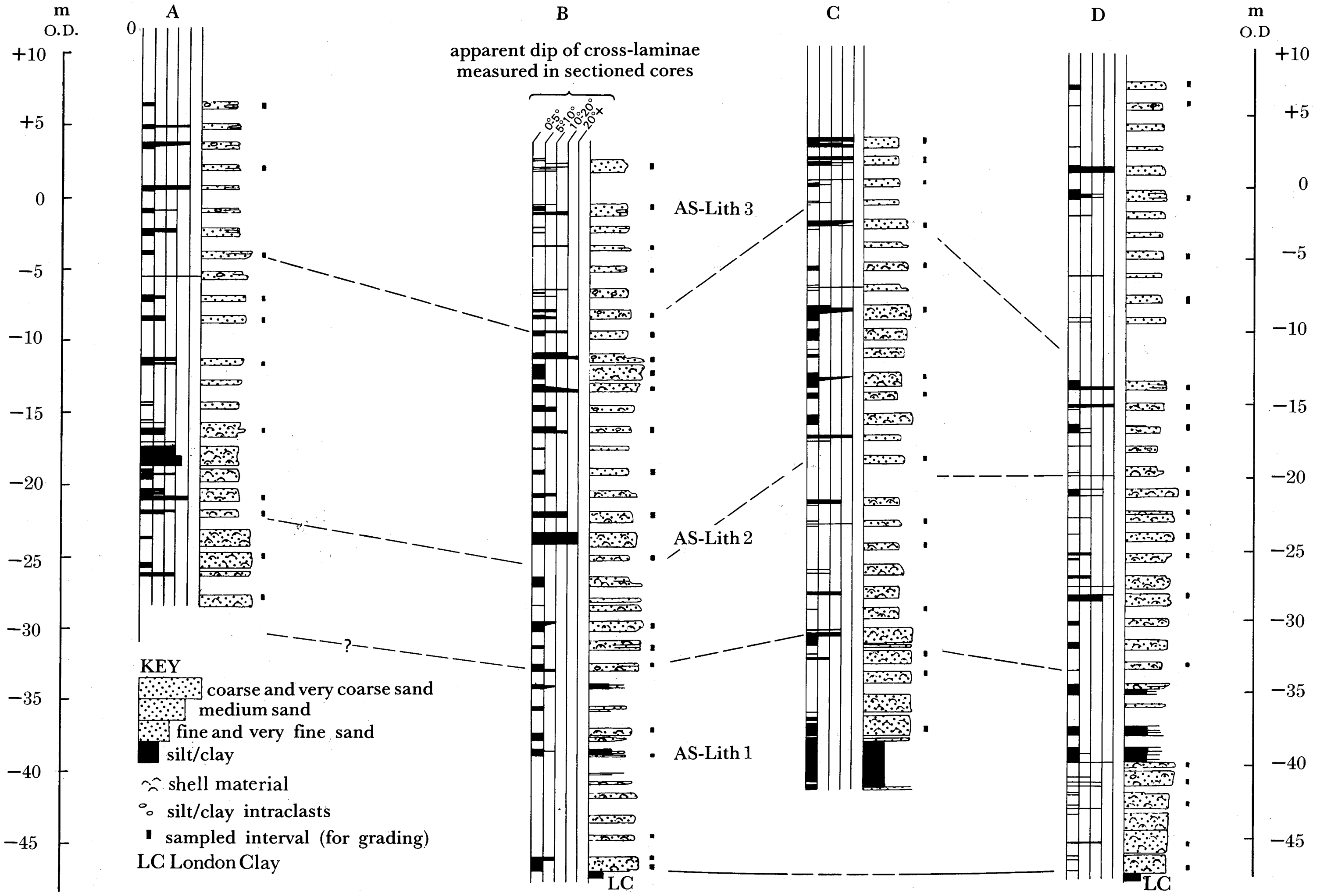


FIGURE 4. Graphic lithological logs of recovered core material from Aldeburgh–Sizewell boreholes A, B, C and D, showing dip of cross-laminae where preserved, and intervals sampled for granulometric analysis (see figure 5).

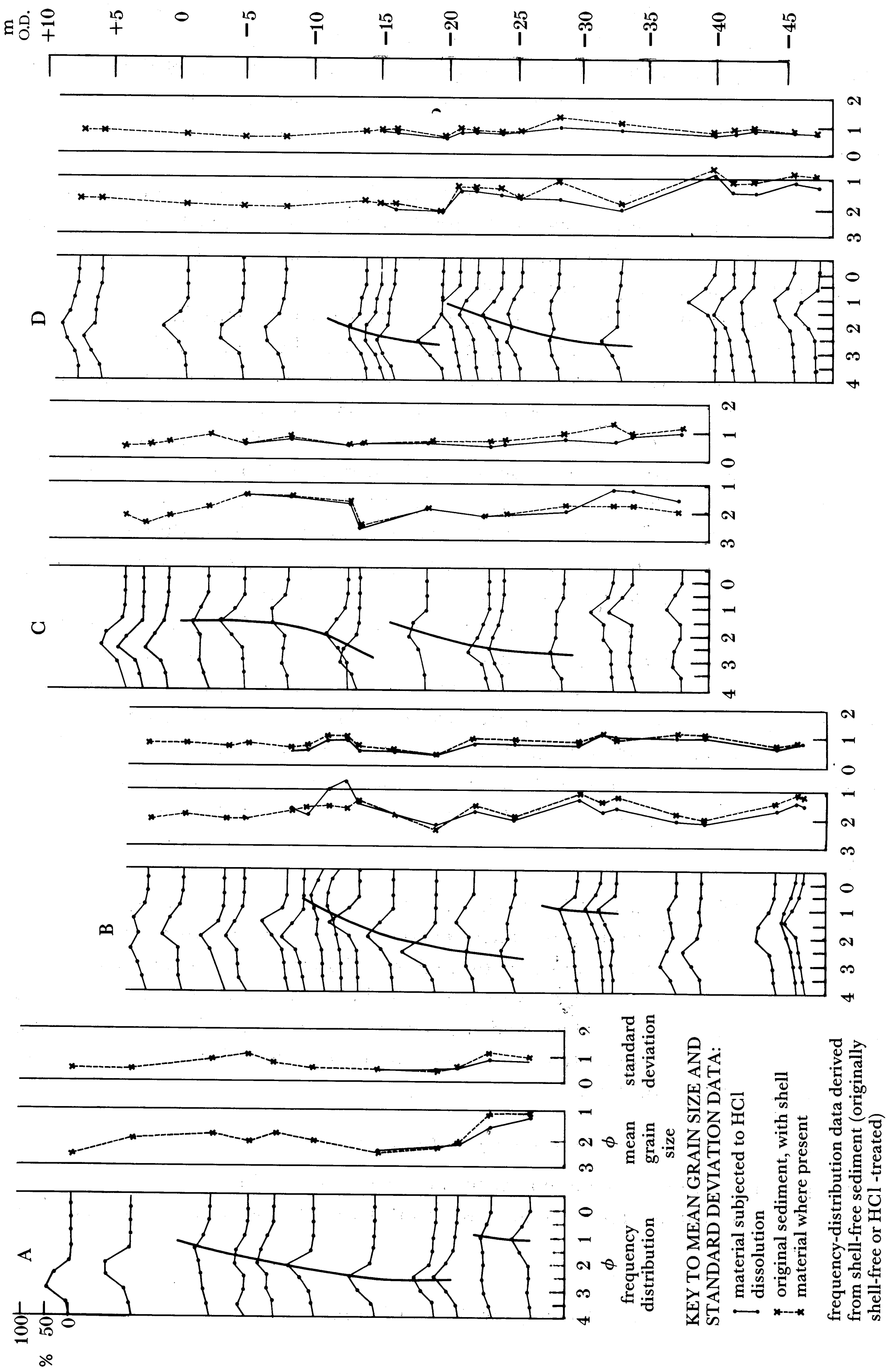


Figure 5. Grain-size distribution data for Aldeburgh–Sizewell boreholes A, B, C and D; coarsening-upward cycles in unit AS-Lith 2 are indicated in frequency-distribution plots.

thickness from barely perceptible grain-thick layers to *ca.* 10 mm. They are commonly ungraded. Contacts with the adjacent clay are generally sharp, with some load structures at the bases of thicker layers. Rarely layers are lenticular (rippled). The dip of these laminae seldom exceeds 5°. Moderate to slight bioturbation is present at a few levels.

(ii) *AS-Lith* 2

This unit is between 20 and 30 m thick, its upper limit lying between −3 and −11 m O.D. It comprises fine to medium, rarely coarse sands and shelly sands with a few laminae and thin beds of silty clay. Above the redox boundary (which occurs at between −20 and −25 m O.D.) the sediments are iron-stained to yellowish brown.

Granulometric analyses showed the presence of coarsening-upward cycles (figure 5) that are between 5 and 15 m thick and typically show a shift of between a half and one ϕ division from base to top. No consistent trends in degree of sorting accompany these shifts in mean grain size. Two coarsening-upwards cycles were recognized in each borehole, allowing a subdivision of this unit (figure 5). Fragmented molluscan material is common within the coarser parts, tending to be less common or absent in the finer layers. Iron-rimmed 'rip-up' clasts of silty clay and rare phosphate pebbles have been observed. A bed of clay with numerous sand/silt laminae is present in borehole D between −16.35 and −16.65 m O.D. In addition laminae of silty clay 1–5 mm thick are present within the sands. These laminae tend to be sharply bounded at top and base and are more common in the finer parts of each cycle.

Sedimentary structures in the sands include laminae and thin beds 10–50 mm thick picked out by differences in grain size, sorting and shell content, together with the clay laminae noted above. Unlike the laminae of shelly sand present in AS-Lith 1, these laminae are commonly sharply defined (figure 7, plate 2) and in places are internally graded, fining upwards. The laminae commonly dip at 20° or more (figure 7). Groups of concordant laminae indicate cross-set thicknesses from 0.1 m to *ca.* 1.0 m. There is no apparent correlation between the position within a coarsening-upward cycle and the observed set thickness or foreset dip.

(iii) *AS-Lith* 3

This unit is up to 18 m thick and forms the uppermost part of the Red/Norwich Crag sequence in all six boreholes. It comprises moderately to well-sorted fine to medium sand. The grain size and sorting are fairly constant throughout (figure 5). Isolated shelly lenses comprising fragmented molluscan valves were observed in boreholes B and D. Iron-oxide-rimmed silty clay laminae 1–5 mm thick and intraclasts are common. The foreset bedding defined by the clay laminae commonly dips at more than 20° (figure 7). Observed cross-set thicknesses are usually less than 0.3 m.

(*c*) *Lithostratigraphical correlation*

At present comparison can be made only with the Aldeburgh–Orford area (Zalasiewicz & Mathers 1985), which lies immediately to the south. In this area the following lithological units have been defined.

Norwich Crag Formation

Chillesford Clay Member: grey silty clays with sand laminae.

Chillesford Sand Member: well-sorted fine to medium sands.

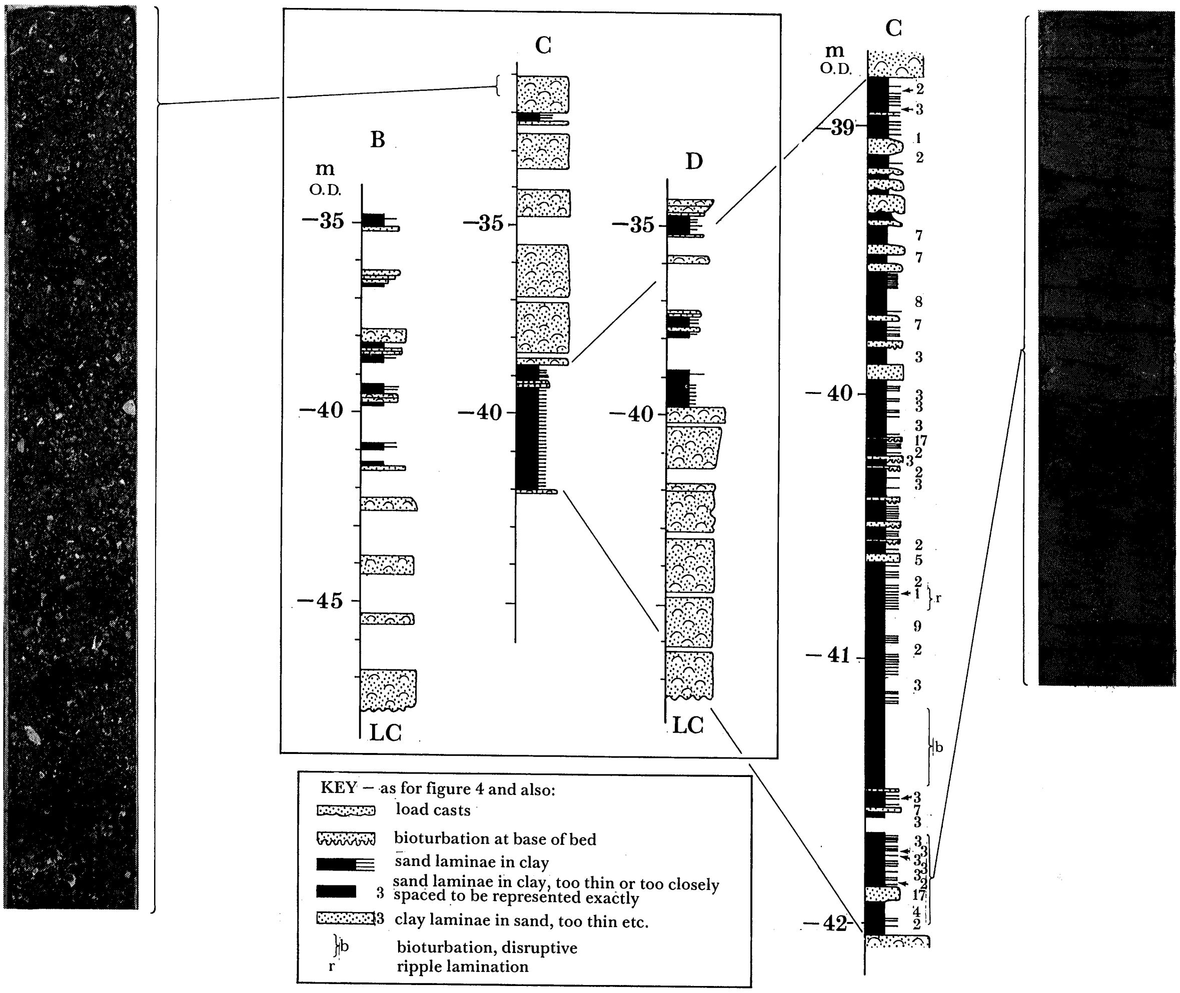


FIGURE 6. Detailed lithology of unit AS-Lith 1.

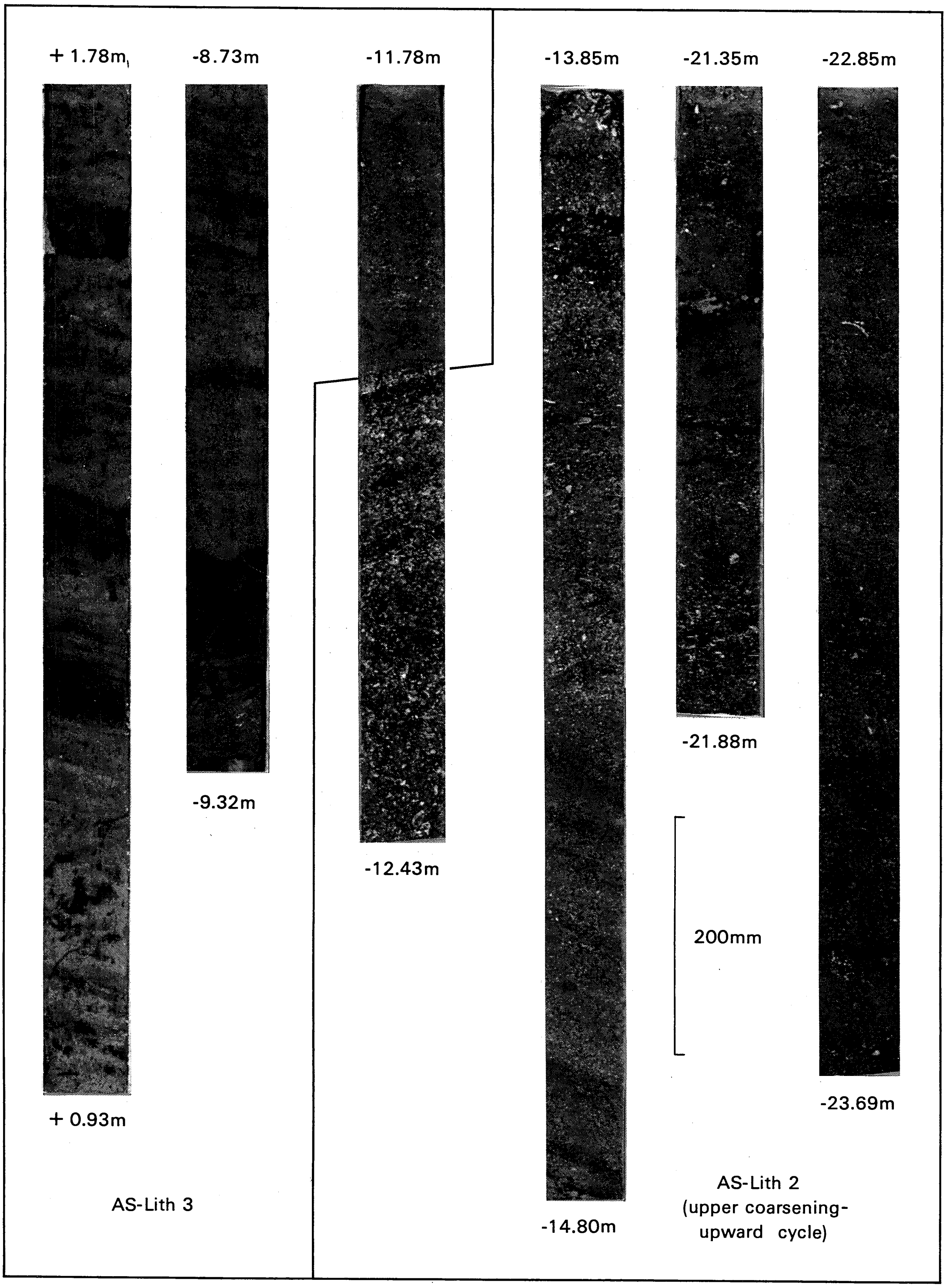


FIGURE 7. Borehole B: photographs of core material of unit AS-Lith 2 illustrating the coarsening-upwards trend, and of unit AS-Lith 3.

Red Crag Formation

Iron-stained medium to coarse shelly sands.

The unit AS-Lith 3 recognized in the present study has been traced by geological mapping by S. J. Mathers into the Chillesford Sand Member of the Norwich Crag Formation. This equivalence is supported by the grain-size parameters. Below the Chillesford Sand, the sequence is more complex than at Aldeburgh–Orford. There, a single unit of medium and coarse shelly sand (the Red Crag Formation) is present, showing a coarsening-upward trend in the type section (figure 6 in Zalasiewicz & Mathers 1985). In the boreholes of the present study, this is replaced by two coarsening-upward cycles in fine to coarse shelly sand (AS-Lith 2) underlain by coarse shelly sand interbedded with clay (AS-Lith 1).

(*d*) *Sedimentological interpretation*

The sedimentary structures in surface exposures of Red/Norwich Crag sediments have been interpreted as tidal in origin (Dixon 1979; Boatman 1976; Zalasiewicz & Mathers 1985). The overall character of the Aldeburgh–Sizewell sediments suggests a similar origin, with accumulation in a tidally dominated shallow-shelf environment, comparable to that of the present-day southern North Sea.

The distinctive feature of unit AS-Lith 1 is the close association of laminated clays/fine sands and coarse shelly sands. This type of sequence is more readily interpreted as intertidal, with the finer sediments representing tidal flats and the coarser sediments representing tidal channels. However, this interpretation is contradicted by the low level of the deposits (−30 to −50 m O.D.) relative to that of the Red Crag Formation in the adjacent Aldeburgh–Orford area (+10 to −10 m O.D. (Zalasiewicz & Mathers 1985)). In the assumed absence of local post-depositional faulting, unit AS-Lith 1 probably accumulated on an irregular surface in a subtidal environment.

The coarsening-upward sequences of unit AS-Lith 2 are open to two interpretations, given a tidal-shelf setting. Firstly, they may reflect changes in the tidal régime along a sand wave field with continued sedimentation. Maximum current speeds vary systematically along tidal-transport paths (Johnson *et al.* 1982) and mean grain size has been shown to show a strong positive correlation with peak tidal-current velocity in this setting (Stride 1970). Alternatively, coarsening-upward cycles may be due to the growth or migration of very-large-scale bedforms, such as tidal sand ridges. The latter interpretation is preferred. Many sand bodies interpreted as storm- or tide-built ridges are characterized by coarsening-upward sequences (Johnson 1978); this has been noted both in ridges forming at the present day (Off 1963) and in sand bodies in the ancient rock record (Evans 1970; Brenner 1978; Berg 1975; Berven 1966; Swift & Rice 1984). A direct comparison with the tidal sand ridges forming at present in the North Sea cannot be made, as these particular structures commonly either have finer sediment at their crests (McCave & Langhorne 1982; Lees 1983) or appear to show no obvious grain-size trends (Houbolt 1982). Nevertheless, we regard the Aldeburgh–Sizewell coarsening-upward sequences as evidence of the growth of large-scale composite bedforms of this type; the alternative – a variable tidal régime – should produce fining-upward patterns as frequently as coarsening-upward patterns.

Unit AS-Lith 3 (the Chillesford Sand Member of the Norwich Crag Formation) is characterized by fine, well-sorted sand with no apparent grain-size trends. Shallow-water indicators have been recorded from surface exposures. These include wave ripple cross-lamination (Dixon 1972) and sublittoral to intertidal macrofossil (West & Norton 1974) and microfossil assemblages (Funnell 1961). This unit may have been laid down as extensive tidal sand flats, similar to those accumulating at the present day in the Wash (Evans 1965). Sedimentary structures present in the core material, such as small- and medium-scale cross-stratification and mud drapes, are consistent with this depositional environment.

4. F

(*a*) *Methodology*

Most recent published accounts of foraminifera from the Red/Norwich Crag are based on microfossils larger than 250 μm. Earlier examples of this work (see, for example, Funnell 1961) used material that had not been separated by carbon tetrachloride flotation; more recent work (see, for example, Funnell 1983) has been based on the floated part of the same size fraction. In the present study, the over 250 μm size fraction was examined to enable comparison with this published work. In addition, all material larger than 75 μm was examined, to give a more complete picture of the assemblages. The microfaunal lists are shown in tables 1–8; separate lists are given for the over 250 μm fraction and for the 75–250 μm fraction.

(*b*) *Biostratigraphy*

The succession can be divided into two major units. The lower of these is designated unit AS-Foram 1 and the upper, unit AS-Foram 2. Each of these units can be subdivided into three sub-units designated AS-Foram 1*A*–*C* and AS-Foram 2*A*–*C* respectively from the oldest to the youngest. In the following descriptions of the preservation of the faunas the specimens that show no evidence of limonitic replacement or staining are referred to as fresh.

(i) *Unit AS-Foram* 1

The microfossils of the majority of samples from this unit have a very fresh appearance with high frequencies of small foraminifers. The unit is also characterized by the presence of *Cassidulina laevigata*, *Elphidium selseyensis* and *E. margaritaceum*. It is recognized in boreholes B (−36.44 to −47.83 m o.d.), C (−31.76 to −41.73 m o.d.) and D (−33.43 to −47.28 m o.d.). The features of the sub-units are as follows:

Sub-unit AS-Foram 1*A*. This is clearly differentiated from the succeeding sub-unit by the presence in the floated fraction of fresh, undamaged specimens, leaving in the residue many large and infilled specimens, including *Ammonia batavus*, *Pararotalia serrata* and *Textularia* sp., clearly reworked from the earlier Red Crag or Coralline Crag. The floated fraction includes *Discorbitura cushmani*, *Elphidium haagensis* and *Faujasina subrotunda*, which have been recorded in both the Coralline Crag and the Red Crag. Also present are small coscinodiscus-type diatoms. The sub-unit is present only at the base of borehole B (−47.83 m o.d.). The presence of *Elphidium haagensis* with *P. serrata*, but unaccompanied by *E.* aff. *subarcticum*, is the important feature of this sub-unit for comparative purposes.

Sub-unit AS-Foram 1*B*. The few foraminifera recovered from either the floated fraction or the resultant residue serve to separate this sub-unit from those above and below. The specimens are

TABLE 1. ALDEBURGH–SIZEWELL BOREHOLE A: PERCENTAGE FREQUENCY OF FORAMINIFERAL SPECIES IN CARBON TETRACHLORIDE FRACTION OVER 250 μm

	2C				*2B*								*2A*						
depth relative to O.D./m	+5.19	+3.61	−2.46	−8.43	−16.03	−16.20	−16.22	−19.40	−19.42	−19.70	−20.89	−21.79	−23.38	−23.91	−24.19	−25.43	−25.85	−26.30	−28.09
no. of specimens	0	0	0	0	60	38	68	64	26	55	31	48	6	22	15	4	4	25	6
Ammonia batavus (Hofker)	.	.	.	.	2	.	3	.	.	+	.	.	.	.	.	.	.	20	.
Bulimina spp.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Cibicides lobatulus (Walker & Jacob)	.	.	.	.	11	8	10	9	19	18	16	8	.	+	.	.	.	.	+
Elphidiella hannai (Cushman & Grant)	.	.	.	.	65	68	59	69	62	69	65	65	85	63	66	100	75	52	83
Elphidium clavata Cushman	.	.	.	.	9	5	7	5	+	+	3	8	.	27	.	.	25	24	.
E. pseudolessoni Dam & Reinhold	.	.	.	.	6	5	9	+	+	+	10	10	.	.	.	.	.	.	.
Guttulina cf. *problema* (d'Orbigny)	.	.	.	.	+	5	3	+	+	.	.	.	30	.	20	.	.	.	.
Monspeliensina pseudotepida (Voorthuysen)	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nonion spp.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Buccella frigida (Cushman)	.	.	.	.	.	+	.	+	.	+	.	.	.	.	.	.	.	.	.
Elphidium aff. *subarcticum* Cushman	.	.	.	.	.	5	9	9	8	4	6	6	.	+	.	.	.	.	.
Oolina spp.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Textularia spp.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Miliolinella subrotunda (Montagu)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	.

Table 2. Aldeburgh–Sizewell borehole A: percentage frequency of foraminiferal species in carbon tetrachloride fraction over 150 μm

	2*C*				2*B*								2*C*						
depth relative to O.D./m	+5.19	+3.61	−2.46	−8.43	−16.03	−16.20	−16.22	−19.40	−19.42	−19.70	−20.89	−21.79	−23.38	−23.91	−24.19	−25.43	−25.85	−26.30	−28.09
no. of specimens	0	0	0	0	169	380	232	161	50	163	213	132	8	29	39	33	65	81	22
Ammonia batavus (Hofker)	.	.	.	.	+	.	+	.	.	+	.	.	.	.	.	.	.	6	.
Bulimina spp.	.	.	.	.	+	+	.	.	.	.	2	.	.	.	.	+	+	12	.
Cassidulina reniforme Norvang	.	.	.	.	+	9	+	2	4	3	+	+	.	+	8	+	6	5	+
Cibicides lobatulus (Walker & Jacob)	.	.	.	.	12	12	+	14	18	16	9	10	.	+	13	18	.	15	+
Elphidiella hannai (Cushman & Grant)	.	.	.	.	49	14	24	42	46	31	25	33	+	51	26	27	10	30	23
Elphidium clavata Cushman	.	.	.	.	18	30	25	15	14	23	32	25	.	28	20	30	48	19	41
E. pseudolessoni Dam & Reinhold	.	.	.	.	11	18	30	13	8	17	15	19	+	.	5	6	10	2	.
Elphidium aff. *subarcticum* Cushman	.	.	.	.	+	9	8	4	4	5	8	5	.	.	.	.	.	.	.
Guttulina cf. *problema* (d'Orbigny)	.	.	.	.	+	+	+	+	+	.	.	.	+	.	8	.	.	.	.
Monspeliensina pseudotepida (Voorthuysen)	.	.	.	.	+	+	.	.	+	+	.	.	.	.	.	.	.	.	.
Nonion spp.	.	.	.	.	+	+	3	6	.	.	+	+	.	+	4	9	+	5	+
Oolina spp.	.	.	.	.	+	.	.	+	.	.	+	.	.	.	.	.	.	+	.
Buccella frigida (Cushman)	.	.	.	.	.	+	.	+	.	+	+	.	.	.	.	.	.	.	.
Cassidulina laevigata d'Orbigny	.	.	.	.	.	4	.	+	.	.	+	2	.	.	.	.	.	.	.
Elphidium excavata (Terquem)	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+
Guttulina lactea (Walker & Jacob)	.	.	.	.	.	+	.	+	+	+	.	+	.	.	.	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	+	8	+	.
Textularia spp.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Elphidium selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+
Fissurina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.
Miliolinella subrotunda (Montagu)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.
Ammonia perlucida (Heron-Allen & Earland)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Rosalina globularis d'Orbigny	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.

CARBON TETRACHLORIDE FRACTION OVER 250 μm

	2*C*				2*B*				2*A*								1*C*							1*B*			1*A*
depth relative to O.D./m	−3.04	−9.01	−11.90	−13.45	−14.57	−15.49	−16.95	−21.46	−24.53	−24.68	−24.97	−24.98	−29.08	−29.45	−31.00	−32.07	−36.44	−36.46	−38.17	−38.43	−39.65	−39.68	−41.54	−45.47	−45.59	−47.28	−47.83
no. of specimens	0	0	54	0	16	126	187	7	0	0	5	6	4	9	0	4	81	37	259	37	43	222	75	0	2	7	58
Bulimia spp.	.	.	6	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Cassidulina reniforme Norvang	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cibicides lobatulus (Walker & Jacob)	.	.	11	.	19	15	9	.	.	.	17	50	25	22	.	.	19	22	18	41	26	60	12	.	.	14	17
Elphidiella hannai (Cushman & Grant)	.	.	59	.	56	66	68	71	.	.	83	33	75	56	.	25	63	59	65	24	51	9	60	.	+	.	40
Elphidium excavata (Terquem)	.	.	13	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
E. pseudolessoni Dam & Reinhold	.	.	+	.	.	4	6	.	.	.	.	.	.	.	.	.	+	.	+	+	.	+	.	.	.	.	.
Guttulina cf. *problema* (d'Orbigny)	.	.	+	.	25	.	+	.	.	.	.	.	.	.	.	50	.	.	.	.	.	.	8	.	s	29	.
Ammonia batavus (Hofker)	.	.	.	.	.	5	5	+	.	.	.	.	.	.	.	.	9	+	6	+	.	.	+	.	.	.	+
Cancris auricula (Fichtel & Moll)	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Elphidium clavata Cushman	.	.	.	.	.	+	3	29	.	.	.	.	.	22	.	.	.	+	+	.	.	.	.	.	.	.	.
E. aff. subarcticum Cushman	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.
Rosalina globularis d'Orbigny	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Textularia spp.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.
Nonion spp.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25	+	.	3	+	.	.	.	.	.	.	.
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	+	.	.	.	.	+
Buccella frigida (Cushman)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	7	.	s	.	+
Elphidium margaritaceum Cushman	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	18	4	.	.	.	.
E. selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	7	5	+	.	.	.	.
Oolina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	4	.	.	.	+
polymorphinid	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.
Fissurina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
planktonic	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.
Globulina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Florilus boueanus (d'Orbigny)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	s	.	+
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	s	.	.
Pararotalia serrata (Dam & Reinhold)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	ss	14	9
Textularia decrescens Cushman & Dam	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	s	.	.
T. sagittula Defrance	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	s	.	.
Pseudopolymorphina variata fischeri (Terquem)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	29	.
Pyrgo williamsoni (Silvestri)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	.
Cassidulina laevigata d'Orbigny	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Discorbitura cushmani Margarel	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+

TABLE 4. ALDEBURGH–SIZEWELL BOREHOLE B: PERCENTAGE FREQUENCY OF FORAMINIFERAL SPECIES IN CARBON TETRACHLORIDE FRACTION OVER 150 μm

	2*C*				2*B*				2*A*								1*C*							1*B*			1*A*
depth relative to O.D./m	−3.04	−9.01	−11.90	−13.45	−14.57	−15.49	−16.95	−21.46	−24.53	−24.68	−24.97	−24.98	−29.08	−29.45	−31.00	−32.07	−36.44	−36.46	−38.17	−38.43	−39.65	−39.68	−41.54	−45.47	−45.59	−47.28	−47.83
no. of specimens	0	0	54	0	73	292	527	36	5	5	23	22	7	43	4	12	713	529	695	1979	503	4638	287	0	4	25	217
Bulimina spp.	.	.	6	.	.	+	.	+	.	+	.	.	.	.	+	.	+	5	9	+	+	.	.	.	.	.	.
Cassidulina reniforme Norvang	.	.	+	.	.	3	5	+	.	.	+	.	.	12	.	.	.	.	.	.	.	.	.	.	.	.	.
Cibicides lobatulus (Walker & Jacob)	.	.	11	.	8	12	9	8	.	+	13	32	+	23	.	+	11	17	17	25	18	19	18	.	.	+	17
Elphidiella hannai (Cushman & Grant)	.	.	59	.	22	32	32	28	+	+	43	18	+	14	+	+	25	14	38	3	12	3	24	.	+	16	19
Elphidium excavata (Terquem)	.	.	13	.	+	+	+	.	.	.	+	+	.	+	.	.	+	+	+	.	.	.	.	.	.	.	.
E. pseudolessoni Dam & Reinhold	.	.	+	.	+	9	13	19	+	.	+	.	.	9	.	.	+	+	2	3	.	+	.	.	.	.	.
Guttulina cf. *problema* (d'Orbigny)	.	.	+	.	5	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	2	.	5	+	.
Cassidulina laevigata d'Orbigny	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	9	15	8	9	17	11	7	.	.	12	6
Elphidium clavata Cushman	.	.	.	.	52	18	22	25	+	+	26	14	.	30	.	+	18	17	.	.	.	.	.	.	.	.	.
Nonion spp.	.	.	.	.	7	.	.	+	+	.	.	+	.	+	+	.	+	+	+	.	+	.	+	.	.	.	+
Quinqueloculina spp.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	+	.	+	+	.	.	.	.	.	5	.
Ammonia batavus (Hofker)	.	.	.	.	.	3	3	+	.	.	.	.	.	.	.	.	2	+	3	+	+	.	+	.	.	+	2
Buccella frigida (Cushman)	.	.	.	.	.	3	.	.	.	.	.	.	+	+	.	.	.	+	+	.	4	+	4	.	5	+	6
Cancris auricula (Fichtel & Moll)	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Elphidium aff. *subarcticum* Cushman	.	.	.	.	.	9	5	+	:	.	.	18	.	.	.	.	+	.	+	+	.	+	.	.	.	.	.
Fissurina spp.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	f	.	.	.	+	f	.	.	+	.	+
Monspeliensina pseudotepida (Voorthuysen)	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rosalina globularis d'Orbigny	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Textularia spp.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	.	+
planktonic	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	f	+	.	+	4	7	+	.	.	+	+
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	+	+	6	4	3	3	.	.	.	3
Elphidium selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	15	12	15	26	24	43	30	.	.	20	17
Bolivina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	f	.	.	.	f	.	.	.	.	.
Elphidium margaritaceum Cushman	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	7	2	9	7	8	7	.	.	.	+
Fursenkoina schreibersiana (Czjzek)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	ff	f	.	.	.	.	.	.	.	.	.
Miliolinella subrotunda (Montagu)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	3	+	.	.	.	.	.	.	.	.
Pararotalia serrata (Dam & Reinhold)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	ss	ss	5
Trifarina angulosa (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	.	.	.	.	+	+	.	.	.	+
Elphidium haagensis Voorthuysen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	.	8
Oolina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	+	.	+	.	+
Globulina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.
polymorphinid	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Nonionella turgida (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	.	.	.	.	.
Florilus boueanus (d'Orbigny)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	s	.	+
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	s	.	+
Texturalia decrescens Cushman & Dam	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	s	.	+
T. sagittula Defrance	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	s	.	+
Pseudopolymorphina variata fischeri (Terquem)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Pyrgo williamsoni (Silvestri)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Discorbitura cushmani Margarel	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Faujasina subrotunda Dam & Reinhold	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Silicosigmoilina sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+

TABLE 5. ALDEBURGH–SIZEWELL BOREHOLE C: PERCENTAGE FREQUENCY OF FORAMINIFERAL SPECIES IN CARBON TETRACHLORIDE FRACTION OVER 250 μm

	2*C*			2*B*						1*C*											
depth relative to O.D./m	+2.96	−2.80	−9.29	−11.91	−14.86	−19.41	−23.91	−26.76	−28.58	−31.76	−31.96	−33.56	−36.26	−38.42	−38.91	−39.66	−39.91	−40.33	−40.66	−41.41	−41.73
no. of specimens	0	0	8	34	480	18	102	45	146	19	18	12	40	69	20	3	371	9	4	22	82
Cibicides lobatulus (Walker & Jacob)	.	.	25	15	10	+	14	13	15	16	22	16	13	14	25	66	39	22	25	23	54
Elphidiella hannai (Cushman & Grant)	.	.	75	53	67	78	55	75	55	84	72	42	83	74	25	.	40	33	50	36	12
Ammonia batavus (Hofker)	.	.	.	+	+	.	.	.	+	.	.	+	+	.	+	.	.	.	.	.	.
Elphidium pseudolessoni Dam & Reinhold	.	.	.	9	12	+	5	.	11	.	.	.	.	4	.	.	+	.	.	.	.
E. aff. subarcticum Cushman	.	.	.	9	4		13	+	7	.	.	.	.	.	.	.	.	.	.	.	.
Guttulina cf. *problema* (d'Orbigny)	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Miliolinella subrotunda (Montagu)	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
polymorphinid	.	.	.	+	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.
Bulimina spp.	.	.	.	.	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	+
Elphidium clavata Cushman	.	.	.		5	+	12		7	.	.	.	.	.	.	.	.	.	.	.	.
Globulina spp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	+	.	+	.	+	+	.	.	.	.	.	.	.	.	.
Elphidium excavata (Terquem)	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.
Pseudopolymorphina var. *P. fischeri* (Terquem)	.	.	.	.	.	.	.	.	+	.	.	16	.	.	.	.	.	.	.	.	.
Elphidium margaritaceum Cushman	.	.	.	.	.	.	.	.	.	.	.	+	.	.	15	33	6	33	.	+	16
E. selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20	.	6	11	25	14	11
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	+
planktonic	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	+	4
Buccella frigida (Cushman)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.
Cassidulina laevigata d'Orbigny	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+
Faujasina subrotunda Dam & Reinhold	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Fissurina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Guttulina lactea (Walker & Jacob)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Nonionella turgida (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Oolina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Ammonia perlucida (Heron-Allen & Earland)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.

TABLE 6. ALDEBURGH–SIZEWELL BOREHOLE C: PERCENTAGE FREQUENCY OF FORAMINIFERAL SPECIES IN CARBON TETRACHLORIDE FRACTION OVER 250 μm

	2*C*			2*B*						1*C*											
depth relative to O.D./m	+2.96	−2.80	−9.29	−11.91	−14.86	−19.41	−23.91	−26.76	−28.58	−31.76	−31.96	−33.56	−36.26	−38.42	−38.91	−39.66	−39.91	−40.33	−40.66	−41.41	−41.73
no. of specimens	0	0	14	47	1688	49	167	81	662	329	31	119	74	311	2724	587	4499	841	820	1246	4978
Cibicides lobatulus (Walker & Jacob)	.	.	21	17	12	+	12	16	14	16	13	11	14	18	24	26	21	20	14	25	21
Elphidiella hannai (Cushman & Grant)	.	.	50	53	27	45	40	54	25	13	61	21	58	31	8	3	13	4	7	8	3
Elphidium clavata Cushman	.	.	29	+	34	51	23	12	25	16	.	20	6	+	.	.	.	.	.	.	.
Ammonia batavus (Hofker)	.	.	.	+	+	.	.	.	+	.	.	+	+	+	+	.	+	.	.	.	.
Bulimina spp.	.	.	.	+	+	+	+	.	+	9	+	7	+	12	+	+	+	+	+	.	+
Elphidium pseudolessoni Dam & Reinhold	.	.	.	6	14	+	5	7	21	7	.	+	.	3	.	.	+	.	.	+	+
E. aff. subarcticum Cushman	.	.	.	6	5	.	13	4	6	+	+	.	.	.	.	+	.	.	2	+	+
Guttulina cf. *problema* (d'Orbigny)	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
polymorphinid	.	.	.	+	.	.	.	.	+	.	.	.	.	+	.	.	.	+	.	.	.
Miliolinella subrotunda (Montagu)	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Cassidulina laevigata d'Orbigny	.	.	.	.	+	.	+	.	+	19	+	22	5	10	11	10	10	8	10	11	14
C. reniforme Norvang	.	.	.	.	+	+	2	+	+	.	.	+	+	3	.	.	.	.	.	.	.
Guttulina lactea (Walker & Jacob)	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.
Nonion spp.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	+	+	.	+	.	.
Oolina spp.	.	.	.	.	+	+	.	.	.	+	.	+	.	+	.	.	+	+	+	.	+
planktonic	.	.	.	.	+	.	.	.	+	+	.	.	.	.	5	4	+	4	6	6	3
Elphidium excavata (Terquem)	.	.	.	.	.	+	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.
Fissurina spp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	+	+	+	.	f	+
Globulina spp.	.	.	.	.	.	+	+	.	.	+	.	.	.	.	.	.	+	.	.	+	.
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	+	.	+	.	+	+	.	.	.	.	.	.	.	.	+
Buccella frigida (Cushman)	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	3	+	+	+	+
Bolivina spp.	.	.	.	.	.	.	.	.	+	+	.	f	.	.	f	f	f	.	f	f	f
Pseudopolymorphina variata fischeri (Terquem)	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.
Elphidium selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	15	10	11	6	15	31	38	31	45	41	32	34
Fursenkoina schreibersiana (Czjzek)	.	.	.	.	.	.	.	.	.	ff	.	f	.	.	.	.	.	.	.	.	.
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	+	+	f	.	+	5	f	+	4	+	3	5
Elphidium margaritaceum Cushman	.	.	.	.	.	.	.	.	.	.	.	4	+	+	8	9	8	10	10	6	9
Ammonia perlucida (Heron-Allen & Earland)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	+	+
Nonionella turgida (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	f	+	+
Pararotalia serrata (Dam & Reinhold)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Elphidium haagensis Voorthuysen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.
Faujasina subrotunda Dam & Reinhold	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Textularia sagittula Defrance	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Trifarina angulosa (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	f
T. bradyi Cushman	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	f	.	f	f
Cancris auricula (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Siphotextularia sculpturata (Cushman & Dam)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+

TABLE 6. ALDEBURGH–SIZEWELL BOREHOLE C: PERCENTAGE FREQUENCY OF FORAMINIFERAL SPECIES IN CARBON TETRACHLORIDE FRACTION OVER 250 μm

	2*C*			2*B*						1*C*											
depth relative to O.D./m	+2.96	−2.80	−9.29	−11.91	−14.86	−19.41	−23.91	−26.76	−28.58	−31.76	−31.96	−33.56	−36.26	−38.42	−38.91	−39.66	−39.91	−40.33	−40.66	−41.41	−41.73
no. of specimens	0	0	14	47	1688	49	167	81	662	329	31	119	74	311	2724	587	4499	841	820	1246	4978
Cibicides lobatulus (Walker & Jacob)	.	.	21	17	12	+	12	16	14	16	13	11	14	18	24	26	21	20	14	25	21
Elphidiella hannai (Cushman & Grant)	.	.	50	53	27	45	40	54	25	13	61	21	58	31	8	3	13	4	7	8	3
Elphidium clavata Cushman	.	.	29	+	34	51	23	12	25	16	.	20	6	+	.	.	.	.	.	.	.
Ammonia batavus (Hofker)	.	.	.	+	+	.	.	.	+	.	.	+	+	+	+	.	+	.	.	.	.
Bulimina spp.	.	.	.	+	+	+	+	.	+	9	+	7	+	12	+	+	+	+	+	.	+
Elphidium pseudolessoni Dam & Reinhold	.	.	.	6	14	+	5	7	21	7	.	+	.	3	.	.	+	.	.	+	+
E. aff. subarcticum Cushman	.	.	.	6	5	.	13	4	6	+	+	.	.	.	.	+	.	.	2	+	+
Guttulina cf. *problema* (d'Orbigny)	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
polymorphinid	.	.	.	+	.	.	.	.	+	.	.	.	.	+	.	.	.	+	.	.	.
Miliolinella subrotunda (Montagu)	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Cassidulina laevigata d'Orbigny	.	.	.	.	+	.	+	.	+	19	+	22	5	10	11	10	10	8	10	11	14
C. reniforme Norvang	.	.	.	.	+	+	2	+	+	.	.	+	+	3	.	.	.	.	.	.	.
Guttulina lactea (Walker & Jacob)	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.
Nonion spp.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	.	+	+	.	+	.	.
Oolina spp.	.	.	.	.	+	+	.	.	.	+	.	+	.	+	.	.	+	+	+	.	+
planktonic	.	.	.	.	+	.	.	.	+	+	.	.	.	.	5	4	+	4	6	6	3
Elphidium excavata (Terquem)	.	.	.	.	.	+	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.
Fissurina spp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	+	+	+	.	f	+
Globulina spp.	.	.	.	.	.	+	+	.	.	+	.	.	.	.	.	.	+	.	.	+	.
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	+	.	+	.	+	+	.	.	.	.	.	.	.	.	+
Buccella frigida (Cushman)	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	3	+	+	+	+
Bolivina spp.	.	.	.	.	.	.	.	.	+	+	.	f	.	.	f	f	f	.	f	f	f
Pseudopolymorphina variata fischeri (Terquem)	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.
Elphidium selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	15	10	11	6	15	31	38	31	45	41	32	34
Fursenkoina schreibersiana (Czjzek)	.	.	.	.	.	.	.	.	.	ff	.	f	.	.	.	.	.	.	.	.	.
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	+	+	f	.	+	5	f	+	4	+	3	5
Elphidium margaritaceum Cushman	.	.	.	.	.	.	.	.	.	.	.	4	+	+	8	9	8	10	10	6	9
Ammonia perlucida (Heron-Allen & Earland)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	+	+
Nonionella turgida (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	f	+	+
Pararotalia serrata (Dam & Reinhold)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Elphidium haagensis Voorthuysen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.
Faujasina subrotunda Dam & Reinhold	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Textularia sagittula Defrance	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Trifarina angulosa (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	f
T. bradyi Cushman	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	f	.	f	f
Cancris auricula (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Siphotextularia sculpturata (Cushman & Dam)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+

Buccella frigida (Cushman)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	4	.	.	+	.	.	.
Elphidium selseyensis (H-A. & E.)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	7	3	10	7	.	.	29	+	.	.
Globulina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	+	.	+	10	.	.	.
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	2	.	.	.	.	.	.
Cassidulina laevigata d'Orbigny	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	.	.
Elphidium haagensis Voorthuysen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.
Cancris auricula (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Faujasina subrotunda Dam & Reinhold	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Textularia spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
planktonic	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+		.	.	.	.	.	.
Planorbulina distoma Terquem	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Fissurina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Florilus boueanus (d'Orbigny)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.
Pararotalia serrata (Dam & Reinhold)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Pseudopolymorphina var. *P. fischeri* (Terquem)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Pyrgo williamsoni (Silvestri)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Textularia decrescens Cushman & Dam	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
polymorphinid	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.

TABLE 8. ALDEBURGH–SIZEWELL BOREHOLE D: PERCENTAGE FREQUENCY OF FORAMINIFERAL SPECIES IN CARBON TETRACHLORIDE FRACTION OVER 150 μm

	2*C*				2*B*								2*A*			1*C*									1*B*		
depth relative to O.D./m	+5.90	+1.30	+1.26	−5.97	−13.51	−16.55	−16.82	−21.15	−22.59	−24.31	−26.98	−27.54	−28.59	−30.16	−31.83	−33.43	−34.87	−36.48	−38.03	−39.17	−39.76	−40.07	−40.70	−42.23	−43.66	−45.43	−47.28
no. of specimens	40	7	0	0	90	1218	318	133	80	33	86	42	7	0	68	258	2035	6270	11524	6706	2445	18	210	160	7	0	0
Elphidiella hannai (Cushman & Grant)	90	+	f	.	64	18	43	37	29	24	30	36	+	.	47	32	7	9	7	3	11	+	8	17	.	.	.
Elphidium clavata Cushman	+	.	.	.	11	32	22	22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
E. margaritaceum Cushman	+	+	.	.	.	.	.	.	.	.	+	+	.	.	+	+	10	7	9	15	18	.	6	4	.	.	.
E. pseudolessoni Dam & Reinhold	+	.	.	.	3	32	17	19	14	15	10	5	.	.	9	+	.	+	.	.	+	.	.	.	.	.	.
Nonion spp.	+	.	.	.	.	4	2	+	+	+	+	+	.	.	.	.	+	.	.	+	+	.	.	.	.	.	.
Cassidulina laevigata d'Orbigny	.	+	.	.	.	.	+	.	.	.	+	.	.	.	.	3	12	15	8	9	.	+	9	6	.	.	.
Cibicides lobatulus (Walker & Jacob)	.	+	f	.	13	4	8	12	5	15	8	12	+	.	+	35	22	25	28	21	24	+	22	14	.	.	.
Elphidium selseyensis (H-A. & E.)	.	+	.	.	.	.	.	.	34	33	33	33	+	.	28	7	31	31	38	37	33	+	46	29	+	.	.
Ammonia batavus (Hofker)	.	.	.	.	+	+	2	+	+	.	.	.	.	.	4	8	.	+	.	.	+	.	.	+	.	.	.
Bulimina spp.	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	3	f	+	+	f	+	.	+	+	.	.	.
Elphidium aff. subarcticum Cushman	.	.	.	.	4	+	2	2	5	.	9	.	.	.	+	.	.	.	+	3	+	.	.	+	.	.	.
Guttulina cf. *problema* (d'Orbigny)	.	.	.	.	+	+	.	.	+	+	.	7	+	.	.	.	.	.	+	.	+	.	.	.	+	.	.
Buccella frigida (Cushman)	.	.	.	.	.	+	+	+	+	.	+	.	.	.	+	+	.	3	+	.	2	.	.	+	.	.	.
Cassidulina reniforme Norvang	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Elphidium excavata (Terquem)	.	.	.	.	.	+	.	.	.	+	+	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.
Fissurina spp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	+	.	+	.	+	.	.	.	.	.	.
Globulina spp.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.
Guttulina lactea (Walker & Jacob)	.	.	.	.	.	+	+	+	.	.	+	.	.	.	.	+	.	+	.	.	+	.	.	.	.	.	.
Textularia spp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.
planktonic	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	+	3	+	2	4	+	.	+	+	.	.	.

Miliolinella subrotunda (Montagu)	.	.	.	.	.	.	.	.	6	+	+	.	.	.	+	+	.	.	.	.	.	.	.	+	.	.	.
Textularia suttonensis Lalicker	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	2	6	2	3	3	5	+	8	+	.	.	.
Trifarina angulosa (Williamson)	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Bolivina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	f	.	f	f	f	.	.	.	.	.	.
Fursenkoina schreibersiana (Czjzek)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	ff	.	.	.	.	.	.	.	.	.	.	.
Nonionella turgida (Williamson)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	.	f	.	.	.	.	+	.	.	.	.
Quinqueloculina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	+	.	+	+	.	.	.
Oolina spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	+	+	.	.	.	.	+	.	.	.
Elphidium haagensis Voorthuysen	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	+	.	.	.
Cancris auricula (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Discorbitura cushmani Margarel	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.
Faujasina subrotunda Dam & Reinhold	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Monspeliensina pseudotepida (Voorthuysen)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.
Pararotalia serrata (Dam & Reinhold)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	s	.	+	.	.	.	.	.	.
Planorbulina distoma Terquem	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Silicosigmoilina sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Trifarina bradyi Cushman	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	+	f	.	.	.	.	.	.	.
Buliminella elegantissima Cushman	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	f	.	.	.	.	.	.	.
Eponides repandus (Fichtel & Moll)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Florilus boueanus (d'Orbigny)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.
Rosalina globularis d'Orbigny	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.
Pseudopolymorphina var. *P. fischeri* (Terquem)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Pyrgo williamsoni (Silvestri)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Textularia decrescens Cushman & Dam	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
polymorphinid	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.

all rolled, limonitized and damaged, and are not indigenous. Species identified include *P. serrata*, *Textularia decrescens* and various miliolids indicating reworking from earlier Red Crag or Coralline Crag. The sub-unit is present in boreholes B (−45.47 to −47.28 m O.D.) and D (−43.66 to −47.28 m O.D.).

Sub-unit AS-Foram 1C. This unit is recognized by the large number of specimens recovered from each sample, the fresh appearance of the foraminifera, the high proportion of small specimens and the scarcity of heavy specimens in the sink fractions. Many species do not range above the top of this sub-unit. A few, including *Cassidulina laevigata* and *E. margaritaceum*, do occur higher, but these have a limonitic preservation mode and are regarded as reworked. In this sub-unit the *E. excavata* species group, which ranges throughout the sequence, is dominated by *E. selseyensis* with subsidary *E. excavata* and rare *E. clavata*. *Textularia suttonensis* and *Noniella turgida* are present towards the top and additionally a large number of *Fursenkoina schreibersiana*, a very slender species seen only in the fine fraction, are present at the top of this sub-unit. The sub-unit is recognized in boreholes B (−36.44 to −41.54 m O.D.), C (−31.76 to −41.73 m O.D.) and D (−33.43 to −42.23 m O.D.).

The appearance of *E.* aff. *subarcticum* in association with reduced numbers of *E. haagensis*, *P. serrata* and planktonic specimens is the feature of this sub-unit. In addition there is a distinctive association of *Textularia suttonensis* and *Noniella turgida* towards the top of the sub-unit that has been reported in other localities.

(ii) *Unit AS-Foram 2*

This unit is characterized by the limonitic preservation of the microfossils and the relative scarcity of small specimens. Species that dominate the unit are *Cassidulina reniforme*, *E. clavata* and *E. pseudolessoni*. The unit is present in boreholes A (+5.19 to −28.09 m O.D.), B (−3.04 to −32.07 m O.D.), C (+2.96 to −28.58 m O.D.) and D (+5.90 to −31.83 m O.D.). The features of the sub-units are as follows.

Sub-unit AS-Foram 2A. The small amount of specimens recovered characterize this sub-unit. Some of the foraminifera appear to be reworked from unit AS-Foram 1. It is present in boreholes A (−23.38 to −28.09 m O.D.), B (−24.53 to −32.07 m O.D.) and D (−28.59 to −31.83 m O.D.).

Sub-unit AS-Foram 2B. A marked increase in the number of foraminifera and species sharply delineates the base of this sub-unit; both the total number and specific variation decreases towards the top. It is present in boreholes A (−16.03 to −21.79 m O.D.), B (−14.57 to −21.46 m O.D.), C (−11.91 to −28.58 m O.D.) and D (−13.51 to −22.54 m O.D.). The dominance of *Elphidiella hannai* with frequent *E. pseudolessoni*, *E. clavata* and *Ammonia batavus* is the important feature of this sub-unit.

Sub-unit AS-Foram 2C. This sub-unit is barren except for sporadic horizons that contain very badly eroded specimens. Its base may represent the limit of strong leaching and the destruction of calcareous microfossils. It is present in boreholes A (+5.19 to −8.43 m O.D.), B (−3.04 to −13.45 m O.D.), C (+2.94 to −9.29 m O.D.) and D (+5.90 to −5.97 m O.D.).

(c) *Interpretation of unit AS-Foram* 1

This unit is assigned to the Pre-Ludhamian Stage, the type-section of which is the Stradbroke borehole (Beck *et al.* 1972; figure 1). The late Pre-Ludhamian was recognized by the occurrence of *Elphidium frigidum* (*Elphidium* aff. *subarcticum* of this paper) in assemblages that had not been subjected to flotation separation (Beck *et al.* 1972; Funnell & West 1977). The older fauna was compared with that of the Walton Crag and the younger with that of the Butleyan. Later work (Funnell & Booth 1983) indicated that *E. frigidum* was absent from assemblages based on floated residues throughout the Pre-Ludhamian. In the Sizewell Power Station boreholes (Funnell 1983) the base of the Ludhamian was placed at the lowest record of *E. frigidum*. It is apparent that the age of the lowest record of *E. frigidum* from reported assemblages of these two boreholes differs depending on the preparation methods used.

In the Aldeburgh–Sizewell core material *E.* aff. *subarcticum* is present both in the floated and residual fractions of sub-unit AS-Foram 1*C*. If comparison is made with the Stradbroke borehole, following the evidence of this species, the lower sub-unit is early Pre-Ludhamian (Waltonian) and the upper sub-unit is late Pre-Ludhamian (Butleyan).

A thin horizon characterized by the association of *T. suttonensis* and *N. turgida* is important for correlation. This association was first reported in the Ludham borehole (Funnell 1961) and there placed at the top of the Ludham Crag, horizon Lf3, which was later regarded as late Ludhamian (Funnell & West 1977). Beck *et al.* (1972) assigned a similar association from the Stradbroke borehole to the later part of the Pre-Ludhamian and basal Ludhamian, although noting that, in the Ludham borehole, a younger age had been proposed for the *T. suttonensis* and *N. turgida* level. These conclusions were restated in 1977 (Funnell & West 1977) and the two species were reported from floated residues from the Stradbroke borehole towards the top of the Pre-Ludhamian (Funnell & Booth 1983), but not from the Sizewell Power Station boreholes (Funnell 1983). However, the two species under discussion are small and evidence from the present study is that in fine-grained sediments the associated foraminifera are small individuals recovered only from the less than 250 μm fraction. This fraction was not examined in the case of the Sizewell Power Station boreholes (Funnell 1983). The *T. suttonensis* and *N. turgida* association has been placed, subsequent to the Ludham borehole assignment, consistently at the boundary of the Pre-Ludhamian and the Ludhamian.

Examination of the smaller-sized foraminifera from Aldeburgh–Sizewell samples has shown for the first time that large numbers of *F. schreibersiana*, a slender species, occur with *T. suttonensis* and *N. turgida*.

Planktonic foraminifera occur in the Butleyan of the Stradbroke borehole. In the Aldeburgh–Sizewell material they are confined to AS-Foram 1*C*.

In the Aldeburgh–Sizewell sequences, the position of *T. suttonensis* and *N. turgida* in relation to both the range of *E.* aff. *subarcticum* and to the presence of planktonic specimens agrees with the view that this horizon lies at the boundary of the Pre-Ludhamian and Ludhamian.

The problem remains to explain the presence of the association of *T. suttonensis* and *N. turgida* in the late Ludhamian of the Ludham borehole. If all records of these species are correlated then the Ludham Crag must be considered as a facies equivalent of the Butleyan. On the other hand, if a second horizon with these species occurs at the top of the late Ludhamian, as interpreted in the Ludham borehole, then it is absent from the Aldeburgh–Sizewell sequences.

It should be noted that the occurrence of this association at two horizons in the same sequence has never been reported.

Faunas of a similar age have been recorded from the Red Crag Formation of the Flemish Bight (Cameron *et al.* 1984). The absence of *Elphidium macellum* from the Aldeburgh–Sizewell material differentiates the two assemblages.

(*d*) *Interpretation of unit AS-Foram 2*

Unit AS-Foram 2 is entirely post Pre-Ludhamian; however, the precise age is difficult to assess. There is a mixture of characteristic Norwich Crag (Icenian) and reworked Coralline Crag species together with taxa found in the Pre-Ludhamian, although it is difficult to establish whether this element is a relict fauna or derived. Such an assemblage has been used in the past to indicate the Ludhamian Stage (B. Funnell, personal communication). However, the high frequency of *E. hannai* and lowered frequency of *Cibicides lobatulus* reflect the fauna of unit Lf5 of the Ludham borehole; unit Lf5 was later placed in the Antian Stage (Funnell & West 1977). Also in the Ludham borehole *A. batavus* (as *Rotalia beccarii*) is recorded throughout the Ludhamian, Thurnian and Antian stages, but the youngest record of this taxon in the Debenham borehole (Funnell & Booth 1983) is in the temperate late Antian.

There is no record of mixed assemblages of differing ages occurring in sediments regarded as Thurnian or Antian. The mixed element in the fauna is regarded as significant in assigning unit AS-Foram 2 to the Ludhamian. Palaeoenvironmental factors are possible causes of differences between the published record of the occurrence of the species discussed above and their association in the Aldeburgh–Sizewell material.

(*e*) *Palaeoclimate*

The Pre-Ludhamian part of the sequence dominated by *E. excavata* forma *selseyense* with *Cassidulina laevigata*, *Bulimina elongata* and *A. batavus* is comparable to the temperate climate of the present southern North Sea.

The absence of *Elphidium macellum* differentiates these assemblages from the otherwise similar Pre-Ludhamian assemblages of the Red Crag Formation in the Flemish Bight (Cameron *et al.* 1984). This tends to suggest a slightly cooler régime in the Aldeburgh–Orford area, thus implying a slight onshore–offshore temperature gradient in the Pre-Ludhamian of the southern North Sea region. However, factors other than temperature, e.g. turbidity, may have affected the distribution of this species.

The ?Ludhamian assemblages with a dominance of *E. excavata* forma *clavata* and *E. hannai* suggest a cooler régime, but this is qualified by the fact that many of the temperate species such as *A. batavus* and *B. elongata* are also present. *Cassidulina reniforme* is a northern species (*sensu* Murray (1971), pp. 8–9) whereas *A. batavus* is a southern form. This association represents the classic mixing of northern and southern taxa, a phenomenon present along the east coast of England today (Murray 1971). Furthermore, it may be that the climatic interpretations based on species that were originally described from cold waters have been overstated in the past; in inshore environments these foraminifera seem to be much more tolerant to wide variation in climatic conditions.

(*f*) *Conditions of deposition*

The general aspect is of moderate tidal energy, typically inner shelf in aspect. On a gently shelving sea floor there is little to differentiate that part of the littoral environment, which is uncovered daily but does not dry out, and the open sub-littoral down to about 50 m. Unit

AS-Foram 1 is marked by an open-sea component among the fauna, which would suggest at least a tendency towards the more seaward limit of the sub-littoral régime. This open-sea influence is missing in unit AS-Foram 2, the fauna being more estuarine. This, coupled with the suggestion made above of rapid facies changes in this unit, would indicate a somewhat shallower depth of deposition than for AS-Foram 1.

(*g*) *Continental correlation*

In The Netherlands the Upper Pliocene/Lower Pleistocene boundary occurs in a zone locally referred to as FA Zone and characterized by an assemblage of *E. hannai* and *Cribrononion excavatum* (= *Elphidium excavata* of this study). The Plio-Pleistocene boundary is placed at the *Elphidiella oregonense* horizon; the species is unrecorded from the British Quaternary. However, the FA2 Subzone (Upper Pliocene), referred to as the *Buccella frigida*/*Cassidulina laevigata* Subzone, has an assemblage similar to that recorded from unit AS-Foram 1.

(*h*) *Conclusion*

Sub-unit AS-Foram 1*A* is Early Pre-Ludhamian (Red Crag, Waltonian).
Sub-unit AS-Foram 1*C* is Late Pre-Ludhamian (Red Crag, Butleyan).
Sub-unit AS-Foram 2*B* is ?Ludhamian.

5. POLLEN AND SPORES

(*a*) *Pollen diagrams*

Samples for pollen analysis were taken from all four boreholes, from argillaceous sediment horizons that might be expected to contain preserved plant microfossils. Of the samples, none in borehole A, four in borehole B, four in borehole C and five in borehole D were found to contain countable pollen and spores. Preparation of samples for pollen analysis in all cases follows the standard chemical procedures in the Subdepartment of Quaternary Research, University of Cambridge (West 1977). The pollen analyses are expressed as percentages of the pollen sum of total pollen and spores excluding aquatic taxa, and are shown in the pollen diagram (figure 8). Pollen type conventions follow Andrew (1970) together with some types listed in Birks (1973). Reworked pre-Neogene pollen and spores, and dinoflagellate cysts, have also been counted and are expressed as percentages of the total land pollen and spores plus each type respectively. Throughout, pollen and spore preservation is poor, many grains being physically damaged, broken and degraded. This poor preservation is reflected in the abundance of indeterminate palynomorphs throughout the profile.

The assemblages derived from the borehole samples are almost all identical and therefore can be described together. All samples from the basal parts of cores (borehole B, −38.5 to −42.4 m O.D.; borehole C, −32.1 to −41.9 m O.D.; borehole D, −35.2 to −39.7 m O.D.) can be grouped into a *Pinus*–*Picea*–Ericales pollen assemblage biozone (PAB). The only exception is level +4.46 m O.D. in borehole D which represents a *Pinus*–*Picea*–*Ulmus*–Gramineae pollen assemblage biozone.

(i) *Pinus*–*Picea*–*Ericales* PAB

All samples from this zone represent a uniform assemblage dominated by the pollen of tree taxa, particularly those of the conifers *Pinus* and *Picea*. Of the deciduous taxa, the spectra include significant amounts of *Alnus* together with low frequencies of *Betula*, *Corylus*, *Salix* and

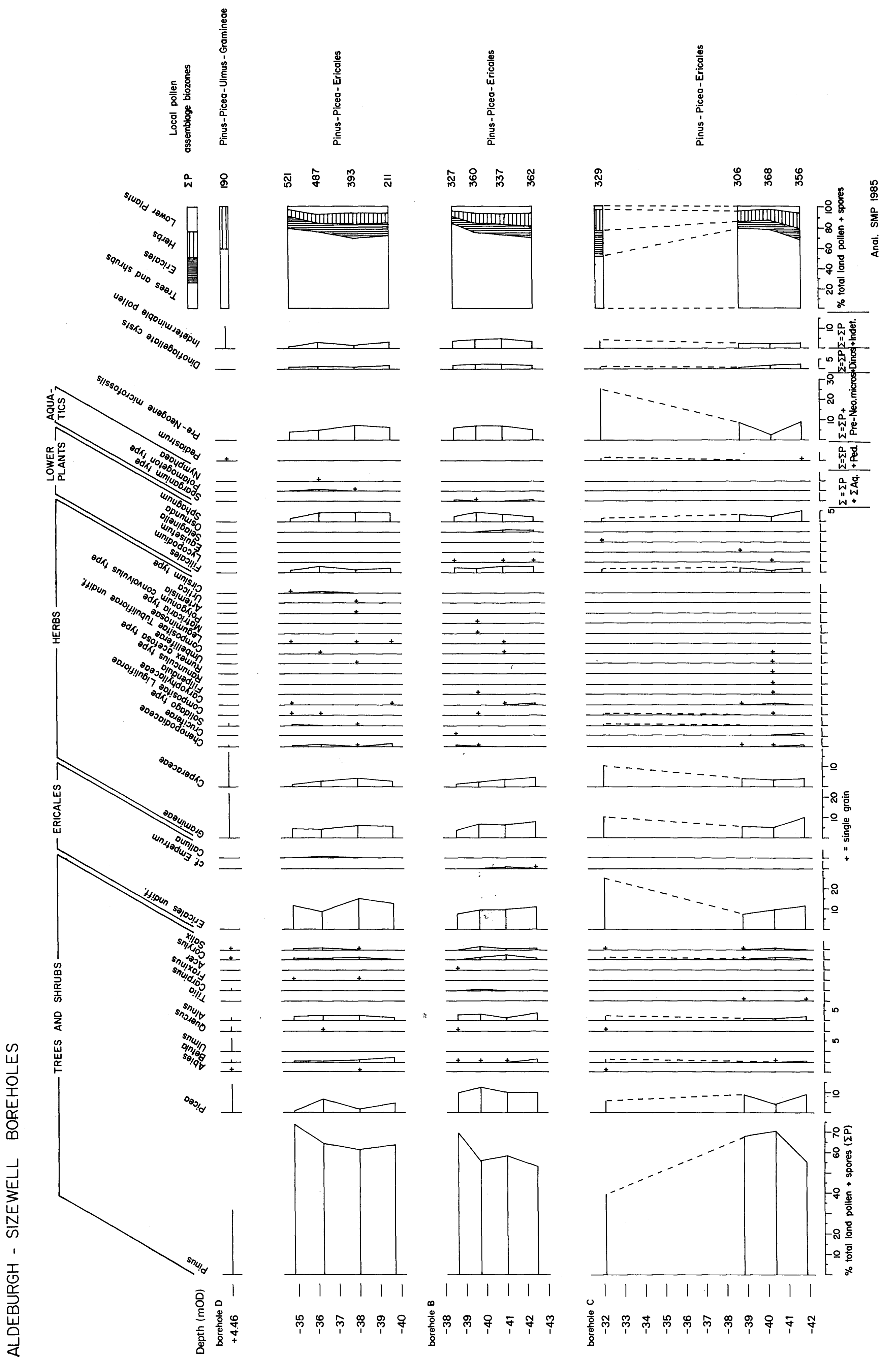


FIGURE 8. Pollen spectra from boreholes B, C and D.

occasional records of *Tilia*, *Fraxinus*, *Quercus* and *Carpinus*. *Abies* is also rarely present. The pollen of the ericaceous heaths is also well represented in all sampled levels, and consistent pollen records of Gramineae, Cyperaceae and low values of other herb taxa are also present. The latter include pollen of open and/or disturbed ground plants such as *Artemisia*, Chenopodiaceae and Compositae. Throughout, spores of *Sphagnum* and of Filicales are abundant and minor occurrences of *Lycopodium*, *Osmunda* and *Equisetem* also occur. Evidence of inwash of reworked sediments is found at all levels to judge from the frequency of pre-Neogene taxa, which reach a peak at over 25% of total palynomorphs in borehole C at −32.11 m O.D. Low frequencies of dinoflagellate cysts are also found in all samples.

(ii) *Pinus–Picea–Ulmus–Gramineae* PAB

The spectrum from this single sample is again dominated by coniferous taxa, *Pinus* being most abundant, with *Picea* reaching a high percentage. These are accompanied by important pollen records of *Ulmus* and, to a lesser extent, *Quercus*, *Alnus*, *Betula* and *Carpinus*. *Corylus*, *Salix* and *Abies* are represented by single grains. Although high levels of Gramineae and Cyperaceae are recorded, other herb types are poorly represented. The poor preservation of palynomorphs in this sample is reflected by the high percentage of indeterminate grains.

(*b*) *Derivation of spectra*

The marine origin of the sediments (see below) analysed in this study raises the question of the possible derivation of the assemblages. Studies of pollen assemblages from marine sediments indicate that pollen recruitment is chiefly dependent on inwash from rivers (Muller 1959; Groot 1966; for summary see West 1980*b*). The highest concentrations of pollen are commonly found in estuaries and opposite the mouths of rivers in modern marine argillaceous sediment (Traverse & Ginsberg 1966, 1967; Heusser & Balsam 1977; Bates 1981). Pollen assemblages therefore represent a homogenization of the vegetation of a broad region, i.e. the river catchment rather than that colonizing the immediate coastal area. It is very difficult to assess the size of this catchment.

In addition, the likelihood of selective sorting during fluvial and subsequent marine transport is problematical. The extent of this effect will clearly depend on factors such as the nature of the environment of deposition, and local wind and current patterns.

Differential sorting of pollen grains resulting from size, shape and density variations from taxon to taxon is a further complication. For instance, the tendency for winged conifer pollen, particularly *Pinus*, to float long distances is known to lead to over-representation of such grains in marine sediments, a feature that becomes more pronounced with distance from land (Traverse & Ginsburg 1966, 1967; Bates 1981; Stanley 1969). A more detailed discussion of the interpretational problems of pollen assemblages from marine sediments of a type similar to those described here is given in West (1980*b*). However, the abundance of pine and the nature of remaining components of the assemblages make it likely that pine was an important constituent of the regional terrestrial vegetation at this time. Further, the richness of the pollen assemblages studied here suggests close proximity to the land from which the spectra were derived.

(*c*) *Vegetational history*

Pinus–Picea–Ericales PAB

This assemblage indicates a regional boreal-type forest of *Pinus* and *Picea*. The open nature of the forest, with unforested areas supporting ericaceous heath, grass and herbaceous communities, is supported by the frequent records for these plants, particularly those of open and/or disturbed ground environments such as Chenopodiaceae, *Artemisia* and Compositae. No vegetational change is apparent in the samples. To judge from the abundance of reworked palynomorphs there was active erosion of the adjacent land throughout the period represented.

Pinus-Picea-Ulmus-Gramineae PAB

The single spectrum from this biozone indicates regional forest dominated by *Pinus* and *Picea*, but with a significant component of temperate taxa, especially *Ulmus* and other genera. There are significant percentages of grass and sedge pollen which may have been derived from coastal or floodplain environments, or which might indicate a more open woodland cover. Because this biozone is represented only by a single pollen assemblage it is difficult to assess the possible effects of reworking or pollen preservation factors, which might alter this interpretation.

(*d*) *Correlations*

The *Pinus–Picea*–Ericales PAB closely resembles spectra recorded by Beck *et al.* (1972) from a sequence of marine clays and sands from the Stradbroke borehole (figures 1 and 2). Here, *Pinus* pollen reached frequencies of up to 80% of total pollen with lower frequencies (about 5%) of *Betula*, *Picea* and *Alnus* and similar low frequencies of Ericales and Gramineae (Beck *et al.* 1972; West 1980*a*). The spectra also closely resemble those obtained by West & Norton (1974) from the lower part of the nearby Sizewell Power Station boreholes (−36 to −37 m O.D.). According to West (1977) this assemblage is characteristic of sediments that predate zone L1 of the Ludham borehole pollen analyses (West 1961) and was therefore assigned to the Pre-Ludhamian (Beck *et al.* 1972).

In a discussion of the possible equivalence of this Pre-Ludhamian Stage to the more complete Netherlands Plio-Pleistocene succession, West (1977, 1980*a*) concludes that it is most likely to be correlated with Substage C of the Reuverian Stage of the Pliocene. However, the pollen flora shows some affinities with that of the earliest part of the Praetiglian of Zagwijn (1960) to judge from the lack of Tertiary-relict genera and the boreal character of the vegetation. It is conceivable that the differences between the Reuverian C flora and that recorded in the Aldeburgh–Sizewell boreholes may in part result from the differing depositional facies, i.e. terrestrial as against marine. However, if a significant element of deciduous trees had occurred close to the Aldeburgh–Sizewell area, they would be better represented in the spectra. Moreover, the assemblages are ecologically consistent in indicating a boreal forest. Thus they could possibly represent Praetiglian rather than Reuverian C.

The *Pinus–Picea–Ulmus*–Gramineae PAB differs in including an element of temperate tree pollen in the spectrum and appears to represent part of a temperate stage. The lack of Tertiary-relict species and the low amounts of *Corylus* pollen, together with the abundance of *Pinus*, *Picea*, *Alnus*, *Betula* and *Carpinus* pollen, strongly suggest that the assemblage should be equated with the Bramertonian Stage of Funnell *et al.* (1979). As pointed out by West (1980*a*), the Bramertonian spectra are very similar to those from Suffolk Crag sites described by

West & Norton (1974), including Sizewell and Chillesford; these are geographically close to the boreholes described in this paper. In particular there is a close correspondence between the Bramerton pollen assemblages and those from the upper part of the Sizewell Power Station boreholes (West & Norton 1974) from +3.0 to +4.5 m O.D. The precise position of the single sample from borehole D within the Bramertonian sequence is difficult to determine. However, the relative abundance of *Pinus* and *Picea* pollen, the low frequency of *Alnus* and the pollen of other tree taxa suggest the sample is later in this stage than those with the abundant pollen of *Quercus* and other temperate genera recorded from the type section by Funnell *et al.* (1979).

6. Dinoflagellate cysts

A suite of 34 samples from borehole D was analysed for dinoflagellate cysts after extraction by using the standard palynological processing technique (Barss & Williams 1973). Sample details and biostratigraphic zonation are shown in figure 9. Dinoflagellate cysts were recovered from the majority of samples processed. Many of the samples contained, however, such poor assemblages as to preclude further comment. There were three units that, in contrast, did contain samples with good assemblages of cysts. Their biostratigraphy is described and discussed below.

(i) *Unit AS-Dino* 1 (−42.23 *to* −43.71 m *O.D.*)

This dinoflagellate-cyst-producing unit consists of two samples only (figure 9), both dominated by *Tectatodinium pellitum* (over 60%). They compare closely with those of unit AS-Dino 2 described below. Neritic warm-temperate to sub-tropical conditions of deposition are envisaged (see the distribution map for *T. pellitum* in Harland (1983)).

(ii) *Unit AS-Dino* 2 (−33.43 *to* −40.62 m *O.D.*).

The assemblages here consist mainly of *T. pellitum*, together with *Spiniferites* spp. and *Protoperidinium* spp. Included in the last-mentioned are a number of undescribed types which have been noted in zone B and recorded in the Ormesby borehole (R. Harland, unpublished information), and which are thought to be Pre-Ludhamian in age. The assemblages of unit AS-Dino 2 are most comparable to those of the Red Crag Formation of the Flemish Bight (Cameron *et al.* 1984) and are thought to be of Waltonian age. The first downhole appearance of *Amiculosphaera umbracula* occurs within this unit.

(iii) *Unit AS-Dino* 3 (+1.30 *to* +1.21 m *O.D.*)

The two samples included in this unit contained dinoflagellate cyst assemblages dominated by *Operculodinium israelianum*. This form is associated with warm-temperate to sub-tropical nearshore or lagoonal environments of deposition (see Wall *et al.* (1977), Dale (1983) and the distribution map for *O. israelianum* in Harland (1983)). This *O. israelianum*-dominated unit is comparable to that recorded from the Westkapelle Formation of the Flemish Bight as recorded in Cameron *et al.* (1984) and thought to be of Thurnian age; to assemblages from the Chillesford Sand at Chillesford Church Pit (R. Harland, unpublished information); and to assemblages recovered from the pollen zones L4 and L5 (Baventian and Pastonian) of the Ludham borehole (Wall & Dale 1968).

Table 9. Aldeburgh–Sizewell borehole C: mollusc assemblages and other animal remains

(× signifies more than 10 specimens counted.)

	unit AS-Mol 2						unit AS-Mol 1								
depth relative to O.D./m	15.07	16.46 –16.71	25.24 –25.46	26.96 –27.33	28.11 –28.36	28.61 –28.32	31.26 –31.71	32.61 –32.91	33.21 –33.51	34.26 –34.86	34.75 34.86	35.66 –35.96	36.51 –36.81	37.26 –37.66	37.76 –38.11
Balanus sp.	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Mytilus edulis Linné	×	7	4	×	×	×	×	×	×	×	×	×	×	×	×
Hiatella arctica (Linné)	6	3	.	1	6	3	3	4	2	2	2	5	3	1	1
Mya truncata Linné	2	.	1	2	3	.	1	.	.	.	.	.	.	.	.
Macoma obliqua (Sowerby)	1	3	3	×	.	.	.	×	2	×	3	×	×	×	×
Natica sp. s.l.	1	.	.	.	.	.	.	.	1	2	.	2	4	.	2
Cerastoderma sp.	×	3	6	×	×	×	×	×	×	×	3	4	×	×	×
Raia clavata Ag.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Corbula gibba (Olivi)	1	1	.	2	2	.	7	×	.	4	2	×	×	1	2
Turritella sp.	3	.	.	3	1	.	6	×	×	3	.	2	.	?	.
Metrar. moniliferum Milne-Edwards	1	.	.	1	1	.	1	3	3	.	4	×	3	5	3
Retepora sp. s.l.	2	.	.	.	.	.	.	.	.	1	.	2	.	.	1
Chlamys opercularis (L.)	3	1	.	×	×	.	×	×	×	×	5	×	×	×	×
Spisula sp.	5	3	1	×	×	×	3	×	×	×	4	×	×	×	.
Yoldia sp.	1	.	.	3	.	.	.	1	2	1	.	.	3	.	.
Celleporoid polyzoan	1	.	.	.	.	.	.	.	1	2	.	.	1	3	.
Acila cobboldiae (Sow.)	.	1	.	.	.	.	1	1	.	1	.	.	2	.	.
Nucella lapillus (Linné)	3	2	.	1	2	1	3	×	2	×	1	2	4	×	×
Pyrene sp.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Mya sp.	.	.	.	5	4	.	2	.	.	.	2	.	.	.	.
Glycymeris sp.	.	.	.	1	.	.	6	4	3	4	1	3	7	3	2
Hinia reticosa (Sow.)	.	.	.	1	.	.	.	.	3	.	.	2	.	.	.
Cliona sp.	.	.	.	2	1	.	2	2	.	2	.	.	.	1	2
Calyptrae chinensis (L.)	.	.	.	.	.	.	.	.	.	1	.	.	1	1	.
Polyzoan	.	.	.	.	1	.	5	2	.	1	.	10	.	8	.
Cerastoderma sp. 'heavy form'	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Macoma sp.	.	.	.	3	3	.	4	.	.	.	.	.	×	×	.
Ditrupa sp.	.	.	.	.	.	.	1	.	.	.	.	1	1	.	.
Shark tooth	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Ensis sp.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.
Cylcocardia sp.	.	.	.	.	.	.	5	2	.	4	3	3	×	2	2
Sphenotrochus intermedius	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.
Echinocyamus pusillus (Mül.)	.	.	.	.	.	.	1	.	.	1	1	.	.	.	.

Laevicardium sp.	.	.	.	.	.	.	1	.	.	1	.	1	.	.	1
Venus fasciata (Da Costa)	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Rissoa sp.	.	.	.	.	.	.	1	3	.	1	.	1	2	.	1
Pholadinae	.	.	.	.	.	.	2	.	2	1	1	.	.	.	.
Astarte obliquata (Sow.)	.	.	.	.	.	.	1	1	.	1	3	1	5	×	.
Astarte (*Isocrassia*) sp.	.	.	.	.	.	.	1	.	.	1	.	3	1	.	.
Macoma praetenuis (Wood)	.	.	.	.	.	.	.	1	.	.	3	3	×	×	.
Buccinum undatum Linné	.	.	.	.	.	.	.	1	.	3	1	1	1	2	2
Pretomeris corbis (Phillipi)	.	.	.	.	.	.	1	1	.	1	1	.	1	.	.
Capulus sp.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	
Turritella incrassata (Sow.)	.	.	.	.	.	.	.	×	×	1	3	5	×	×	5
Lucinoma borealis (Linné)	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.
Nucula sp.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	.
Dosinia exoleta (Linné)	.	.	.	.	.	.	.	5	1	.	.	.	.	.	1
Arctica islandica (Linné)	.	.	.	.	.	.	.	3	.	.	.	.	.	.	2
Mactra sp.	.	.	.	.	.	.	.	1	.	1	.	.	.	1	1
Digitaria sp.	.	.	.	.	.	.	.	1	.	.	.	1	.	1	.
‘*Anomia*’ sp. s.l.	.	.	.	.	.	.	.	.	2	1	1	.	1	1	2
Cancer pagurus Linné	.	.	.	.	.	.	.	.	1	.	1	1	1	.	1
Irregular echinoid	.	.	.	.	.	.	.	.	1	.	1	.	3	2	.
Modiolus sp.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Abra sp.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Verruca strömia Müller	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Calliostoma sp.	.	.	.	.	.	.	.	.	.	1	1	2	.	.	.
Hinia dolfussi (Harmer)	.	.	.	.	.	.	.	.	.	2	1	2	.	.	.
Gibbula sp.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Ringicula sp.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
Donax sp.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.
Diodora sp.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Glans senilis (Lamarck)	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Ocenebra sp.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Crustacean indet.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.
Regular echinoid	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Trivia coccinelloides (Sowerby)	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Terebratula sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Neptunea lyratodespecta (Strauch)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Zirfea crispata (Linné)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1

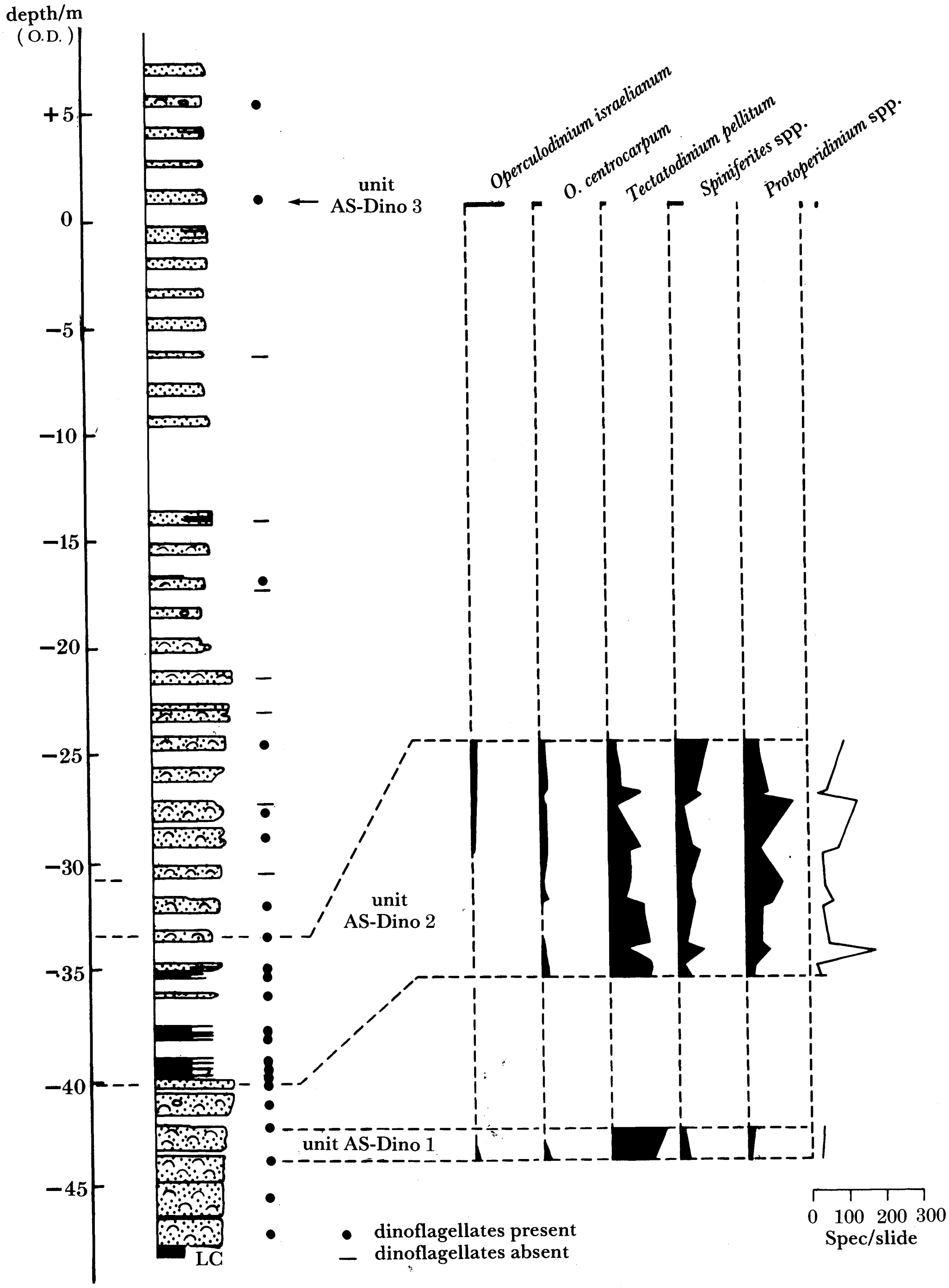


FIGURE 9. Dinoflagellate cyst assemblages from borehole D.

7. MOLLUSCA

(a) *Biostratigraphy*

Bulk samples of 0.5–1.0 kg were taken from borehole C, washed, dried and picked for macrofossils. The distribution of identified macrofauna is shown in table 9. Two faunal assemblages are present: unit AS-Mol 1 is a relatively diverse assemblage, occurring between

−31.26 and −38.11 m O.D., and unit AS-Mol 2 is a relatively restricted assemblage, occurring between −14.67 and −28.82 m O.D.

(b) *Interpretation*

All the material has been transported, at least locally, before burial. The comminuted and abraded nature of the specimens indicates a great deal of reworking. Derived material from the Coralline Crag is present throughout, with small clasts of Coralline Crag occurring towards the base of the sequence. However, no *in situ* Coralline Crag is present as the lowest sample contains *Nucella* and *Neptunea*, genera that appear only in sediments younger than the Coralline Crag.

Unit AS-Mol 1 contains several typical Red Crag species. However, the general aspect of the assemblage differs from that of the exposed Red Crag at outcrop. It suggests more an 'Icenian' (*sensu* Harmer 1902) assemblage that is contaminated by the addition of a considerable amount of derived material.

Unit AS-Mol 2 largely comprises long-ranging forms, but with much less derived material. This limited fauna can also be ascribed to the Icenian.

Although considered Icenian, the samples contain none of the distinctive forms recorded from the exposed Norwich Crag, such as occur at the nearby Thorpe Aldringham locality (West & Norton 1974). The best comparison seems to lie with the fauna of the lower part of the Chillesford Sand at Chillesford Church Pit, where a great deal of derived material is also present, and with the Crag of the Debenham borehole (interpreted as Ludhamian by Funnell & Booth (1983)). It is thought possible that the entire fauna recorded from borehole C may represent a deep-water facies of the Chillesford Sand.

8. PALAEOMAGNETISM

(a) *Methodology*

Samples were taken from clay-rich levels in boreholes B, C and D for determination of the direction of remanent magnetism. The samples, oriented with respect to the way-up of individual core lengths, were taken from the core some 3 months after the boreholes were drilled. Measurements of inclination, declination and intensity were made with a Digico fluxgate spinner magnetometer, and the values of inclination and declination are shown in figure 10. The cores were not oriented with respect to present magnetic north during drilling; nor are individual core lengths, even within a single borehole, in a similar relative orientation. Each core length therefore has its own arbitrary declination datum. Only the results for magnetic inclination are interpreted and discussed below.

Selected samples were incrementally demagnetized in an AC field of 200 Oe (*ca.* 16 kA m^{-1}) peak value (figure 10). Both reversed samples in boreholes B and C showed a major decrease in inclination, which is assumed to reflect unstable magnetization, whereas the three reversed samples in borehole D appeared to be stable. Those normally magnetized samples with a low natural remanent magnetization inclination showed a relatively large shift on demagnetization, whereas those with a high inclination appear relatively stable.

(b) *Results*

The data (figure 10) demonstrate a single magnetic reversal within the sequence. The lowest parts of the cores are consistently normally magnetized, while a thin clay-rich interval in the

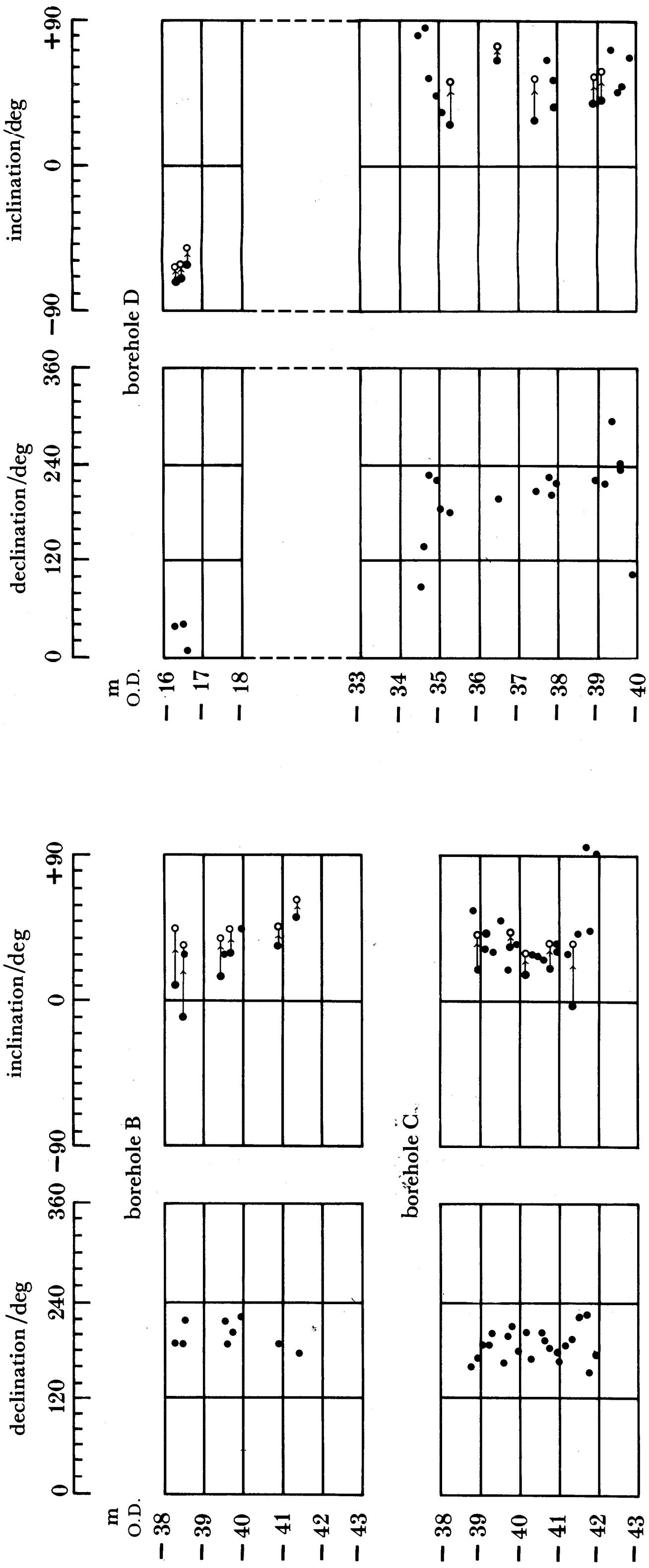


FIGURE 10. Palaeomagnetic results from boreholes B, C and D. Open circles show results of demagnetization on inclination values.

sand-dominated upper part of the sequence shows reversed polarity. More magnetic reversals may be present within the sequence, though remaining undetected owing to the generally unfavourable lithology.

(*c*) *Interpretation*

The results cannot be interpreted in isolation, given that at least three changes of event status from normal to reversed polarity have taken place in the past three million years (McDougall 1979). Correlation can be attempted, however, with the nearest comparable sequence of Crag sediments from which palaeomagnetic data have been obtained, that of the Stradbroke borehole (van Montfrans 1971; Beck *et al.* 1972). There, the lower part of the sequence shows normal polarity, no data being obtained from the upper part (van Montfrans 1971). The normally magnetized sediments at Stradbroke were initially interpreted as indicating an episode of normal polarity as old as the Gilsa (= Olduvai) event (1.66–1.87 Ma BP) and perhaps older (Beck *et al.* 1972). Curry *et al.* (1978) subsequently correlated these Stradbroke sediments with the normally magnetized sediments below the Gauss/Matuyama polarity reversal (2.41 Ma BP).

9. AMINO ACID RACEMIZATION

For some years, the preservation and subsequent alteration of proteinaceous matter contained in fossil shell material has been used as an indicator of the relative age of the sediments in which the shell was found. It has been found in practice that only the Quaternary and Upper Tertiary sediments can be correlated by using this technique. In this study, the amino acids from various identified shell genera separated from core sections of borehole B were analysed. It was hoped to establish firstly, whether the results correlate with depth and, secondly, whether any substantial time breaks within the sedimentary sequence could be identified. The work described here is documented in more detail in Nicholson *et al.* (1985).

(*a*) *Laboratory procedure*

Lengths of sediment core from ten different sections between −12.23 and −47.00 m O.D. were taken. The samples were sieved in cold water and dried at room temperature. Shells were selected from various sections, with tweezers to minimize contamination, and identified to genus level. Methods used for cleaning and dissolution of shell material and the subsequent recovery and determination of their amino acid content have been described by Stuart & Vickers (1985).

No individual genus was present throughout the recovered core length examined, although balanomorphid and *Cerastoderma* fragments were present in all but one of the sections. *Chlamys*, *Mytilus* and *Spisula* were also present in moderate amounts. Nine individual amino acids were identified in all cases and results for the ratios of their D-enantiomeric and L-enantiomeric forms are given in table 10. In table 10 a zero indicates that either of the two chromatographic peaks necessary for the ratio calculation could not be identified accurately or was subject to interference from adjoining peaks. Glycine does not show any optical activity, but glycine/alanine ratios may be useful indicators of the relative states of preservation of the fossils (Weiner & Lowenstam 1980).

Table 10. Aldeburgh–Sizewell borehole B: amino acid L:D ratio for shelly material

(Ala, alanine; Val, valine; Thr, threonine; Ile, isoleucine; Pro, proline; Leu, leucine; Asp, aspartic acid; Phe, phenylalanine; Glu, glutamic acid.)

depth relative to (o.d.)/m	Ala	Val	Thr	Ile	Pro	Leu	Asp	Phe	Glu
median *Balanus*									
−12.23	0.93	0.54	0.27	0.50	0.75	0.60	0.58	0.59	0.53
−12.55	0.85	0.57	0.41	0.56	0.68	0.71	0.60	0.60	0.58
−21.73	0.95	0.61	0	0	0.73	0.65	0.42	0.75	0.78
−29.48	0.93	0.55	0.57	0.71	0.81	0.74	0.60	0.60	0.57
−30.68	0.93	0.59	0.44	0.55	0.85	0.75	0.60	0.62	0.57
−36.35	0.91	0.54	0.37	0.48	0.80	0.72	0.57	0.56	0.56
−37.85	0.92	0.54	0	0.77	0.60	0.79	0.49	0.66	0.58
−44.13	0.87	0.54	0.38	0.68	0.74	0.60	0.54	0.61	0.55
−46.85	0.88	0.52	0.34	0	0.69	0.57	0.59	0.61	0.50
mean *Cerastoderma*									
−12.23	0.60	0.50	0.27	0.31	0.64	0.53	0.48	0.48	0.47
−12.55	0.63	0.47	0.40	0.19	0.56	0.40	0.71	0.44	0.55
−21.73	0.78	0.56	0.42	0.43	0.69	0.58	0.78	0.53	0.61
−23.78	0.73	0.41	0.58	0.38	0.72	0.47	0.56	0.47	0
−29.48	0.53	0.34	0.26	0.46	0.44	0.41	0.56	0.44	0.45
−30.68	0.47	0.37	0.24	0.26	0.57	0.45	0.38	0.38	0.65
−36.35	0.61	0.49	0	0.20	0.65	0.46	0.59	0.45	0.66
−37.85	0.63	0.30	0	0	0.59	0.59	0.40	0	0
−44.13	0.75	0.44	0.24	0	0.60	0.47	0.57	0.56	0.58
median *Chlamys*									
−12.23	0.84	0.56	0.32	0.68	0.45	0.76	0.53	0.53	0.60
−12.55	0.81	0.62	0.33	0.33	0.75	0.62	0.57	0.62	0.56
−29.48	0.86	0.62	0.25	0.33	0.79	0.70	0.60	0.66	0.53
−30.68	0.88	0.59	0.33	0.33	0.79	0.66	0.60	0.73	0.55
−36.35	0.84	0.57	0.21	0.21	0.77	0.66	0.58	0.61	0.56
−37.85	0.79	0.54	0.12	0.43	0.75	0.63	0.64	0.73	0.47
−44.13	0.91	0.63	0.59	0.22	0.74	0.67	0.60	0.48	0.60
−47.00	0.91	0.68	0.51	0.45	0.82	0.73	0.68	0.67	0.63
median *Mytilus*									
−12.23	0.74	0.59	0.17	0.49	0.83	0.77	0.64	0.72	0.74
−12.55	0.84	0.69	0.58	0.38	0.84	0.79	0.65	0.71	0.70
−21.73	0.69	0.56	0.10	0.29	0.64	0.77	0.49	0.55	0.50
−23.78	0.67	0.77	0	0.64	0	0.85	0.72	0.85	0.64
−29.48	0.52	0.60	0.33	0.54	0.89	0.80	0.71	0.75	0.70
−36.35	0.56	0.51	0.64	0.45	0.84	0.81	0.74	0.79	0.70
−37.85	0.70	0.60	0.38	0.86	0.86	0.82	0.73	0.82	0.70
−44.13	0.83	0.67	0.55	0.76	0.82	0.88	0.75	0.78	0.76
mean *Spisula*									
−12.23	0.87	0.58	0.28	0.32	0.71	0.66	0.67	0.58	0.54
−12.55	0	0.48	0.20	0.49	0.82	0.70	0.71	0.71	0.52
−36.35	0.84	0.52	0.18	0.25	0.90	0.63	0.77	0	0
−37.85	0.73	0.49	0.42	0	0.64	0.72	0.56	0.54	0.55
−44.13	0.94	0.64	0.12	0.29	0.84	0.62	0	0	0

(*b*) *Results*

Previous work on the Red/Norwich Crag fossils from East Anglia (Miller *et al.* 1979; Davies *et al.* 1982) has been mainly confined to the genera *Mya*, *Macoma* and *Corbicula*. Although both *Mya* and *Macoma* are present in borehole B, the amount of material recovered was too small to permit useful work.

(i) *Balanus*

The use of *Balanus* for aminostratigraphy has been reported by Miller (1982) but no details are yet published. In this study, the results obtained were extremely variable. Median values for the ratio of D-alloisoleucine range between 0.48 and 0.77 for approximately seven determinations on each sample from each depth profile. These data seem rather low when compared with those of Miller *et al.* (1979) and Davies *et al.* (1982), but it should be noted that *Balanus* did not appear in any of their results and it is known that different shells from the same section give different ratios (Wehmiller 1982). Calculated correlation coefficients indicate that only the isoleucine parameter shows any relation with depth, and even this correlation is not very significant at 0.497.

The high variability of the results, with no measurable isoleucine data from shell samples at two depths within the core (table 10) may be due to diagenetic alteration, or to inter-individual variation. Comparison with the work of Weiner & Lowenstam (1980) indicates the latter. They showed that an increase in D-alloisoleucine content accompanied by a concomitant increase in glycine content, as shown by the glycine/alanine ratio, indicates diagenetic change. No consistent relation is present between these parameters in the borehole B *Balanus* material.

(ii) *Cerastoderma*

Table 10 shows that only glutamic acid, and phenylalanine to a much lesser extent, have any relation with depth of burial. As with *Balanus*, there is no consistent relation between the glycine/alanine and the D-alloisoleucine/L-isoleucine ratios. Considerable intrashell variations within this species have been found by Davis (1980).

(iii) *Chlamys*

Aspartic acid shows good correlation with depth, followed by proline and alanine. Isoleucine is again variable with results ranging from 0.21 to 0.68. Overall ratios of amino acids are similar to those obtained from *Balanus*. Miller (1982) reports that *Chlamys islandica* has been used for aminostratigraphy but reports no conclusive results.

(iv) *Mytilus edulis*

All amino acids except alanine and valine appear to show some correlation with depth although only the leucine, isoleucine and aspartic acid results are of any consequence. Isoleucine is again very variable with a range of ratios from 0.29 to 0.86.

(v) *Spisula*

Although glutamic acid shows a relatively high correlation with depth, this is only the result of duplicate determinations on three samples, so it should be viewed with suspicion. Results generally appear similar to those found in the other shell genera analysed. Isoleucine ratios are again low (0.25–0.49) and hence similar to those of *Cerastoderma*.

(*c*) *Interpretation*

Results throughout the borehole sequence are extremely variable, and subdivision of the sequence on the basis of these results is not possible. Direct comparison with previous data is very difficult; there are little or no published data available for many of the shell genera that were selected for analysis in this study, because well-preserved *Mya* and *Macoma* were not present in the material examined.

In general, results are somewhat lower than those reported elsewhere for Red/Norwich Crag fossils (Miller *et al.* 1979; Davies *et al.* 1982), and the D-alloisoleucine/L-isoleucine ratios seem to indicate a somewhat younger age for the Crags than has hitherto been thought. The results appear to show no consistent time-discontinuity within the interval examined. A few, e.g. aspartic acid in *Chlamys*, show positive correlation with depth; the majority, however, show little or no such correlation.

The poor preservation of the material casts serious doubts on any interpretation. The mechanical breakdown associated with prolonged marine reworking is likely to have severely reduced the amount of available organic component, reducing the amino acid content, at its extreme, to immeasurably low levels. This action may account for the loss of the D-alloisoleucine peak in some of the samples. Thus amino acid stratigraphy may not be a viable method in such relatively old, strongly reworked marine deposits. Future study of material from this part of the stratigraphic column may need to concentrate on better-preserved material from lower-energy, mud-dominated environments.

10. Synthesis

(*a*) *Discussion of the units identified*

A summary of the units identified and their mutual relations are shown in figure 11. Major units persist laterally and both the lithostratigraphical units (figures 4 and 5) and the biostratigraphical units (foraminifers, tables 1–8; pollen, figure 8) show considerable internal consistency. Major units of different type also coincide; it is evident that bodies of sediment, each with a distinctive fauna and flora, are present and can be correlated from borehole to borehole. This is particularly well seen in the coincidence of the lowermost sedimentary unit (AS-Lith 1) with the *Pinus–Picea*–Ericales pollen zone and the foraminifer zone AS-Foram 1.

Some of the more subtle distinctions, however, seem not to form valid stratigraphical units. In particular, the sub-units of the upper foraminifer unit, AS-Foram 2, do not generally coincide with the lithostratigraphic subdivisions (figure 11). These subzones probably represent local fluctuations of the transport, sorting and preservation. The limits of biostratigraphical analysis in such high-energy, shallow marine sediments are thus indicated.

(*b*) *Correlation of the Aldeburgh–Sizewell boreholes with other sequences*

The three major lithostratigraphical units identified can be placed, with varying degrees of confidence, within the standard British stage system (Mitchell *et al.* 1973) on the basis of their enclosed faunas and floras (figure 12). There is considerable unanimity on the lowermost unit (AS-Lith 1). Foraminifers, pollen, dinoflagellate cysts and the normal magnetic polarity strongly indicate the Pre-Ludhamian Stage (cf. Beck *et al.* 1972). In addition, the foraminifer and dinoflagellate assemblages point to an internal division into a lower 'Waltonian' and an upper 'Butleyan' unit, as also occurs in the type Pre-Ludhamian sequence of the Stradbroke borehole (Beck *et al.* 1972). The molluscan assemblages are more problematical. Although Red Crag (*sensu* Funnell & West 1977) species are present, these are interpreted as reworked. Given the weight of the other evidence, it seems more likely that the deposits do belong to the Red

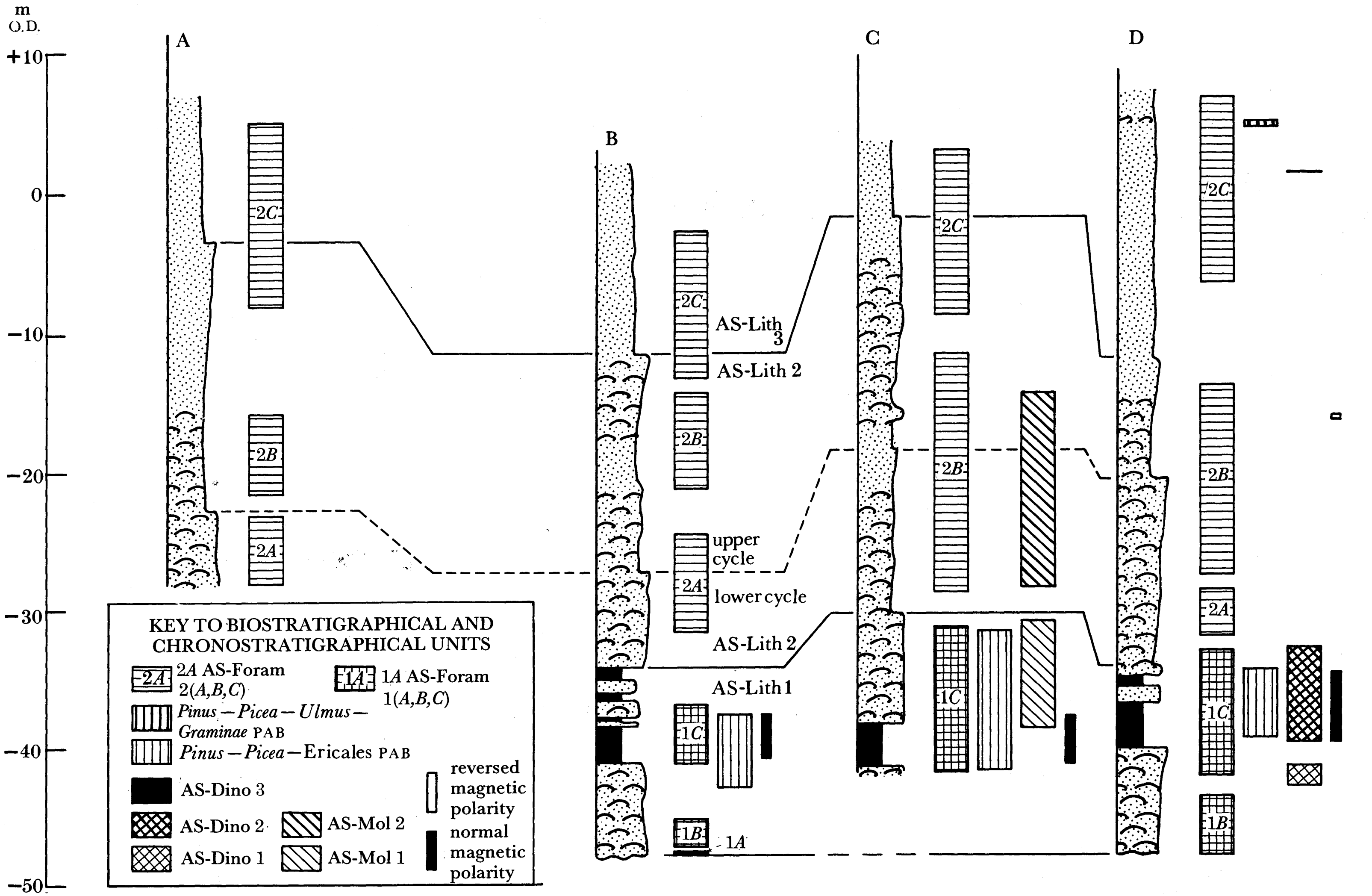


FIGURE 11. Comparison of lithostratigraphical, biostratigraphical and chronostratigraphical data from Aldeburgh–Sizewell boreholes A, B, C and D.

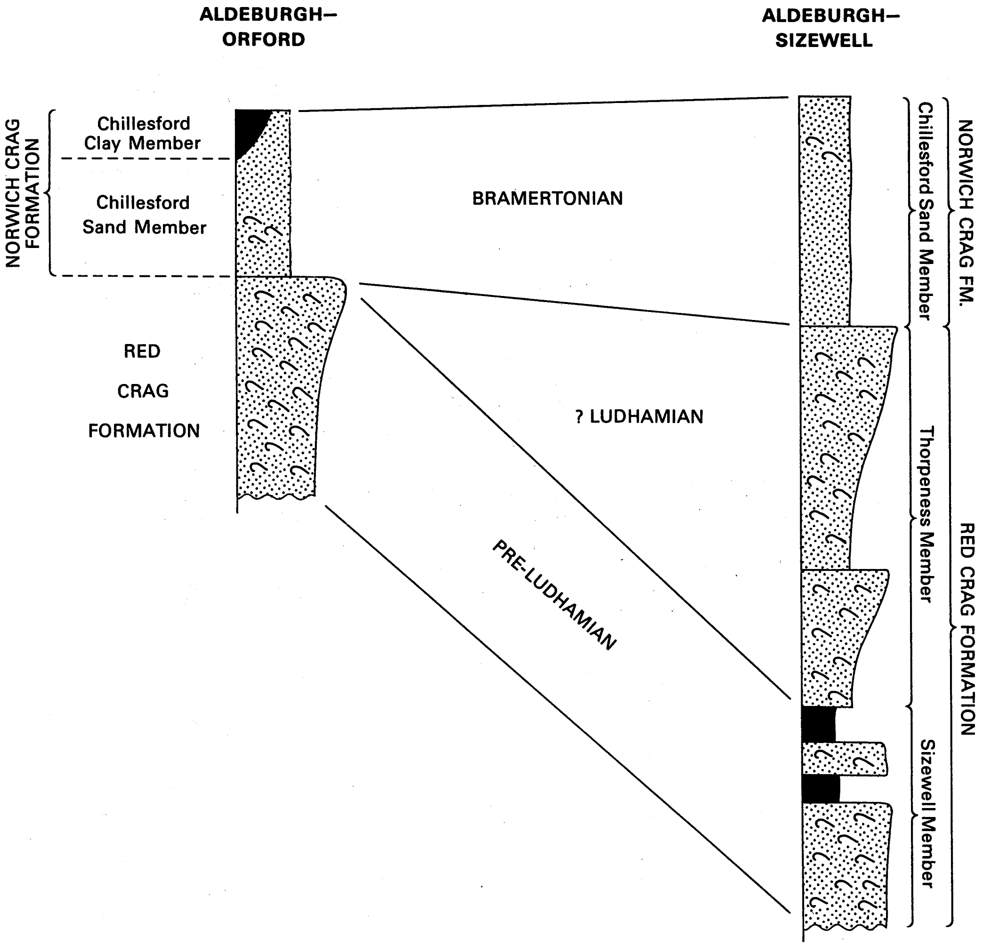


FIGURE 12. Summary of the stratigraphy of the Red and Norwich Crag formations in the Aldeburgh–Orford area (Zalasiewicz & Mathers 1985) and in the Aldeburgh–Sizewell area (this study).

Crag; environmental control and/or current sorting may have given rise to the differences between the Aldeburgh–Sizewell faunas and those of 'typical' Red Crag.

Correlation of the Pre-Ludhamian with The Netherlands is carried out mainly on the basis of pollen and the normal magnetic polarity. The pollen spectra show affinities with both Substage C of the Reuverian (West 1977, 1980*a*) and the earliest part of the Praetiglian (§5*d* above). Zagwijn's (1985 and personal communication) most recent assessment suggests that the Praetiglian lies entirely within a period of reversed magnetization just above the Gauss/Matuyama boundary. If this is so, the normally magnetized Pre-Ludhamian unit AS-Lith 1 cannot correlate with the Praetiglian, and is more likely to be of Reuverian age. However, Zagwijn's earlier (1975) synthesis indicated that the Praetiglian includes episodes of both normal and reversed polarity. According to J. D. de Jong (personal communication), both interpretations are based on the work of van Montfrans (1971), whose only sampled section in the Praetiglian was the Reuverian/Praetiglian boundary section at Mols (van Montfrans (1971), figure 4*a*; normal polarity at the base of the section, and reversed polarity at the top). The lack of palaeomagnetic data for the greater part of the Praetiglian means that correlation of the Aldeburgh–Sizewell *Pinus–Picea*–Ericales PAB with the Praetiglian cannot be precluded;

this situation highlights the need for further study of the pollen/magnetic history of the Lower Pleistocene of the North Sea basin.

The middle lithostratigraphical unit (AS-Lith 2) contains sparser fossil assemblages, and correlation is much more difficult. No identifiable pollen or dinoflagellate assemblages were obtained from these clay-poor sediments, and the foraminifera and mollusc assemblages are strongly reworked and less diverse than those of the underlying Pre-Ludhamian. The foraminifera suggest a correlation with the Ludhamian, and this further emphasizes the similarity of the Aldeburgh–Sizewell sequence with that of the Stradbroke borehole (Beck *et al.* 1972) (see figure 2). In the adjacent Sizewell Power Station boreholes the ?Thurnian and ?Antian Stages were originally recognized at this level (Funnell 1983); these have since been reinterpreted as belonging to the Ludhamian, following discussion of the results presented in this paper (B. M. Funnell, personal communication).

The distinctive coarsening-upward cycles of unit AS-Lith 2 are of some stratigraphical significance in this context. Each cycle represents a single depositional episode, possibly the growth of a large-scale bedform. Thus no major hiatus can be expected to occur within a cycle; such breaks can be present only at the upper and lower bounding surfaces. Such a recognition is important in poorly fossiliferous sediments of this type, for it limits the number of climatic stages that can be represented as episodes of sedimentary deposition, within a sequence where the faunas are inadequate to allow the recognition of such stages.

Unit AS-Lith 2 is unrepresented in the adjacent Aldeburgh–Orford area, where the sequence with which this succession is compared was defined (Zalasiewicz & Mathers 1985). In broad terms, both units AS-Lith 1 and AS-Lith 2 correspond to the Red Crag Formation of that area in being dominated by medium to coarse, relatively poorly sorted, shelly sands. The lithological differences between this formation in the two areas, and the presence of a twofold division in the Aldeburgh–Sizewell sequence, necessitate the naming of two members within the Red Crag Formation of the latter (figure 12): a lower Sizewell Member (AS-Lith 1) and an upper Thorpeness Member (AS-Lith 2). Type sections are designated within borehole D; that for the Sizewell Member is the preserved interval between −47.57 and −34.34 m O.D., and that for the Thorpeness Member is the preserved interval between −34.34 and −13.34 m O.D.

The assignment of the Thorpeness Member to the Red Crag Formation is provisional. This is because the foraminifera are of 'Norwich Crag' aspect (though there is no reason why the boundary of a lithostratigraphical unit should coincide with that of a biostratigraphical one), and there are poorly understood lithological changes within the Red Crag and Norwich Crag formations northwards in East Anglia, within which it is not known how the Thorpeness Member relates. Ultimately, it may prove more appropriate to consider the Thorpeness Member as part of the Norwich Crag Formation. However, the present arrangement is consistent with the overall lithological character of the Thorpeness Member, with the inclusion of the Ludham Crag within the Red Crag Formation by Funnell & West (1977) and with the proposal of Funnell (1987) that Pre-Ludhamian to Thurnian age deposits are the product of a single phase of sedimentation during a high sea-level stand post-3.2 Ma and pre-2.4 Ma BP.

Geological mapping by S. J. Mathers has shown that the uppermost lithostratigraphical unit (AS-Lith 3) is directly correlatable with the Chillesford Sand Member of the Norwich Crag Formation. This has an extensive outcrop to the south and west in the Aldeburgh–Orford area (Zalasiewicz & Mathers 1985) and is characterized by the 'Chillesford pollen assemblage'

(West & Norton 1974), now regarded as Bramertonian in age (Funnell *et al.* 1979). This correlation is supported by the very close similarity of the *Pinus–Picea–Ulmus*–Gramineae pollen assemblage biozone present in this unit to the Chillesford pollen assemblage. The associated dinoflagellate assemblage, being comparable to assemblages recovered from the Chillesford Sand at Chillesford Church Pit (R. Harland, unpublished information) lends weight to such an interpretation, without being definitive; similar assemblages have been recovered from strata assigned to the Thurnian, Pastonian and Beestonian (Cameron *et al.* 1984; Wall & Dale 1968; R. Harland, unpublished information).

(*c*) *Palaeoenvironments*

(i) *Palaeoclimates*

The Pre-Ludhamian, as represented by unit AS-Lith 1, was characterized by cool temperature conditions on the basis of pollen, but warm-temperate to subtropical conditions on the basis of dinoflagellate cyst assemblages. The foraminiferal evidence can be used only to substantiate a temperate climate, because doubt about the absence of the warm-temperate species *Elphidium macellum* inhibits a restriction as to either warm or cool temperate. Similar conflicts of palaeoenvironmental interpretation were noted by Cameron *et al.* (1984) in the Quaternary of the southern North Sea; there, though, the foraminifera could be used to point definitively to warm-temperate conditions. Cameron *et al.* (1984) suggested that the Lower Pleistocene was marked by very different oceanic circulation patterns, with warm-temperate masses of water extending further north along the eastern seaboard of the North Atlantic than at present.

The Ludhamian of unit AS-Lith 2 may represent slightly cooler conditions, on the basis of the foraminifers. If the stage identification is correct, then this is at first sight unusual, considering that the pollen spectra of the type Ludhamian (West 1961) indicate a warmer climate than in the Pre-Ludhamian. However, as noted above (§4*e*), environmental factors other than climate may have significantly affected the distribution of the foraminifer species. Besides, as also noted above, the adjacent marine and terrestrial environments may well have been decoupled to some extent as regards palaeotemperature.

Pollen spectra from the Bramertonian of unit AS-Lith 3 give evidence of the warmest terrestrial conditions seen in these borehole sequences, with a significant temperate-forest element mixed with the conifers. Mollusc assemblages from surface exposures of this deposit (West & Norton 1974) indicate palaeotemperatures similar to those of modern boreal seas. The dinoflagellate cyst indications, of warm-temperate to subtropical conditions, are again at variance here.

(ii) *Environments of deposition*

Successive sedimentary units show evidence of deposition in successively shallower marine environments. In unit AS-Lith 1, the open sea foraminifers, neritic dinoflagellates and relatively diverse molluscan faunas indicate subtidal conditions. Unit AS-Lith 2, with its more estuarine foraminifers and relatively restricted mollusc assemblages, is evidently a more nearshore deposit, and this is consistent with the possible presence of tidal sand ridges, as inferred from the coarsening-upward cycles. The sedimentary structures in unit AS-Lith 3 most closely resemble those of intertidal sandflats, an interpretation supported by the nearshore to lagoonal dinoflagellate cyst assemblages and the shallow/intertidal molluscan faunas from surface exposures of the Chillesford Sand Member (West & Norton 1974). The relatively high proportion of non-marine molluscs (see Appendix) and small vertebrate remains (Mayhew & Stuart 1986) from at or near the level of unit AS-Lith 3 northwards from Sizewell may indicate the influence of a large river mouth discharging terrestrial debris into this area.

This generally shallowing upward signature is characteristic of the thinner, simpler Red/Norwich Crag sequence in the adjacent Aldeburgh–Orford area (Zalasiewicz & Mathers 1985) and, probably, more generally throughout southern East Anglia.

11. Conclusions

(*a*) Detailed studies on a series of cores from closely spaced boreholes of a thick Red/Norwich Crag sequence show that an internally consistent stratigraphy can be recognized on the basis of sedimentological and biological, and to a limited extent on chronological (palaeomagnetic), data.

(*b*) The limits of stratigraphical resolution in these sediments are indicated. Major units indicated by the different disciplines show good agreement. Some of the minor units, however, do not, and these seem to represent purely local events of little or no correlatory value.

(*c*) The recognition of grain-size trends in poorly fossiliferous parts of the sequence indicates intervals of relatively continuous sedimentation. This limits the number of stages that can be thought to be represented, and constrains the positions of any stratigraphical gaps present.

(*d*) A sequence of three major units can be recognized (figure 12). The lowermost comprises shelly sands and laminated clays and is here named the Sizewell Member of the Red Crag Formation; it is unambiguously Pre-Ludhamian in age and probably correlates with an interval within the Reuverian C to Praetiglian stages of The Netherlands. The middle unit comprises sparsely fossiliferous shelly sands in large-scale coarsening-upward cycles and is here named the Thorpeness Member of the Red Crag Formation; it is probably Ludhamian in age. The upper unit of fine to medium, largely non-shelly sands is the Chillesford Sand Member of the Norwich Crag Formation, and Bramertonian in age.

(*e*) The Thurnian and Antian stages, recognized in Norfolk, do not appear to be represented. The Baventian, tentatively identified as a thin interval beneath the Bramertonian in earlier research at Sizewell, has not been recognized in this study.

We thank J. Hallam and C. Cole, who organized and did the technical aspects of the drilling, the landowners on whose ground this work was carried out, and Professor R. G. West and Dr R. S. Arthurton for their critical reading of the manuscript. Some of the palaeomagnetic measurements were undertaken by T. A. Austin and L. LaRoche at the University of East Anglia. This paper is published with the permission of the Director of The British Geological Survey (NERC).

Appendix. Non-marine Mollusca from the Norwich Crag Formation at Sizewell

By R. C. PREECE

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Shells of land and freshwater molluscs have been recovered from the Norwich Crag at two locations near Sizewell: (1) from a disused sand-pit on the rifle range (now infilled) at TM 475639, mainly collected in 1955; and (2) from the excavations for the Sizewell B Power Station at TM 473635, mostly from a white shelly sand *ca.* 1.8 m up the south end of the west face, collected on 16 August 1978. Most of the specimens were collected by Dr P. E. Long and his brother, D. C. Long, but a few records are based on museum material.

The lithostratigraphy of the sites is not yet clearly established as they lie outside the limits of the recent geological mapping by S. J. Mathers, with the sections being no longer accessible. The level of the fossil-bearing material, at *ca.* 1–2 m O.D. (P. E. Long, personal communication), indicates that correlation with unit AS-Lith 3 (the Chillesford Sand Member of the Norwich Crag Formation) appears most reasonable. However, the relatively high proportion of non-marine molluscs, small vertebrate remains (Mayhew & Stuart 1986) and the composition of the marine molluscan assemblages, all serve to differentiate this horizon from typical Chillesford Sand assemblages of, for example, Chillesford Church Pit (see, for example, West & Norton 1974). Rather, a link is suggested with typical 'Norwich Crag' shelly faunas further north in East Anglia, for example at Bramerton Pit (see, for example, Funnell *et al.* 1979) (P. E. Long, personal communication). All these localities have been placed within the Bramertonian Stage, largely on the basis of the foraminiferal and pollen assemblages (Funnell *et al.* 1979). The differences in macrofaunal assemblages remarked on above may be due to age differences, as yet unreported, or to regional facies variations.

The following species have been detected.

	rifle range	Sizewell B
approximate dry weight of sediment	40–50 kg	15–20 kg
freshwater/brackish-water species		
Viviparus medius (S. Woodward)	4	8
Valvata piscinalis (Müller)	8	1
Hydrobia ulvae (Pennant)	many	many
H. ventrosa agg.	many	many
Bithynia tentaculata (Linné) opercula	—	3
Cerithium tricinctum icenicum (Harmer)	many	many
Ellobium pyramidale (J. Sowerby)	many	many
Ovatella myosotis (Draparnaud)	8[a]	3
Lymnaea palustris (Müller)	13	3
Planorbis planorbis (Linné)	6	3
Anisus leucostoma (Millet)	4	—
Planorbarius corneus (Linné)	—	2
Sphaerium icenicum Holyoak & Preece	1	1
Pisidium amnicum (Müller)	3	—
P. amnicum/clessini	—	1
P. casertanum (Poli)	1[b]	—

	rifle range	Sizewell B
approximate dry weight of sediment	40–50 kg	15–20 kg
terrestrial species		
Succinea oblonga Draparnaud	4	—
Succinea cf. *putris* (Linné)	1	—
cf. *Oxyloma pfeifferi* (Rossmässler)	7	5
Pupilla muscorum (Linné)	2	3
Vallonia pulchella (Müller)	—	—
Trichia cf. *plebeia* (Draparnaud)	2	—
T. hispida (Linné)	—	1
larger helicid (indeterminate apex)	—	1

[a] Specimen in Ipswich Museum (960-102-11); pit unspecified.

[b] Seven shells collected by P. E. Long plus one other shell labelled '*Leuconia fusiformis* A. Bell' in Ipswich Museum (954-107-A); pit unspecified for the latter.

This list greatly extends the few records of non-marine shells recovered by West & Norton (1974) from Sizewell and now comprises over twenty taxa. The occurrence of such a variety of non-marine shells in the Norwich Crag at Sizewell suggests near-shore deposition close to the outfall of a moderately sized river. As might be expected, the shells represent a heterogenous mixture of terrestrial, freshwater and brackish species. The last group, which includes *Hydrobia* spp. and *Ovatella myosotis* as well as two extinct taxa, *Ellobium pyrimidale* and *Cerithium tricinctum*, constitutes by far the largest proportion and suggests proximity to estuarine or saltmarsh habitats. This conclusion therefore supports the interpretation that these sediments 'accumulated on a sheltered or wadden-area tidal flat with reduced salinity and temperatures similar to those of modern Boreal seas' (West & Norton 1974). The freshwater species are composed primarily of common palaearctic taxa but also include two forms that are now extinct. *Viviparus medius* is similar to the modern *V. viviparus*, but possesses a smaller, narrower and much more solid shell. It is known from one, or possibly two, Red Crag sites and from many other sites of Norwich Crag age but is unknown thereafter. The *Sphaerium* from Sizewell and certain other Norwich Crag sites (e.g. Thorpe, Bramerton Common, Norfolk and Bulcamp, Suffolk) has recently been recognized as an undescribed species and named *S. icenicum* by Holyoak & Preece (1986). Indeed, the specimen from the Rifle Range was selected as the type specimen, making Sizewell the type locality. A second specimen from Sizewell, this time from the more recent excavations for Sizewell B, has also recently come to light. It is a left valve measuring 11.7 mm × 9 mm, the largest specimen known. It was inadvertently omitted from the paper by Holyoak & Preece (1986). This species is unknown from deposits younger than the Norwich Crag and may therefore have some stratigraphic value. *S. icenicum* has not yet been recognized in The Netherlands where another *Sphaerium* species (as yet undescribed) is also known from the Early Pleistocene (T. Meijer, unpublished information).

I thank Dr P. E. Long and Mr R. A. D. Markham for allowing me to examine material in their possession.

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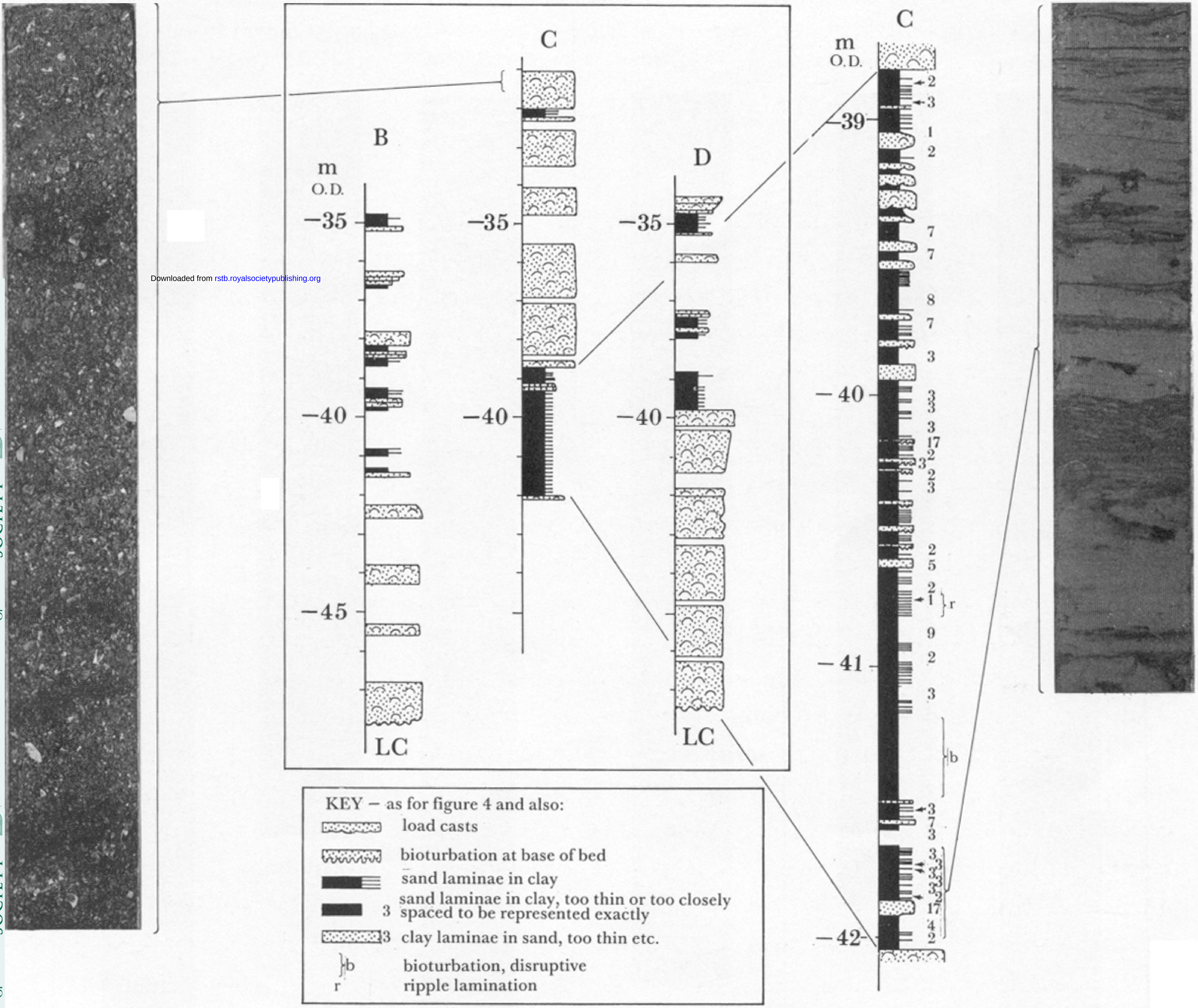

FIGURE 6. Detailed lithology of unit AS-Lith 1.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

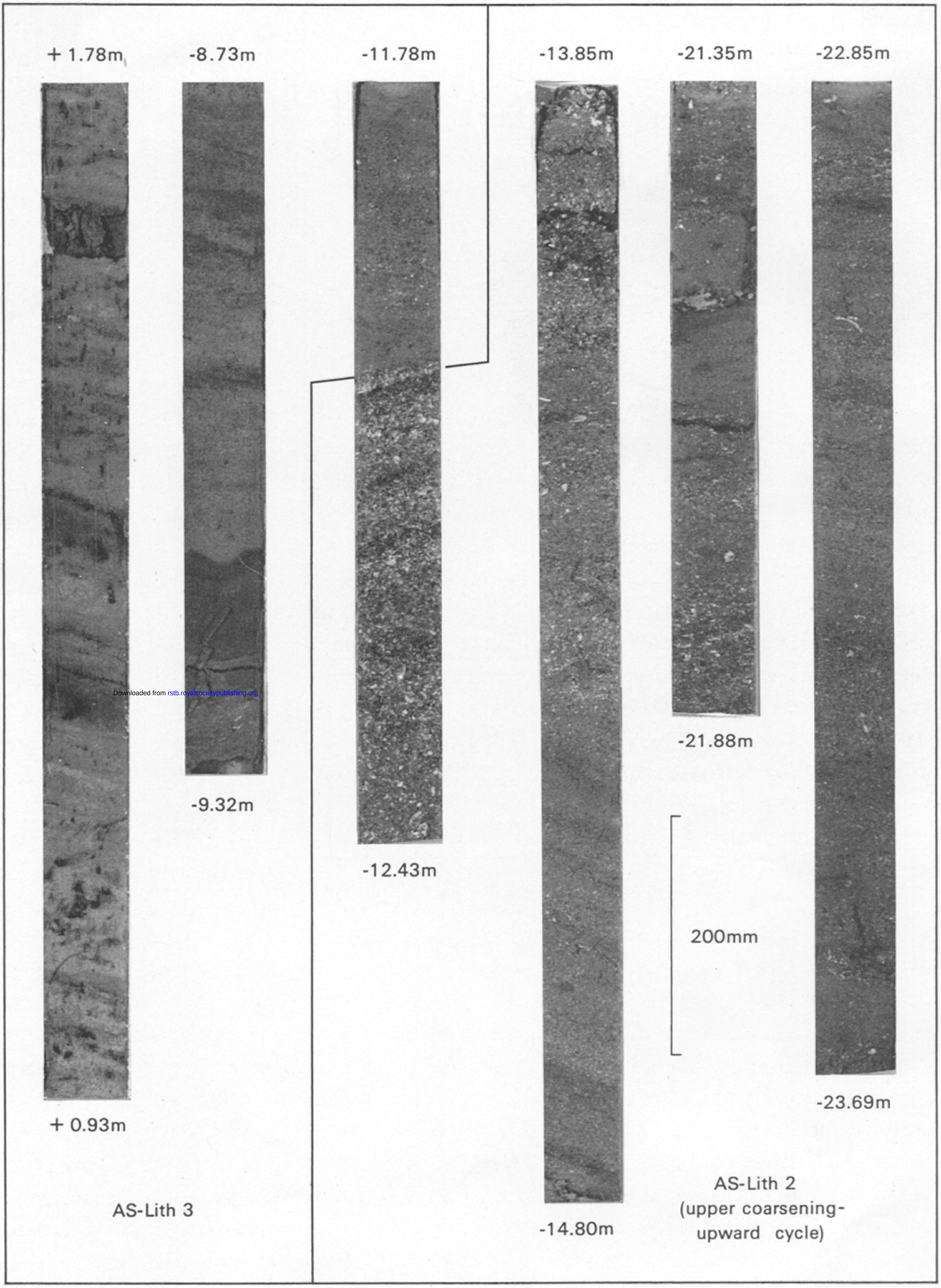

Figure 7. Borehole B: photographs of core material of unit AS-Lith 2 illustrating the coarsening-upwards trend, and of unit AS-Lith 3.