An Early Pleistocene cold marine episode in the North Sea: pollen and faunal assemblages at Covehithe, Suffolk, England

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Pollen spectra indicating grass-heath with *Empetrum* are recorded from a c. 2 m thick Baventian marine clay bed at Covehithe, Suffolk, deposited in a sublittoral to intertidal environment. For the first time arctic assemblages of both foraminifers and molluscs are recorded from this Baventian clay, which is now confirmed as representing the first cold stage of truly glacial intensity in the English marine Early Pleistocene succession.

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The cliff section at Covehithe, Suffolk (location in Fig. 1), has been observed for many years and from time to time descriptions have been published of the stratigraphy and, more rarely, of the contained fossils. Whitaker (1887) described two lithostratigraphical units in the section, the sands and gravels of the 'Pebbly Series' overlying the laminated clays of the 'Chillesford Beds'. Hey (1967) showed that the 'Pebbly Series' at Covehithe consisted of two types of gravel, the lower of the Westleton Beds type and the upper of quartzose gravel type (Kesgrave Sands and Gravels of Rose, Allen & Hey (1976)). The laminated clays below the gravels can be traced south for 3 km in the intermittent cliff sections to Easton Bavents, where the cliff section has been described by Larwood & Martin (1954), Funnell & West (1962), Norton & Beck (1972), and West & Norton (1974). The grey-blue laminated clays at Easton Bavents are the type sediments of the Early Pleistocene Baventian cold stage (Mitchell et al. 1973) and contain a characteristic pollen assemblage, predominantly of non-tree pollen, described by Funnell & West (1962). A similar pollen assemblage has been found in samples of laminated clay from boreholes made inland from the Covehithe cliff section in 1957, at levels near and below O.D. The positions, depths and pollen content of these samples are described by West (1979), together with a sketch of the cliff section in 1974 (West 1979: fig. 48).

Along the Covehithe cliff section shelly crag occurs below the Baventian laminated clay in these boreholes, and Crag mollusc faunas have been described by Long (1974) from sediments below the laminated clay in the cliff section at the Warren 1.5 km south of Covehithe. However, in the Covehithe cliff section itself marine shells have been seen but rarely, and these occur in the laminated clays. They were noted by Spencer (1971). Long (1974) described in detail a mollusc fauna collected in 1958–1960 from the clays on the foreshore. The fauna is of particular interest because this is the only site known where clay correlated with the Baventian can be seen to contain shells.

In October 1977 Mr. R. A. D. Markham of the Ipswich Museum informed us that a scour had laid bare a section on the foreshore at Covehithe, showing a good shell fauna in laminated grey-blue clays like those of Easton Bavents. The section shown in Fig. 2 was recorded within a few days. The grey-blue clays proved to contain pollen, foraminifers and molluscs. Moreover, a series of mud crack horizons in the upper part of the section, showing small polygons in horizontal view, gave evidence of contemporary sea-levels, previously not known from Baventian sections. Thus the new section provides a rich

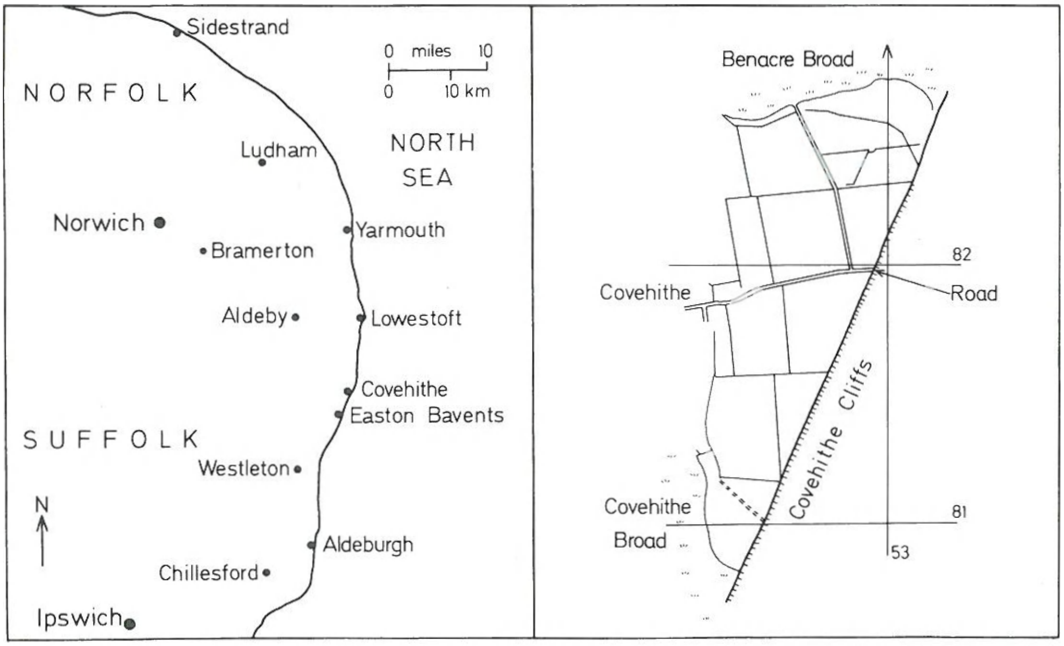

Fig. 1. Location of the Covehithe (km grid squares) and adjacent sites.

source of evidence for Baventian flora, fauna and sea-level.

The nomenclature of the biozones is as follows. *L* refers to the Ludham borehole (Funnell 1961; West 1961); *B* refers to the Bramerton site (Funnell 1961; Funnell, Norton & West 1979); *p* and *f* refer to pollen and foraminifer assemblage biozones at these sites (see also Funnell & West 1977). The Baventian cold stage includes the pollen assemblage biozones *L p 4b* at Ludham and *L p 4a* at Easton Bavents.

Stratigraphy

The section on the foreshore, recorded in Fig. 2, was 130 to 140 m north of the intersection of the cliff and the road in October 1977 (see Fig. 1). It formed a ledge on the foreshore up to 2 m depth at the southern end and to 1.5 m depth at the northern end. The depth at this northern end was increased to 2 m by digging. The southern part of the section showed 1.4 m brown bedded clay and silt with sand seams overlying a shelly silty sand 15 cm thick which tapered out to the north to a brown shelly clay. This shell horizon is similar to that described by Long (1974), and it overlay brown bedded silts and clays, containing a thin grey-blue horizon, shown in Fig. 2. Northwards the silts and clays became grey-blue in colour and more richly fossiliferous. At sampling point A 80 cm of grey-blue sandy silty clay, affected by bioturbation, with shells, overlay the shelly seam seen further south, and below this seam 45 cm of laminated grey-blue clay with shells was seen, resting on brown silty clay and sand. The laminated grey-blue clay resembled that seen at Easton Bavents very closely.

In the centre part of the section, the grey-blue silty clay at sampling point C showed at its upper limit a desiccation surface with mud cracks, followed upwards by a further series of four desiccation surfaces with mud cracks. The detail of this section is shown in Fig. 2. In horizontal section the cracks showed as polygons, up to 20 cm across. Graded bedding (fining upwards) was observed in the laminated sediment units between the mud crack horizons, with coarser sandier laminations occurring at the base of each sedimentation cycle. The sequence indicates intermittent exposure of water-saturated tidal sediment in an intertidal zone. The present O.D. level of this intertidal zone is about 1 m O.D. (levelled by relation to tide tables).

The sediments showing the mud cracks and polygons were confined to the slight basin seen

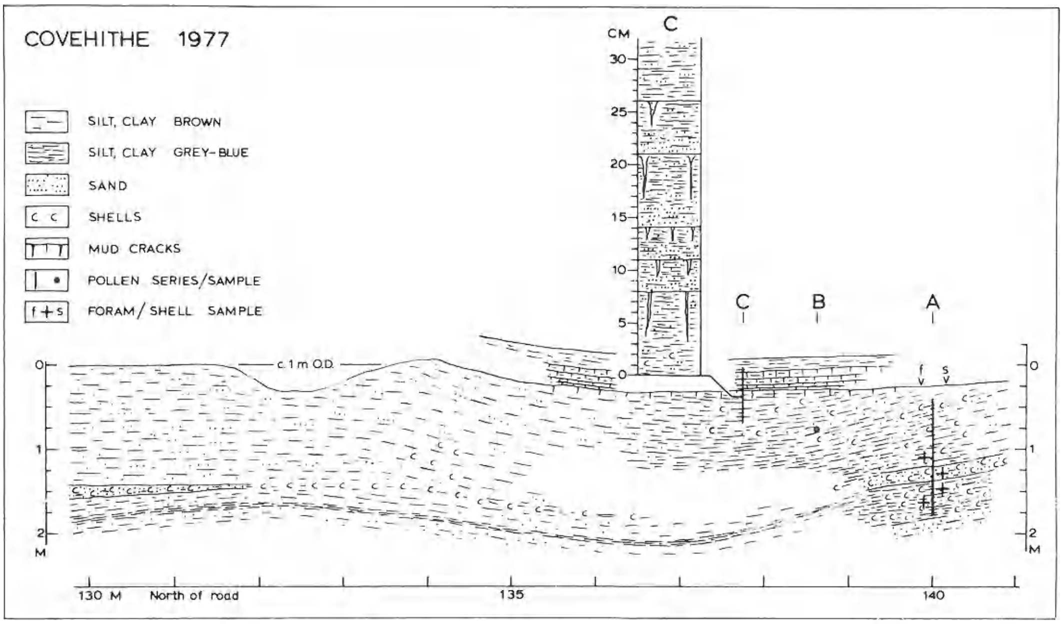

Fig. 2. Stratigraphy of the foreshore section at Covehithe.

in the middle of the section. They were sealed by more massive bedded clays of the type seen at the base of the cliff section some 6 m to the west.

The foreshore section thus shows a marine sequence in a nucleus of sediment relatively unaffected by decalcification, a situation contrasting with the main unfossiliferous exposures of the brown bedded clays in the lower part of the Covehithe cliff section.

Palynology

Slides for pollen analysis were prepared by standard methods used in the Sub-department of Quaternary Research (West 1977), using hydrochloric acid or sodium hydroxide to disperse calcareous and organic sediments respectively, sieving, removal of inorganic fractions by hydrofluoric and hydrochloric acid treatment, acetolysis with glacial acetic acid and sulphuric acid, oxidation by glacial acetic acid and sodium chlorate and mounting in safranin-stained glycerine jelly.

Samples taken from the cliff section in previous years contained no well-preserved pollen, but two analyses were possible of Baventian blue-grey clays from boreholes inland from the cliff and made in 1957. These analyses from boreholes LC3 and LC5 are given in Fig. 47 of West (1979), and they closely resemble those now reported from the foreshore exposures, showing an Ericales p.a.b. (pollen assemblage biozone) and an Ericales–Gramineae p.a.b. respectively.

Pollen samples from the foreshore section shown in Fig. 2 were taken as vertical series from point A and from point C with a single sample from the intermediate point at B, of sediments more recent than the topmost sample of A, but older than the basal sample of C. The pollen analyses are presented in Fig. 3. The pollen spectra are similar in showing around 50% AP (arboreal pollen), represented by low (10–20%) percentages of *Pinus, Alnus* and *Betula,* with lower percentage of *Picea*. The NAP (non-arboreal pollen) is mostly composed of Ericales, the great majority of which are of *Empetrum*-type, and Gramineae pollen, with low frequencies of Cyperaceae pollen and even lower frequencies and more sporadic occurrences of a limited diversity of herbs.

Filicales and *Sphagnum* spores are represented through the diagram by low continuous frequencies, with *Lycopodium* and *Osmunda* occurring more sparsely. Dinoflagellate cysts are present throughout the sequence, and the curves for derived spores and pollen show increased frequency towards the upper part of the section.

The pollen spectra show a close resemblance in their composition of AP and NAP to the two pollen spectra from the inland boreholes already analysed and to the pollen spectra from the laminated blue-grey clays at Easton Bavents at the type section of the Baventian cold stage; the clays at both these other sites can be firmly correlated stratigraphically with the foreshore clays at Covehithe. They are also similar to pollen spectra from laminated blue-grey clay at Aldeby, Norfolk (Norton & Beck 1972) and to pollen spectra from the clays of zone *L p 4b* of the Ludham borehole (West 1961). The location of Aldeby and Ludham are shown in Fig. 1. There is no stratigraphical or palynological evidence at present to indicate more than one cold stage with this type of pollen spectrum in East Anglia, and all are therefore placed in the Baventian cold stage.

The pollen assemblages seen in the clays from the Covehithe foreshore section indicate the presence of a relatively treeless landscape, the only tree genera consistently represented (*Pinus, Alnus, Betula, Picea*) being hardy genera able to withstand severe climatic conditions. The NAP is primarily of Ericales and Gramineae, with *Sphagnum* spores, indicating the presence of an oceanic grass heath, as discussed in relation to the Ludham pollen spectra by West (1961). It is to be noted that the majority of the Ericales pollen is of *Empetrum* type, as in the *L p 4b* zone at Ludham, with a low proportion of this being the large (c. 36 μm) *E. hermaphroditum*-type (see West 1979:111).

Empetrum heaths occur widely, often in exposed situations, in coastal and montane regions of the North Atlantic area, including northern Scandinavia, Iceland and Greenland. Pollen rain studies from grass heaths with *Empetrum* in arctic areas (Iceland, Greenland) have been summarised by Birks (1973). The representation of *Empetrum* and Gramineae pollen in some of these contemporary samples is of the same order of magnitude as in the Covehithe spectra, though it appears that the representation of *Empetrum* is rather localised, with a low regional dispersal.

The regional vegetation thus appears to have been grass heath with the low representation of pollen of tree genera probably deriving from woodland in more sheltered places in the catchment. It is not possible to say whether some of

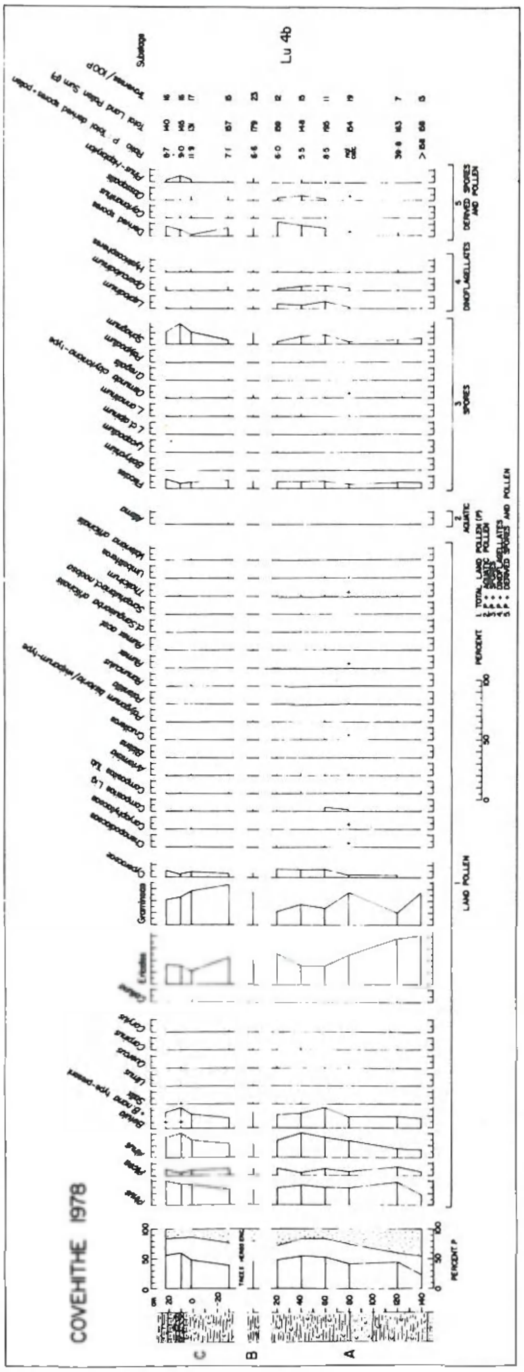

Fig. 3. Pollen diagram from Covehithe.

this AP is transported from long distance with over-representation because of low local pollen productivity. There seems no reason to suggest that a long distance component is of any importance in the pollen spectra.

The pollen spectra in Fig. 3 can be grouped into a number of assemblages. The two basal pollen spectra of the A series show very high frequencies of Ericales pollen, with low frequencies of Cyperaceae pollen and *Sphagnum* spores, and derived spores and pollen. These spectra may be included in an Ericales p.a.b. The three uppermost spectra of the A series show slight increases in *Alnus* and *Betula* pollen, reduced frequencies of Ericales, with increased diversity of herb pollen taxa, *Sphagnum* spores, dinoflagellate cysts and derived pollen and spores. The spectrum at A 80 cm is intermediate between these two groups. A further type of assemblage is seen in the B spectrum and the C series of spectra, showing a much greater frequency of Gramineae pollen. These spectra may be included in an Ericales–Gramineae p.a.b. In summary, we have segregated an Ericales p.a.b. at the base, an Ericales–Gramineae p.a.b. in the upper part of the section and an intermediate series of samples (A 20–80 cm).

This differentiation of the pollen spectra may be related to environmental changes indicated by the sediment sequence. This sequence shows shallowing of the marine environment, with laminated clay sediments at the base (point A), with the Ericales p.a.b., succeeded by shelly silty sand. The sandier bioturbated sediment in the upper part of the A section shows the intermediate type of pollen assemblage, succeeded by the Ericales–Gramineae p.a.b. at B and C. The same assemblage, but with higher pollen frequencies of *Alnus* and *Betula*, is associated with the intertidal sediments in the upper part of the C section. In this section high frequencies of Gramineae pollen are found. In the intertidal sediments of the upper part of the C section higher frequencies of *Alnus*, *Betula* (with *B. nana*-type pollen recorded) and *Sphagnum* are recorded. The increase of Gramineae associated with the shallowing may be a consequence of increased representation of salt marsh or local swamp species, as may be also the increased frequencies of Cyperaceae pollen. The sparse occurrence of Chenopodiaceae pollen is not unexpected since this family is not well-represented in present day arctic and sub-arctic salt marsh communities around the North Atlantic (Chapman 1968), in contrast to more temperate situations, where its pollen may be abundant in intertidal sediments (West 1961). It has been noted in pollen studies of the pre-glacial sediments elsewhere on the coast that Gramineae frequencies were higher in nearshore sediments (West 1979:7).

The variation in the frequency of derived spores and pollen is clearly seen in Fig. 3, which shows curves for derived spores, *Caytonanthus*, *Classopollis* and *Pinus-Haploxylon*, and the ratio of total land pollen (P) to total derived pollen and spores. The Ericales p.a.b. at the base shows very low frequencies of derived spores and pollen. There is a substantial rise in the upper part of the A section in the bioturbated sandy silty clay, with a slight fall in the spectra of the Ericales–Gramineae p.a.b. associated with the intertidal sediments of the C section. This sequence indicates that the derived spores and pollen are associated with shallower water sediments rather than the deeper water sediments. If the pollen assemblage of the deeper water sediment is sedimented after dispersal in flowing water (see West 1979:6), then the derived components of the assemblages, becoming important in the shallower water and coarser sediment, probably originates by longshore drift in the shore zone.

The separation of types of *L p 4b* pollen assemblage at Covehithe related to intertidal or deeper water sedimentation may be extended to other sites where *L p 4b* assemblages are recorded. The inland spectra at Covehithe already mentioned show an Ericales–Gramineae p.a.b. just below O.D. (borehole LC5) and an Ericales p.a.b. at – 10 m O.D. (borehole LC3, 425 m N of LC5) (West 1979). The origin of the differences in the assemblages again probably lies in water depth. The Easton Bavents assemblage (Funnell & West 1962), at c. 5 m O.D., is of the high Ericales type indicating deeper water conditions. The Aldeby assemblage (Norton & Beck 1972; Beck 1971) at c. 1.4 to 0.1 m O.D. is of the high Ericales type, but the topmost sample at c. 1.4 m O.D., in laminated grey silty clay alternating with yellow-brown silty sand, shows a great increase in Gramineae pollen frequency. This level is 3 cm above what is described as a grey-yellow clay seam with a sun-cracked surface, below which after a few centimetres is a massive blue-grey laminated clay with the high Ericales assemblage. The stratigraphy and change in pollen content recall that seen at

Table 1. Percentage representation of foraminiferal species in the 500–250 μm size range.

No. in sample Level in section A (cm)	264 60–80	25 120–130
Ammonia beccarii		(4)
Buccella inusitata	0.5	
Cibicides lobatulus	2	
Elphidiella hannai	85	(76)
Elphidium excavatum clavatum	2	(8)
E. frigidum	3	
E. macellum var. *granulosum*	3	
E. orbiculare	1.5	(4)
Globulina myristiformis		(4)
Lenticulina rotulata	1	(4)
Oolina spp.	1.5	

Covehithe, with a desiccation horizon with an Ericales–Gramineae p.a.b. overlying an Ericales p.a.b. The Ludham assemblage (*L p 4b*), – 13.4 m to – 14.9 m O.D. is of the high Ericales type indicating deeper water deposition.

Foraminifera

Foraminifera were examined from two samples taken at 120–130 cm and 60–80 cm at point A. Only 25 specimens in the 500–250 μm size range were obtained from the lower (120–130 cm) sample, but over 250 specimens were obtained from the upper (60–80 cm) sample. Percentages of species represented are given in Table 1.

Both assemblages are dominated by *Elphidiella hannai* (76 and 85% respectively of the total population). This is a ubiquitous species in littoral and inner sublittoral deposits of the Early Pleistocene of the North Sea basin.

The lower (120–130 cm) sample also contains *Elphidium excavatum clavatum*, *Ammonia beccarii*, *Elphidium orbiculare*, *Globulina myristiformis*, and *Lenticulina rotulata*. All of these, except the two last-named species, have previously been recorded (Funnell & West 1962) from the shelly sands of the *L p 4a* (Baventian) sub-zone of Easton Bavents (Funnell & West 1977). Compared with the Easton Bavents samples *Ammonia beccarii*, a temperate littoral species, may be less well represented, and *Elphidium orbiculare*, a boreo-arctic littoral to sublittoral species, better represented in the lower (120–130 cm) sample at Covehithe. The presence of *Globulina myristiformis*, a temperate inner sublittoral species, more common in the Ludham and earlier Crags, and of *Lenticulina rotulata*, a widespread species of occasional occurrence, cannot be attributed any particular significance.

The upper (60–80 cm) sample, in addition to *E. hannai*, also contains *E. excavatum clavatum*, *E. orbiculare* and *L. rotulata*, together with *Buccella inusitata*, *Cibicides lobatulus*, *Elphidium frigidum*, *Elphidium macellum* var. *granulosum*, and *Oolina* sp. Of the five last-named species, the first three are equally at home in Boreal and Arctic waters, and may be found at the northern limits of temperate waters (but then only in association with temperate species which themselves do not extend further north). *E. macellum* var. *granulosum* and *Oolina* sp. have no certain climatic implications. All of the species present in this upper sample at Covehithe were also recorded from the shelly sands of the *L p 4a* (Baventian) sub-zone of Easton Bavents (Funnell & West 1962, 1977), except for *E. macellum* var. *granulosum*. However, the temperate littoral species *A. beccarii* is no longer present at Covehithe and *E. frigidum* and *E. orbiculare*, both littoral or inner sublittoral boreo-arctic species, are clearly more abundant.

This indication of cooling provided by the foraminifera corresponds with the parallel indications of increasing cold provided by the pollen (transition from *L p 4a* of the clay of Easton Bavents to *L p 4b* of the clay of Easton Bavents and Covehithe), and by the molluscs (compare the molluscs listed from the shelly sands of Easton Bavents (Funnell & West 1962) with those recorded in this paper from the clay of Covehithe). The difference between Easton Bavents and Covehithe is that whereas the *L p 4b* clay of Easton Bavents contained no foraminifera (or molluscs, except possibly for those recorded by earlier authors – see Funnell & West 1962), the *L p 4b* clay of Covehithe does contain both foraminifera and molluscs, and both foraminifera and molluscs indicate colder marine conditions than those which characterised the *L p 4a* sub-zone below.

Taken together the Covehithe foraminifera may be compared with those previously recorded from Sidestrand, the *L f 6* and *L f 7* zones of Ludham, and the *B f 3* zone of Bramerton (Funnell 1961; Funnell & West 1977). Of these all except the *L f 6* zone of Ludham lack *A. beccarii*, and all except the *B f 3* zone of

Bramerton (where *E. orbiculare* is not recorded) consistently contain *E. frigidum* and *E. orbiculare*. *E. hannai* is always dominant (79 to 93%), except in the *L f 6* zone at Ludham (where it is 54–62%). In discussing these assemblages previously Funnell (1961:357) concluded that the combination of the presence of *E. orbiculare* with the absence of *A. beccarii* probably indicated semi-glacial (i.e. in the North Sea basin context equivalent to Late Glacial) conditions, and they probably implied a Scandinavian ice-cap and at least valley glaciers in Scotland and northern England. In addition to the species recorded at Covehithe the Norfolk occurrences also occasionally contained additional arctic species such as *Elphidiella* aff. *E. sibirica* and *Elphidium* cf. *E. bartletti*.

Current pollen-analytical interpretation of these occurrences (Funnell, Norton & West 1979; West 1979) is that Covehithe and the *Lf6* zone of Ludham belong to *L p 4 b* sub-zone of the Baventian cold stage, and that Sidestrand, the *L f 7* zone of Ludham, and the *B f 3* zone of Bramerton belong to a later Pre-Pastonian (Pre-Pa a sub-zone) cold stage. Unfortunately, although the foraminifers agree in indicating cold conditions in both cases, there is nothing in the composition of the foraminiferal assemblages that allows the two stages to be distinguished.

In addition to indicating a cold marine climate the Covehithe foraminifera also indicate a sublittoral or low intertidal environment. No trace was found in the samples examined of arenaceous, high intertidal or salt-marsh species. The upper part of the clay section showing presumably high intertidal desiccation cracks does not contain foraminifers. On the other hand the common occurrence of *Elphidiella hannai* and various species of *Elphidium* suggests a depositional environment not far removed from the low-tide level. *Elphidium orbiculare* is common at the present-day in estuaries around Hudson Bay and James Bay, and in Tracadie Bay, Prince Edward Island, Canada. As far as the foraminifers are concerned therefore, the Covehithe clay could represent an accumulation commencing sublittorally and culminating in a high intertidal environment.

Marine molluscs

Samples were taken from point A, at 80–100 cm, equivalent to the horizon described by Long (1974), and at 100–120 cm. These samples were investigated using the methods referred to by Norton (1977). Table 2 gives the counts of shells from these samples. For comparison a list supplied by Long (1974 and pers. comm.) is included in this table.

100–120 cm sample

This sample weighed 1400 g and yielded 28 molluscs, of which three were gastropods. The most frequent shells were all >500 μm in diameter and comprise:

Yoldia sp.	4 individuals	
Macoma obliqua	$3\frac{1}{2}$	"
M. calcarea	$3\frac{1}{2}$	"
Corbula gibba	$3\frac{1}{2}$	"

There were also one or two individuals of *Arctica islandica*, *Macoma praetenuis*, *Spisula* sp. and *Macoma* sp. *Mytilus edulis*, *Retusa* sp. and *Cerastoderma edule* (not found in the 80–100 cm sample) were recovered in insignificant amounts. These latter are littoral forms but the other species are of sublittoral affinity and typical of silty seabeds. Brackish water forms are absent. *Serripes groenlandicus*, *Macoma calcarea* and *Yoldia* (arctic taxa at the present) comprise 30% of the assemblage. *Macoma obliqua* is extinct and *Corbula gibba* a boreal-lusitanic form. This assemblage is interpreted as representing a boreal, open-coast facies, the shells being drawn almost entirely from sublittoral silty seabed areas adjacent to the site.

80–100 cm sample

At this level information is available from Long's (1974) horizon, which is equivalent, as noted above. 58.5 mollusca were recovered from 2230 gms of sediment. These included only four gastropods. There were few shells smaller than 500 μm in diameter. The most frequent species were:

Yoldia sp.	13 individuals	
Macoma calcarea (incl. *M.* cf. *calcarea*, 1)	$7\frac{1}{2}$	"
Serripes groenlandicus	$7\frac{1}{2}$	"
Macoma sp.	$6\frac{1}{2}$	"
Hiatella arctica	4	"

Table 2. Analysis of marine Mollusca.

	100–120 cm	80–100 cm	P. E. Long (equivalent to 80–100 cm)
	28.5 individuals 1413 g	58.5 individuals 2230 g	No counts
	No. of individuals	No. of individuals	L, apparently not reworked; D, apparently derived from older or distant sources; U, valves united
Littorina littorea (L)	1	1	D
Rissoid?	1	–	–
Boreoscala groenlandica (Chemnitz)	–	–	L
Amaura candida (Möller)	–	–	L
Amauropsis islandica (Gmelin)	–	–	L
Natica catena (Da Costa)	–	–	L
* *N.* cf. *pallida* Broderip et Sowerby	–	–	L
Natica sp.	–	1	–
Boreotrophon cf. *clathratus* (L)	–	–	L
Buccinum undatum (L)	–	–	L
Lora cf. *turricula* (Montagu)	–	–	L?
Retusa sp.	1	–	–
?*Actaeon* sp.	–	1	–
Gastropod (columella. unid.)	–	1	–
Nucula cobboldiae (Sowerby)	–	–	D
N. tenuis (Montagu)	–	–	L U
Yoldia myalis Couthouy	–	–	U
Y. cf. *myalis*	–	1.5	–
Yoldia sp.	4	13	–
Mytilus edulis L	fr	–	–
Astarte montagui (Dillwyn)	–	0.5	D
A. cf. *montagui*	1	–	–
Arctica islandica (L)	1.5	0.5	–
Lucinoma borealis (L)	–	–	D ?
Spaniorinus nortoni (Spaink)	–	–	L
Cerastoderma edule (L)	0.5	fr	D ?
Laevicardium cf. *interruptum* (S. Wood)	–	–	L U
* *Serripes groenlandicus* (Brugiere)	1	7.5	L U
Donax vittatus (Da Costa)	–	–	D
cf. *Donax* sp.	0.5	–	–
Macoma calcarea (Gmelin)	3.5	6.5	L U
M. cf. *calcarea*	–	1	–
M. obliqua (Sowerby)	3.5	–	D ?
M. praetenuis (Leathes)	1.5	0.5	–
M. cf. *praetenuis*	–	–	D ?
Macoma sp.	2	6.5	–
Spisula elliptica (Brown)	–	–	D ?
Spisula sp.	3	1.5	–
Mya truncata L	–	–	L U
M. arenaria L	0.5	–	–
Corbula gibba (Olivi)	3.5	–	–
C. cf. *gibba*	–	0.5	–
Hiatella 'arctica' L	–	4	L U
Sphenia binghami (Turton)	–	2	–
Bivalve, unid. hinge	–	0.5	–

*Larger than normal size.

There was no evidence that any *Yoldia* species other than *Y. myalis* were present, and it is thought that most of the *Macoma* sp. were *M. calcarea*. No species associated with brackish water are present. All the above species, which comprise 60% of the assemblage, are typical members of well-described arctic sublittoral animal communities at the present day (Ockelmann

1958; East Greenland). These modern communities are sublittoral, with units of them known from inner sublittoral waters. They occur in a variety of silty seabeds, and it was noted that fine sand and silt predominate in the sediment from which the shells were recovered. Although they could perhaps have populated sediments such as these, the shells were not observed *in situ* and it is uncertain whether they represent an autochthonous shell bed or an allochthonous shell deposit. However, Long records shells with valves united (Table 2), which implies that they lived close to the deposition site, and he also recorded *Macoma calcarea*, *in situ*, slightly above this level. There are very few typically littoral shells. It is concluded that climatic conditions at this time were arctic, consequently the littoral remained unpopulated, and the sublittoral fauna has lost the 'old boreal' character commented on by Norton (1977): i.e. no paradoxical lusitanic/arctic elements exist in this assemblage, the lusitanic ones having disappeared and the boreal element decreased to a minority. In the inner sublittoral were deposited local and sublittoral shells which had previously been exhumed from elsewhere by wave and current action and transported to this site. Epifauna, gastropods and small shells appear to have been removed from the assemblage by differential transportation. Long, collecting more extensively, was more successful in recovering gastropods.

Summarising, this assemblage represents an arctic (low-arctic) open coast, inner sublittoral facies with fossils of local provenance, derived from the silty inner sublittoral and sublittoral sediments.

Comparison of the two samples

It is seen that neither assemblage is numerous nor diverse, neither was deposited *in situ* (though there are indications that the 80–100 cm assemblage was nearly so), and that the lists of the most frequent species differ in the two cases as noted. This difference does not appear to reflect change in water depth, but may be interpreted as due to a deterioration in climate after the 100–120 cm unit had been deposited. At 100–120 cm the fauna is comparable to many other boreal, open-coast, impoverished facies assemblages in the Crag deposits. No correlation is attempted, owing to the poverty of this assemblage (a summary of facies recognised from Mollusca in the Crags is given in Funnell, Norton & West 1979). At 80–100 cm the fauna apparently reflects the existence of truly arctic molluscan communities in the area.

Conclusions

The important malacological conclusion from this study is that truly arctic molluscan communities occurred in the Crag basin at this time, a conclusion which had not been reached in previous modern studies of the Crag Mollusca. The 'coldest' assemblage found so far has been that described from the Chillesford *Mya*-bed (West & Norton 1974). This contains an assemblage which was held to reflect existence of high-boreal or low-arctic communities. At Chillesford the 'old-Boreal' assemblage (including *Calyptraea chinensis* and 16% of 'arctic' forms) is apparently present in a 'northern' form, at the end of the (temperate) Bramertonian stage. At Covehithe, in the preceding Baventian (cold) stage we have, uniquely at present, a marine mollusc assemblage interpreted as arctic. This finding represents an important modification of previous climatic interpretations based on Mollusca (see Norton 1977:50), in that truly arctic molluscs can now be interpreted as having reached the Crag basin, at least in the Baventian. Full evaluation of this, however, requires further finds, preferably in deposits of other cold stages and of assemblages with larger numbers of Mollusca. Finally, it is important to note that *Macoma balthica* (L.) is absent in the Covehithe faunas. This mollusc is present abundantly in the cold Pre-Pastonian substage deposits of the Norfolk coast, which are post-Bramertonian in age, and is also present in the 'Bure Valley Beds' of uncertain age but considered post-Bramertonian (Funnell, Norton & West 1979). It had evidently not reached the southern North Sea basin in Baventian (and Bramertonian) times.

Conclusions

The c. 2 metre thick silty clay bed at the base of Covehithe cliffs is shown to belong to zone *L p 4b* of the Baventian cold stage of the Early Pleistocene of East Anglia.

In the lower 0.45 m of the clay, the pollen spectra comprise an Ericales p.a.b., interpreted as contributed by grass heath. Foraminifers from this part of the section are consistent with sublit-

Table 3. Heights of Baventian (*L p 4b*) sediments in East Anglia.

Easton Bavents	4.4 m to 6.1 m O.D.	(Norton & Beck 1972)
Covehithe	−1 m to 1 m O.D.	
Aldeby	c. 0 m to 1.4 m O.D.	(Beck 1971)
Ludham	−14.9 m to −13.4 m O.D.	(West 1961)

toral sedimentation under cold (boreo-arctic) conditions. The molluscs belong to a sublittoral, boreal, open-coast facies, containing 30% arctic forms and at least 10% of one boreo-lusitanic form.

Intermediate pollen spectra, between 0.45 m and 1.25 m above the base of the clay, coincide with sublittoral or low intertidal foraminifers of more distinctly boreo-arctic or even arctic aspect, and with molluscs representing sublittoral and inner sublittoral arctic (low-arctic) open coast conditions, with 60% arctic forms in the assemblage.

In the upper, approximately 0.60 m of the clay, the pollen spectra constitute an Ericales–Gramineae p.a.b., interpreted as indicating increased representation of salt marsh or local swamp taxa. No foraminifers or molluscs have been obtained from this upper part of the clay, but desiccation cracks formed in association with a shallow depression in the upper surface of the clay are taken to indicate high intertidal conditions.

A similar transition from an Ericales p.a.b. below to an Ericales–Gramineae p.a.b. above is also observed at another *L p 4b* sub-zone clay bed at Aldeby in Norfolk, indicating that the clays at these sites were deposited during a comparable transition from low to high intertidal conditions.

The biological evidence for a cold environment at the time of deposition of the *L f 4b* Baventian clays is complemented by the analysis of the heavy minerals at Easton Bavents (and Covehithe) by J. D. Solomon (in Funnell & West 1962). He considered that the deposit consisted, in the main, of outwash material of a northern ice sheet, and he noted that a similar assemblage was found in the post-Cromerian North Sea Drift tills.

Present-day differences in the levels of Baventian clays, indicated in Table 3, may be attributed to post-depositional vertical movement. If this proves to be correct, then the Baventian clay horizon will be a most useful datum point for the determination of post-Baventian warping on the western margin of the southern part of the North Sea basin.

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