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The Icenian Crag of Southeast Suffolk

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THE ICENIAN CRAG OF SOUTHEAST SUFFOLK

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CONTENTS

Sections in the Icenian Crag at Chillesford, Aldeburgh, Thorpe Aldringham, Sizewell, Dunwich, Wangford and Southwold are described. Pollen and mollusc assemblages from these sites are tabled. The Icenian Crag is shown to contain a temperate pollen assemblage, resulting from a regional deciduous forest of the time. The assemblage is provisionally correlated with the Pastonian stage of the Middle Pleistocene, as *Tsuga* is very poorly represented and *Abies* is absent. The mollusc assemblages are divided into a sublittoral or infralittoral facies, a sheltered estuarine or wadden area facies, an open coast facies and a high-boreal or sub-arctic silty deposit facies, probably infralittoral.

The unconformable relation of the Icenian Crag to Red and Coralline Crags at Chillesford and Aldeburgh and to Baventian sediments at Easton Bavents indicates a strong marine transgression over Lower Pleistocene deposits in Pastonian times. The beach plain of the Westleton Beds is included within this transgressive phase.

Pollen assemblages from deep boreholes at Sizewell and Southwold show that the transgression deposits overlie Lower Pleistocene sediments correlated with the Pre-Ludhamian, Thurnian and Baventian stages.

A correlation is suggested between the Pastonian and the Cromerian III Interglacial of the Netherlands.

1. Introduction

Harmer (1920) described the Icenian Crag of East Anglia as the product of an open and shallow sea, characterized by sands and clays containing an impoverished marine fauna, and sandwiched between the Red Crag, with its much richer fauna, and the Cromer Forest Bed Series. Figure 1 shows the extent of the Icenian Crag in Suffolk and of the Red and Coralline Crags which it overlies to the south. Within the Icenian Crag, Harmer distinguished three horizons: the Norwich horizon at the base, of marine sands; the Chillesford horizon, of estuarine clays; and the Weybourne horizon, of variable lithology, with an abundance of *Macoma balthica* (Linné).

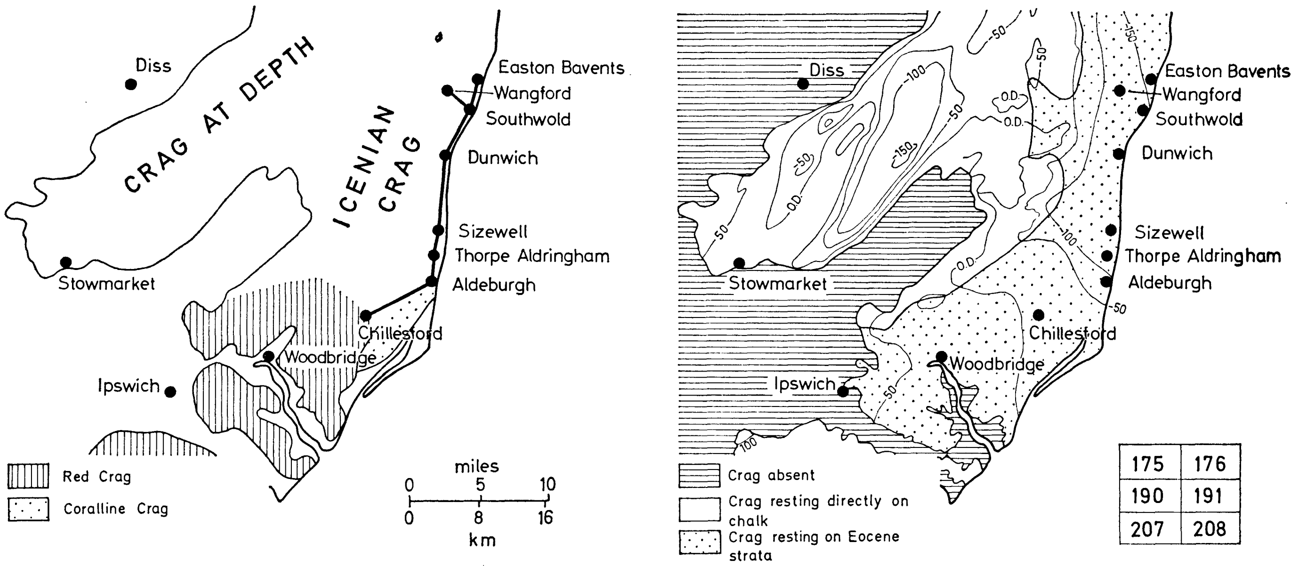

FIGURE 1. Maps of East Suffolk, with sites, outline Crag distribution, contours of the Crag base (after West 1972), and showing the line of section in figure 12.

These Lower Pleistocene marine and estuarine beds have not received much attention since Harmer's time, and their stratigraphical relation to the sequence of cold and temperate stages of the Lower Pleistocene, established in East Anglia in recent years (West 1961, 1972), has remained obscure. Pollen analytical and malacological studies of open sections and boreholes have now been made at several sites in southeast Suffolk, including the type site for the Chillesford horizon, and the results of this work enable a synthesis to be made of the environmental conditions under which the sediments of the Icenian sea were deposited and of the correlation of the sequence with Pleistocene stages already identified elsewhere.

2. Stratigraphy

(a) *Chillesford*

The sections in sandpits around Chillesford Church (figure 2) have been studied for over a hundred years, and there are numerous descriptions in the literature, summarized by Reid (1890). Our own observations of the sections were made in 1958 in a shallow excavation, point X in figure 2, and in 1968, when the pit had been greatly extended and deepened, at points A–F in figure 2. Our observations tally with those of earlier observers. In particular the 1968 sections were deep enough to show the relation between the upper ('*Scrobicularia*') Crag and the Red Crag below, a relation much discussed in earlier literature, because the contact could not be certainly seen in the Churchyard Pit, though Red Crag was known in the neighbouring Stackyard Pit at a lower elevation.

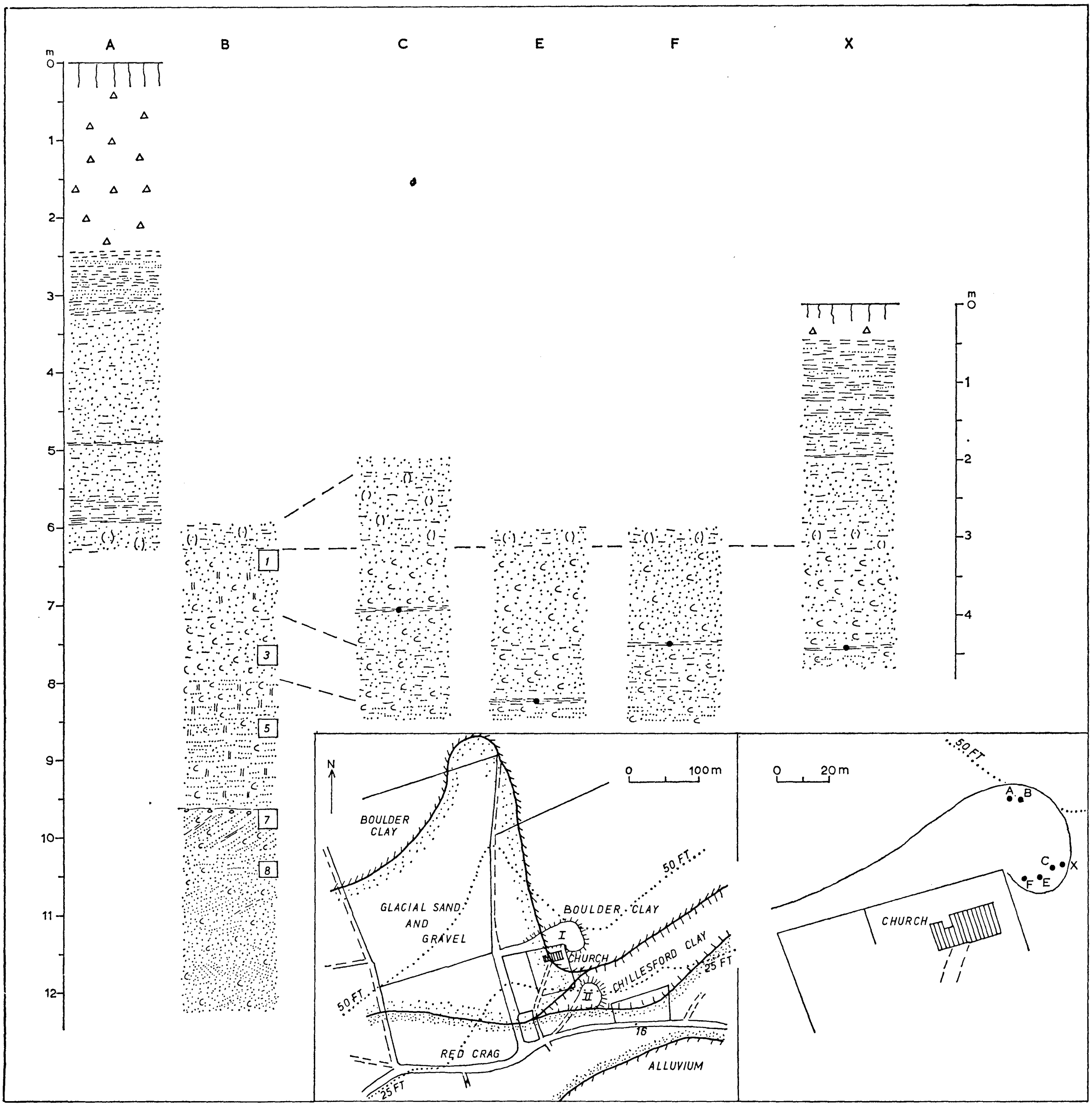

FIGURE 2. Chillesford: map and sections. I and II of the left-hand inset map are the Churchyard and Stackyard pits respectively. Key to symbols in figure 6.

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The section at A and B in 1968 was as follows:

cm	
0–240	soil, then pale brown chalky boulder clay
240–330	laminated grey silty clay, interbedded with brown sand
330–490	brown and pale silty sand
490–491	grey silt
491–558	as at 330–490 cm
558–590	as above but with thin grey silt seams
590–596	grey laminated silt
596–628	brown silty sand, with *Mya* in position of life

At B, 5 m to the east:
0 at 596 cm of section A, at top of *Mya* bed:

cm		
0–30	(596–626 cm)	brown silty sand, with *Mya* in position of life
30–120	(626–716 cm)	brown shelly sand with worm tubes, more ferrugineous at base
120–200	(716–796 cm)	brown silty sand, scattered shells throughout, more shelly at 130, 160 and 195 cm
200–280	(796–876 cm)	brown shelly sand, many worm tubes, generally level-bedded
280–370	(876–966 cm)	brown sand, level-bedded, with worm tubes, less shelly, but with heavily comminuted shells
370–430	(966–1026 cm)	brown-red sand, oblique-bedded, dipping W, with silt partings and comminuted shells; a few pebbles at the top
430–630	(1026–1225 cm)	brown-red sands, more level-bedded, shelly in places; Red Crag with *Neptunea contraria*

The section is drawn in figure 2, which also shows the sampling levels for pollen and molluscs. In general, the sequence shows a series of sublittoral and intertidal sands, with worm tubes, resting on the Red Crag, and overlain by tidal finer laminated sediments towards the top of the section. Details of various sedimentary structures in this section have been given by Dixon (1972). The mollusc analyses described later confirm this interpretation of the sequence.

(*b*) *Aldeburgh*

Sections were sampled at two sites within the Aldeburgh Brickworks (TM 452572), 9 km northeast of Chillesford, at positions shown in figure 3. The westernmost site, A, showed 1.2 m of Icenian Crag overlying Coralline Crag of bryozoan rock-bed type. A 2.5 cm thick horizon of grey-brown silty clay near the base of the Crag yielded a pollen spectrum. The easternmost site, B, showed the following stratigraphy:

cm	
0–25	soil
25–100	pale stony sand, with a concentrate of stones at the base
100–340	grey-brown micaceous silty clay, laminated in places; narrow vertical pockets of sand occur at the top and an ice wedge case was also seen penetrating this silty clay
340–390	brown silty sand and silt with casts of *Mya* in the position of life
390–500	shelly sand (Icenian Crag), with a thin brown silt horizon at 420 cm

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A pollen spectrum was obtained from the silt at 420 cm, and a mollusc sample from the Crag immediately below it. No pollen was found in the grey-brown silty clay.

The sections at Aldeburgh Brickworks show laminated silty clay, similar to that at Chillesford, overlying a *Mya* bed, as at Chillesford. Below the *Mya* bed, at both Aldeburgh and Chillesford, occurs Icenian Crag, with thin silty clays yielding pollen. The Icenian Crag overlies Coralline Crag at Aldeburgh, and Red Crag at Chillesford. The Crag Pleistocene sequence at Aldeburgh thus lithologically and environmentally parallels that at Chillesford, with sublittoral or intertidal shelly sands overlain by finer laminated tidal sediments.

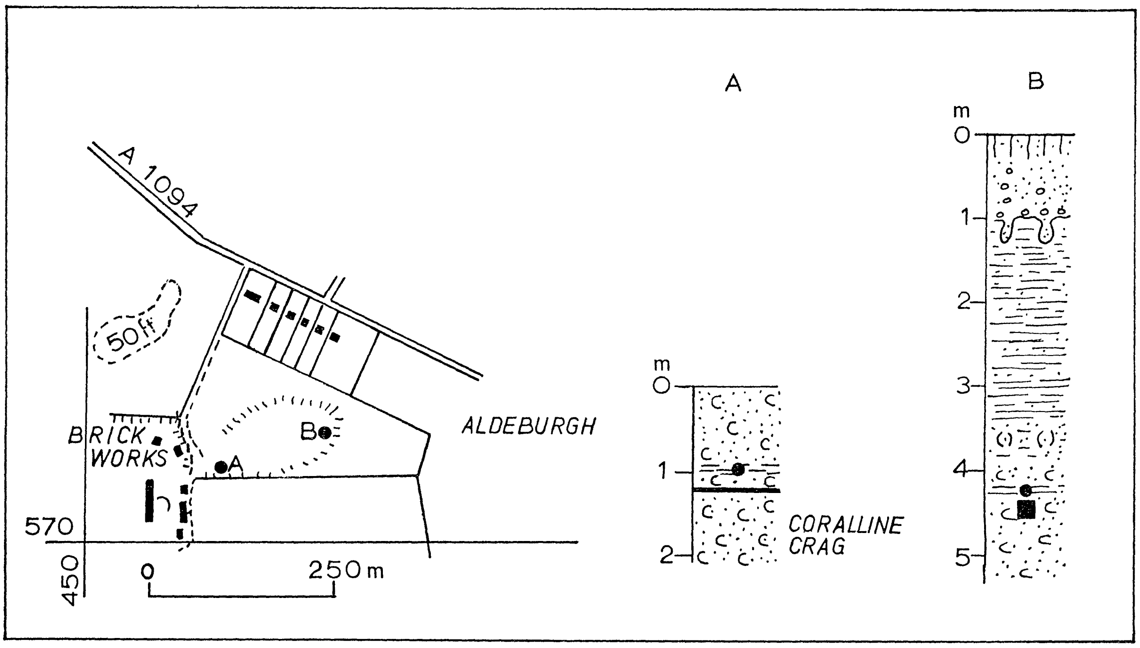

FIGURE 3. Aldeburgh: map and sections. Key to symbols in figure 6.

(*c*) *Thorpe Aldringham*

The old series 1 in geological map of this area (sheets 495 and 505E; Dalton 1886) depicts 'Chillesford Crag' overlying 'Red Crag', as shown in figure 4. The Crag is of Icenian type (Reid 1890). The 'Chillesford Clay' is in the main concealed by glacial sand and gravel, apart from the outcrop shown in the figure. Two sites were chosen for investigation (figure 4), one where Crag is mapped, at an old Crag pit near Shellpit Cottages, and a second at a higher elevation just west of the mapped outcrop of Chillesford Clay.

Shellpit Cottages (TM 46606088). Height 2.32 m O.D. A 250 cm deep 3.5 cm auger hole was made in 1965 in the crag pit at the east margin of the western concrete ramp near its centre point. Very shelly sand was found throughout the auger hole, except at 230 cm where a thin horizon of brown silt was proved. The pollen analysis was made from this silt. Mollusc samples were taken at 30 and 100 cm depth from a hole dug next to the auger hole. In 1970 a 9.1 m (30 ft) deep auger hole was made next to the previous auger hole, proving shelly sand to that depth.

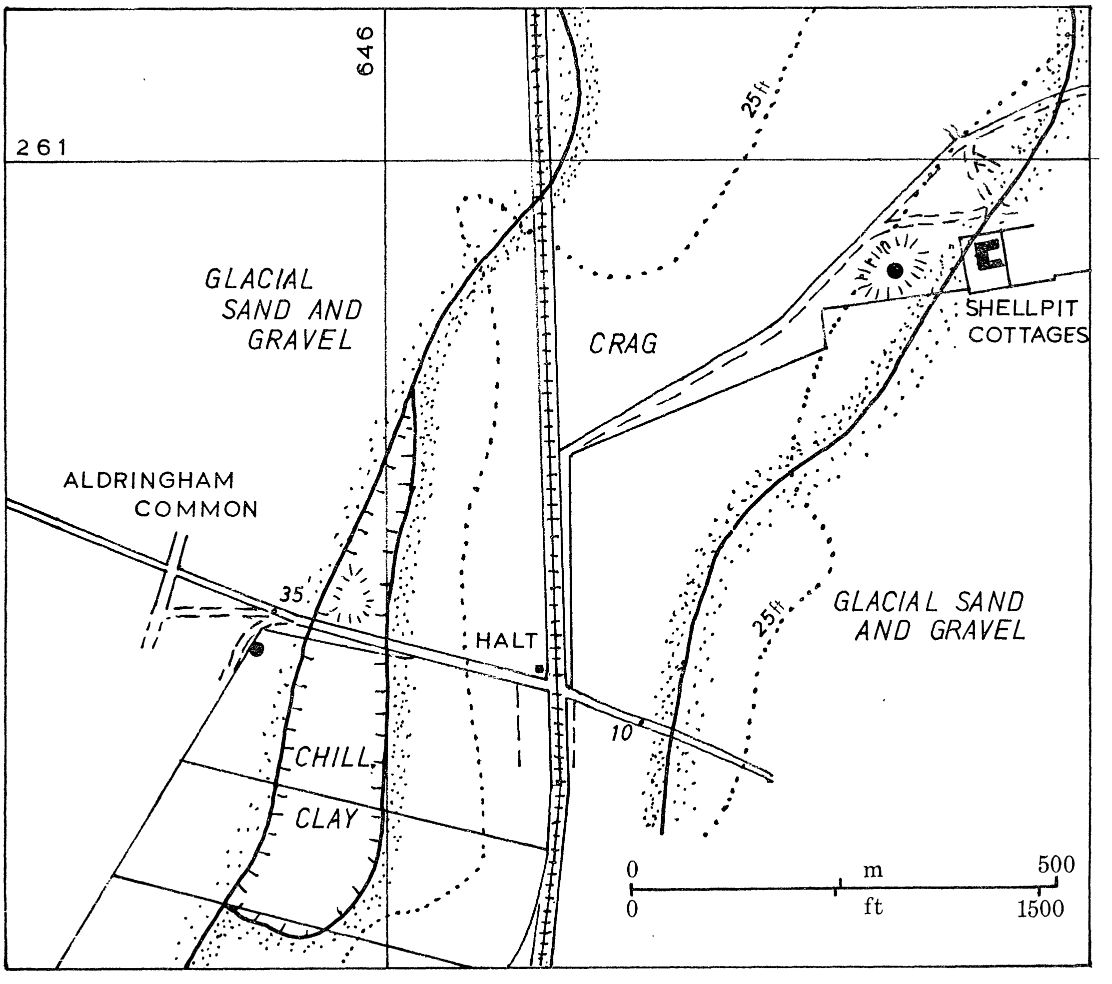

FIGURE 4. Thorpe Aldringham: map and geology.

Aldringham Common (TM 458604). Height 10.84 m O.D. A 9.1 m auger hole was made at the point shown in figure 4, designed to prove a sequence of glacial sand and gravel, 'Chillesford Clay' and Crag. Samples at 0.9 m (3 ft) intervals were found as follows:

m	(ft)	
0.9	(3)	purple podzol-type soil with stones
1.8	(6)	dark brown sand
2.7	(9)	coarse brown sand
3.6	(12)	coarse brown sand with silty pieces from 3.45 m (11.5 ft), at 3.75 m (12.5 ft) clean yellow sand.
4.5	(15)	yellow sand
5.4	(18)	yellow sand; at 6.7 m (20 ft) pieces of clay in brown sand
6.4	(21)	brown sand with silty pieces
7.3	(24)	orange brown sand
8.2	(27)	orange brown silty sand
9.1	(30)	orange brown silty sand

The sand with silts and clays must correspond to the Chillesford Clay of Dalton, but crag mapped as underlying it was not reached. No pollen or molluscs were found at this site.

The section, figure 12, summarizes the map and borehole information in this area. Sands with thin clay and silt layers may overlie crag of Icenian type.

(*d*) *Sizewell*

Sections were seen during the construction of the Sizewell 'A' power station in 1961 and of the 'B' power station in 1970. In addition borehole logs obtained during site investigations were made available by the Central Electricity Generating Board, together with a number of borehole samples.

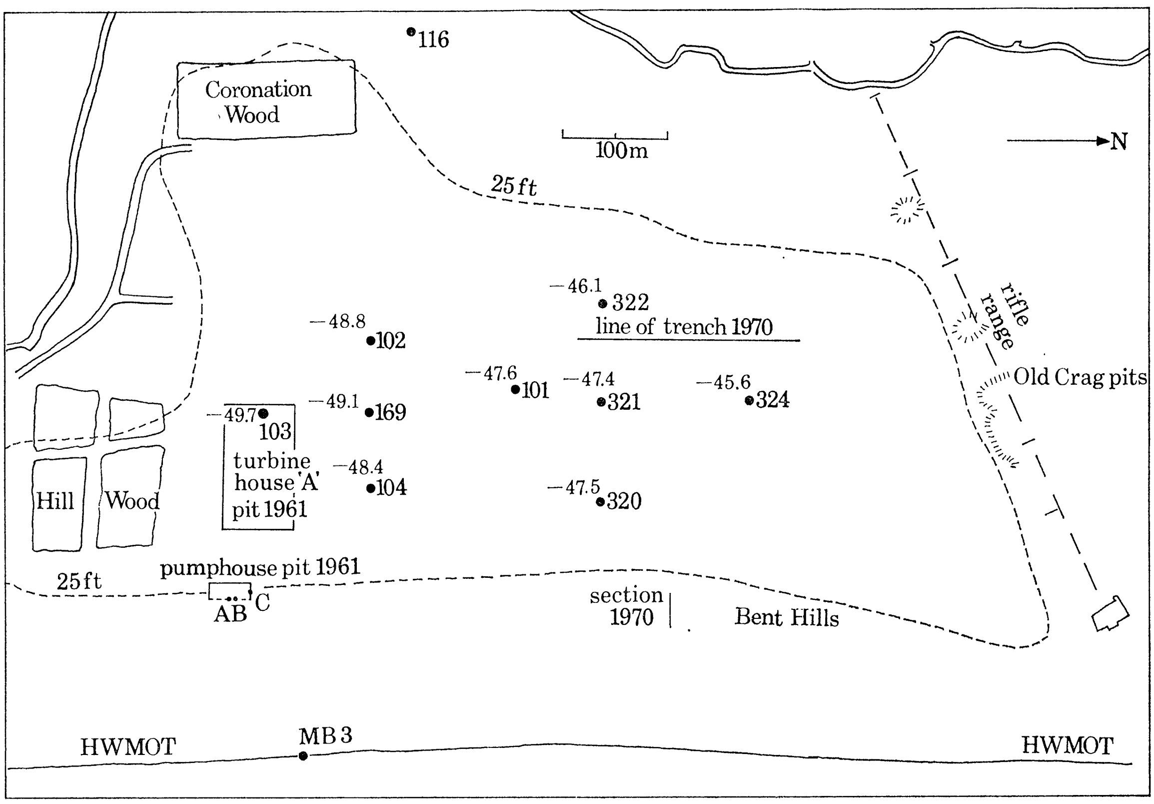

FIGURE 5. Sizewell: locations of 1961 and 1970 sections and boreholes.

(i) *Sections*

The positions of these sections and drawings of them are given in figures 5 and 6.

(1) '*A*' *power station* (1961): *turbine pit*. The north side of the face of the pit was from *ca.* +10m O.D. to O.D. The section showed stratified sands exhibiting current bedding and with laminations of thin brown micaceous silts, in part indurated. From +3 m O.D. to O.D. the silt laminations were more frequent. Vertical structures interpreted as worm tubes were present in the section. The silts of this section did not yield pollen, neither were any molluscs seen. The other three faces of this pit showed a similar section. The sediments indicate an intertidal or sublittoral environment during their formation.

'*A*': *pumphouse pit*. Sections A, B, C (plan in figure 5, sections in figure 6). This pit had been

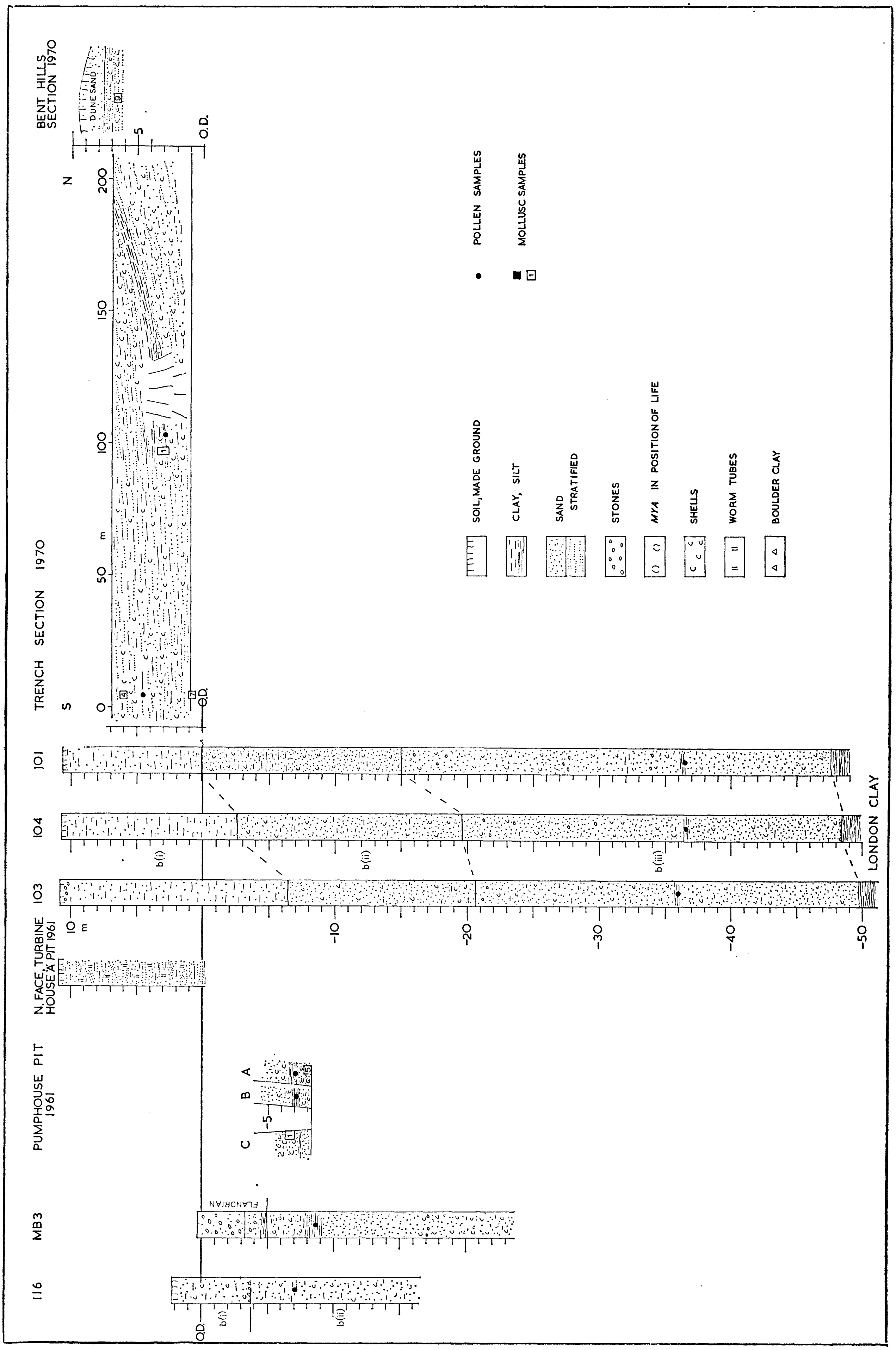

FIGURE 6. Sizewell: sections and boreholes, with key to symbols.

dug to −8.2 m O.D. On the north face of the pit decalcified current-bedded sands with occasional silt horizons were seen at C, then below:

cm	
0–150	brown shelly sand
150–160	grey and rusty silty clay interlaminated with brown sand
160–240	brown sand (240 cm is −8.2 m O.D.)

At A, on the east face of the pit, the following section was observed, depths in metres O.D.:

m	rusty shelly sand
−6.55–6.70	grey and rusty laminated silty clay
−6.70–7.10	yellow and rusty sand with thin grey silty clay horizons
−7.10–8.20	light brown sand with fine shell fragments

At B, 6 m farther N, on the east side of the pit, the same grey and rusty laminated silty clay was seen with a thickness of 40 cm, base at −7.31 m O.D., with yellow brown shelly sand beneath.

Shell samples were taken from below the silty clay in A (−7.4 m) and above the silty clay in C. Pollen was found in a sample of grey silt at −6.7 m O.D. in section A, and in the silty clay at 7.1 m O.D. in section B.

The sediments in these sections again suggest an intertidal or sublittoral environment for their formation.

(2) *'B' power station.* A long north–south trench, depth 6 m, base at +1 m O.D., was examined in 1970. The plan is shown in figure 5 and the drawing of the section in figure 6. The section showed current-bedded shelly sands with laminations of grey-brown silty clay. The positions of pollen samples in these silty clays and mollusc samples from the shelly sands is shown in the section. A further mollusc sample (9) was taken from brown shelly sand at +7 m O.D., 3 m below soil level, in a trench cut east–west through the Bent Hills (plan in figure 5; section in figure 6). As in the turbine pit section of the 'A' power station, with a base also at O.D., the sediments indicate intertidal or sublittoral environment for their formation.

(ii) *Borehole data*

Borehole logs for the site investigations of the 'A' and 'B' power stations and a selection of samples from the 'A' investigations were put at our disposal through the courtesy of the Central Electricity Generating Board. The logs show that the crag at Sizewell overlies London Clay, proved at depths between −45.4 m (149 ft) and −49.7 m (163 ft) O.D., giving a crag thickness of up to 61 m (200 ft) (figure 6).

The crag sediment is mainly sand with shell fragments and occasional thin layers of brown and grey silty clay, often iron-indurated. The subdivision of this sequence is made difficult by the general similarity of the lithology throughout and by the lack of palaeontological data. A subdivision based on lithology was made by the soil investigation contractors (Soil Mechanics Ltd reports 3315 and 3184; G. Wimpey & Co Ltd report S/6517), as follows:

b (i)	brown fine to medium sand with thin layers of brown silty clay with shell fragments below +5 m O.D.	6–17 m thick (average 12 m)

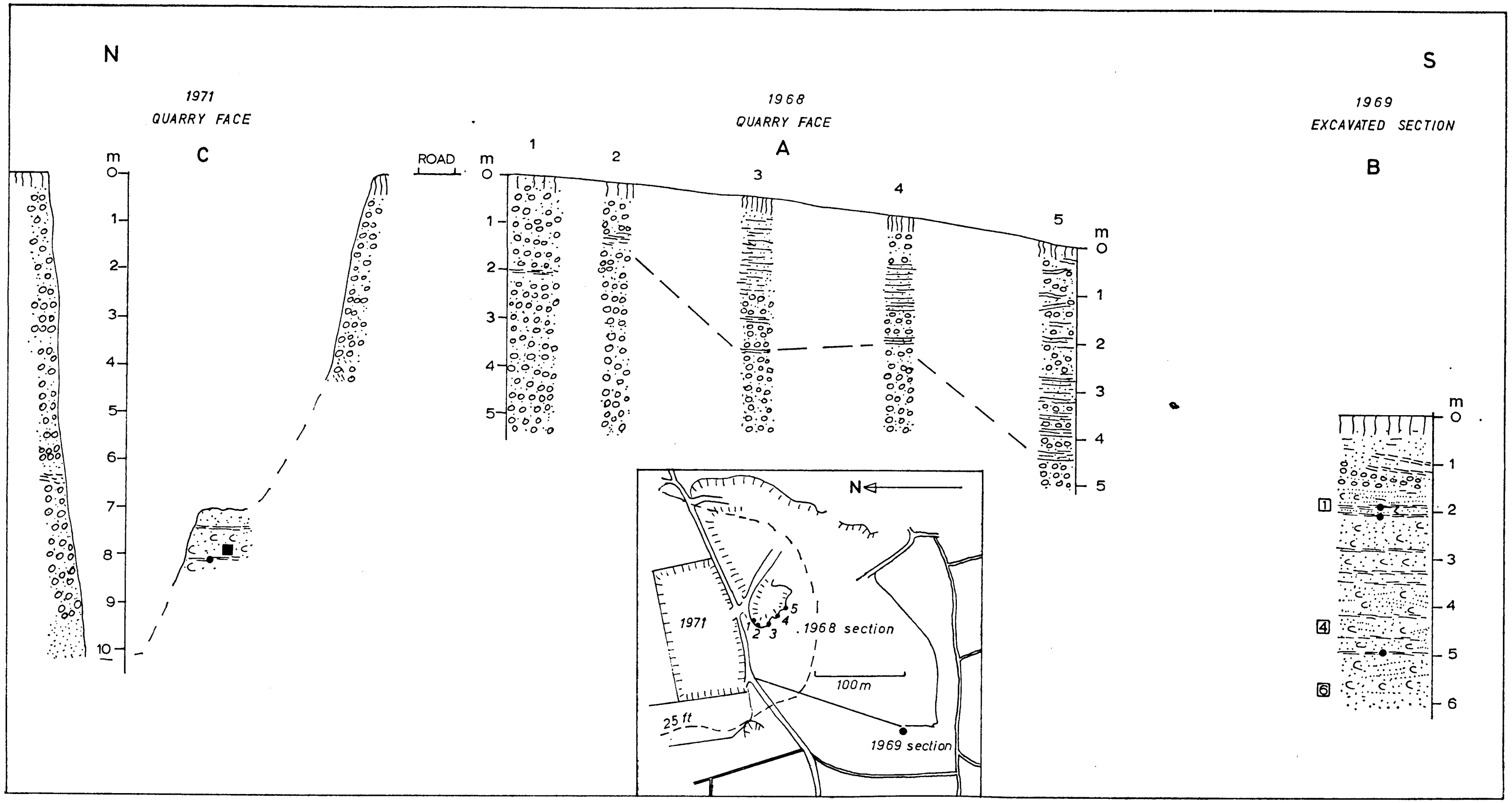

FIGURE 7. Wangford: map and sections. Key to symbols in figure 6.

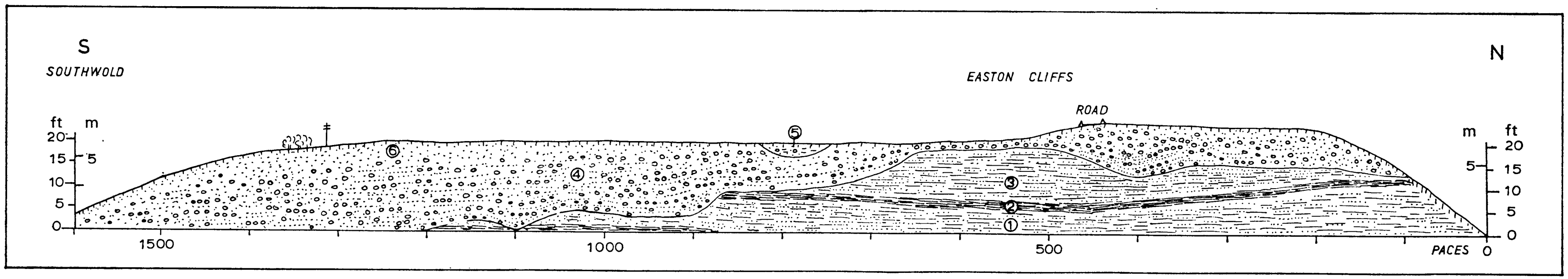

FIGURE 9. Cliff section between Easton Bavents and Southwold in May 1970. Thirty-five paces are equal to 30 m (100 ft). 1, Red and grey stratified sand and silt; 2, laminated blue-grey clay (Baventian); 3, grey and pale stratified sand and silt; 4, pale and red stratified stony sand (Westleton Beds); 5, red stony loam (decalcified till?); 6, recent dune sand.

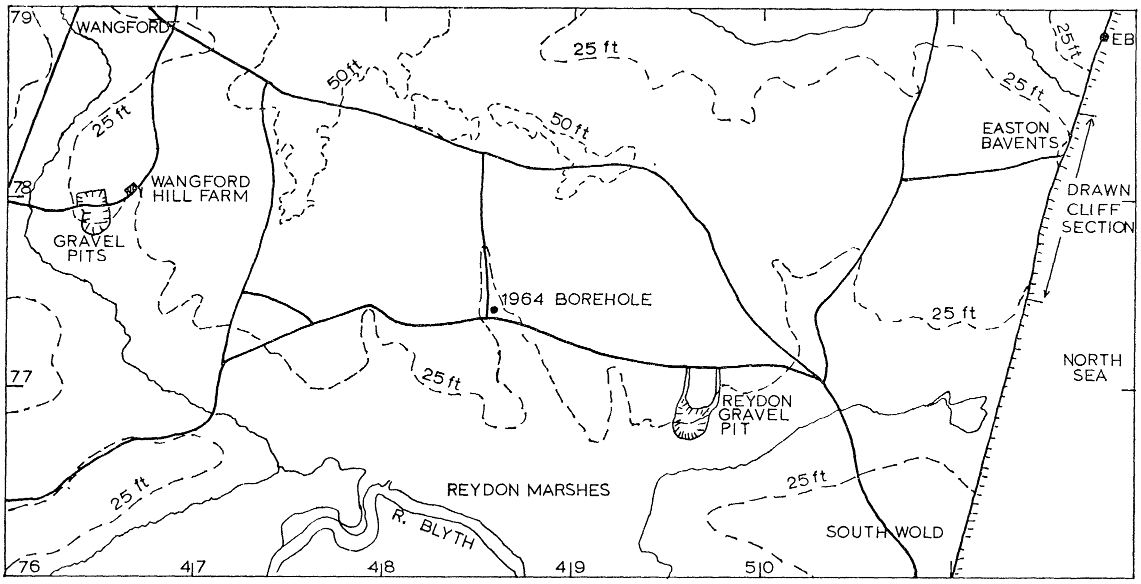

FIGURE 8. Map of Southwold area, showing position of Wangford quarries, the 1964 borehole, the drawn cliff section of figure 9, and the position (EB) of the Baventian type site.

b (ii)	dark brown medium sand with shell fragments and occasional layers of brown silty clay	7–21 m thick; in 'B' investigations, upper surface at −0.3 to −3.7 m O.D. and clay layers thicker and more closely spaced at −5.5–−8.5 m O.D.
b (iii)	grey medium and coarse very dense sand with shell fragments, occasional layers of grey silty clay, and siltstone inclusions. Thin stone bed at base	29–36 m thick: in 'B' investigations distinct upper surface forms ridge at −10.4 m O.D. and drops to −20.7 m O.D.
c	London Clay	

Pollen analyses were obtained from strata b (i), b (ii) and b (iii), and shell samples from b (i) and b (ii). From the pollen analyses (figure 10) it is clear that more than one pollen assemblage zone is represented. The sequence obviously merits more detailed palaeontological investigation with well-documented borehole samples, even though there may be difficulties of interpretation because of sediment reworked from the Pliocene (Coralline) Crag which lies on London Clay and outcrops 2 km to the south.

From the evidence presently available, the whole sequence is clearly of marine origin, with tidal laminated fine sediments occurring in b (i) and b (ii). It is the uppermost horizon, b (i), which can be related to the Icenian Crag sections described from the other sites. The correlation of b (ii) and b (iii) will be discussed in a later section.

(*e*) *Wangford*

Extensive sections have been exposed in the Wangford Hill Farm gravel pit (TM 464779) in the last few years. This pit is mainly in the sandy shingle of the Westleton Beds (Hey 1967; see Plate 13A), but laminated tidal silty clays occur above and within this shingle and shelly Icenian Crag occurs below it. Three sections were examined: the first in the main pit (section A) in 1968, the second in a pit excavated in 1969 to obtain a section of Icenian Crag (section B), and the third in the pit to the north of the road where Icenian Crag could be seen below the Westleton Beds in 1971 (section C). The positions of these three sections is shown in figure 7.

Section A

This section (figure 7) shows the development of laminated tidal silty clays within and above the main thickness of Westleton Beds in the Wangford pit. The tidal sediments thicken towards the south. No pollen or molluscs were found in the sediments of this section.

Section B

A pit was dug by an excavator to expose the Icenian Crag which was known to outcrop on the valley side south of the main pit. The section exposed was as follows;

cm	
0–80	soil, then brown sandy loam
80–83	mottled grey silt
83–110	brown sandy loam
110–112	laminated mottled grey silt
112–120	brown sandy loam
120–150	gravelly sand, partly stratified
150–179	yellow laminated silty sand, with shells
179–610	yellow shelly sand, with a 1 cm thick horizon of brown silt at 200 cm, and thinner brown indurated silts at 190, 270, 325, 340, 410, 460 and 490 cm

It is probable that the silt horizons at 83 and 112 cm and the gravelly sand are the tidal sediments and Westleton Beds better seen in section A.

Section C

On the north side of the road a large pit showed 10 m of sandy shingle of the Westleton Beds underlain by pale shelly sands with red and grey indurated silt layers, as in section B.

The sections at Wangford thus show the relation of tidal sediments and Icenian Crag to the beach plain development which resulted in the formation of the Westleton Beds (Hey 1967).

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(*f*) *Southwold*

A water supply borehole was put down in 1964 at Quay Lane, Reydon, near Southwold (G.R. TM 486776) (figure 8), surface at 4.54 m O.D. The well-sinker's stratigraphy was as follows:

	m	(ft)
topsoil	0–0.9	(0–3)
sand	0.9–1.8	(3–6)
yellow sand	1.8–3.0	(6–10)
light sand	3.0–5.1	(10–17)
red sand	5.1–7.3	(17–24)
ballast	7.3–9.1	(24–30)
blowing sand	9.1–10.8	(30–35.5)
soft brown clay	10.8–11.1	(35.5–36.5)
ballast	11.1–14.2	(36.5–46.5)
blowing sand	14.2–27.4	(46.5–90)
blowing green sand	27.4–28.6	(90–94)
blowing grey sand	28.6–28.9	(94–95)
soft blue clay	28.9–30.1	(95–95.5)
blowing grey sand	30.1–31.0	(95.5–102)
soft blue clay	31.0–31.2	(102–102.5)
blowing grey sand with shells	31.2–35.6	(102.5–117)
soft blue clay	35.6–46.0	(117–151)
grey sand	46.0–50.0	(151–164)
hard blue and brown clay (London Clay)	50.0–52.1	(164–171)

The 'ballast', a term usually applied to the Westleton Beds of the area, may be correlated with the Westleton Beds at similar levels at Reydon, 1 km to the southeast (figure 8), and at Wangford 2 km to the west. Correlation of the beds below the 'ballast', based on pollen analyses from clays below 30 m, is discussed in a later section.

(*g*) *Easton Bavents to Dunwich Cliffs*

The cliff section at Easton Bavents is well known and has been described recently (Larwood & Martin 1953; Funnell & West 1962; Hey 1967). Westleton Bed shingle overlies blue silts and clay of tidal facies, these forming the type sediments for the Baventian stage of the Lower Pleistocene. The cliff section to the south shown in figure 9 was drawn in 1970. It shows the Westleton Beds cutting out the Baventian sediments to the south, so that at Southwold, Westleton Beds occupy the cliff face. The depth reached by the Westleton Beds on the Southwold cliffs accords with depths found in the Southwold Waterworks Borehole in 1886/7 (Whitaker 1887), the first 11.2 m (37 feet) of this borehole at about 12 m (40 ft) O.D. being 'Pebbly Series', and at Reydon 1.5 km inland from Southwold.

The cliff section at Dunwich (figure 12) (Hey 1967), maximum height about 15 m, shows 2–3 m of Westleton Beds, of the shingle facies, at the top, with pale bedded sands with thin red and brown silt horizons below. The silt horizons were found to be barren of pollen. In 1872 crag was found beneath this sand, with a rich mollusc fauna (Whitaker 1887). This has not been seen since.

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3. Palynology

(a) *Introduction*

Twenty-six samples for pollen analysis were taken from marine silts and clay horizons associated with the Icenian Crag in the sections or from the boreholes described above. Samples were prepared by breaking down in dilute HCl, bleaching with sodium chlorate, glacial acetic acid and sulphuric acid, and by removing inorganic fractions with boiling HF and warm dilute HCl. The state of preservation of pollen and spores in the finer sediments of the Crag is not generally good, and considerable numbers of pollen grains and spores were rendered unidentifiable by corrosion and degradation. However, the similarity of the pollen spectra obtained to those already published from the Lower Pleistocene of East Anglia indicates that no great errors have been introduced by deficiencies in the state of preservation.

The results of the pollen analyses are shown in figure 10. The interpretation of pollen spectra from marine sediments is made difficult by the possibilities of reworking and of over-representation by differential rates of transport, and of separating the waterborne from airborne components of the pollen influx. These matters were discussed by West (1961) in respect of the interpretation of the pollen diagram of the Ludham borehole. As with the Ludham diagram, the following interpretation of the pollen spectra is based on the assumption that the pollen influx is generally representative of the regional vegetation. There is support for this assumption in the fact that there is agreement of the evidence for climatic change given by the changes both in generic pollen frequencies and in the a.p./n.a.p. ratio.

(b) *Chillesford Churchyard pit*

Four samples (figure 2) from the Crag at depths 700–850 cm were found to contain pollen. Pollen was not found in the higher silts or Chillesford Clay. The four analyses (figure 10) are generally similar and show high frequencies of arboreal pollen (a.p.), with the genera *Ulmus*, *Quercus*, *Alnus*, *Carpinus*, *Pinus*, *Picea* and *Betula* well represented. Low frequencies of pollen of Gramineae, Ericales and Chenopodiaceae are present, with higher frequencies of Filicales spores. The Dinoflagellate cysts *Operculodinium israelianum* and *Tectatodinium pellitum* are present.

This assemblage reflects the regional presence of largely deciduous forest, growing under temperate conditions of climate. It characterizes a period of marine sedimentation post-dating the Red Crag, and in the following discussion is informally termed the Chillesford pollen assemblage.

(c) *Aldeburgh*

Two horizons of silt associated with Icenian Crag in the brickworks at Aldeburgh (figure 3) were analysed. Their O.D. level, 6–7 m, is very similar to the analysed levels at Chillesford, and the stratigraphy at both sites is similar. The two pollen spectra (figure 10) are similar to the Chillesford pollen assemblage, except for a higher frequency of Ericales in one sample and lower frequencies of Filicales.

(d) *Thorpe Aldringham*

The single sample analysed is associated with the shelly crag of Shellpit Cottages pit at O.D. The spectrum (figure 10) is again similar to the Chillesford pollen assemblage.

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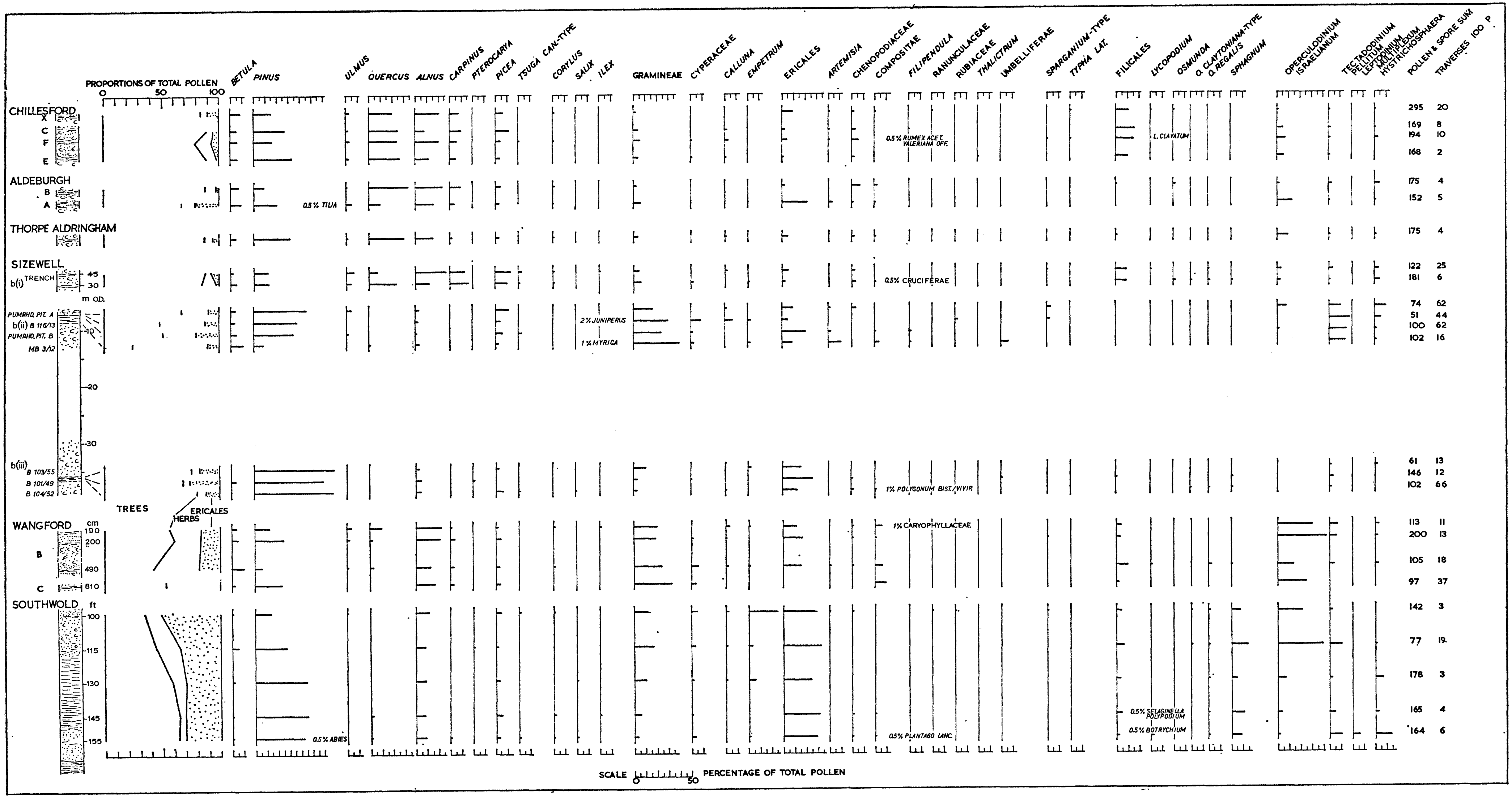

FIGURE 10. Pollen spectra from Crag sites in southeast Suffolk. Key to symbols in figure 6.

(e) *Sizewell*

Two pollen samples from the 1970 trench gave pollen spectra of the Chillesford pollen assemblage type, at levels 3.0–4.5 m O.D. This level is contained within the sequence of sediments with tidal laminations of stratum b (i) (figure 6).

Four pollen samples were analysed from silts of stratum b (ii) at Sizewell, at −7 to −9 m O.D. This group of pollen spectra is very different from the Chillesford type. They show much higher frequencies of n.a.p., in particular of pollen of Gramineae and Ericales, and a much more restricted representation of tree genera, with the thermophilous genera almost absent. Only *Pinus*, *Picea*, *Betula* and *Alnus* are well represented. *Tectadodinium pellitum* is present in higher frequencies than in the Chillesford assemblage. In the pollen diagram the four samples are placed in order of O.D. depth, but this order is unlikely to be correct as each sample is from a different section or borehole. Within the group of four, the basal sample (MB 3/12) shows the highest n.a.p. frequency (75 %) and this high n.a.p. and the tree genera represented make the spectrum similar to those from sediments of the Baventian cold stage, pollen zone L4b, of the Ludham borehole (West 1961) and Easton Bavents (Funnell & West 1962). The two middle spectra (Pumphouse Pit B and 116/13) show higher frequencies of *Pinus*, and the highest sample (pumphouse Pit A) higher frequencies of *Pinus*, *Picea* and *Ulmus*, and lower frequencies of Gramineae. These three spectra show some resemblance to the zone L4c pollen spectra at Ludham.

Whatever the correct stratigraphical order of the spectra, the upper three provide evidence of a relatively treeless vegetation of a boreal or cooler type, while the lowermost provides evidence of regional herb vegetation with a more severe climate.

The three basal pollen spectra at Sizewell at levels between −36 and −37 m O.D. are from stratum b (iii) and are different from those related to b (i) and b (ii). They show very high frequencies of *Pinus*, with *Alnus* and *Picea* poorly represented. The Ericales frequencies are between 10 % and 25 % and the Gramineae frequencies rather lower. The spectra indicate the regional presence of coniferous woodland of a cool temperate type. They are similar to spectra described from −15 to −38 m O.D. in the basal part of the deep borehole at Stradbroke Priory, Suffolk (Beck, Funnell & Lord 1972).

(f) *Wangford*

Three samples were obtained from silts in the crag of the 1969 excavation, B, and one from silt in the crag at the base of the quarry, C. The pollen spectra show quite high frequencies of n.a.p. (39–57 %), but the a.p. genera present, as well as including those genera normally well represented in high n.a.p. spectra in the East Anglian Pleistocene, *Pinus*, *Betula*, *Picea* and *Alnus*, also show *Ulmus*, *Quercus* (except spectrum C) and *Carpinus*. The absence of *Quercus* from spectrum C, even though *Alnus* and *Carpinus* are present, may be the result of oxidation. The sample was from a thin red silt indurated by iron oxide. Thus there is evidence for regional deciduous forest, though the pollen frequencies are depressed by high frequencies of Gramineae and Ericales. The spectra are, therefore, not similar to the Chillesford assemblage, but they resemble it, rather than the high n.a.p. type of Sizewell stratum b (ii).

Of the Chillesford type assemblages, the Wangford spectra most resemble the spectrum from Aldeburgh A with relatively high Ericales frequencies. They do not resemble so closely the pollen spectra associated with crag at the Easton Bavents type section 5.5 km to the east. This crag lies below the Baventian clay which underlies Westleton Beds at the cliff section. The pre-Baventian spectra show 20–30 % *Tsuga* pollen, and a transitional spectrum shows high frequencies of *Pinus* and *Picea*, very low frequencies of *Ulmus*, *Quercus* and *Carpinus*, and high frequencies of the cysts of *Tectadodinium pellitum*. The Wangford spectra show high frequencies of *Operculodinium israelianum*.

(*g*) *Southwold*

Five samples from the water supply borehole at Reydon, near Southwold were analysed. The pollen spectra (figure 10), depths −25.9 to −42.7 m O.D. show rising frequencies of n.a.p., principally Ericales, with *Pinus*, *Picea*, *Alnus* and *Betula* as the main a.p. genera. This constitution, together with the scarcity of *Tsuga*, suggest a correlation of the borehole sequence with a high n.a.p. stage of the Lower Pleistocene. The spectra are in fact very similar to those of zone L 2 of the Ludham borehole (West 1961). Thus the trend of rising Ericales frequencies and falling *Pinus* frequencies are common to zone L 2 and the Southwold spectra. The Dinoflagellate assemblage are also similar with *O. israelianum* more abundant than *T. pellitum*, and *Leptodinium multiplexum* at the base.

(*h*) *Correlation of the Chillesford pollen assemblage*

Ths temperate deciduous forest pollen assemblages of the Chillesford type must belong to a temperate stage in Middle to Lower Pleistocene. As at present known, the two oldest temperate stages of the Ludham sequence, the Ludhamian and the Antian, both contain considerable frequencies of pollen of *Tsuga*. Few grains of *Tsuga* were encountered in the spectra of the Chillesford assemblage, and this makes a correlation with the Ludhamian or Antian improbable. A correlation with a post-Baventian temperate stage is therefore indicated, either with the Cromerian or Pastonian temperate stages. The Chillesford assemblage shows a major dissimilarity with the Cromerian assemblages in the scarcity of *Tilia* pollen and absence of *Abies* pollen. *Abies* pollen frequencies are relatively high in the marine facies of the Cromerian. On the other hand, the Chillesford assemblage is similar to pollen spectra from Pastonian sediments on the Norfolk coast (West 1972). These characteristically show *Pinus* with the deciduous forest genera, *Ulmus*, *Quercus*, *Alnus* and *Carpinus* (but not *Tilia*). Pollen of *Tsuga* occurs sporadically in the later half of the stage. It is concluded, therefore, that the Chillesford assemblage should be provisionally correlated to the Pastonian.

But it should be stated that in the Netherlands three temperate stages have been identified in the Dutch 'Cromerian' (Zagwijn, van Montfrans & Zandstra 1971) and it is possible that the Chillesford assemblage is to be correlated with a temperate stage known from the Netherlands but as yet not identified in East Anglia.

(*i*) *Conclusions*

The pollen spectra from the Icenian Crag localities at Chillesford, Aldeburgh, Thorpe Aldringham and Sizewell were deposited in a period with regional temperate deciduous forest, at a time provisionally correlated with the Pastonian stage of Norfolk. At Sizewell the sediments of this period are underlain by sediments with herb-dominated pollen spectra correlated with the Baventian stage. At depth at Sizewell, conifer-dominated spectra are correlated with the Pre-Ludhamian stage.

At Wangford, pollen spectra from crag below the Westleton Beds are tentatively correlated with those showing the Chillesford assemblage. At Southwold, pollen spectra very similar to those of zone L2 (Thurnian stage) at Ludham are present at depth. In the Southwold area, therefore, there are sediments correlated with the Thurnian at −25.9 to −42.7 m O.D. in the

Southwold borehole, sediments correlated with the Antian and Baventian at 1–6 m O.D. at Easton Bavents (Funnell & West 1962), and sediments correlated with the Pastonian at Wangford at 2–6 m O.D.

4. Marine mollusc assemblages

(a) *Analyses*

Nineteen mollusc samples are discussed, from the levels already detailed at Chillesford, Aldeburgh, Thorpe Aldringham (Shellpit Cottages), Sizewell 'A' (sections A and C), Sizewell 'B' and Wangford (sections B and C). Bulk samples of several kilogrammes were subdivided to provide about 1 kg and analysed, by means of the method described by Norton (1967). Sieves with apertures of 3350, 2000, 420 and 250 μm were used. Cumulative curves for certain

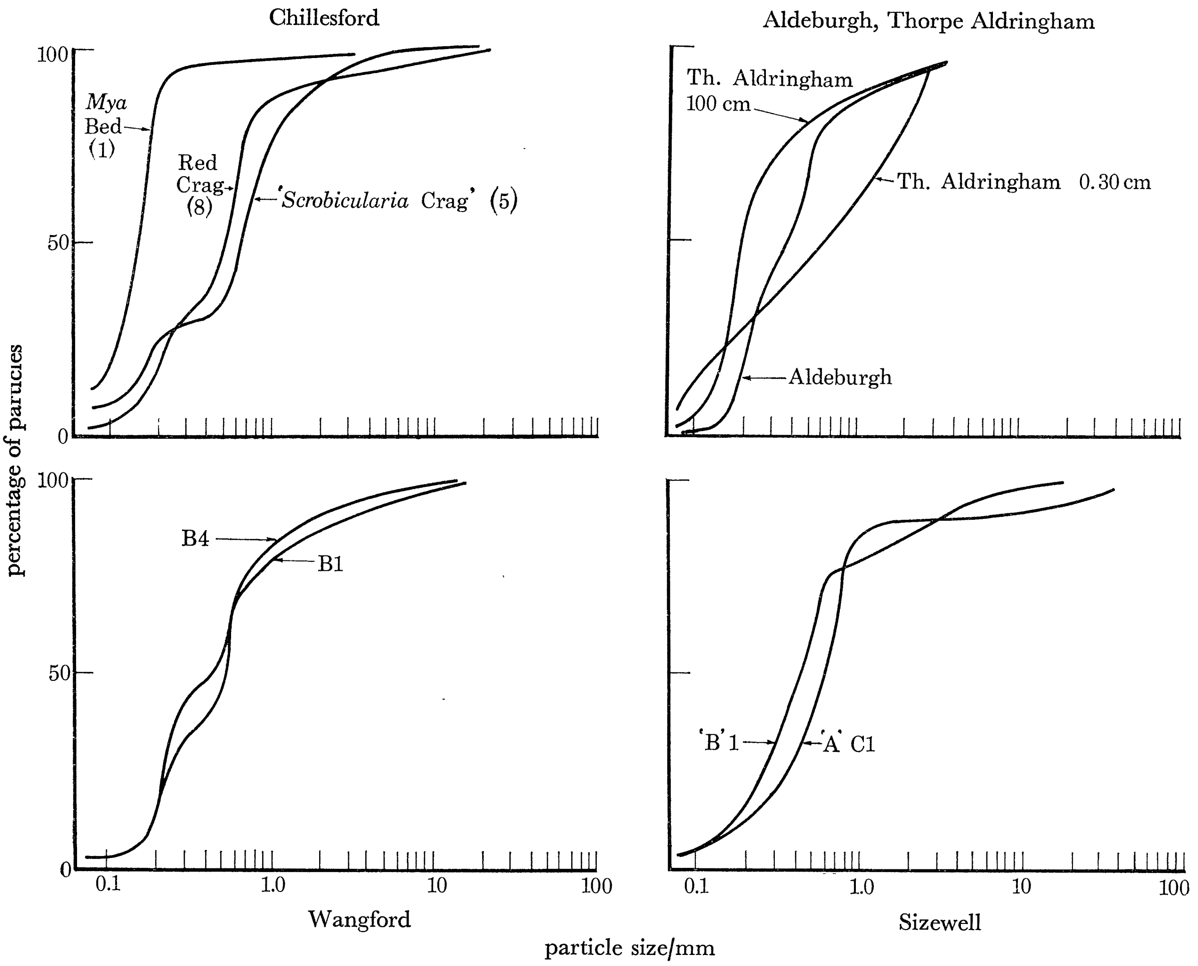

Figure 11. Particle size analyses of Crag sediments in southeast Suffolk. Vertical scale shows percentage of particle not larger than the sizes (mm) on the horizontal scale.

of the fossiliferous sediments are shown in figure 11. The results of counting the shells are shown in table 1. The fossil mollusc assemblages were found to correspond to present-day boreal assemblages, categorized in table 2. An exception is the Chillesford *Mya* Bed assemblage which contains arctic elements.

Table 1. Analysis of mollusca†

		Mya Bed	Chillesford 1: 636–696 cm	Chillesford 3: 756 cm	Chillesford 5: 806–826 cm	Chillesford 7: 966–986 cm	Chillesford 8: Red Crag	Aldeburgh	Thorpe Aldringham 0–30 cm	Thorpe Aldringham 100 cm	Sizewell 'B' 6.40–7.00 m O.D. (9)	Sizewell 'B' 5.80–6.40 m O.D. (4)	Sizewell 'B' 2.60–3.60 m O.D. (1)	Sizewell 'B' 1.00–1.05 m O.D. (7)	Sizewell 'A' −6.20 to −7.00 m O.D. (C1)	Sizewell 'A' −7.70 to −8.20 m O.D. (A5)	Wangford C	Wangford B1: 180 cm	Wangford B4: 450 cm	Wangford B6: 610 cm
1	Loricate, indet.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
2	gastropod, indet.	1	4	4	3	15	—	3	1	4	0	0	1	0	10	9	—	0	2	4
3	cf. *Diodora* sp.	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
4	*Fissurella* sp.	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	*Gibbula* sp.	1	—	—	—	—	—	0	—	—	2	0	0	1	—	2	—	—	—	—
6	*Littorina* sp.	—	—	—	—	—	—	—	—	—	1	0	—	—	—	—	2	1	0	—
7	*L. littorea* (L.)	f	—	—	—	—	—	0	6	3	10	0	0	5	—	—	1	2	0	3
8	*L. saxatilis* (Olivi)	—	—	—	—	—	—	—	—	1	0	1	0	—	—	—	1	1	—	—
9	rissoacean, indet.	—	—	—	—	—	—	—	2	0	—	—	—	—	—	—	—	—	—	—
10	*Hydrobia ulvae* (Pennant)	—	—	—	—	—	—	—	63	48	32	76	88	36	—	—	2	—	22	31
11	*Cingula semicostata semicostata* (Montagu)	—	—	—	—	—	—	f	—	—	—	—	—	—	—	—	—	—	—	—
12	*Rissoa* sp.	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
13	*R.* c.f. *obsoleta* (S. Wood)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
14	*Turritella* sp.	—	f	f	1	5	—	f	f	—	—	—	—	—	f	—	f	—	0	—
15	*T. tricarinata tricarinata* (Brocchi)	4	1	1	1	—	*	0	0	—	—	—	—	—	—	—	—	—	—	0
16	*Caecum* sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	f	—	—	—	—
17	*C. mamillatum* (S. Wood)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
18	*Cerithium tricinctum icenicum* (Harmer)	—	—	—	1	—	—	—	0	—	0	0	0	0	—	—	—	—	—	0
19	*Triphora* c.f. *perversa* (L.)	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20	*Epitonium clathratulum minutum* (Sowerby)	—	—	—	—	—	—	9	—	—	—	—	—	—	—	—	—	—	—	—
21	*Calyptraea chinensis* (L.)	4	—	1	1	2	—	6	—	—	—	—	—	—	2	1	—	—	0	0
22	*Natica* sp.	1	—	—	1	—	—	0	0	0	0	0	—	0	1	—	1	—	0	0
23	stenoglossan indet.	1	—	—	—	—	—	f	—	—	—	—	—	—	—	—	1	—	—	—
24	*Thais lapillus vulgaris* (S. Wood)	—	f	1	1	f	*	0	1	—	—	0	—	—	f	—	1	0	0	1
25	*Neptunea antiqua* (L.)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
26	*N. contraria* (L.)	—	—	—	—	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—
27	*Buccinum undatum* (L.)	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	*Nassarius* sp.	—	—	—	f	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	c.f. *Actaeon* sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—
30	*Ringicula buccinea* (Brocchi)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
31	*Retusa* sp.	—	—	—	—	—	—	0	0	3	7	5	3	5	—	—	—	—	—	1
32	*R. alba* (Kanmacher)	—	—	—	—	—	—	—	—	—	—	0	0	5	—	—	—	—	2	—
33	pyramidellid indet.	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	1
34	*Chrysallida indistincta* (Montagu)	—	—	—	—	—	—	—	—	—	—	f	—	—	—	—	—	—	—	—
35	*C.* c.f. *indistincta*	—	—	—	—	—	—	—	0	—	—	—	—	—	—	f	—	—	—	—
36	*C. spiralis* (Montagu)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
37	*Odostomia* sp.	—	—	—	—	—	—	0	—	—	—	—	—	—	—	f	—	—	—	—
38	*Eulimella* sp.	—	—	—	—	—	—	—	—	—	0	—	0	—	—	—	f	—	0	0
39	c.f. pteropod indet.	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	*Planorbis planorbis* (L.)	—	—	—	—	—	—	—	—	—	—	0	0	—	—	—	—	—	—	—
41	*Succinea pfeifferi* Rossmässler	—	—	—	—	—	—	—	—	—	0	0	0	—	—	—	—	—	1	—
42	*Trichia hispida* (L.)	—	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—
43	*Dentalium* sp.	—	—	—	—	f	—	—	—	—	—	—	—	—	—	—	—	—	—	—
44	bivalve indet.	4	23	16	11	21	—	3	2	5	2	0	0	—	20	14	—	5	2	2
45	*Nucula* sp.	6	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—
46	*N.* c.f. *nucleus* (L.)	1	—	—	—	—	—	f	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 1 (*cont.*)

		Mya Bed	Chillesford 1: 636–696 cm	Chillesford 3: 756 cm	Chillesford 5: 806–826 cm	Chillesford 7: 966–986 cm	Chillesford 8: Red Crag	Aldeburgh	Thorpe Aldringham 0–30 cm	Thorpe Aldringham 100 cm	Sizewell 'B' 6.40–7.00 m O.D. (9)	Sizewell 'B' 5.80–6.40 m O.D. (4)	Sizewell 'B' 2.60–3.60 m O.D. (1)	Sizewell 'B' 1.00–1.05 m O.D. (7)	Sizewell 'A' −6.20 to −7.00 m O.D. (C1)	Sizewell 'A' −7.70 to −8.20 m O.D. (A5)	Wangford C	Wangford B1: 180 cm	Wangford B4: 450 cm	Wangford B6: 610 cm
47	*N. cobboldiae* (Sowerby)	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
48	*Yoldia* sp.	—	—	1	—	—	—	0	0	0	0	—	—	—	2	—	1	0	0	0
49	*Y. lanceolata* (Sowerby)	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50	*Y.* c.f. *lanceolata*	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
51	*Y.* c.f. *myalis* (Couthouy)	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
52	*Glycymeris* sp.	—	1	1	1	—	—	0	—	0	—	—	—	—	—	—	—	—	—	—
53	c.f. *Modiolus* sp.	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
54	*Mytilus edulis* L.	2	3	2	3	3	*	17	1	1	4	2	1	1	1	f	4	1	1	2
55	pectinid indet.	—	—	—	—	f	—	—	—	—	—	—	—	—	—	—	—	—	—	—
56	*Chlamys* sp.	—	—	—	—	—	—	f	—	—	—	—	—	—	—	—	—	—	—	—
57	*C. opercularis* (L.)	—	—	1	—	—	—	0	—	—	—	—	—	—	f	—	—	—	—	—
58	*C. varius* (L.)	—	—	—	1	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—
59	*C.* c.f. *varius*	—	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60	*Anomia* sp.	0	1	f	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
61	*Ostrea* sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—
62	*Laevastarte* sp.	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
63	*Astarte* sp.	—	5	1	2	1	—	0	—	0	—	—	—	—	8	1	—	—	—	—
64	*A.* c.f. *montagui* (Dillwyn)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	0	—	—
65	*A.* c.f. *omalii* de la Jonkaire	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
66	*Cardita* sp.	—	—	—	2	f	*	—	—	—	—	—	—	—	—	—	—	—	—	—
67	c.f. *Cardita* sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
68	*C. corbis* Leathes	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
69	*Arctica islandica* (L.)	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—	0
70	*Lucina borealis* (L.)	—	—	—	—	—	—	0	—	—	0	—	—	0	—	—	—	0	—	0
71	*Divaricella* sp.	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
72	erycinid indet.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—	0
73	*Lepton* sp.	—	—	—	—	—	—	—	—	—	1	0	—	2	—	—	—	—	—	—
74	*Lepton* or *Montacuta* sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—
75	*L. nitidum* Turton	—	—	—	—	—	—	0	0	0	1	2	0	—	—	—	—	—	—	—
76	*Cardium* sp. *sens lat*	—	1	7	19	12	*	0	—	—	—	—	—	—	—	—	—	—	—	—
77	*Cerastoderma edule* (L.)	—	4	5	1	—	—	1	11	16	21	7	3	28	7	6	20	19	10	11
78	*C.* c.f. *edule*	—	6	—	—	—	*	0	—	—	—	—	—	—	—	—	—	—	—	—
79	*Parvicardium papillosum* (Poli)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
80	*Serripes groenlandicus* (Brugière)	2	—	—	—	—	—	—	—	—	—	0	0	—	—	—	—	—	—	—
81	*S.* c.f. *groenlandicus*	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
82	*Venerid* indet.	—	7	5	9	4	*	0	1	0	0	—	0	—	—	—	—	0	0	0
83	*Venus* sp.	—	—	—	—	—	—	0	—	1	0	0	—	—	—	—	—	—	—	—
84	*V. ovata* Pennant	—	—	—	—	1	—	0	—	0	—	—	—	—	—	—	—	—	—	—
85	*V. imbricata* da Costa	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
86	*Venerupis* sp.	—	2	1	—	1	*	—	—	0	—	—	—	—	9	3	—	—	—	—
87	*V.* c.f. *aurea* Gmelin	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
88	*Spisula* sp.	1	20	21	11	8	—	14	1	1	9	2	0	4	3	4	1	1	1	—
89	*S. subtruncata* (da Costa)	—	—	—	—	—	*	30	0	1	—	—	—	—	2	4	—	—	—	—
90	*S.* c.f. *subtruncata*	—	0	2	2	—	—	—	—	—	1	1	0	6	—	—	—	—	0	1
91	*S. elliptica* (Brown)	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
92	*S.* c.f. *elliptica*	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
93	*S. solida* (L.)	—	—	—	—	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—
94	*Donax* sp.	—	3	—	2	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—
95	*D. vittatus* (da Costa)	—	f	—	—	—	—	—	1	1	—	—	—	—	0	—	27	37	34	25
96	*Abra* sp.	43	13	17	1	22	—	0	—	—	1	1	0	2	—	—	—	1	1	—
97	*A. alba* (W. Wood)	—	—	—	—	—	—	3	—	2	—	—	—	—	26	50	0	—	—	—

TABLE 1 (*cont.*)

		Chillesford							Thorpe Aldringham		Sizewell 'B'				Sizewell 'A'		Wangford			
		Mya Bed	1: 636–696 cm	3: 756 cm	5: 806–826 cm	7: 966–986 cm	8: Red Crag	Aldeburgh	0–30 cm	100 cm	6.40–7.00 m O.D. (9)	5.80–6.40 m O.D. (4)	2.60–3.60 m O.D. (1)	1.00–1.05 m O.D. (7)	−6.20 to −7.00 m O.D. (C1)	−7.70 to −8.20 m O.D. (A5)	C	B1: 180 cm	B4: 450 cm	B6: 610 cm
98	*A.* c.f. *alba*	—	—	—	10	—	*	3	—	—	—	—	—	—	—	—	—	—	—	—
99	*Scrobicularia plana* (da Costa)	—	0	1	—	—	—	—	—	—	0	0	0	—	—	—	1	0	0	1
100	*S.* c.f. *plana*	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
101	tellinid indet.	—	—	—	—	—	—	3	4	7	—	—	—	—	4	1	—	—	—	—
102	*Macoma* sp.	6	—	4	7	f	—	—	—	—	2	0	0	5	—	—	9	4	3	3
103	*M. obliqua* (Sowerby)	—	—	—	1	1	*	1	1	0	—	0	0	0	—	—	1	—	0	0
104	*M.* c.f. *obliqua.*	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
105	*M. calcarea* (Gmelin)	—	—	—	—	—	—	—	—	—	—	1	0	—	—	—	—	—	—	—
106	*M.* c.f. *calcarea*	0	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
107	*M. praetenuis* (Leathes)	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
108	*M.* c.f. *praetenuis*	—	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
109	*Angulus fabulus* (Gmelin)	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—
110	*Hiatella 'arctica'*	0	—	1	f	1	—	0	0	—	1	0	0	1	1	2	1	—	—	0
111	*H.* c.f. *'arctica'*	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
112	*H. 'rugosa'*	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—
113	*Corbula gibba* (Olivi)	1	3	3	4	4	*	0	1	3	2	1	0	0	2	2	25	23	16	12
114	*Sphenia binghami* Turton	—	—	1	—	—	—	0	—	0	0	—	—	—	—	—	—	—	—	—
115	*Mya* sp.	2	0	—	1	—	—	0	1	1	0	0	0	2	—	—	1	3	1	2
116	*M. arenaria* L.	—	—	1	—	f	*	0	0	0	—	—	—	—	1	1	1	—	—	—
117	*M. truncata* L.	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
118	*M.* c.f. *truncata*	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—
119	*Zirfea* sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	1
120	*Thracia* sp.	1	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	0	—	—
121	*T. pubescens* (Montagu)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—
122	*T. phaseolina* (Lamarck)	—	—	—	—	—	—	0	—	—	0	—	—	—	—	—	—	—	—	0
123	*T.* c.f. *phaseolina*	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—

† Symbols: —, absent; *, present (not counted); f, fragments only; 0, less than 1 %. Numerals indicate percentage frequency.

(*b*) *Chillesford Churchyard pit*

'Scrobicularia *Crag*'. Samples 7, 5, 3 and 1 may be treated as a unit (sample 8 is from Red Crag). The assemblage shows a very large number of reworked shells, many from the Red Crag. Of the shells, 91–76 % in the samples are badly abraded. Figure 11 shows particle size analyses for the Red Crag and '*Scrobicularia* Crag'. There is an increase of typically intertidal shells through samples 7, 5, 3 and 1, beginning with 'intertidal' shells half as frequent as 'sublittoral' shells and ending with the converse. However, we are dealing only with small numbers of identifiable shells and this may weaken the argument. The typical boreal *Spisula* spp. and *Corbula gibba* are common here in apparently the same ecological context as *Yoldia* in the *Mya* Bed above, indicating the presence of boreal palaeotemperatures.

Mya *Bed*. Deposition of the shells in the *Mya* Bed is partly autochthonous, but mainly allochthonous. *Mya truncata* was observed in the life position. With *Turritella tricarinata*, *Nucula nucleus*, *Yoldia myalis* and *Corbula gibba*, it composes 21 % (nearly three quarters of the 'informatives') of the assemblage. The sediments are of fine-grained type (figure 11) with shell fragments, as

TABLE 2. MOLLUSCA GROUPED FOR PALEOECOLOGICAL INTERPRETATION

(The numerals refer to table 1. Only the most frequent Mollusca are listed under each group.)

	Chillesford						Aldeburgh	Thorpe Aldringham		Sizewell 'B'				Sizewell 'A'		Wangford			
	Mya Bed	1: 636–696 cm	3: 756 cm	5: 806–826 cm	7: 966–986 cm	8: Red Crag		0–30 cm	100 cm	6.40–7.00 m O.D. (9)	5.80–6.40 m O.D. (4)	2.60–3.60 m D.O. (1)	1.00–1.05 m O.D. (7)	−6.20 to −7.00 m O.D. (C1)	−7.70 to −8.20 m O.D. (A5)	C	B1: 180 cm	B4: 450 cm	B6: 610 cm
non-marine: 40, 41, 42 *Planorbis, Succinea, Trichia*	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	1	—
intertidal																			
rocks: 7, 8, 36, 54 *Littorina, Mytilus*	2	3	2	3	3	—	17	7	5	14	3	2	6	—	—	6	4	2	5
sand (esp. reduced salinity): 10, 99, 100 *Hydrobia, Scrobicularia*	—	—	1	—	—	—	—	63	48	32	76	88	36	—	—	3	—	22	32
sand (reduced or normal salinity): 32, 77, 78 *Cardium, Retusa*	—	10	5	1	—	—	1	11	16	21	7	3	33	7	6	20	19	12	11
intertidal (E.L.W.S.) and shallow sublittoral sand: 87, 95, 116 *Venerupis, Donax, Mya arenaria*	—	—	1	—	—	—	—	2	3	—	—	—	—	1	1	28	37	34	25
muddy: 117, 118 *Mya truncata*	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
total shallow marine	5	13	9	4	3	—	18	83	72	67	86	93	75	8	7	57	56	70	73
sublittoral																			
infaunal																			
mud without stones, etc.: 15, 46, 64, 70, 97, 98, 109, 121 *Turritella, Abra*	5	1	1	11	—	—	7	—	2	—	—	—	—	26	50	—	—	—	—
mud with stones, etc.: 51, 69, 81, 89, 90, 91, 92, 105, 106, 113, 122 *Yoldia, Spisula, Corbula*	13	3	7	6	4	—	32	1	4	5	2	1	6	4	6	25	23	16	14
wide tolerance: 84 *Venus ovata*	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
epifaunal																			
stones, etc.: 19, 21, 57, 58, 59, 60, 61, 110 *Calyptraea, Hiatella 'arctica'*	4	—	3	2	3	—	7	—	—	1	—	—	1	4	3	1	—	—	1
boring: 111, 112, 114, 119 *Hiatella 'rugosa', Sphenia*	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
with echinoderms: 75 *Lepton nitidum*	—	—	—	—	—	—	—	—	—	1	2	—	—	—	—	—	—	—	—
total sublittoral	22	4	12	19	8	—	47	1	6	7	4	1	7	37	59	26	23	16	15
uninformative categories																			
incompletely determined: 1, 2, 3, 4, 5, 6, 9, 12, 14, 16, 22, 23, 28, 29, 31, 33, 43, 44, 45, 48, 52, 53, 55, 56, 60, 61, 62, 63, 66, 67, 72, 73, 74, 76, 82, 83, 86, 88, 94, 96, 101, 102, 115, 119, 120	67	82	79	73	89	—	31	14	24	26	11	7	22	57	33	17	17	14	16
not known living: 13, 17, 18, 20, 24, 26, 47, 49, 50, 65, 85, 103, 106, 107, 108	4	—	3	3	2	—	11	2	—	—	1	1	1	—	—	2	—	1	2
living, but ecology pooly recorded: 30, 68, *Ringicula buccinea, Cardita corbis*	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
total uninformatives	71	82	82	76	91	—	43	16	24	26	12	8	23	57	33	19	17	15	18

inhabited by these species at the present day. However, 67 % of the assemblage are abraded, no doubt by rolling and redeposition. 5 % (one sixth of the 'informative' shells) of the assemblage are typically littoral or infralittoral, and 22 % (five sixths of the 'informative' shells) are typically sublittoral, indicating a shallow-water sublittoral, perhaps infralittoral, life assemblage. This conclusion is based on the range of the taxa in the boreal seas. If conditions were subarctic, arctic emergence suggests an infralittoral depth estimate.

Yoldia myalis (12 %, just under half of the 'informative' shells) occurs now around North America, south to Massachusetts and Puget Sound (Ockelmann 1954). This suggests palaeotemperatures equivalent to subarctic or high boreal modern seas, colder than those inferred from any of the other assemblages considered.

(*c*) *Aldeburgh*

There is no correspondence between the Aldeburgh sediment (figure 11; '*Scrobicularia* Crag') and the substratum selected by the most common species. Numerous ecotones are represented in the assemblage, with 11 % of extinct shells (mainly *Epitonium clathratulum minutum*; the extant subspecies *E. clathratulum clathratulum* has a Lusitanian distribution) and 1 % of southern forms (*Ringicula buccinea*, *Cardita corbis*). These three species are known from the Coralline Crag but are unusual in the Icenian and derivation is suspected. Thus, the assemblage is allochthonous and varied, with extinct and southern forms (perhaps derived) either because of an exceptionally benign and varied environment or because of derivation from the underlying Coralline Crag. The presence of *Mytilus edulis*, 17 %, indicates deposition in shallow water; *Spisula subtruncata*, 30 %, indicates redeposition of shells derived from one of the dense sublittoral patches formed by populations of this species (Davis 1923). The assemblage is likely to have been formed in intertidal or infralittoral conditions, with palaeotemperatures similar to those of modern boreal seas (perhaps low-boreal).

In the silts at 340–390 cm, casts of *Mya* and *Yoldia* were observed, paralleling the occurrence of these taxa above crag at Chillesford.

(*d*) *Thorpe Aldringham and Sizewell 'B'*

The assemblages are interpreted as having accumulated on a sheltered estuarine or wadden-area tidal flat with reduced salinity and temperatures similar to those of the modern Boreal seas. A sediment analysis from Sizewell is shown in figure 11. *Hydrobia ulvae* and *Cardium edule* dominate the assemblages, with some *Donax*, *Venerupis* and *Mya arenaria*. All these forms are characteristic within the habitat mentioned in the modern Boreal region. Few shells are abraded and unidentifiable which indicates comparatively sheltered conditions. These findings apply to the samples TA 0–30 and TA 100 but the characters mentioned are much more strongly developed in the upper sample. They also apply to Sizewell 'B' samples 4, 1 and 7 and generally to sample 9. At Sizewell 'B' the reduced-salinity tidal flat conditions are most strongly represented in sample 1. There are more *Cardium edule* and worn shells in sample 7. In the highest sample, 9, more of the characteristics of a normal intertidal assemblage appear. There is 10 % of *Littorina littorea* and 4 % of *Mytilus edulis* (epifauna of rock, etc.) and 26 % of abraded shells (particularly *Spisula* sp. – sublittoral – and *Retusa* sp. – usually intertidal).

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(*e*) *Sizewell 'A'*

Sublittoral and allochthonous deposition of the shells is indicated, beds of *Abra alba* having been winnowed and redeposited. A sediment analysis is shown in figure 11. *Spisula*, *Tellina* and other bivalve shells, much abraded, are very common, no doubt due to rolling and redeposition. All these species indicate temperatures similar to those of modern boreal seas.

(*f*) *Wangford*

The assemblages are considered to have formed intertidally, or infralittorally, on an open sea coast, with many sublittoral shells being moved up from stony or shelly muds in deeper water. Sediment analyses are shown in figure 11. The figures indicate a fall in the shallow water category and a rise in the sublittoral category as deposition progressed, though this may be a purely statistical effect due to the disappearance of *Hydrobia ulvae* and thus reflect a change from relatively brackish to more open-coast conditions. Samples B1 and C are considered on the basis of stratigraphy to be the same age, just before the onset of deposition of the Westleton Beds. The close similarity between the molluscan assemblages of these two samples is clearly seen.

(*g*) *Discussion and conclusion*

Each of the assemblages discussed gives a local rather than regional picture of the palaeo-ecological conditions. It is possible to recognize, from the Mollusca, four faunal facies in the deposits concerned.

A

Sublittoral (or infralittoral) facies, in which deposition of shells was allochthonous, and many of the shells abraded in the process. *Abra*, *Spisula* and *Corbula* are particularly common, indicating a life habitat of shallow sublittoral muddy seabeds, with stony or shelly gravel in many places (the shells are deposited in clean, well sorted, fine sand). The deposits are physically similar in appearance at the three sites, with inclined seams of shells, and worm tubes. This facies is seen at Sizewell 'A' (Pumphouse Pit) and Chillesford ('*Scrobicularia* Crag'). If the unidentified *Abra* sp. at Chillesford is *Abra alba* the similarity to the Sizewell 'A' assemblages becomes much greater, though, as described above, the pollen assemblages are very different. Possibly the Aldeburgh '*Scrobicularia* Crag' assemblage is a less worn and more varied expression of the same facies, with a high percentage of *Mytilus* (from shallow water) and extinct shells (perhaps derived).

B

Sheltered estuarine or wadden-area assemblages, as at Wangford B6 and B4, Sizewell 'B' 1 and 4, and Thorpe Aldringham. *Hydrobia ulvae*, the characteristic species, normally indicates reduced salinity. The silts which occur between samples 1 and 4 at Sizewell 'B' and below the shell sample at Thorpe Aldringham both contain the Chillesford pollen assemblage.

C

Open-coast facies, succeeding the sheltered tidal-flat facies, at Wangford B1 and C, and Sizewell 'B' 9. At Sizewell 'B', similar conditions are less clearly displayed in sample 7. Characteristic species are *Littorina littorea*, *Cardium edule*, a few *Hydrobia ulvae* and some *Spisula* and *Corbula gibba*. There are more abraded shells than in the sheltered facies.

D

High-Boreal or subarctic silty deposit facies assemblages, with *Yoldia myalis*, *Mya truncata* (*in situ*) and many worn shells. This is the only assemblage with autochthonous deposition of shells.

These findings are supplemented by published work on nearby sites at Easton Bavents and on Dunwich.

The shelly Crag exposures at Wangford and Easton Bavents are 5 km apart on the ground (figure 8). Both show shelly successions below Westleton Beds (with a thick intervening clay at Easton Bavents). However, the succession of palaeo-environments deduced from the Mollusca at the two sites is not the same. At Wangford, as described above, assemblages interpreted as representing tidal-flat conditions are succeeded by assemblages interpreted as representing open-coast littoral conditions. At Easton Bavents, Norton & Beck (1972) described an assemblage representing open-coast littoral conditions, passing up into others representing infralittoral or inner-sublittoral and sublittoral conditions. Thus the Wangford succession of mollusc assemblages is not regarded as similar to the Easton Bavents succession.

At Dunwich, red sands with shells were seen in the base of the cliff and on the foreshore below the ruined church in 1872. The cliff has since eroded 63 m further inland. Crowfoot & Dowson (1879, quoted by Whitaker 1887) found *Trophon antiquus* L. var. *striatus-contrarius* (= *Neptunea contraria* L. ?) and 41 other species. The list suggests the presence of a Red Crag fauna. These deposits are at the same level as the Icenian Crag at Thorpe Aldringham described above, and deserve reinvestigation in view of their reported mollusc content and stratigraphical position.

5. Discussion and conclusions

(*a*) *Stratigraphy*

Figure 12 shows a long section from Chillesford to Easton Bavents, with all the sites examined levelled to O.D. The identifiable sediment units are labelled at each site, and each sediment unit is labelled with the type of pollen assemblage it contains.

At the southern end of the section, at Chillesford and Aldeburgh the Icenian Crag overlaps the Red and Coralline Crags. The Icenian sea evidently transgressed the older Crags, with a sea-level rise to at least 12 m O.D. This transgression is provisionally correlated with the Pastonian stage, so that a considerable unconformity is present, with much of the Lower Pleistocene missing. Presumably it was in the period of emergence between the deposition of the Red and Coralline Crags and the Icenian Crag that the weathering and oxidation of the Red Crag took place.

To the northeast, the Crag basin deepens rapidly, and at Sizewell the Icenian Crag overlies silts here correlated with the Baventian stage. Further to the north, Westleton Beds overlie Icenian Crag at Dunwich and Wangford, and Baventian deposits at Easton Bavents. There is a clear unconformity between the Baventian sediments and the Westleton Beds. At Wangford the Westleton Beds are associated with Icenian Crag and it appears that the Icenian transgression seen on the southern edge of the basin is represented in the Southwold area by the overlap of the Westleton Beds over the Baventian sediments.

At depth in the Crag basin Pre-Ludhamian and Thurnian sediments have been recognized at Sizewell and Southwold respectively. The Pre-Ludhamian has been correlated with the

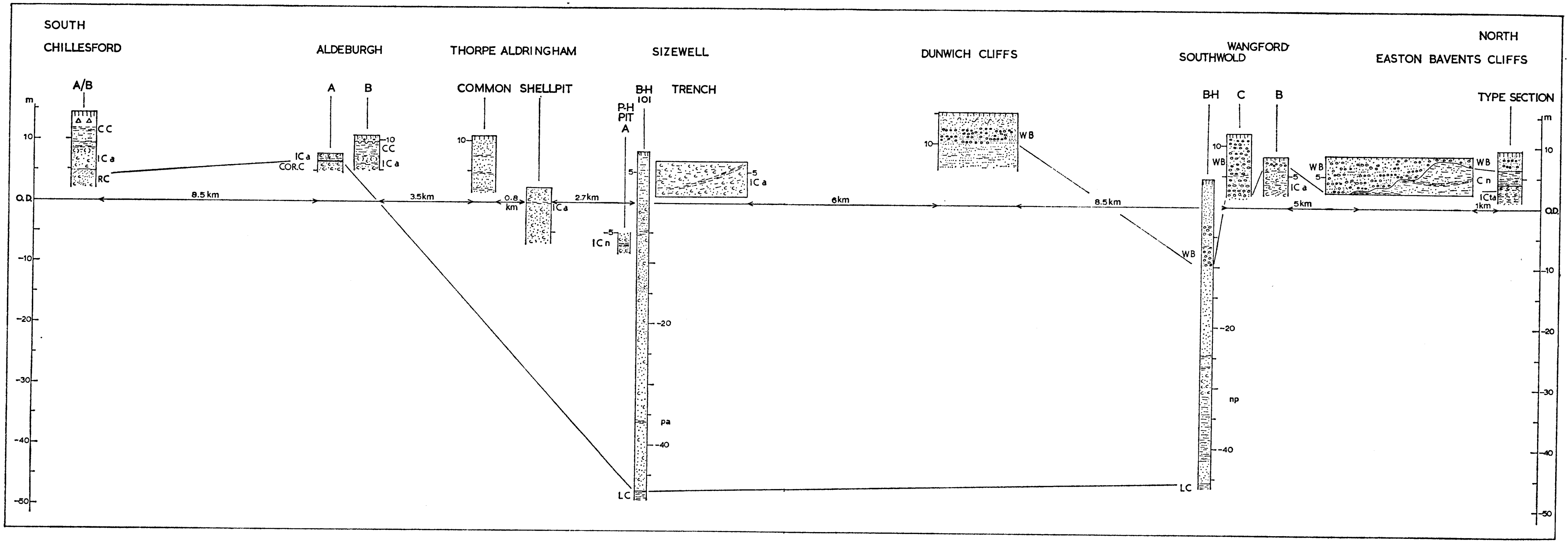

FIGURE 12. Section from Chillesford to Easton Bavents. The line of section is shown in figure 1. Sediment units: LC, London Clay; COR.C, Coralline Crag; RC, Red Crag; IC, Icenian Crag; C, Clay at Easton Bavents (Baventian); WB, Westleton Beds; CC, Chillesford Clay. Pollen assemblages: a, a.p. dominant pollen spectra with mixed oak forest genera; ta, a.p. dominant pollen spectra with *Tsuga* and other conifers; pa, a.p. dominant pollen spectra with *Pinus*; np, pollen spectra with high frequencies of *Pinus* and Ericales; n, n.a.p. dominant pollen spectra.

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Red Crag of southeast Suffolk (Beck *et al.* 1972), so that Red Crag of the type area and its basin-filling equivalent to the northeast were deposited unconformably on the Coralline Crag. The exact relation between the deposits at depth in the Crag basin remain to be investigated in detail, but it appears from the Sizewell and Southwold borehole data that the Pre-Ludhamian sediments are cut out and replaced further north by Thurnian sediments.

(*b*) *Palaeo-environments*

At Chillesford and Aldeburgh the shelly sediments contain a boreal mollusc fauna indicating sublittoral or infralittoral conditions in the Crag facies of the succession. At this time temperate deciduous forest was the regional vegetation. The temperate conditions are born out by the foraminiferal fauna of the 'Chillesford Crag' at Chillesford, described by Funnell (1961) as interglacial in type, with an abundance of '*Rotalia*' *beccarii* indicating a tidal flat or lagoonal environment. The overlying Chillesford Clay contains a fauna suggesting shallowing of the sea, as do the laminated finer sediments overlying the crag at Chillesford and Aldeburgh, with a life assemblage of high-boreal or subarctic affinities. These changes may be associated with the later parts of the Pastonian stage at the end of the transgression when colder conditions obtained.

At Thorpe Aldringham and Sizewell 'B' the mollusc fauna indicates a mainly sheltered estuarine or tidal flat (wadden area) situation, with a temperate climate and regional deciduous forests. Sizewell 'B' shows a more open-coast facies. The older fauna of Sizewell 'A', associated with pollen spectra indicating cooler conditions with conifer forest or herb vegetation is of the sublittoral or infralittoral facies.

At Wangford, a similar sheltered estuarine or tidal flat situation is indicated by the fauna in the bottom half of the B section (samples 6 and 4) with a pollen spectrum tentatively correlated with the Chillesford type of assemblage. In the upper part of the section and at section C an open-coast fauna is present. The overlying Westleton Beds at Wangford show a southeasterly dip, as do other Westleton Beds sections in the area (Hey 1967). Hey described the shingle of the Westleton Beds as beach plain deposits generally prograding towards the southeast. They have not been identified south of the Minsmere River, the Dunwich–Minsmere Cliffs showing the most southern exposures. Thus they are not present in the Sizewell area. Either the progradation did not reach as far south as Sizewell or the shingle has been removed by erosion. In view of the good preservation of the Westleton Beds farther north in Suffolk, the former seems more likely.

The progradation of the Westleton Beds beach plain then appears to be in a later part of the Icenian transgression, postdating the sediments with Icenian Crag in the Dunwich to Wangford area.

(*c*) *Correlation*

A provisional correlation of the Chillesford pollen assemblage to the temperate Pastonian stage has already been made. A further tentative correlation between the deposits containing the Chillesford assemblage and the Netherlands Pleistocene may be suggested. In the western Netherlands, 200 km to the east, a strong period of marine regression occurred in the Tiglian pollen subzone TC 4c (Zagwijn 1963), and marine sediments were replaced by fluviatile sediments. A further series of marine sediments were deposited during a transgression correlated with the Cromerian III interglacial. The pollen characteristics of this interglacial (Zagwijn *et al.* 1971), as far as they are presently known, resemble those of the Chillesford assemblage in the importance of *Ulmus* and in the lack of *Abies* (W. H. Zagwijn, personal communication). This similarity in pollen assemblages and the similarity of the transgression over Lower Pleistocene sediments suggests that the temperate stage indicated by the Chillesford assemblage may be correlated with Cromerian III of the Netherlands. But much more evidence must be obtained before this correlation can be regarded as firm.

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