Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Pleistocene Sea-Level and Neotectonic History of the Eastern Solent, Southern England

R. C. Preece, J. D. Scourse, S. D. Houghton, K. L. Knudsen and D. N. Penney

Phil. Trans. R. Soc. Lond. B 1990 **328**, 425-477
doi: 10.1098/rstb.1990.0120

References Article cited in:
http://rstb.royalsocietypublishing.org/content/328/1249/425#related-urls

Email alerting service Receive free email alerts when new articles cite this article - sign up in the box at the top right-hand corner of the article or click **here**

To subscribe to *Phil. Trans. R. Soc. Lond. B* go to: **http://rstb.royalsocietypublishing.org/subscriptions**

This journal is © 1990 The Royal Society

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Phil. Trans. R. Soc. Lond. B **328**, 425–477 (1990) [425]
Printed in Great Britain

THE PLEISTOCENE SEA-LEVEL AND NEOTECTONIC HISTORY OF THE EASTERN SOLENT, SOUTHERN ENGLAND

By R. C. PREECE[1], J. D. SCOURSE[2], S. D. HOUGHTON[3]†, K. L. KNUDSEN[4] and D. N. PENNEY[4]

[1] *Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, U.K.*
[2] *School of Ocean Sciences, University College of North Wales, Menai Bridge, Gwynedd LL59 5EY, U.K.*
[3] *Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, Buckinghamshire MK7 6AA, U.K.*
[4] *Geologisk Institut, Aarhus Universitet, DK-8000 Aarhus C, Denmark*

(*Communicated by R. G. West, F.R.S. – Received* 18 *August* 1989 – *Revised* 18 *January* 1990)

[Plate 1; pullouts 1–3]

CONTENTS

† Present address: The Robertson Group, Llandudno, Gwynedd LL30 1SA, U.K.

The Royal Society is collaborating with JSTOR to digitize, preserve, and extend access to *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences.* www.jstor.org

Downloaded from rstb.royalsocietypublishing.org

In the eastern extremity of the Isle of Wight, near Bembridge, marine interglacial deposits occur at a variety of different elevations. The highest of these, the Steyne Wood Clay, is an estuarine deposit that lies between 38 and 40 m O.D. and rests on Bembridge Marls (Lower Oligocene). The Steyne Wood Clay, which had previously been assigned to the post-temperate substage of a Middle Pleistocene interglacial, has now yielded a diverse coccolith assemblage dominated by *Gephyrocapsa oceanica* and *G. caribbeanica*. The absence of both *Pseudoemiliania lacunosa*, with a last occurrence datum at *ca.* 0.475 Ma BP. and *Emiliania huxleyi*, with a first occurrence datum at *ca.* 0.275 Ma BP, suggests deposition during this time interval. The dating of the Steyne Wood Clay is further constrained by palaeomagnetic data, indicating normal geomagnetic polarity, and by amino acid ratios consistent with an early Middle Pleistocene age. An extended and revised list of Foraminifera and Ostracoda is given, including the description of *Leptocythere steynewoodensis* sp.nov.

The low-level interglacial deposits make up the Bembridge Raised Beach, here formally defined as consisting of high-energy beach gravels, intertidal sands and organic muds, which represent a single fining-upwards sequence. Pollen analysis of the organic muds indicates that these accumulated during the early and late-temperate substages of the Ipswichian interglacial (Ip IIb–III). Thermoluminescence dates of *ca.* 115 Ka BP have been obtained from sand lenses within the Raised Beach itself, which also support correlation with the Ipswichian.

The Bembridge Raised Beach occupies an altitudinal range of 5–18 m O.D. and thickens rapidly in a westerly direction where it abuts a cliff cut into the Bembridge Marls. Details are given of the composition, morphology and sedimentology of the gravels constituting the Beach, and similarities to recent cuspate foreland and split accumulations are highlighted. A similar origin is proposed for this feature.

The upper surface of the Beach has been soliflucted and deposits of matrix-supported gravel, rich in clay, thicken downslope in an easterly direction. This solifluction has been disturbed by cryoturbation. Both the *in situ* and soliflucted beach are mantled by brickearth, a reworked aeolian silt, which reaches a maximum thickness of 10 m. A Late Devensian age for this unit has been established by thermoluminescence dates in the range 16.0 ± 1.5 to 21.5 ± 2 Ka BP.

Near Lane End, a sedge-peat rich in plant macrofossils and insects occurs between two gravel units. These appear to post-date the Raised Beach and are interpreted as of fluvial origin. The gravel capping the cliffs at Priory Bay, the richest source of Palaeolithic artefacts on the Isle of Wight, occurs between 29 and 33 m O.D. and is also thought to be a fluvial aggradation unrelated to the Raised Beach.

The relationship of these marine deposits to those occurring on the adjacent mainland are considered. The Steyne Wood Clay is correlated with the Slindon Sands at Boxgrove, part of the Goodwood–Slindon Raised Beach, which occur at an identical elevation and have produced a similarly diverse coccolith assemblage. Additional palaeontological evidence from Boxgrove suggests that the interglacial deposits should be assigned to a temperate stage falling in the latter part of the 'Cromerian Complex'. Correlation of the Steyne Wood Clay and Slindon Sands with oxygen isotope stage 9, 11 or 13 seems very probable. Reasons for the occurrence of marine deposits of this age at *ca.* 40 m O.D. are considered and it is thought that neotectonic activity is at least partly responsible. Mean rates of uplift of between 5.3

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

and 15.5 mm ka^{-1} have been calculated from age estimates for stages 9, 11 and 13 derived from the deep-sea record. However, it is unlikely that the uplift was uniform in either rate or direction.

The diverse coccolith assemblages preserved in the Steyne Wood Clay and in the Slindon Sands indicate a full open connection with the marine waters of the central English Channel, and suggests that a thermocline was then present in the Channel at a time when the Straits of Dover were probably closed.

The interglacial channel deposits on the modern foreshore of Bracklesham Bay near Earnley have produced a limited coccolith assemblage. Because the altitudinal and palynological differences between these deposits and the Steyne Wood Clay are so great, they are thought to belong to different interglacial stages.

The Bembridge Raised Beach is thought to equate with similar deposits on the northern shore of the Solent at Selsey, Stone and West Wittering, which has also now yielded pollen, reported here.

1. Introduction

Thick Pleistocene gravel deposits are widespread in the northeastern quadrant of the Isle of Wight. The cliff sections between Bembridge Foreland (SZ 658877) and Howgate (SZ 648869) are particularly impressive and have become known informally as the 'Bembridge Raised Beach' (figure 1). A marine origin has also been assumed for the other gravel spreads between here and Ryde, and they are mapped as such on the 1:50000 Geological Survey map (Special sheet: parts of sheets 330, 331, 344 and 345) of the region.

The 'Raised Beach' at the Foreland contains no shells and its age has never been precisely determined, although an Ipswichian (Last Interglacial) age has been assumed largely on the basis of its relatively low elevation (see, for example, Jones 1981).

A re-investigation of the 'Bembridge Raised Beach' and juxtaposed deposits is timely for two important reasons. First, the recent discovery of Middle Pleistocene interglacial deposits of intertidal origin at widely discordant altitudes at Bembridge School, Isle of Wight, and at Earnley, Sussex, has made this a critical area for Pleistocene sea-level studies. Second, the advent of two techniques, thermoluminescence (TL) dating and amino acid analysis, and their application to the problem of dating raised beaches offers a realistic hope of clarifying Pleistocene sequences. This expectation is greatly increased because of the relative wealth of organic deposits associated with different interglacial sea-level events in this region, providing an independent means of biostratigraphic correlation. The realization that coccoliths are also preserved in several of these marine deposits offers enormous potential, not only as a means of relative dating but also in providing a direct link with the oxygen-isotope record obtained from the deep-sea environment. Few, if any, other areas of Britain offer such potential.

2. High-level deposits

(a) *Steyne Wood Clay*

(i) *Previous work*

The occurrence of a fossiliferous Pleistocene deposit in the grounds of Bembridge School has been known for over 60 years (Jackson 1924; Reid & Chandler 1924). In 1924 deep sewer trenches exposed an organic clay containing seams of 'peat' with plant macrofossils, including wood, in the upper levels. These were studied by Reid & Chandler (1924) who identified the wood as spruce (*Picea*) and who recovered the fruits of an arctic buttercup (*Ranunculus hyperboreus*) among a limited flora.

Downloaded from rstb.royalsocietypublishing.org

The deposit was recently re-investigated by Holyoak & Preece (1983) who formally named it the Steyne Wood Clay and who showed from the contained fossils (diatoms, Mollusca, Ostracoda, foraminifera) that it accumulated in an estuarine environment. The pollen diagram (Holyoak & Preece 1983, figure 2) suggested that this occurred during the post-temperate zone of a Middle Pleistocene interglacial.

The Steyne Wood Clay occurs between 38 and 40 m O.D., rests on Bembridge Marls (Lower Oligocene) and is overlain by up to 3 m of mottled orange-brown clay with scattered flint pebbles, interpreted as solifluction. Jackson (1924) reported seams of 'compact peat' towards the top of the deposit but only thin lenses of plant-rich debris were found in the two boreholes made by Holyoak & Preece (1983).

(ii) *Present study*

In 1985 further work on the Steyne Wood Clay was undertaken. Through the courtesy of the Nature Conservancy Council (GCR Unit) a deep pit was dug by means of a Hymac excavator to expose the Steyne Wood Clay in open section. This pit was located on waste ground behind the squash courts (SZ 64218652) about 50 m south of borehole A (Holyoak & Preece 1983). Here the cover of solifluction was about 1 m less (i.e. only 2 m thick) and the Steyne Wood Clay, unlike its facies in the other two boreholes, was virtually devoid of shells. However, discrete lenses of black carbonized wood (10 cm thick) were present on the surface of the Steyne Wood Clay. These may well be the 'compact peat' mentioned by Jackson (1924).

In an attempt to improve the dating of the Steyne Wood Clay, a further series of analyses have recently been undertaken.

(iii) *Palaeomagnetism*

The palaeomagnetic polarity was determined from nine samples collected from three stratigraphic levels throughout the deposit. Perspex boxes (20 mm × 20 mm × 16 mm) were carefully pressed into a vertical face cut into the Clay. The orientation of the face was noted but precise orientation measurements for each box were not made. This means that there may be orientation errors in the NRM directions of *ca.* $\pm 10°$.

The measurements were undertaken for us by Dr T. J. F. Austin (University of East Anglia). With the exception of one anomalous measurement, all the samples yielded NRM directions of Normal Polarity. Of the eight samples, five have inclinations within 10° of the axial dipole inclination for the site (68°). The mean of these five NRM directions (declination = 12° relative to magnetic north; inclination = 77°) is remarkably close to a normal field considering the potential sampling errors and the fact that no alternating field (AF) demagnetization has been done to remove possible viscous magnetic components. The remnant intensities are fairly weak, only one order of magnitude above the noise level of the magnetometer. This may account for some of the scatter in the data. However, it is clear from these results that the Steyne Wood Clay was deposited during a period of Normal Geomagnetic Polarity.

(iv) *Amino acid analyses*

As shells were virtually absent in the 1985 excavation, unprocessed samples from a previous borehole (B; Holyoak & Preece 1983) were washed in water and fragments of the bivalve *Macoma balthica* (L.) carefully extracted and air dried. This species has been shown to produce highly consistent and reproducible results in comparative studies (Miller & Mangerud 1985).

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The fragments were submitted to Dr J. T. Hollin and Dr G. H. Miller (INSTAAR, University of Colorado, Boulder, U.S.A.) for amino acid analyses.

The theory of aminostratigraphy and the laboratory procedures of INSTAAR are reviewed by Miller & Mangerud (1985). Ideally, five shells should be analysed from each stratigraphic level and, because of possible epimerisation variations within the shell, samples of bivalves are usually taken from the inner layers near the umbo. It was not possible to provide whole shells from the Steyne Wood Clay, but only nine fragments. These were divided into four subsamples and D-alloisoleucine to L-isoleucine peak-height ratios for the total hydrolysate (free and bound) amino acid fraction determined. A mean ratio of 0.32 ± 0.04 ($n = 4$) was obtained (table 1).

TABLE 1. AMINO ACID DATA FROM *MACOMA BALTHICA* FROM THE STEYNE WOOD CLAY

number of shells	D:L ratio	mean	laboratory reference number
1	0.265, 0.317	0.291	AAL-4612*a*
1	0.342, 0.354, 0.327	0.341	AAL-4612*b*
1	0.295, 0.295, 0.290	0.293	AAL-4612*c*
1	0.364, 0.397, 0.364	0.375	AAL-4612*d*

To obtain some idea of the possible intra-shell variations within *M. balthica*, three valves from an as yet undated Quaternary site in northwest Germany were analysed both at the umbo and at the growing edge (J. T. Hollin and G. H. Miller, personal communication). In each case, the ratio at the umbo (mean 0.09 ± 0.01, $n = 3$) was higher than at the growing edge (mean 0.065 ± 0.015, $n = 3$). For the purpose of the inter-site comparisons below, the Steyne Wood Clay ratio of 0.32 might have to be multiplied by anything between 1 and 0.09/0.065, which might raise this ratio to 0.45. However, this must be regarded as a maximum value, and care must be taken when comparing this value with ratios from other sites.

Miller & Mangerud (1985) list ratios obtained from *M. balthica* from marine sites in northwest Europe belonging to different interglacial stages. The mean ratios relevant to the present study are as follows

Eemian (Ipswichian): Bergen 0.18, Zunderdorp 0.19 (both Netherlands);

Holsteinian: Scharhörn 0.29 (northwest Germany), Herzeele 0.29 (northern France);

'Cromerian': Noordbergum 0.46 (type-site of Cromerian IV; Netherlands).

According to Miller & Mangerud (1985) the Noordbergum shells were possibly heated during extraction, which would cause the value of 0.46 to be too high, so the 'Cromerian' values are probably lower than 0.46. If it is assumed that minimal inter- and intra-shell variation occurs and that all shells have experienced a similar thermal history, then the data support a Middle Pleistocene age for the Steyne Wood Clay with ratios higher than 'Holsteinian' values.

(v) *Calcareous nannofossils*

Samples for coccolith analysis were taken from boreholes A and B of Holyoak & Preece (1983). The nannofossil assemblages recorded from borehole B are listed in table 2. Samples 83-G to 83-I (3.51–3.74 m depth below surface) are devoid of coccoliths and other micron-sized carbonate. The coccolith assemblages recovered from the lower section of the borehole

Downloaded from rstb.royalsocietypublishing.org

TABLE 2. NANNOFOSSIL SAMPLES AND ASSEMBLAGES

(A: abundant (over 10%); C: common (1–10%); R: rare (less than 1%); +: species present (no estimate of abundance given); –: species absent.)

taxa	Boxgrove	Steyne Wood Clay	Earnley	Stone
Emiliania huxleyi (Lohmann) Hay & Mohler	–	–	–	+
Gephyrocapsa ericsonii McIntyre & Bé	–	–	–	+
Gephyrocapsa oceanica Kamptner	A	A	+	–
Gephyrocapsa caribbeanica Boudreaux & Hay	A	C	–	–
Dictyococcites productus (Kamptner) Backman	C	A	+	–
Calcidiscus leptoporus (Murray & Blackman) Loeblich & Tappan	R	R	–	+
Coccolithus pelagicus (Wallich) Schiller	R	R	+	–
Reticulofenestra spp.[a]	C	A	+	–
Syracosphaera pulchra Lohmann	R	R	–	–
Pontosphaera sp.	R	R	–	–
Braarudosphaera bigelowii (Gran & Braarud) Deflandre	R	R	–	–
Discosphaera tubifera (Murray & Blackman) Ostenfeld	R	R	–	–
Oolithotus fragilis (Lohmann) Okada & McIntyre	R	–	–	–
reworked Mesozoic forms	A	A	+	+
reworked Palaeogene forms	R	R	+	+

[a] Represents at least two species.

contain 11 Pleistocene species and are dominated by *Gephyrocapsa oceanica*, *G. caribbeanica*, *Reticulofenestra* spp. and *Dityococcites productus*. Subordinate species include *Discosphaera tubifera*, *Syracosphaera pulchra*, *Braarudosphaera bigelowii*, *Coccolithus pelagicus* and *Calcidiscus leptoporus*. Pleistocene nannofossils constitute less than 5% of the fine fractions of the Steyne Wood Clay and their preservation ranges from good to poor with some evidence of dissolution. The sediments contain abundant reworked Mesozoic nannofossils and some derived Tertiary forms. Reworked nannofossils constitute more than 25% of the total assemblages.

The decline in coccolith numbers, culminating in their absence in the upper part of the Steyne Wood Clay, is consistent with a negative sea-level tendency and a reduction in salinity. The absence of coccolith and other micron-sized carbonate in the upper levels may indicate a transition from open intertidal mudflats to a saltmarsh environment, as micron-sized carbonate is consistently absent from Holocene saltmarsh sediments from the coast of southern Britain (Houghton 1986). Alternatively, their absence may be due to post-depositional decalcification or a combination of both.

(vi) *Foraminifera*

A preliminary analysis by Mr D. J. Carter of the foraminifera from the two boreholes (A and B) from the Steyne Wood Clay has already been published (Holyoak & Preece 1983). The foraminiferal assemblages were found to be dominated by three species that were identified as *Elphidium articulatum* (d'Orbigny), *Haynesina germanica* (Ehrenberg) and *Haynesina paralia* (Tintant).

Foraminifera have been re-examined from four samples, each weighing 500 g, from borehole

Downloaded from rstb.royalsocietypublishing.org

B at Bembridge School (Holyoak & Preece 1983). Foraminiferal tests were concentrated from the size fraction greater than 125 μm by using ethylene dibromide diluted with absolute alcohol to a specific gravity of 1.80 g ml^{-1}. About 400 specimens were identified and counted from each sample (table 3).

Table 3. Foraminifera from the Steyne Wood Clay, Bembridge, B (Holyoak & Preece 1983)

(The numbers indicate percentages; × indicates less than 0.5%. Faunal diversity is according to Walton (1964).)

Quaternary taxa	sample Q 5.09–5.20 m	O 4.86–4.98 m	M 4.64–4.75 m	K 4.19–4.30 m
Ammonia batavus (Hofker)	1	1	×	—
Angulogerina angulosa (Williamson)	×	—	—	—
Astrononion sp.	—	×	—	—
Aubignyna perlucida (Heron-Allen & Earland)	23	16	18	49
Bolivina sp.	—	—	—	×
Buccella frigida (Cushman), var. *calida* (Cushman & Cole)	—	1	—	×
Cibicides lobatulus (Walker & Jacob)	×	1	—	×
Elphidium advenum (Cushman)?	—	1	—	—
Elphidium albiumbilicatum (Weiss)	—	—	—	×
Elphidium excavatum (Terquem) forma *selseyensis* (Heron-Allen & Earland)	5	4	1	×
Elphidium gerthi van Voorthuysen	×	×	×	×
Elphidium incertum (Williamson)	—	×	—	—
Elphidium magellanicum Heron-Allen & Earland	—	×	×	—
Elphidium margaritaceum Cushman	×	1	1	×
Elphidium williamsoni Haynes	19	18	40	18
Epistominella sp.	—	—	—	×
Haynesina germanica (Ehrenberg)	52	57	40	31
Lagena clavata (d'Orbigny)	—	—	×	×
Lagena semistriata (Williamson)	—	×	—	×
Miliolinella subrotunda (Montagu)	—	—	—	×
Nonion pauperatum (Balkwill & Wright)	—	—	—	×
Oolina hexagona (Williamson)	—	—	×	×
Oolina lineata (Williamson)	—	—	—	×
Oolina melo d'Orbigny	—	—	—	×
Oolina squamosa (Montagu)	—	—	—	×
Patellina corrugata Williamson	—	1	×	×
Polymorphinidae	×	—	×	—
Rosalina williamsoni (Chapman & Parr)	—	—	×	×
Quaternary foraminifera per 100 g	390	150	760	1850
faunal diversity	4	5	3	3
number of species	10	15	13	21
pre-Quaternary foraminifera per 100 g	35	44	58	14

A total of 28 Quaternary taxa occur in these samples. Specimen numbers range from 150 to 1850 per 100 g sediment, and a few pre-Quaternary foraminifera are also present in each sample (table 3).

The general environmental conclusions of the earlier study remain unaffected, though certain taxonomic revisions are necessary. The assemblages are dominated by three taxa: *Elphidium williamsoni* (previously referred to as *E. articulatum*), *Haynesina germanica* and *Aubignyna*

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

perlucida (previously referred to as *Haynesina paralia*). These are all shallow, euryhaline species and their dominance over other taxa in the samples indicates stringent environmental conditions. Low percentages (4–5%) of *Elphidium excavatum* forma *selseyensis* in samples Q and O at the base of the marine sequence, decreasing upwards in the succeeding samples, may indicate a change from an initial open tidal flat to a more restricted brackish environment. The main accessory species in the uppermost sample (K) may partly have been redeposited from a more open marine habitat.

(vii) *Ostracoda*

Ostracoda were re-examined from the same four samples from borehole B at Bembridge (Holyoak & Preece 1983). All ostracods were identified and counted from the fraction of 500 g greater than 125 μm (table 4). A total of 30 Pleistocene species were recovered, compared with ten in the original analyses by Dr J. E. Robinson. The increase in species numbers probably resulted from the difference in sample size and the sieve mesh used (Dr Robinson examined the fraction of 100 g retained on the 140 μm sieve). Pre-Quaternary taxa were not counted in this

TABLE 4. OSTRACODA FROM THE STEYNE WOOD CLAY, BEMBRIDGE

(c, carapaces; f, fragments; v, valves; R, remanie (not part of indigenous fauna); all samples were of 500 g dry mass.)

		sample			
Quaternary taxa	remanie	Q 5.09–5.20 m	O 4.86–4.98 m	M 4.64–4.75 m	K 4.19–4.30 m
Cyprideis torosa (Jones)		—	—	1v	1v
Cythere lutea (O. F. Müller)		—	—	—	1v
Cytherois fischeri Sars		—	—	16v	—
Cytheropteron latissimum (Norman)	R	—	—	—	6v
Cytheropteron nodosum Brady	R	8v	1v	28v	178v
Cytheropteron sp.	R	—	—	—	5v
Elofsonia pusilla (Brady)	R	—	—	—	4v
Eucythere argus (Sars)	R	1v	1v	—	4v
Finmarchinella (*B*) *angulata* (Sars)	R	—	—	—	18v
Hemicythere villosa (Sars)		16v	1v	24v	30v
Hemicytherura cellulosa (Norman)		—	—	—	1v
Hemicytherura clathrata (Sars)	R	8v	2v	1v	62v
Hirschmannia viridis (O. F. Müller)		1v	1v	—	8v
Ilyocypris sp.		8v	1f	—	—
Leptocythere baltica Klie	R	12v	—	—	1v
Leptocythere steynewoodensis sp. nov.		12v	—	174v	146v
Leptocythere castanea (Sars)		4c, 380v	2c, 210v	776v	224v
Leptocythere lacertosa (Hirschmann)		16c, 328v	63v	444v	60v
Leptocythere pellucida (Baird)	R	1v	1v	8v	1v
Leptocythere psammophila Guillaume		80v	5v	16v	16v
Leptocythere tenera (Brady)	R	—	—	—	12v
Robertsonites tuberculatus (Sars)	R	—	—	1v	8v
Sagmatocythere multifora (Norman)	R	—	—	—	1v
Sclerochilus gewemuelleri Dubowsky		1f	—	—	4v
Semicytherura affinis (Sars)	R	—	—	1v	8v
Semicytherura angulata Brady	R	—	1v	1v	36v
Semicytherura nigrescens (Baird)		—	—	2v	4v
Semicytherura sella (Sars)	R	8v	1v	8v	22v
Semicytherura undata (Sars)	R	—	—	—	12v
Urocythereis britannica Athersuch	R	—	—	—	10v
Tertiary taxa		12c, 336v	11c, 231v	55v	—

Downloaded from rstb.royalsocietypublishing.org

investigation. The two commonest species are the Oligocene *Hemicyprideis montosa* (Jones & Sherborn) and *Cytheromorpha zinndorfi* Lienenklaus.

The Quaternary species are dominated by the leptocytherids, in particular *Leptocythere castanea*, a common species of near-shore, intertidal environments; *L. lacertosa*, a euryhaline species that also thrives in the intertidal zone; *L. psammophila*, which normally prefers sandier substrates; and *L. steynewoodensis* (see Appendix A). These species are represented by adults of both sexes and juvenile stages, and are thus considered to represent the indigenous fauna. The remaining taxa are represented almost exclusively by juvenile valves that were often stained black. These include *Cytheropteron nodosum*, *Hemicytherura clathrata*, *Hemicythere villosa*, *Semicytherura sella*, and *Semicytherura angulata*, and they are particularly important in sample K (4.19–4.30 m) near the top of the marine sequence. These are all outer estuarine and marine taxa, but their size distribution indicates that they have undergone *post mortem* transportation, probably by weak tidal currents. They are consequently unreliable as palaeoenvironmental indicators and are differentiated from the indigenous fauna with an R (= remanie) in table 4.

The ostracod assemblages in the Steyne Wood Clay at Bembridge indicate the presence of euryhaline, tidal flat conditions. The presence of adult and juvenile specimens of Oligocene taxa in the samples suggests erosion of Oligocene strata within the intertidal zone. Oligocene ostracods are particularly important in samples Q and O, near the base of core B, whereas none are present in sample K. As deposition progressed these outcrops were therefore eventually covered by tidal sediments, and thus protected from further erosion.

Leptocythere steynewoodensis is particularly common in samples M and K at the top of the marine sequence. The ecological requirements of this species are not known, but they could conceivably be similar to those of *L. porcellanea* (Brady), a closely related species that is confined to brackish, estuarine creeks, on stable mud substrates today (Horne & Whittaker 1985). The assemblages in the Steyne Wood Clay could therefore reflect shallowing-upwards conditions, the initial, relatively open, tidal flat environment of samples Q and O being replaced by marsh-creek conditions in samples M and K. The funnelling effect of these creeks probably resulted in the concentration of *Cytheropteron nodosum* and other outer-estuarine and marine taxa up-estuary by the flood tide, and ebb tide currents were too weak to return these taxa to their original environment.

Only three of the ostracod species found in the Steyne Wood Clay do not now occur in British estuaries and inshore waters. These are *Semicytherura affinis*, *Cytheropteron* sp. (see Appendix A), and *Leptocythere steynewoodensis* sp. nov. None of these species has been recorded previously from British interglacial deposits, although *S. affinis*, which lives today in the Arctic and along the Norwegian coast (see, for example, Brady & Norman 1889; Neale & Howe 1975) has been observed in the Flandrian (8500–6000 years BP) Carse Clays (Claret Beds) in the Grangemouth area, Scotland (Browne *et al.* 1984). To some authors *Hemicytherura clathrata* is not a species living in British waters today, although empty valves are often encountered in both recent and Holocene marine strata. Of the remaining taxa, only *Leptocythere baltica* and *Sclerochilus gewemuelleri* have not been recorded in the British Pleistocene before, although these two species have probably been confused with *Leptocythere porcellanea* and *Sclerochilus contortus* (Norman) respectively. Both species are present in Eemian (last interglacial) tidal flat deposits in southwest Denmark.

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(*b*) *Discussion*

The main objective of the nannofossil studies is to try and integrate the Steyne Wood Clay and other deposits from the Solent region within the time framework established in oceanic sediments. Coccoliths have great potential as biostratigraphic tools as their first-occurrence datums (FODs) and last-occurrence datums (LODs) have been shown to be broadly synchronous, and have been correlated with the isotopic and palaeomagnetic framework established for the deep-sea environment. To achieve these aims the nannofossil assemblages described above must be integrated with those reported from the adjacent northeast Atlantic and other oceans.

The most important nannofossil datum in the Middle Pleistocene is the extinction of *Pseudoemiliania lacunosa*, which occurs consistently worldwide during the middle of oxygen isotope stage 12 at *ca.* 0.45 Ma BP (Gartner & Emiliani 1976; Thierstein *et al.* 1977). The absence of *P. lacunosa* and *Emiliania huxleyi*, a species that has a FOD at 0.275 Ma BP (Thierstein *et al.* 1977), from the Steyne Wood Clay assemblages suggests an age range between 0.275 and 0.475 Ma BP. Based on the nannofossil biostratigraphical evidence, the sediments are therefore thought likely to have been deposited during oxygen isotope stage 9 or 11. The dominance of *Gephyrocapsa oceanica* and *G. caribbeanica*, but absence of small (under 3.5 μm) *Gephyrocapsa* spp. are other useful pointers to the age of this deposit. In a detailed study of northeast Atlantic Pleistocene cores Pujos-Lamy (1977*a*, *b*) found that the time interval of *ca.* 0.275–0.475 Ma BP was dominated by *G. oceanica* and *G. caribbeanica*, whereas small *Gephyrocapsa* spp. (*G. ericsonii* and *G. aperta*) tended to be absent or rare. Brunhes nannofossil assemblages younger and older than this interval may have a significant but much smaller *Gephyrocapsa* component.

Of particular stratigraphic interest is the abundance of the foraminifer *Aubignyna perlucida* (figure 11, plate 1, j–l). This normally lusitanian species occurs commonly in many Holsteinian/Hoxnian deposits in the southern North Sea. Assemblages composed exclusively of *Aubignyna perlucida* are found at Kirmington, Yorkshire (Knudsen 1980, 1987) and it is also common in the Nar Valley Clay in Norfolk (Knudsen 1980). Both of these deposits are thought to be Hoxnian in age (Lord & Robinson 1978; West & Whiteman 1986). On the continent *Aubignyna perlucida* is common in the Holsteinian deposits of northwest Germany, East Germany, and southwest Denmark, whereas it only occurs sporadically in Holocene and Eemian interglacial deposits (Knudsen 1980, 1988).

The deposits at Noordbergum in The Netherlands (type-site of 'Cromerian interglacial IV') are also rich in *Aubignyna perlucida* (samples kindly placed at our disposal in Aarhus by J. W. C. Doppert and N. Neele, Rijks Geologische Dienst, The Netherlands), but both the foraminiferal and ostracod assemblages at Noordbergum show much greater affinity to the North Sea Holsteinian assemblages than to Middle Pleistocene assemblages in southern Britain (Knudsen 1980; Lord & Robinson 1978; Lord *et al.* 1990; Penney 1987). These differences may partly be a reflection of environmental control. The Noordbergum deposits, like most of the Holsteinian deposits in the southern North Sea, accumulated in shallow, inner neritic embayments rather than under intertidal, estuarine conditions and direct comparison is not therefore very meaningful. In addition, very little is known about Cromerian foraminiferal and ostracod faunas, and it is not yet clear if these can be separated from the better-known Holsteinian faunas.

No clear datum has been established for Middle Pleistocene ostracods and Foraminifera in the English Channel. The situation is further aggravated by the lack of published accounts on

Downloaded from rstb.royalsocietypublishing.org

which to base any meaningful conclusions. The ostracods *Leptocythere steynewoodensis* and *Cytheropteron* sp., both of which could suggest an age, are only known from the Steyne Wood Clay, and the ostracod species list from Bembridge has little in common with either Earnley (nine common species) or Noordbergum (ten common species). Moreover, none of the taxa found at Earnley that could suggest an age are present in the Bembridge deposits (cf. West *et al.* 1984). In contrast, 19 of the ostracod species found in the Steyne Wood Clay are also present in the Ipswichian intertidal deposits at Selsey (Whatley & Kaye 1971).

On the basis of the above discussion, the foraminiferal faunas in the Steyne Wood Clay suggest a Hoxnian age or older, whereas the Ostracoda suggest a Middle Pleistocene age. Further work on Middle Pleistocene microfaunas in the English Channel is required, based on material that can be accurately dated using several independent methods, before any worthwhile comparisons can be made.

3. Low-level deposits: Bembridge Raised Beach and associated deposits

(a) *Bembridge Foreland*

(i) *Background*

The occurrence of deposits of gravel near Bembridge Foreland was noted by many early workers (see, for example, Godwin-Austen 1855; Forbes 1856) but it was apparently Prestwich (1859) who first regarded the 'great shingle-cliff at Bembridge' as a marine deposit and a westward extension of the raised beach at Black Rock, Brighton. In a later paper (Prestwich 1892) he lists the lithological composition of the raised beach at Bembridge, but it was Codrington (1870) who gave the most detailed account of these deposits. He not only noted the existence of two discrete 'peat-beds' but also distinguished between a lower 'orange-gravel' and an upper 'white-gravel' rich in clay. Moreover, he described the overlying brickearth and recorded an Acheulian hand-axe from the section at Howgate. Further mention is made by Reid & Strahan (1889) and White (1921) but they add little to Codrington's account.

More recently an Ipswichian age has generally been assumed for the raised beach at Bembridge (see, for example, Jones 1981). However, Arkell (1943) not only thought that it was deposited under cold conditions but also correlated it with the 'Boyn Hill or Middle Acheulian Interglacial' presumably because of Codrington's find of an Acheulian hand-axe in the overlying brickearth.

(ii) *Stratigraphy and geomorphology*

The low-level Pleistocene sequence at Bembridge forms a terrace-like feature extending from Lane End to the Bembridge School area (figure 1). The upper surface of the terrace lies at around 5.5 m O.D. at Lane End and rises, gradually at first and then more steeply, as far as Howgate (site W; figure 2) where it lies at 20.5 m O.D. A steeper slope separates the terrace from the hill (maximum height 44 m O.D.) on which the Steyne Wood Clay occurs. The terrace dips towards the eastnortheast, and underlies most of Bembridge itself (figure 1). The terrace, which in general presents a uniformly dipping planar surface, is dissected by a river valley that formerly reached the sea near Lane End.

The terrace is underlain by a range of Pleistocene sediments, the stratigraphical relationships of which are shown in figure 2. The base of the Pleistocene sequence is marked by an erosional

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

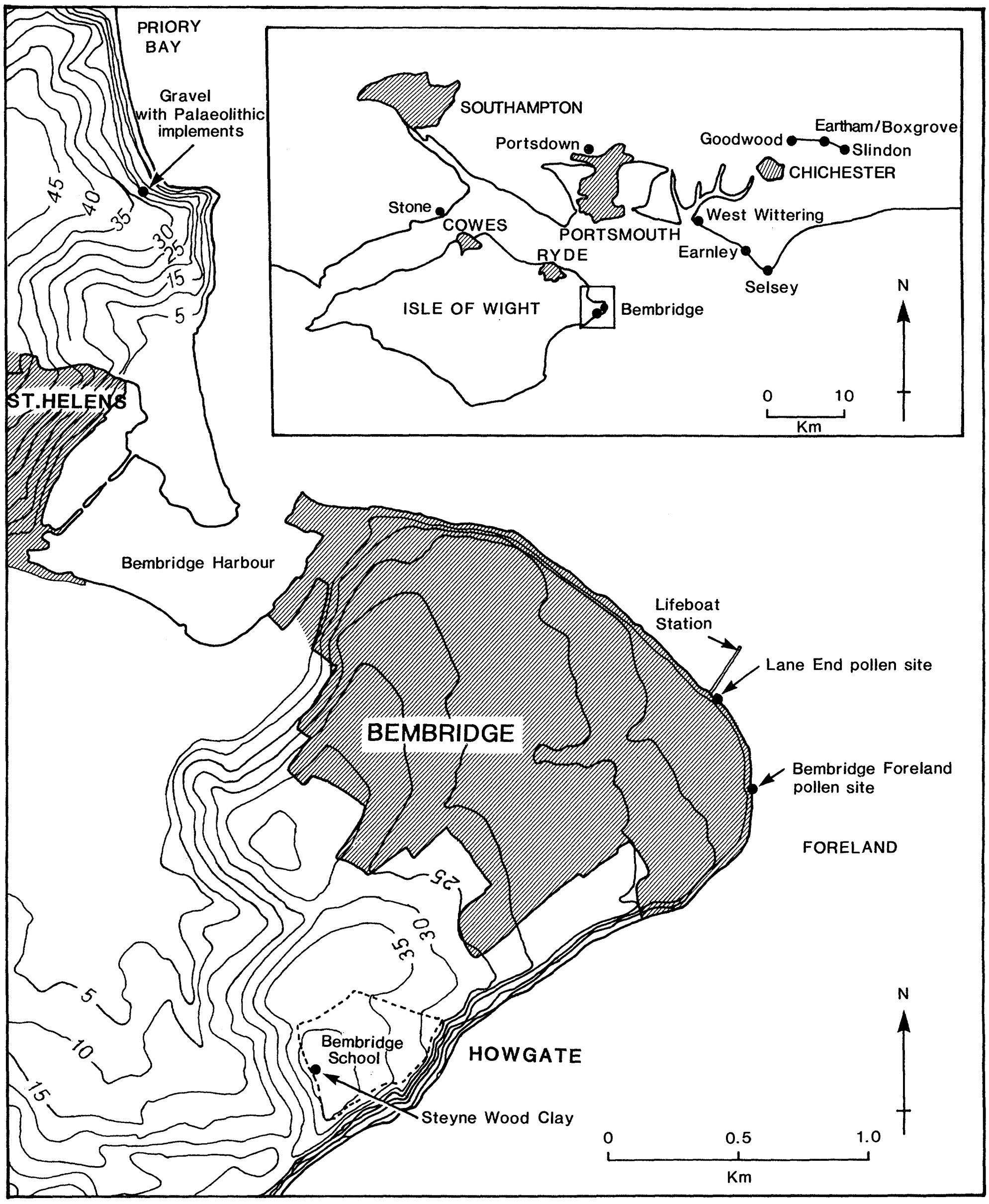


FIGURE 1. Location map for sites mentioned in the text. Contours are in metres.

unconformity cut into Bembridge Marls (Lower Oligocene). This surface lies at around 3.5 m O.D. from Lane End for about 1.4 km along the section towards the southwest. The erosional unconformity and the gently inclined terrace surface above it define the intervening wedge of Pleistocene material. Between sites W and X the erosional unconformity rises at a steeper gradient than the overlying terrace, so that the Bembridge Marls reach the ground surface 100 m to the southwest of site U at 27.5 m O.D.. The Bembridge Marls immediately

FIGURE 2. Pleistocene cliff section from Bembridge School to Lane End. The stratigraphy indicated at Bembridge School is known from excavation and boreholes; the remainder is exposed in coastal section.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

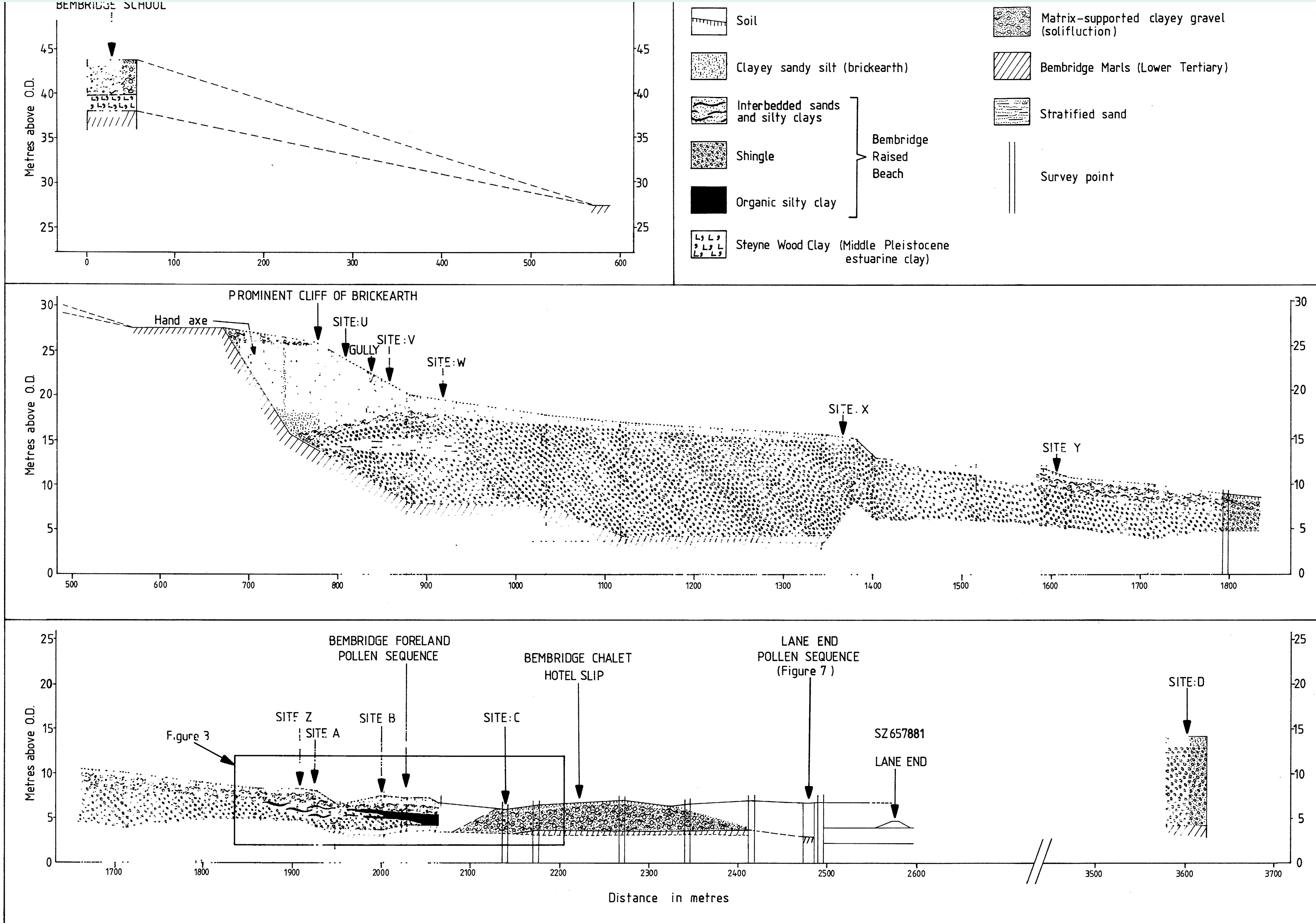


Figure 2. For description see opposite.

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

underlie the land surface between this point and the Steyne Wood Clay sequence on Bembridge School hill (SZ 641866).

The lowest unit in the Pleistocene sequence is a well-bedded orange flint gravel that reaches a maximum observed vertical thickness of 12 m between sites X and W. The base of this unit is defined by the erosional unconformity.

The distinction between a lower orange bedded gravel and an upper white clay-rich gravel has been emphasized by earlier workers: 'A little to the north of the Coast-Guard Station, where the cliff loses height, the deep red-brown shingle gravel is overlain by a white shingle, the junction being slightly irregular, and dipping about 3° northwards' (Codrington 1870). In contrast to the orange gravel, the white gravel is in most places matrix-supported, the matrix being a poorly sorted mixture of clay, silt and sand and is poorly bedded. It overlies the orange gravel and is up to 2.5 m thick between sites Y and Z and in the vicinity of sites U and W; it overlies interbedded sands and silty clays, and organic silty clays between sites Z and C, and from site C to Lane End directly overlies the Bembridge Marls. It reaches a maximum thickness of 3.5 m in the vicinity of the Bembridge Chalet Hotel slipway. It is important to note that where the surface of the well-bedded orange gravel reaches its maximum, between sites X and W, it is not overlain by the white matrix-supported gravel.

A thin clayey sandy silt with occasional scattered flints, described as brickearth by earlier workers, overlies both the gravel units between site W and Lane End. The brickearth is thinnest near Lane End, in contrast to the matrix-supported gravel, and gradually thickens towards the southwest. At Howgate Cliff, immediately southwest of site W, the brickearth thickens to some 10.5 m. At this point it overlies the white matrix-supported gravel, the surface of which dips towards the southwest. The brickearth therefore infills a basin-like feature, bounded on the northeastern side by the dipping matrix-supported gravel and on the southwestern side by the rising surface of the Bembridge Marls. At Howgate Cliff the upper slopes of the brickearth are veneered by a second, higher, unit of white matrix-supported gravel.

Smaller exposures of other sediments occur at specific points along the section. Between site U and W horizontally bedded sands and silts form a well-defined lens within the well-bedded orange gravels. A complicated but critical sequence occurs between sites Z and C (figure 3). Fifty metres southwest of site Z, interbedded orange-white sands and light blue-grey silty clays occur between the orange well-bedded gravels and the white matrix-supported gravel. This unit thickens towards site Z reaching a maximum of 1.5 m at site A. Between sites A and B it is divided by a thin (up to 0.5 m) bed of orange bedded gravel. Traced towards the northeast the interbedded sands and silts grade into highly organic, structurally homogeneous, dark grey-brown silty clays. This material joins to form one unit at site B and further thickens towards the northeast, reaching a maximum of just over 1.5 m immediately southwest of a heavily vegetated and obscured section. The sediments are visible again a few metres to the southwest of site C, but here there is no trace of the organic silty clay or orange gravel, only matrix-supported white gravel and a thin layer of brickearth†.

One kilometre northwest of Lane End, towards Priory Bay, is site D where well-bedded orange gravel reaches 8 m thick, lies directly on Bembridge Marls, and is overlain by a metre

† Since recording this sequence most of the section between sites B and C has been covered by landfill as part of a coastal protection scheme. Only a small 'window' of organic silty clay is now visible some 60 m northeast of site B.

Downloaded from rstb.royalsocietypublishing.org

of white matrix-supported gravel. Site D lies almost at the point where the 15 m contour reaches the coast and so reflects the intersection of the present coastline with the inclined surface of the gravel terrace.

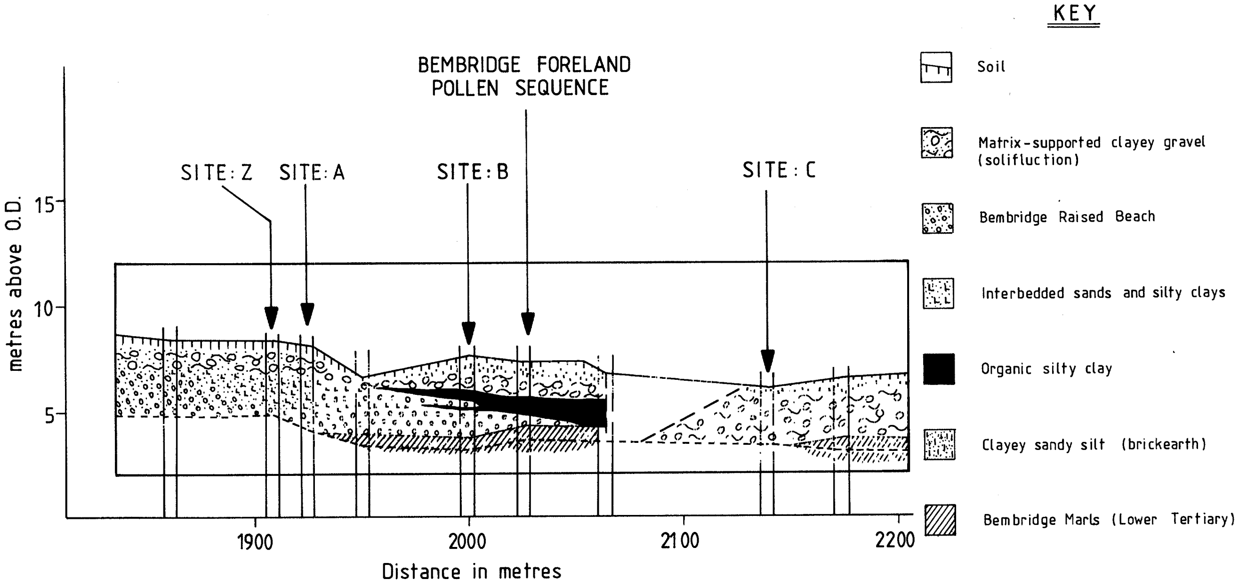


FIGURE 3. Detail of section between sites Z and C.

(b) *Bembridge Raised Beach*

(i) *Sedimentology*

Three units make up the Bembridge Raised Beach: the well-bedded orange clast-supported gravel, the interbedded sands and silty clays and the organic silty clay (see lithostratigraphic definition below).

The orange gravel beds are inclined throughout the length of the section towards the northeast. Individual beds have an apparent dip of 6–10° and a true dip of 8–13°, orientated down-dip at measured sites between 39° and 79°. The dip of the gravel units is therefore concordant with, but greater than, the overall gradient of the terrace surface. The gravels are heavily iron-stained throughout. As recognized by Reid & Strahan (1889) and White (1921), the grade of the pebbles increases from east to west, the coarsest material occurring between sites W and X. In the inclined gravel beds the clasts support each other, but sand beds occur throughout that contain occasional matrix-supported flints. These sand beds are most frequent at the southwestern end of the section, being comparatively rare to the northeast of site Y. Most are inclined parallel with the juxtaposed dipping gravel beds, but between sites U and W a lens composed of sands and silty clays is horizontally-bedded. At site U this lens consists of grey-orange mottled silty clays, but it grades laterally into cross-bedded sands with an intervening gravel bed at site W. These fine sediments were obscured by vegetation to the northeast of site W.

The interbedded sands and silty clays that overlie the orange gravel between sites Z and C contain occasional flints. The sand varies from 2 mm to 63 μm in size, and in colour from bleached white to heavily iron-stained orange. In places the orange sand is mottled olive-grey (5Y 6/4). The sand beds are structureless, but contain frequent interbeds or partings of light

Downloaded from rstb.royalsocietypublishing.org

blue-grey silty clay. These silty clay partings become thicker and more frequent downwards, and at site Z a bed 10 cm thick occurs at the base of the unit directly overlying the orange gravels. Samples of this silty clay were analysed for coccoliths and samples were submitted to Dr R. J. N. Devoy (University College, Cork) for diatom analysis, but the sediments were devoid of both fossil groups.

The organic silty clay is very dark grey-brown (10YR 3/1) when exposed to the air, but is very dark metallic blue when unoxidized. It is lighter towards its base, where it becomes grey (5Y 6/1), whereas its upper surface is weathered to yellowish-brown (10YR 5/6). It contains occasional rounded to subangular black flints up to 3.5 cm in diameter, and occasional pale grey lenses of coarser sands with reduced organic content. Otherwise the sediment is structurally homogeneous, and although highly organic it lacks plant macrofossils and microfauna.

(ii) *Lithological composition and morphology of the gravel clasts*

The angularity/roundness of the flint fraction and the total lithological composition of the orange clast-supported gravel unit of the Bembridge Raised Beach has been analysed by Dr D. R. Bridgland (Nature Conservancy Council). In these analyses the 16–32 mm size fraction was used, and the angularity/roundness classes were based on a modification (Fisher & Bridgland 1986) of Powers' (1953) roundness scale for sedimentary particles. The data are presented in table 5 and figure 4.

TABLE 5. CLAST LITHOLOGICAL DATA FROM BEMBRIDGE AND RELATED SITES: PROVENANCE

(Abbreviations: nod, nodular; Gsd, Greensand (chert + other lithologies); Jur, Jurassic chert (excepting *Rhaxella*); Rhax, *Rhaxella* chert (Portlandian); irn, ironstone (Wealdon type; Carstone types counted with Gsd); ign, igneous; sch, schorl; n-d, non-durable; *, cannot be separately recognized.)

	flint			chert								
locality	nod	beach	oth	Gsd	Jur	Rhax	irn	qtz	ign	sch	n-d	total
Priory 1	12.5	7.3	71.1	5.7	1.8	0.3	—	1.3	—	—	—	384
Priory 2	7.6	11.3	67.1	12.5	0.8	—	1.4	—	—	—	0.2	513
Bembridge 1	3.8	*	87.8	3.8	2.0	0.4	—	1.2	0.7[a]	0.4	—	557
Bembridge 2	7.1	*	76.9	7.5	3.2	0.1	2.0	2.0	0.8[b]	—	0.4	693
Lane End	8.9	14.8	65.5	6.2	3.4	0.6	—	0.7	—	—	—	676

[a] Includes two weathered acid igneous rocks and one medium-grained igneous porphyritic rock.
[b] Includes a pale coarse-grained igneous rock, a dark coarse-grained igneous rock and a granite clast.

Two samples were taken from the Raised Beach, one from the gravel between sites Y and Z (sample 1) and one from the gravel at site Y (sample 2). These two samples are very similar in being dominated by flint but with significant minor amounts of Greensand and Jurassic chert, ironstone and quartz. Other trace lithologies include *Rhaxella* chert (Portlandian), some igneous rocks (table 5), tourmalinized schorl-rock and a distinctive low-grade metamorphic clast, probably from Start Point, Devon (identified in thin section by Dr G. Chinner, Department of Earth Sciences, University of Cambridge). This assemblage indicates a provenance from the west along the south coast of England. In particular, the *Rhaxella* chert is typical of the Dorset Portlandian, containing types of spicule that are unknown from the Yorkshire Corallian *Rhaxella* chert. The Greensand chert could be derived from the Isle of Wight itself, but the Jurassic chert is probably derived from exposures on the south coast to the

Downloaded from rstb.royalsocietypublishing.org

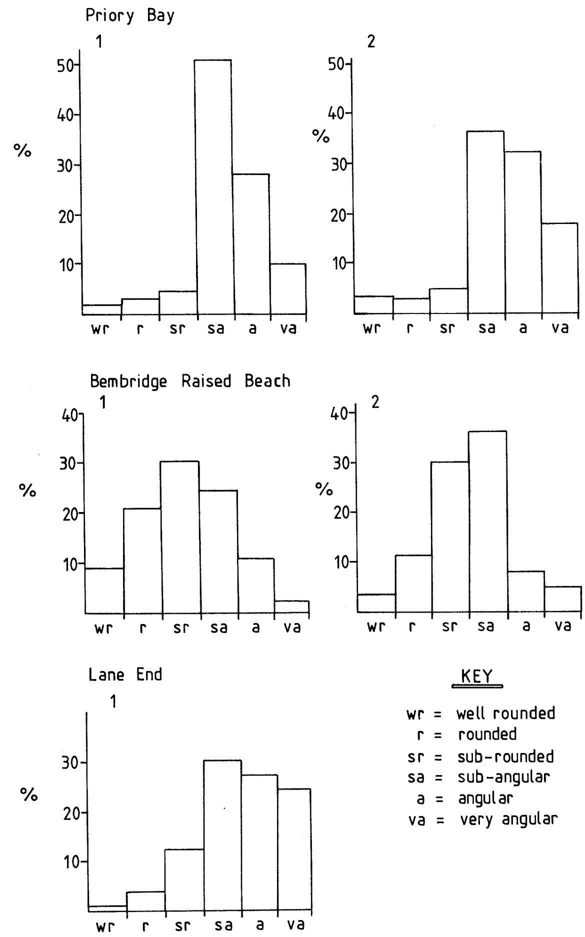


FIGURE 4. Roundness/angularity data for clasts from gravels at Priory Bay, the Bembridge Raised Beach and Lane End. The Priory Bay and Lane End gravels are significantly more angular than the Bembridge Raised Beach, and, based on this and additional data, are interpreted as fluvial in origin. Two discrete samples were analysed from both Priory Bay and the Bembridge Raised Beach (see text).

west. Schorl-rock is present in the Pleistocene gravels of the Solent, and these earlier fluvial deposits could provide the source for this lithology in the Raised Beach (L. Allen, personal communication 1987).

The flint pebbles are dominated by clasts showing microfeatures such as crescentic chatter-marks, which are typical of beach-wear, and these clasts are also significantly rounded compared with other flint clasts from local gravels (table 5 and figure 4). Sample 1 has a modal class in the sub-rounded category and sample 2 a modal class in the subangular category. These angularity/roundness data support the hypothesis of a beach origin for the clast-supported gravel unit of the Bembridge Raised Beach.

(iii) *Thermoluminescence dating*

It has recently been shown that thermoluminescence dating can be successfully applied to beach and dune sands (see, for example, Singhvi *et al.* 1982; Southgate 1985). A TL sample from a sand lens within the Bembridge Raised Beach at site X (figure 2) was therefore submitted to G. A. Southgate. He reported that the age determinations indicated that the beach was deposited during the last interglacial. His full report appears as Appendix B.

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(iv) *Pollen analysis*

Serial samples were taken from the organic silty clay for pollen analysis at the point marked on figures 1, 2 and 3 (Bembridge Foreland pollen sequence).

The detailed stratigraphy at the sampling site was as follows

0–6 cm Modern soil.

6–70 cm Brickearth with scattered flints.

70–144 cm Matrix-supported gravel with subangular to rounded flints. Cryoturbated throughout. Coarse sand at base.

144–246 cm Very dark grey-brown (10YR 3/1), highly organic silty clay becoming paler downwards. Basal 5 cm grey (5Y 6/1). Upper 1 cm weathered to yellowish-brown (10YR 5/6). Occasional black rounded to subangular flints up to 3.5 cm diameter scattered irregularly throughout unit. Occasional pale grey sand lenses.

246–270 cm Mottled grey and bright orange stony clay, with some sand lenses.

270–305 cm Pale olive (5Y 6/4) sand becoming more silty downwards.

305–340 cm Coarse orange sand and fine gravel (continuing).

Pollen samples from 16 levels in the sequence were prepared by using the standard treatment with hydrochloric acid, hydrofluoric acid and acetolysis mixture (Faegri & Iversen 1975). In addition, they were treated with sodium pyrophosphate as outlined by Bates *et al.* (1978) for the preparation of clay-rich samples. The residues were mounted in silicone oil. The addition of known quantities of *Lycopodium* spores by tablet (Benninghoff 1962; Matthews 1969; Bonny 1972) to volumetric subsamples of the sediment enabled the calculation of pollen concentrations (figure 6). Of the 16 levels prepared, five samples contained less than 4000 grains cm^{-3}. This has been found to represent a useful practical threshold beyond which pollen counting becomes an inefficient and unnecessarily time-consuming exercise (Scourse 1985). For each level at least 500 total identifiable land pollen and spores were counted. Unidentifiable pollen was recorded as crumpled, broken, corroded, degraded or concealed (Birks 1973).

An understanding of taphonomic processes is an essential prerequisite to the interpretation of the pollen assemblages, and this in turn is dependent on the interpretation of the depositional environment of the sediments themselves.

The sediments suggest that the organic silty clay was deposited in a low-energy coastal environment, probably in a saltmarsh. The homogeneous organic silty clays with occasional grey sand lenses are extremely similar to modern saltmarsh sediments, the darker finer sediments representing vegetatively trapped material on the saltmarsh flats, the sand lenses former creeks.

A number of the pollen taxa support this interpretation based on the sediments alone. In such a situation most pollen would be of extremely local derivation, from the saltmarsh vegetation itself, with smaller extra-local and regional components (Jacobsen & Bradshaw 1981) derived from estuarine waters as high tide and freshwater inputs through creek discharge at low tide.

The pollen diagrams (figures 5 and 6) can be divided into two local pollen assemblage zones (PAZS), which can readily be assigned to the interglacial substages of Turner & West (1968). The latter are indicated on the pollen diagrams. The boundary between the two zones is drawn at 215 cm and is defined by the rise in *Carpinus*.

The diagram is dominated by tree and shrub taxa with a very low diversity of herb taxa;

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

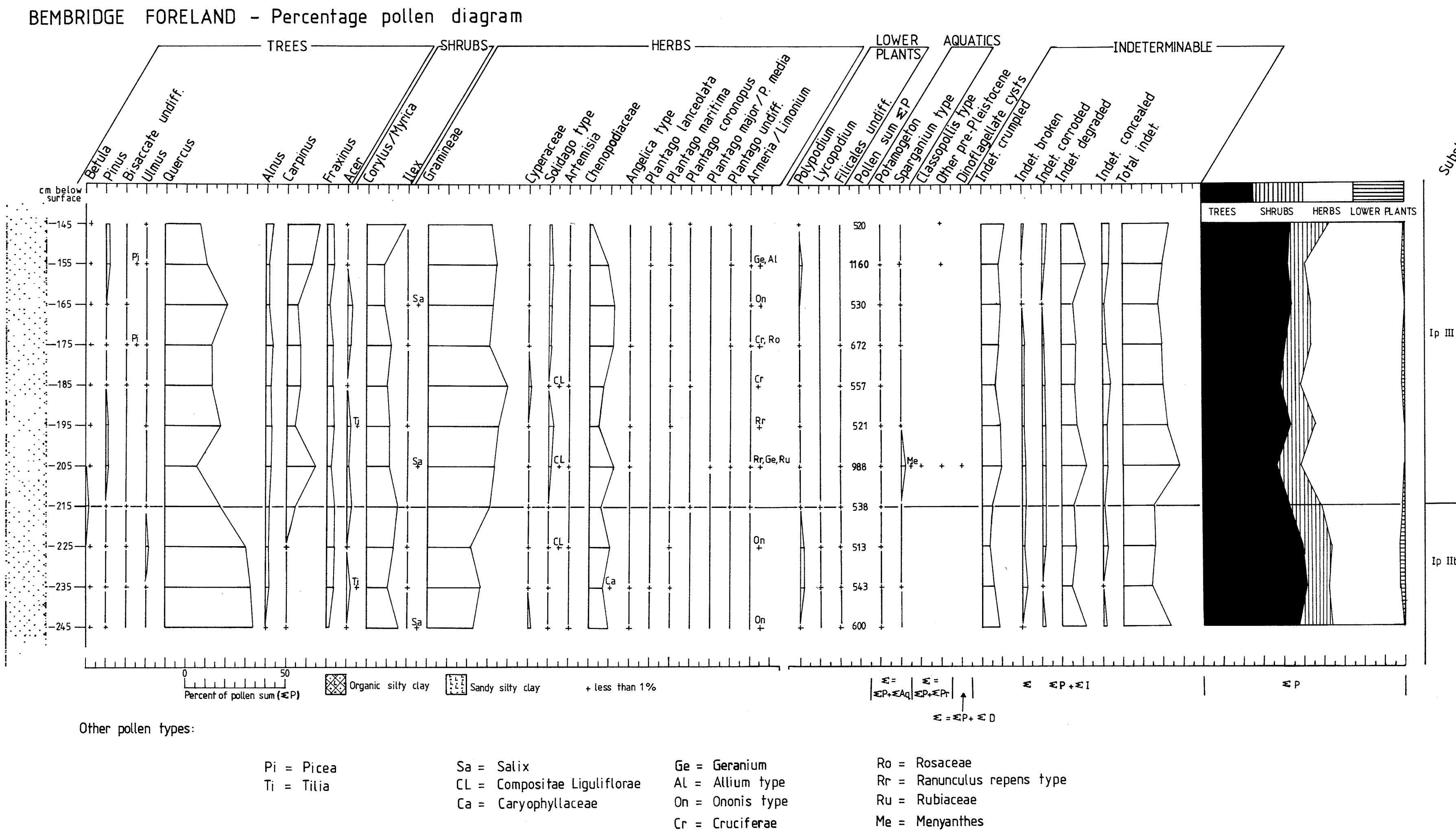


FIGURE 5. Bembridge Foreland: percentage pollen diagram. Tree, shrub, herb and lower-plant frequencies are expressed as percentages of total dry land pollen and spores (P), aquatics as P+aquatics, pre-Pleistocene grains as P+pre-Pleistocene grains, dinoflagellate cysts as P+dinoflagellate cysts (D) and indeterminable grains as P+indeterminable grains. The summary diagram is calculated from percentages of P. Pollen taxonomy is based on Birks (1973). The *Betula* curve includes all species; Bicaccate undiff, includes all isolated air sacs not attributable with certainty to either *Pinus* or *Picea*, and *Sparganium* type includes *Typha angustifolia*. Lithological symbols follow Troels-Smith (1955). Analysed by J. D. Scourse, February 1986.

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

the high frequencies of specific herb taxa, however, such as Gramineae and Chenopodiaceae, are important throughout.

The *Quercus–Fraxinus–Corylus* PAZ (245–215 cm) is dominated by *Quercus* (40–43 %), *Fraxinus* (2–4 %), *Corylus*/*Myrica* (11–16 %), Gramineae and Chenopodiaceae (6–11 %). Other continuous records for tree taxa include *Acer*, *Alnus*, *Pinus* and *Betula*, whereas there are discontinuous records of *Ulmus*, *Carpinus* and *Ilex*. Towards the top of the zone *Carpinus* values rise to 5 % (215 cm).

The *Quercus–Carpinus* PAZ (215–145 cm) covers the greater part of the sequence. Apart from the rise of *Carpinus*, which ranges between 4 and 17 %, other features differentiate it from the lower zone. These include reduced *Quercus* values (16–31 %), a continuous but low frequency of *Pinus* and increased Gramineae values (31–40 %). The overall contribution of trees and shrubs to the pollen sum drops in the upper zone and this is a corresponding increase in herb values.

The concentration diagram (figure 6) indicates a background level of around 360000 grains cm^{-3} but with an increase to over 1 million grains cm^{-3} at 205 cm. This level coincides with an increase diversity of herbaceous taxa, a percentage increase in indeterminable pollen, increased frequencies of the aquatic taxon *Potamogeton*, and records for *Menyanthes* and reworked pre-Pleistocene taxa. These features, in combination, may well result from a sedimentary change at this level undetected in the lithology, and would be compatible with a temporary shift to saltmarsh creek from saltmarsh surface sedimentation, the pollen source area being temporarily increased by fluvial catchment. Otherwise, the general lithological homogeneity permits the interpretation of the pollen assemblage changes as palaeovegetational trends rather than as artefacts of taphonomy or preservation.

The taxa that indicate saltmarsh include the high values of Chenopodiaceae and Gramineae that occur throughout. Plants of probable coastal affinities are represented by *Armeria*/*Limonium* and *Plantago maritima*. In addition, grains very similar to *Erodium*, another possible coastal indicator, were observed at 205 and 155 cm; uncertainties in precise identification necessitated their inclusion within the *Geranium* taxon.

The assemblage of tree and shrub taxa indicate fully temperate conditions, with probable closed forest away from the local environs of the saltmarsh itself. *Quercus*, *Corylus* and *Carpinus* appear to have been the main components of this forest vegetation, with significant amounts of *Alnus*, *Fraxinus*, and *Acer*. *Fraxinus* is a low pollen producer (Andersen 1970), and *Acer* is primarily entomophilous (Huntley & Birks 1983), so both these taxa may well be under-represented in the pollen diagrams (West 1980*a*). Huntley & Birks (1983) regard values of more than 1 % and less than 5 % for *Fraxinus* as indicating a local presence, and even the presence of *Acer* pollen as indicative of possible local abundance.

An unequivocal correlation can be made with substages IIb and III of the Ipswichian interglacial. Ipswichian IIb is characterized by high values of *Quercus* and *Corylus* with important contributions from *Acer*, *Ulmus*, *Alnus* and *Betula*, along with the presence of *Tilia* (West 1980*a*). The presence and relative frequencies of these taxa in the *Quercus–Fraxinus–Corylus* PAZ are entirely consistent with this substage. The main difference between this zone and Ip II b elsewhere is the extremely low frequencies of *Pinus*. This is all the more surprising given its high productivity, good dispersal abilities, resistance to decay and known over-representation in intertidal sediments. The low frequencies certainly suggest a correlation with Ip III rather than Ip II a where *Pinus* values reach their maximum during the

Downloaded from rstb.royalsocietypublishing.org

entire interglacial. It must be concluded that *Pinus* was an insignificant component of the forest vegetation in this region during Ip IIb. It is noteworthy that Brown *et al.* (1975) also record relatively low values of *Pinus* during Ip IIb at Stone, Hampshire, although West & Sparks (1960) record higher frequencies during the early temperate substage at Selsey, Sussex, which are more consistent with East Anglian sites (West 1980*a*).

The *Carpinus* rise defines the boundary between Ip IIb and Ip III (West 1980*a*). Ip III is also characterized by reduced levels of *Quercus*, *Corylus* and other thermophilous tree taxa, and low frequencies of *Picea* (West 1980*a*). This site satisfies these requirements in the rise of *Carpinus*, reduced frequencies of *Quercus* and the occasional presence of *Picea*. However, *Corylus*, *Acer* and *Fraxinus* continue to the upper level of the sequence in significant quantities. This may well indicate that only the initial stages of Ip III are represented. However, there is limited evidence at the top of the sequence for a rise in *Pinus* values, which usually heralds the transition from Ip III to Ip IV. The decrease in tree and shrub frequencies about 215 cm also supports the correlation with Ip III; such a decrease characterizes the Ip IIb/III transition at Wing, Rutland (Hall 1980).

A notable feature at Bembridge Foreland is the significant contribution of *Fraxinus*. This is an important component of Ip III at Wretton, Norfolk, where it is thought to have been favoured by more open conditions as indicated by the associated high non-arboreal pollen (Sparks & West 1970), and during Ip III at Wing (Hall 1980). West (1980*a*) identifies *Fraxinus* as most abundant during periods of forest instability or openness, occupying seral situations in the regional forest. The relatively high values of *Fraxinus* throughout this sequence may be a reflection of the locus of sedimentation, *Fraxinus* occupying a seral, unshaded, transitional zone between the saltmarsh and the closed forest. In this area, such a situation would also probably be characterized by moist soils of high base status, which would additionally favour *Fraxinus* at the expense of *Pinus* which tends to avoid such habitats (Huntley & Birks 1983). It appears that *Fraxinus*, here, may well have replaced *Pinus* as a forest margin species.

Bembridge Foreland is notable as an Ipswichian site in that it records the transition from Ip IIb to Ip III only previously recorded in the literature at Wretton (Sparks & West 1970) and Wing (Hall 1980).

(v) *Lithostratigraphic definition of the Bembridge Raised Beach*

We here formally define the Bembridge Raised Beach as a lithostratigraphic unit comprising not only the well-bedded orange clast-supported gravel, which is the material to which the term has been informally applied in the literature (compare Mottershead 1977), but also the interbedded sands and silty clays, and the organic silty clay from which the pollen record has been obtained.

(*c*) *Associated deposits*

(i) *Solifluction*

The white gravels overlying the orange clast-supported gravels are interpreted as a solifluction deposit (see figure 2). These gravels are dominantly matrix-supported, the matrix consisting of an admixture of clay, silt and sand. The fabric of the sediment and its matrix is variable both laterally and vertically, but the deposit becomes increasingly clay-rich towards the northeast where it is invariably matrix-supported. The sediment is heavily cryoturbated in

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

the form of discrete well-sorted sand bodies and concentrations of white flints forming highly localized clast-supported 'nests'. Both the sand bodies and stone nests are interpreted as products of periglacial ground-ice processes, which are known to induce sorting (French 1976). Associated ground-ice processes would also explain the vertical orientations of clasts in the upper levels of this unit. Both the cryoturbation structures and the vertical clast orientations are particularly well exposed in the vicinity of the Bembridge Chalet Hotel slipway (see figure 2).

At site C the soliflucted gravel contains a variable black-grey lens of organic silt similar to the interglacial deposits described above. A sample of this material was found to lack pollen and contain only highly resistant chitinous residues. It would appear to be a reworked lens of interglacial organic sediment, oxidized during solifluction.

The thickest sequences of the soliflucted gravel occur at relatively low elevations (see figure 2), but are completely absent between sites W and X where the underlying orange bedded gravel reaches its thickest expression and highest elevation. This pattern of deposition suggests an origin by solifluction, the upper levels of the orange gravel between sites W and X providing the upslope source material. The soliflucted gravel contains a higher proportion of clay and silt than could be provided by the underlying orange gravel alone. The most likely source for this additional fine sediment is the Bembridge Marls, which would have been extensively exposed in the vicinity of the site U before the deposition of the overlying brickearth.

(ii) *Brickearth*

The brickearth is essentially a well-sorted silt with subsidiary fractions of clay and fine sand. Median grain sizes of three samples from Howgate gave values between 19.4 and 12.6 μm, the mean grain size being 9.6 μm (D. A. Parks, personal communication 1987). It is not as well sorted as primary loess identified at certain sites in southern England (Catt 1977). Neither does it display the columnar jointing and rootlet-derived pinhole voids characteristic of true loess. However, it is very similar to other brickearths in southern England that have been interpreted as loesses reworked by colluvial or fluvial processes (see, for example, Gibbard *et al.* 1987). In common with these reworked loesses this material is, in places, clearly bedded containing pebble stringers, and forms a thin cover rarely exceeding 1.5 m over most of the section. However, it thickens into a major sedimentary body, up to 10 m thick, near Howgate, in the vicinity of site U, infilling what must originally have been a depression or basin bounded by a steep slope or cliff of Bembridge Marls on the southwestern side and the soliflucted gravels on the northeastern side. The infilling of this depression was probably achieved through the colluvial reworking of primary loess deposited on the slope above, this downslope movement causing the ingestion of the underlying Bembridge Marls.

At least three Acheulian ovates have been discovered in this immediate area (Holyoak & Preece 1983), the first and most important being that recorded by Codrington (1870) actually from the brickearth itself. This fine unabraded specimen has been figured by Evans (1897, figure 467). The other implements came from the face of the cliffs in the vicinity of Bembridge School but their stratigraphic provenance is less secure. It is probable that these ovates are not in primary position but became incorporated into the brickearth during the process of colluviation.

Thermoluminescence dates have recently been obtained from the brickearth cliff at Howgate and from the thinner spread that immediately overlies our pollen sampling site at

Downloaded from rstb.royalsocietypublishing.org

Bembridge Foreland. Late Devensian ages, in the range 16.0 ± 1.5 to 21.5 ± 2.0 ka BP, have been obtained from these sites (Parks & Rendell 1988). Codrington's hand-axe, although firmly stratified within the Howgate brickearth, is clearly not contemporary with the deposit.

(*d*) *Discussion*

The basal shingle of the Bembridge Raised Beach forms one of the thickest and laterally most extensive high-energy raised beach deposits in southern England. Its base is defined by an eroded surface cut into the Bembridge Marls, and its southwestern terminus is bounded by a fossil cliff cut into the same material. This fossil cliff trends at approximately 90° to the coastal section in which it is exposed. The sedimentology of this material, and its geomorphological expression, suggest that this shingle accumulation may represent a fossil spit or cuspate foreland at the eastern extremity of the Isle of Wight. The internal structures of such beaches that are pebbly or actively prograding or both have received scant attention in the literature (Hey 1967; Carter & Orford 1984). However, there are a number of modern or Holocene analogues for cuspate foreland accumulations, including the Ayre Raised Beach at the northern end of the Isle of Man (Thomas 1985) and the deposits underlying the Dungeness Foreland in Kent (Hey 1967). These cuspate forelands are being actively remodelled at the present, and are particularly useful analogues because they demonstrate a direct continuum between the Holocene succession exposed in gravel pits and the coastal processes active today. The Ayre Raised Beach in particular has five features in common with the basal shingle of the Bembridge Raised Beach:

(1) distinctive fossil cliff line;
(2) inclined beds, with dips of 8–10° towards the seaward side;
(3) grade of pebbles;
(4) surface slope dipping towards the landward side at the back of the shingle accumulation;
(5) surface terrace form.

The structures within the Bembridge Raised Beach are identical to those described by Hey (1967) at Dungeness where the strike of the bedding-planes of the gravel is parallel to the strike of beach ridges in the vicinity. These successively abandoned low parallel-ridge systems of uncertain origin occur at Ayre and Dungeness but have not been observed at Bembridge, probably because these relatively subtle geomorphological features were removed during the phase of solifluction that followed. The dip directions at Dungeness show that most of the gravel must have been laid down on the shore-face slope, with backshore deposits being confined to the top of the section. The fine sediments interbedded within the gravel at site W may well have been deposited behind a beach ridge at the highest elevation in the system in some form of backshore lagoon. Similar fine backshore basin infills are associated with the Ayre Raised Beach (Thomas 1985).

The Ayre Raised Beach and the Dungeness Foreland deposits both represent Holocene beach-plain (Johnson 1919) accumulations. If these analogous situations are relevant to the Bembridge sequence, it would imply a significant supply of material by longshore drift from the southwest, a suggestion supported by the lithological composition of the clasts.

It is clear from the palynology of the Bembridge Foreland sequence that the organic silty clay was deposited in a saltmarsh environment. The origin of the overlying interbedded sands and silty clays is less easy to explain in the absence of palaeontological data or definitive sedimentary structures. The sharp lithological contrast without gradation between the

Downloaded from rstb.royalsocietypublishing.org

interbeds of sands and silty clays is none the less typical of intertidal environments, and the direct association of these sediments with the juxtaposed saltmarsh sequence and the underlying beach shingle support this interpretation.

The three lithological units that make up the Bembridge Raised Beach, the basal high-energy shingle, the interbedded sands and silty clays, and the saltmarsh organic silty clays, are genetically related as one conformable fining-upwards sequence. The correlation of the saltmarsh sequence with the early-temperate and late-temperate substages of the Ipswichian interglacial therefore implies the deposition of the underlying shingle and interbedded sands and silty clays during the same high-stand of sea-level. This interpretation from the sediments alone is supported by the TL dates on sand beds within the basal shingle, which are also consistent with an Ipswichian age.

There is one significant difference between the Bembridge Raised Beach basal shingle and the Ayre Raised Beach and Dungeness Foreland beach-plain deposits. The upper surface of the Bembridge shingle accumulation possesses a gradient of 0°40′, falling from a maximum of 18 m at site W to 5 m a few metres to the northeast of site B, a total distance of 1.1 km. Neither the Ayre or Dungeness accumulations are reported to have any overall surface gradient. There are four possible explanations of this gradient.

1. *Post-depositional modification of the upper surface by solifluction* The lack of surface beach ridges at Bembridge and the presence of a significant overlying body of soliflual sediment has been invoked above as evidence for a phase of solifluction post-dating the beach shingle. It is possible that the shingle accumulation originally attained a thickness up to 18 m O.D. for the entire length of the section but was then differentially lowered by solifluction in the northeast. This is thought inherently unlikely because a primary slope would be necessary to initiate solifluction and it would also imply the removal of a massive amount of sediment, which is not represented in the overlying soliflual sequence. A slope angle of 0°40′ is relatively low for active solifluction (French 1976), but this slope reflects the stabilized post-solifluction slope; the pre-solifluction slope would have been somewhat greater.

2. *Tectonic uplift* An originally horizontal upper surface to the shingle accumulation could have been tilted by differential tectonic movement, i.e. relative uplift at the southwestern end of the section. Any tectonic hypothesis at Bembridge has to accommodate the consistent dip of the inclined shingle beds from southwest to northwest, the similarity of the dip angles with the Holocene analogues of Ayre and Dungeness, and the horizontal bedding in the underlying Bembridge Marls. Rigid block-like tectonic uplift of the southwestern end would result in exaggerated angles of dip, and flexuring would lead to dip differentials from southwest to northeast. Tectonic activity in the eastern Isle of Wight during the Pleistocene can therefore only have been on a regional rather than local scale and could not have involved local block movement or flexuring. Local tectonic movement is therefore unable to explain the upper gradient of the shingle. The regional tectonic background is considered in more detail below.

3. *Sea-level regression* The Bembridge Foreland pollen sequence indicates a local saltmarsh environment and is superposed on the high-energy beach shingle at Site B. It is therefore tempting to suggest that the mass of shingle must have been deposited before substages IIb/III of the Ipswichian, thus implying transgression relatively early within the interglacial. The upper shingle gradient could then be associated with shingle progradation at a time of gradual regression during the middle and towards the end of the interglacial, the overlying fine sediments forming a conformable sequence of associated decreasing energy conditions.

Downloaded from rstb.royalsocietypublishing.org

However, the pollen sequence is only laterally superposed to the main mass of shingle, and there is no evidence to confirm that the shingle between sites W and X is earlier than the saltmarsh sediments at Bembridge Foreland. The shingle could alternatively be directly contemporary with or later than the saltmarsh, but still with the proviso that the whole sequence was deposited sometime during the Ipswichian high-stand of sea-level. The pollen-stratigraphic correlation with the Ipswichian and the TL dates on the shingle cannot illuminate this problem because the substages of this interglacial are of unknown duration and the error bars of the TL dates are too wide.

4. *Local physiographic/environmental gradients at a time of stable sea level.* The Bembridge Foreland organic sequence lies between 4 and 6 m O.D. Being a saltmarsh, it was probably deposited somewhat higher than contemporary O.D., which may have stood at around 2–4 m O.D. If a stable sea-level is then invoked, along with broad contemporaneity between the saltmarsh and shingle deposition, a height differential of shingle accumulation at 14–16 m and saltmarsh deposition at 2–4 m above contemporary sea-level is obtained. Though large, this differential is entirely consistent with the height above O.D. obtained by extensive shingle accumulations in high-energy situations today. The maximum height of Chesil Bank is currently 14 m O.D. near Chesilton (Carr & Blackley 1973). This analogue suggests that the apparent discordantly high elevation of the basal shingle is compatible with the reported data on sea-levels in southern Britain during the Ipswichian interglacial (West 1972). However, apart from a similarly high storm beach in New Zealand, Chesil Bank is an exceptional feature and possibly unreliable as an analogue (R. J. Nicholls, personal communication, 1988). Hurst Castle Spit, with crest elevations up to 4.9 m O.D. (Nicholls 1985), may represent a more realistic analogue, which would imply that the spread in elevation of the Bembridge sequence must involve a component of sea-level change. Whichever of these modern features is the more likely analogue, they both imply an open coastline with a high-energy wave climate fundamentally different from the present rather protected, low-energy situation at Bembridge. The altitudinal spread also suggests that the shingle accumulation is more likely to represent a Chesil Bank or Hurst Castle Spit-type shingle 'barrier' beach rather than a cuspate foreland *sensu stricto*, despite the fact that there is no structural evidence for recurves in the shingle gravel. At Bembridge these would probably take the form of sets of northwesterly dipping units.

This final hypothesis is thought to be the most likely explanation for the Bembridge Raised Beach sequence, with the added proviso that regression during the middle/later parts of the interglacial may have controlled the patterns and processes of sedimentation.

The low-level Pleistocene sequence that includes all the units attributable to the Bembridge Raised Beach represents the high-stand of sea-level during the middle part of the Ipswichian interglacial. A range of littoral environments are represented in the Raised Beach sequence, from high-energy shore-face shingle, possibly associated with a spit-like feature, to low-energy saltmarsh environments. The apparently high elevation of the beach shingle can be partly explained in terms of exposure on a high-energy coastline. The role of purely local tectonism can be discounted as an explanation either for the elevation of the shingle or its upper gradient. This gradient is more likely to be the result of the existing section obliquely bisecting a spit-like accumulation rather than being solely the product of regression.

The temperate high sea-level event during the middle of the interglacial was followed by a period of solifluction that must have occurred during the Devensian before 21.5 ± 2.0 ka BP. During this phase of solifluction, the upper levels of the beach shingle and organic deposits were

Downloaded from rstb.royalsocietypublishing.org

removed and mixed with Bembridge Marls as they moved downslope. Subsequent periglacial ground ice processes caused the development of cryoturbations and associated structures in the solifluction deposits themselves. During the continuing periglacial conditions, loess deposits then blanketed the landscape. These aeolian silts were subsequently mobilized by colluvial processes, perhaps including solifluction, causing the infilling of downslope hollows. This final phase of slope movement may have been responsible for the deposition of the solifluction deposit above the brickearth to the southwest of site U.

4. Low-level deposits: Lane End and Priory Bay

(a) *Lane End*

(ii) *Background*

The discovery of organic deposits at Lane End (SZ 656880) was apparently first made by Edward Forbes but it was Godwin Austen (1855, p. 116) who first mentioned them in the literature. His passing reference to organic deposits 'near St.Helen's' is contained within the same paragraph as a description of other organic deposits at Brook on the southwest coast of the Island. These latter deposits contain numerous tree-trunks and considerable quantities of hazelnuts, and are now known to be mid Post-glacial in age (Clifford 1936). In his summarizing sentences it is not clear whether Austen is recording 'the remains of trees of large size' and insects specifically from the Bembridge deposit rather than from Brook.

Codrington (1870) gives a much fuller description, noting the occurrence of two discrete 'peat-beds' at Bembridge. He clearly thought from Austen's account, probably mistakenly, that his 'peat-beds' had yielded 'remains of large trees, hazel-nuts and beetles' (Codrington, 1870, p. 542). Codrington's own account is also slightly ambiguous, as he considered that his two peats merely belonged to the same bed and he records only a single section: (*a*) dark grey clay with black pebbles overlying Bembridge Marls 'a few feet above high water mark'; (*b*) 'peat-bed', not exceeding 1 foot; (*c*) grey clay, 6 inches thick; (*d*) red clayey sand; (*e*) clayey pebbly gravel. However, it is clear that this sequence relates primarily to the larger of his two peat-beds, the one at Lane End.

Neither Godwin Austen (1855) nor Codrington (1870) commented on the relation of the organic deposits to the Raised Beach. However, Reid & Strahan (1889) noted that the peat and gravel at Lane End filled a hollow within the 'older gravel' (i.e. Raised Beach). Moreover, they recognized that they represented the 'Alluvium of the small stream which now flows through Lane End', although they inexplicably found 'no determinable fossils' in the peat.

(ii) *Stratigraphy*

The Lane End organic deposits were relocated on the steep vegetated slope between the car park and the coastal protection revetment immediately south of the Lifeboat Station. The detailed stratigraphy of the site was as follows

0–50 cm Modern soil.

50–200 cm Matrix-supported angular flint gravel.

200–240 cm Brownish-yellow (10 YR 6/8) silty sand passing downwards into olive (5 Y 5/4) silty sand.

240–267 cm Humified sedge-peat with macrofossils of *Carex* and *Menyanthes*. Some small flints.

Downloaded from rstb.royalsocietypublishing.org

267–287 cm Very dark grey (10 YR 3/1) silty gravel with *Menyanthes* seeds, becoming sandier and stonier downwards (continuing).

There was a clear erosional contact at the 240 cm level, with some evidence of channelling. The levelled section at Lane End is shown in relation to the other sedimentary units in figure 2.

No sediments were exposed in this section which resembled those constituting the Bembridge Raised Beach sequence.

(iii) *Gravel lithology and morphology*

The angularity/roundness of the flint and the total lithological composition of a sample of the matrix-supported gravel at Lane End have been analysed and compared with similar analyses from the Bembridge Raised Beach and Priory Bay (table 5 and figure 4).

The Lane End sample has a modal class in the subangular category (figure 4). There are strong morphological and lithological similarities between the gravels at Lane End and Priory Bay, but significant differences between these and the gravel composing the Bembridge Raised Beach. The gravel at Lane End is clearly a quite different aggradation from the basal shingle of the Bembridge Raised Beach. The lithological data indicates a local (inland Isle of Wight) origin for the Lane End gravel with an absence of igneous material, and the morphological data suggests a fluvial rather than marine origin. This conclusion is further supported by evidence from the underlying organic sequence.

(iv) *Pollen analysis*

Serial samples were taken through the sedge-peat, with single samples being taken from the underlying silty gravel and the overlying silty sand (figures 7 and 8).

Pollen samples from eight levels were prepared as described above. All the samples contained in excess of 4000 grains cm^{-3} sediment. For each level at least 300 total identifiable land pollen and spores were counted.

The pollen diagrams (figures 7 and 8) can be divided into three pollen assemblage zones (PAZS): BLE1, BLE2 and BLE3. The base of BLE2 at 267 cm is defined by the rise in Cyperaceae, whereas the base of BLE3 at 245 cm is defined by the rise in Gramineae and *Pinus*. The diagram is dominated by herb taxa but with significant frequencies of tree taxa in BLE1 and BLE3.

The *Pinus*–*Quercus*–Gramineae PAZ (BLE1), consisting of only the basal level (272 cm), is dominated by these three taxa, but with significant quantities of *Picea*, Cyperaceae and Chenopodiaceae.

The central Cyperaceae–Gramineae PAZ (BLE2) (267–245 cm) covers most of the sequence, and is dominated by herb taxa. Apart from Cyperaceae, which ranges between 33 % and 71 %, and Gramineae, which ranges between 7 % and 24 %, significant herb taxa include Cruciferae, *Ranunculus* (*repens* and *trichophyllus* types) and Compositae Liguliflorae.

The upper *Pinus*–Gramineae PAZ (BLE3) again only consists of one level (240 cm). It is characterized by increases in tree taxa, notably *Pinus* (15 %) and *Picea* (3 %), and in Gramineae (38 %), and by a sharp decrease in Cyperaceae values to 15 %.

Comparison of both the percentage (figure 7) and the concentration (figure 8) diagrams with the stratigraphy indicates that almost all the significant changes, including those that define the zone boundaries, can be attributed to local variations in sedimentation rather than

Downloaded from rstb.royalsocietypublishing.org

to vegetational changes on a regional scale. Figure 8 indicates that the highest pollen concentrations (440 000 grains cm^{-3}) occur in the basal level (267 cm) of the sedge-peat, and that these decline upwards through this unit. In contrast, a background level of around 10 000–20 000 grains cm^{-3} are present in the underlying and overlying inorganic sediments.

In a body of autochthonous sedge-peat the pollen assemblages will be dominated by extremely local representation with perhaps a minor extra-local addition (Jacobsen & Bradshaw 1981). Clearly much of the pollen in BLE2, dominated by Cyperaceae, is of local origin.

Direct comparison of the percentage (figure 7) and concentration (figure 8) diagrams indicates that the high frequencies of *Pinus* and *Picea* in BLE1 and BLE3, the major peak of Cyperaceae at 247 cm, and the high values for indeterminable pollen in BLE3 are all artefacts of the percentage calculations. There are significant increases in derived pre-Pleistocene taxa in the inorganic sediments both above (BLE3) and below (BLE1) the sedge-peat. These increases are likely to have resulted from fluvial reworking of bedrock within the catchment. It is also noteworthy that a wide variety of resistant Pteridophyte spores were also present at these levels, suggesting preferential preservation, as might occur during fluvial transport. The low concentrations for all taxa in BLE3 would also be consistent with a fluvial origin for the upper sandy silt.

The diagrams clearly indicate temperate wetland conditions, but any regional contribution to the pollen assemblages, which might be biostratigraphically significant, has been diluted through over-representation of the purely local vegetation. Although inadequate, perhaps the best indications of regional vegetation are provided by the spectra from BLE1 and BLE3. Those from BLE1 suggest significant *Pinus*, *Picea* and *Quercus*, but by the later zone both *Picea* and *Quercus* have decreased. A very tentative correlation may be made with the post-temperate substage of the Ipswichian interglacial on the basis of these three taxa. The occasional occurrence of *Carpinus* and *Acer* pollen may also be significant in this context, and the high concentration of Chenopodiaceae in BLE1 certainly suggests affinities with the Bembridge Foreland sequence. It must be stressed, however, that this correlation is extremely weak and further dating evidence is required before secure correlation can be proposed for the Lane End sequence.

(v) *Plant macrofossils*

Three samples were taken through the organic deposits for the analysis of plant macrofossils. The lowest (below 267 cm) came from the upper levels of the unit immediately underlying the sedge-peat. Because this was rather clay-rich, disaggregation was aided by the addition of a small quantity of hydrogen peroxide (H_2O_2). The sedge-peat itself was felted and required immersion for 24 h in 10% (by volume) sodium hydroxide (NaOH) to effect disaggregation. A sample size of 250 ml was chosen for all three samples but only *ca.* 40% of the two sedge-peat samples (257–267 cm, 247–257 cm) were analysed. All plant macrofossils retained by a 150 μm sieve were picked and counted (table 6).

(vi) *Insects*

Samples of the sedge-peat (*ca.* 5 kg) were submitted to Dr G. R. Coope (University of Birmingham, U.K.) for insect analysis. Although insect remains were present, they were not common and were poorly preserved, allowing identification only to generic level in most cases.

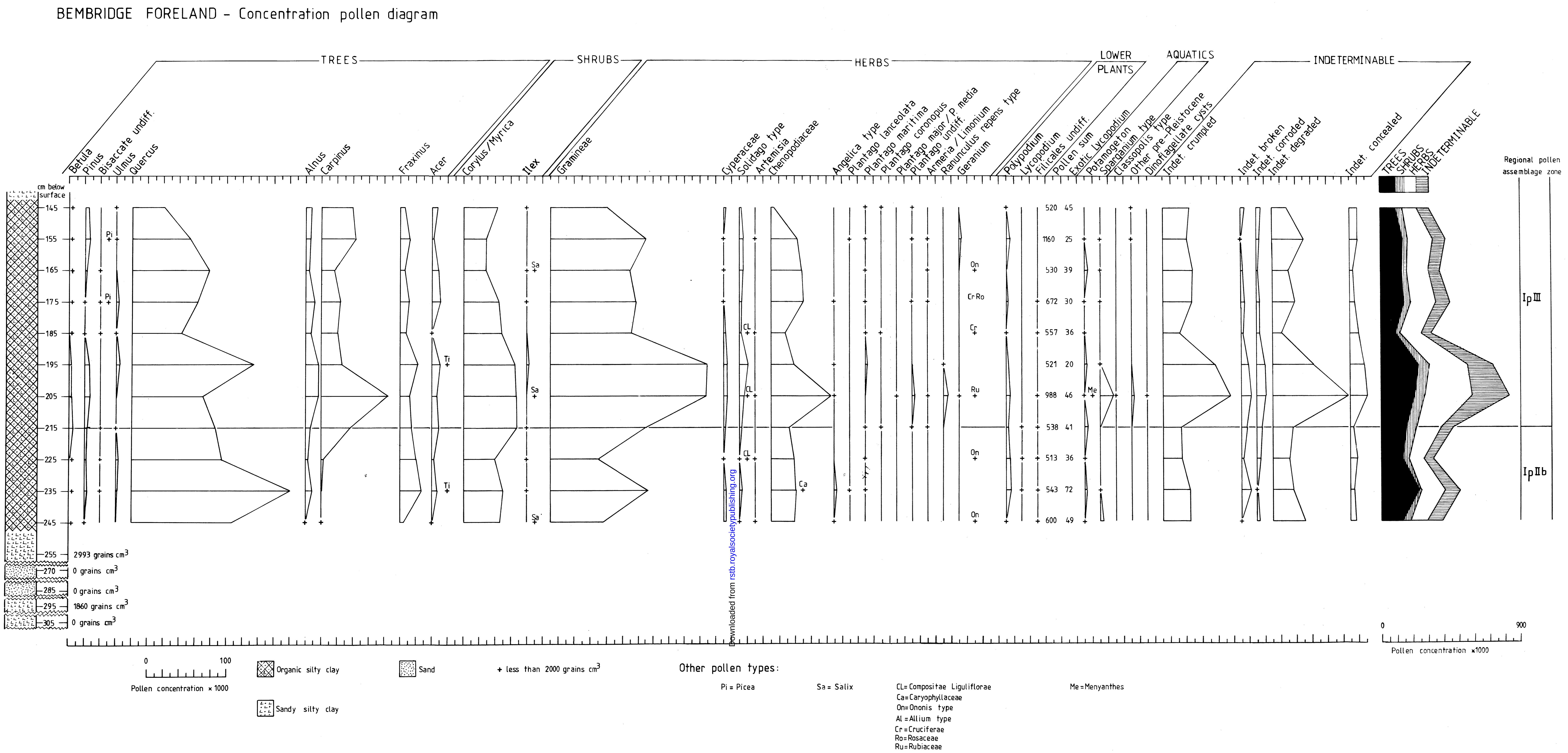


FIGURE 6. Bembridge Foreland: concentration pollen diagram. Pollen concentrations are expressed as grains per cubic centimetre for each taxon. Other conventions as in figure 5. The summary diagram is plotted from concentration calculations. Analysed by J. D. Scourse, February 1986.

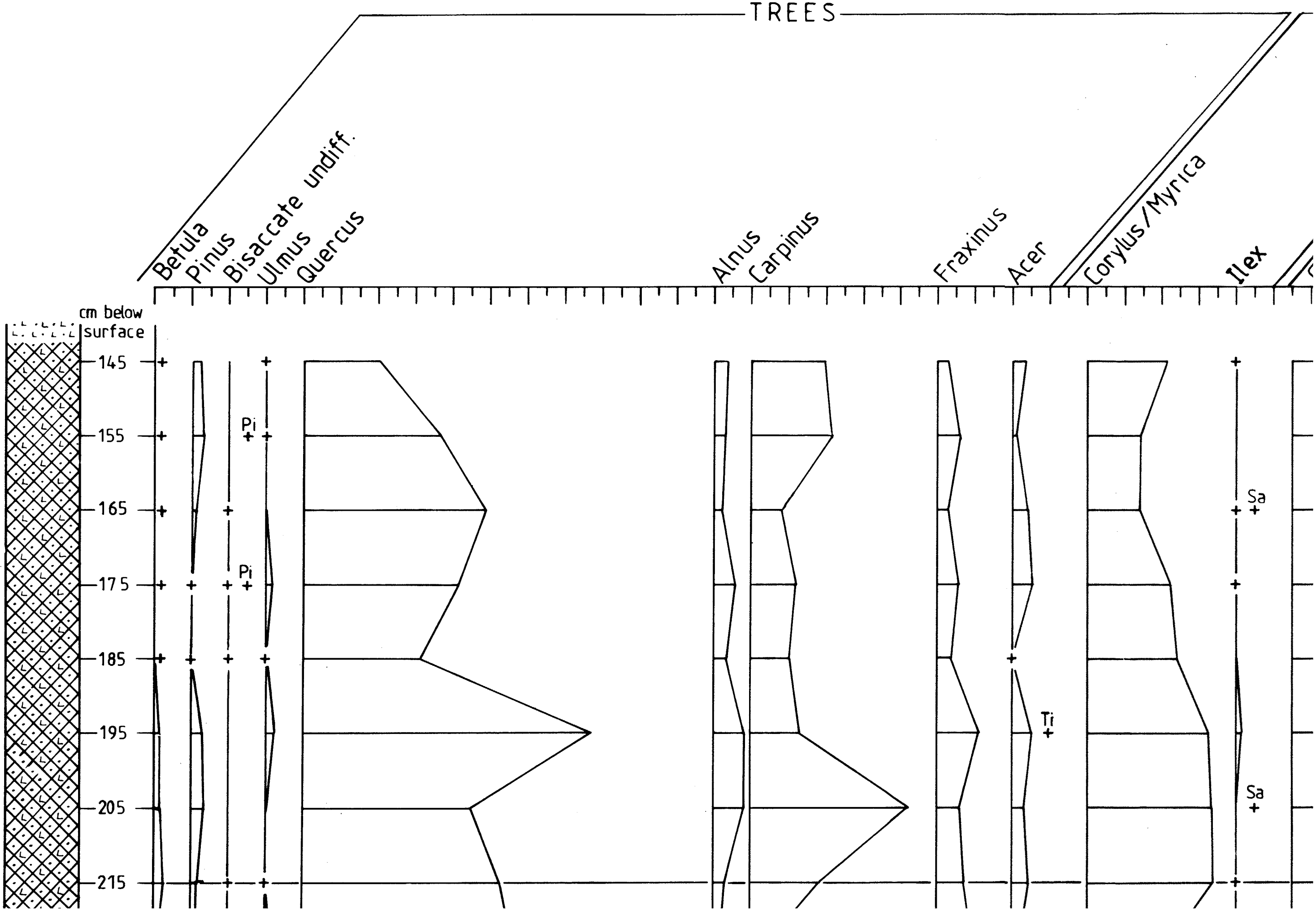
Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

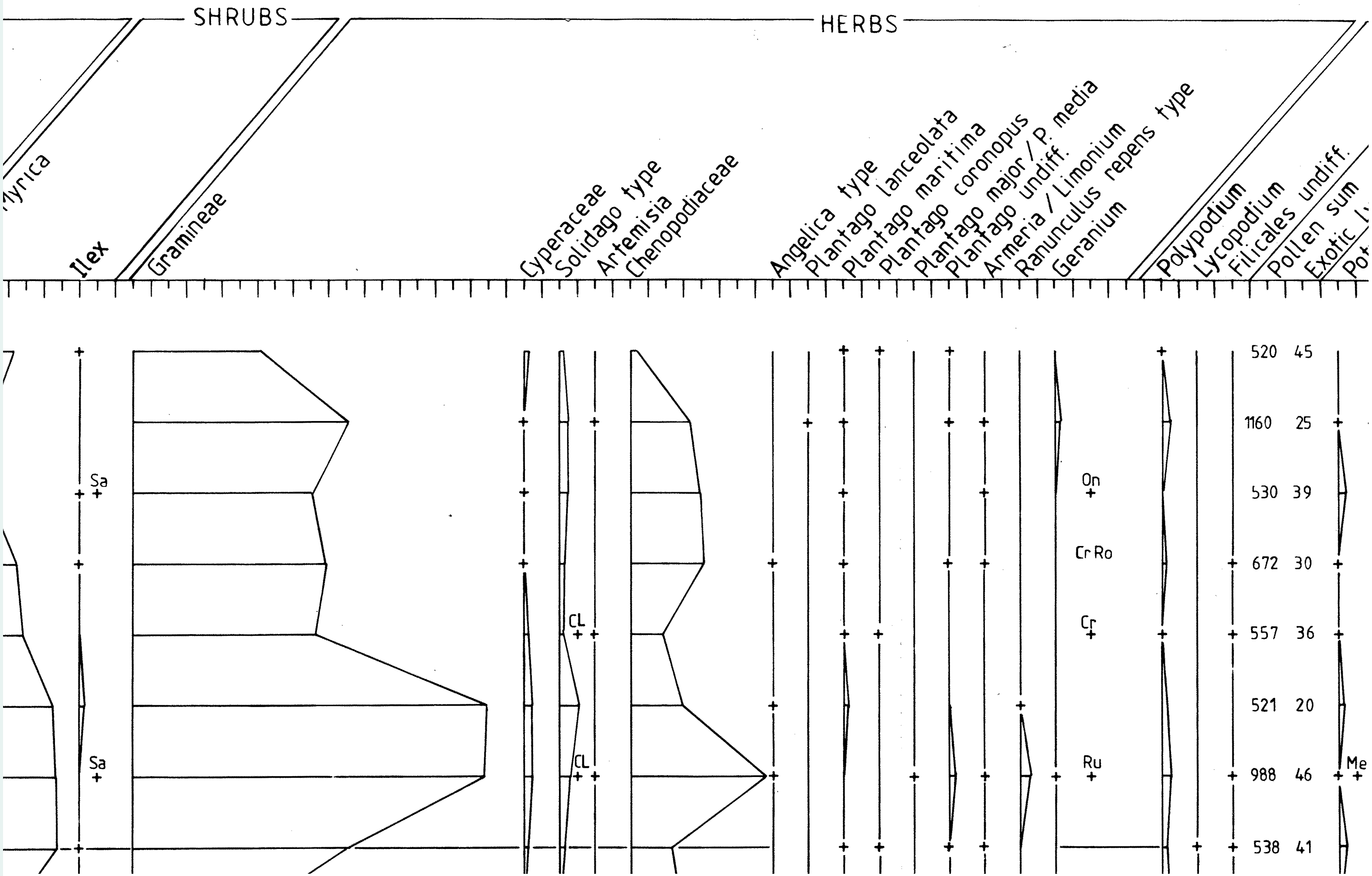
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

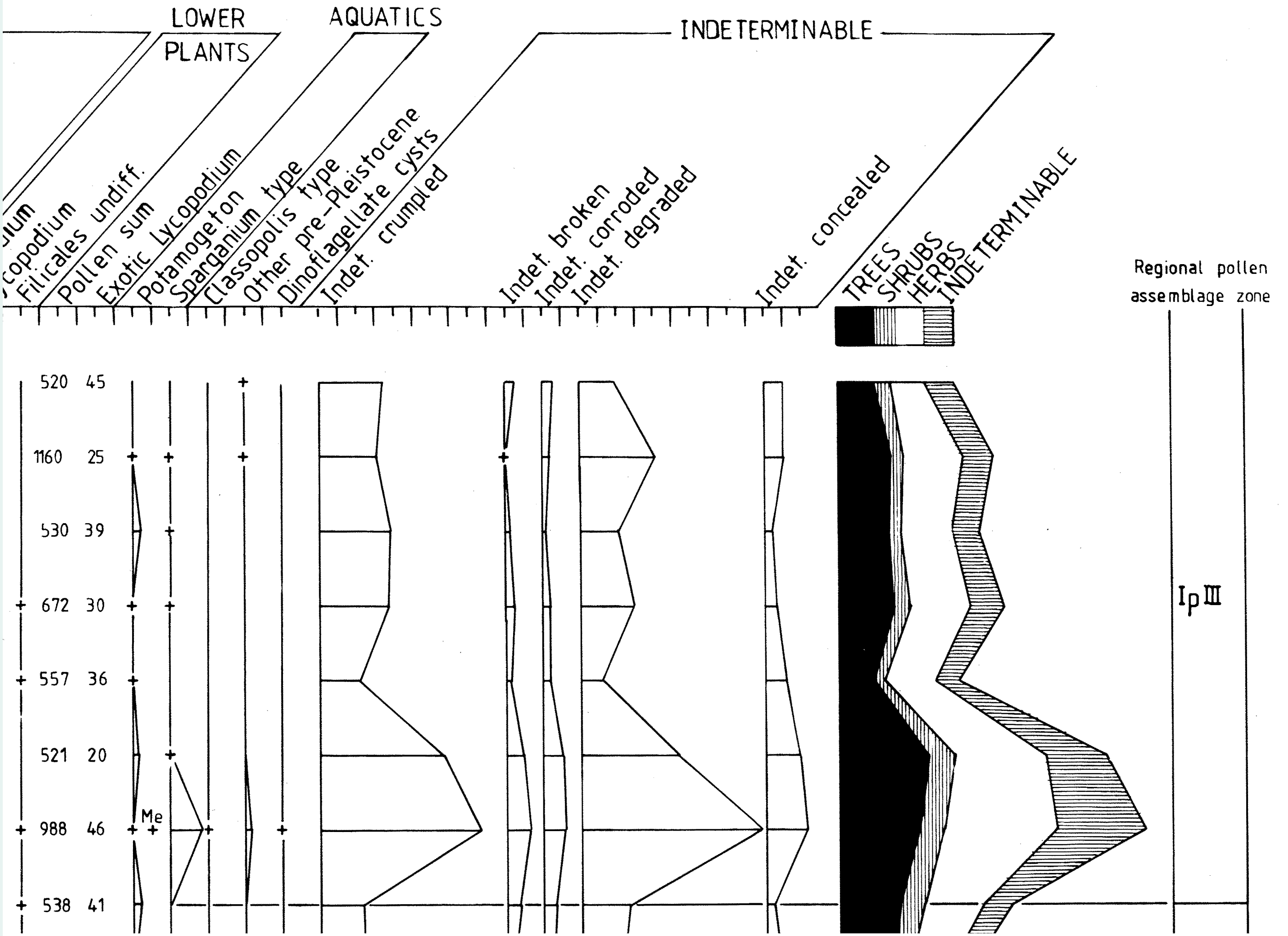
BEMBRIDGE FORELAND - Concentration pollen diagram



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

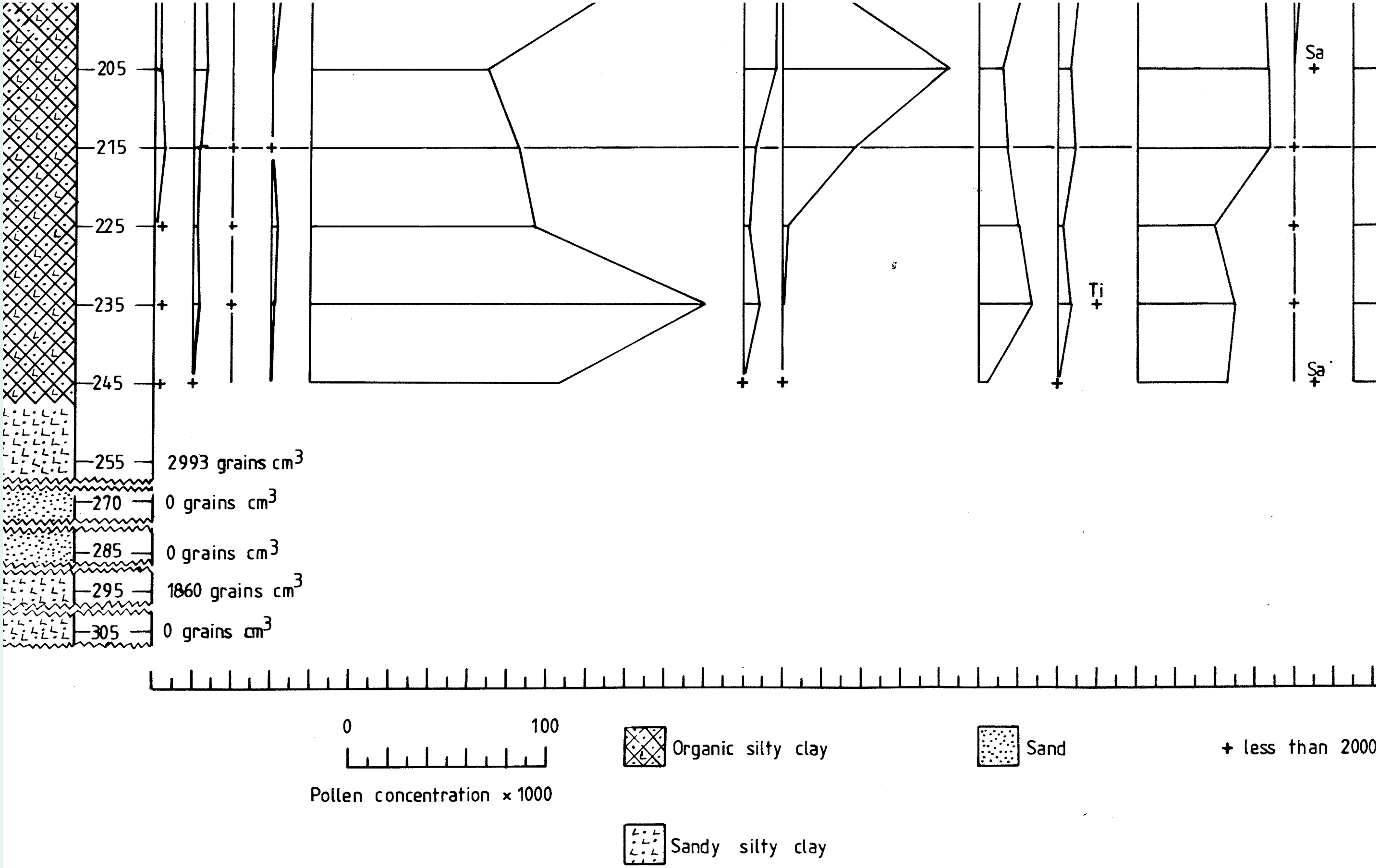
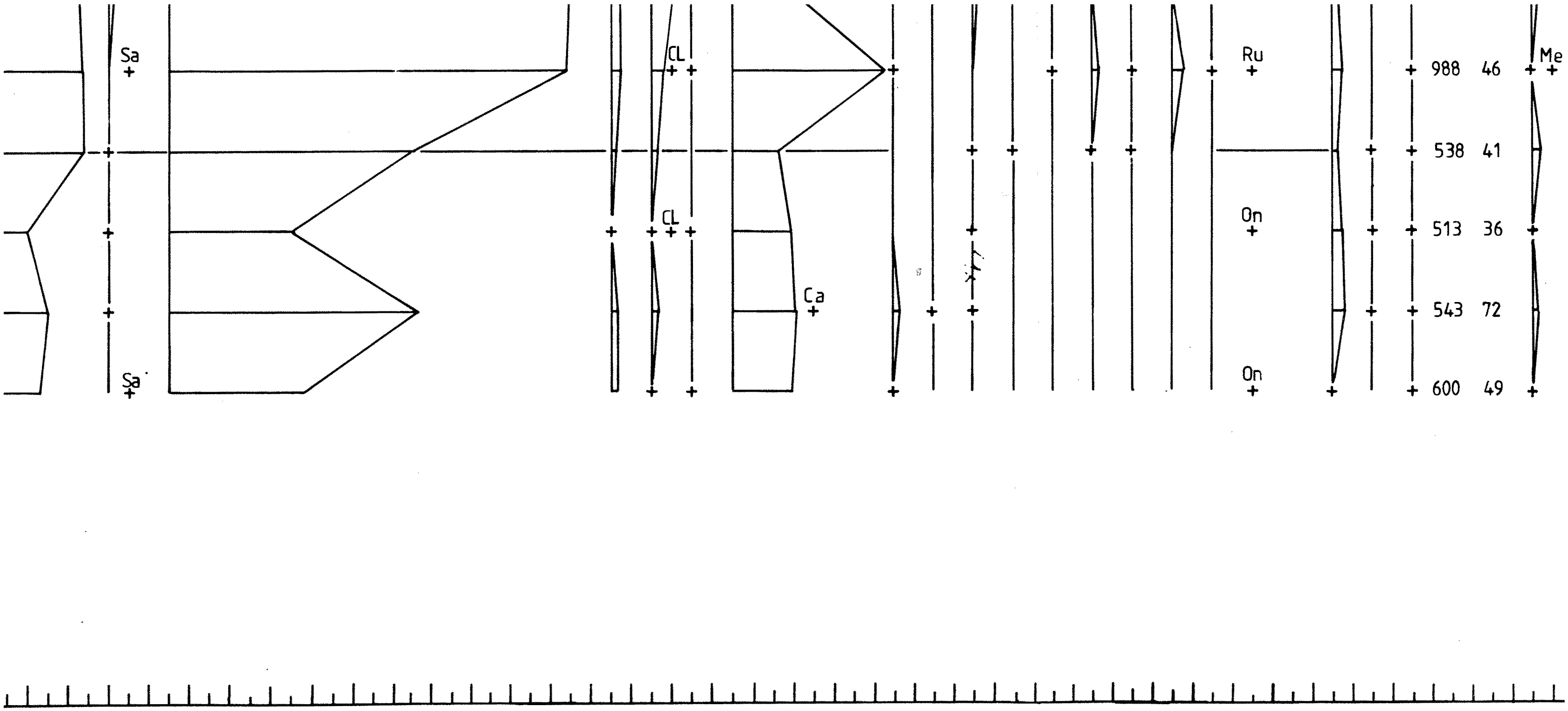


FIGURE 6. Bembridge Foreland: concentration pollen diagram. Pollen c

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



+ less than 2000 grains cm^3

Other pollen types:

Pi = Picea

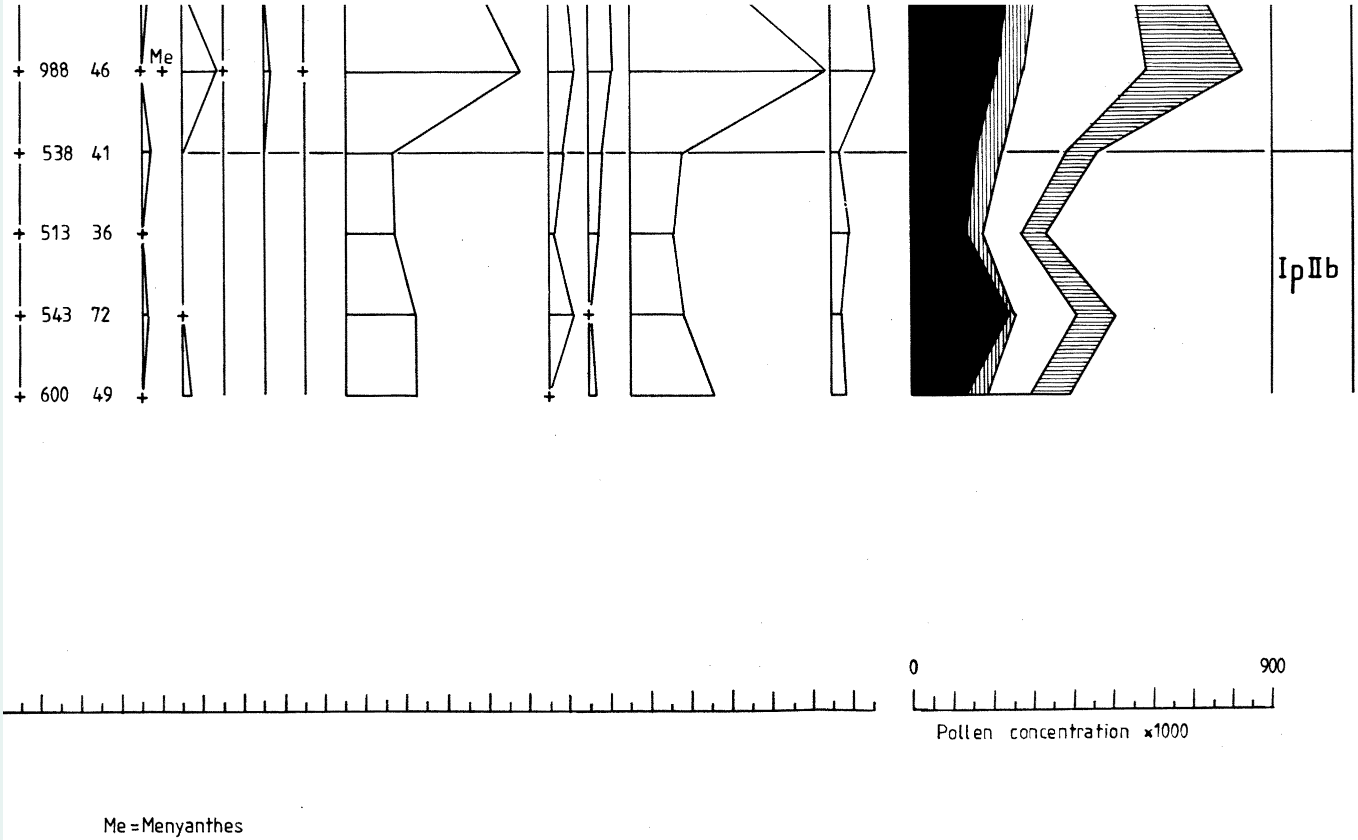
Sa = Salix

CL= Compositae Liguliflorae
Ca= Caryophyllaceae
On= Ononis type
Al = Allium type
Cr = Cruciferae
Ro= Rosaceae
Ru= Rubiaceae

Me = Men

diagram. Pollen concentrations are expressed as grains per cubic centimetre for each taxon. Other conventions as in figure 5. The summary diagram is pl

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



.ry diagram is plotted from concentration calculations. Analysed by J. D. Scourse, February 1986.

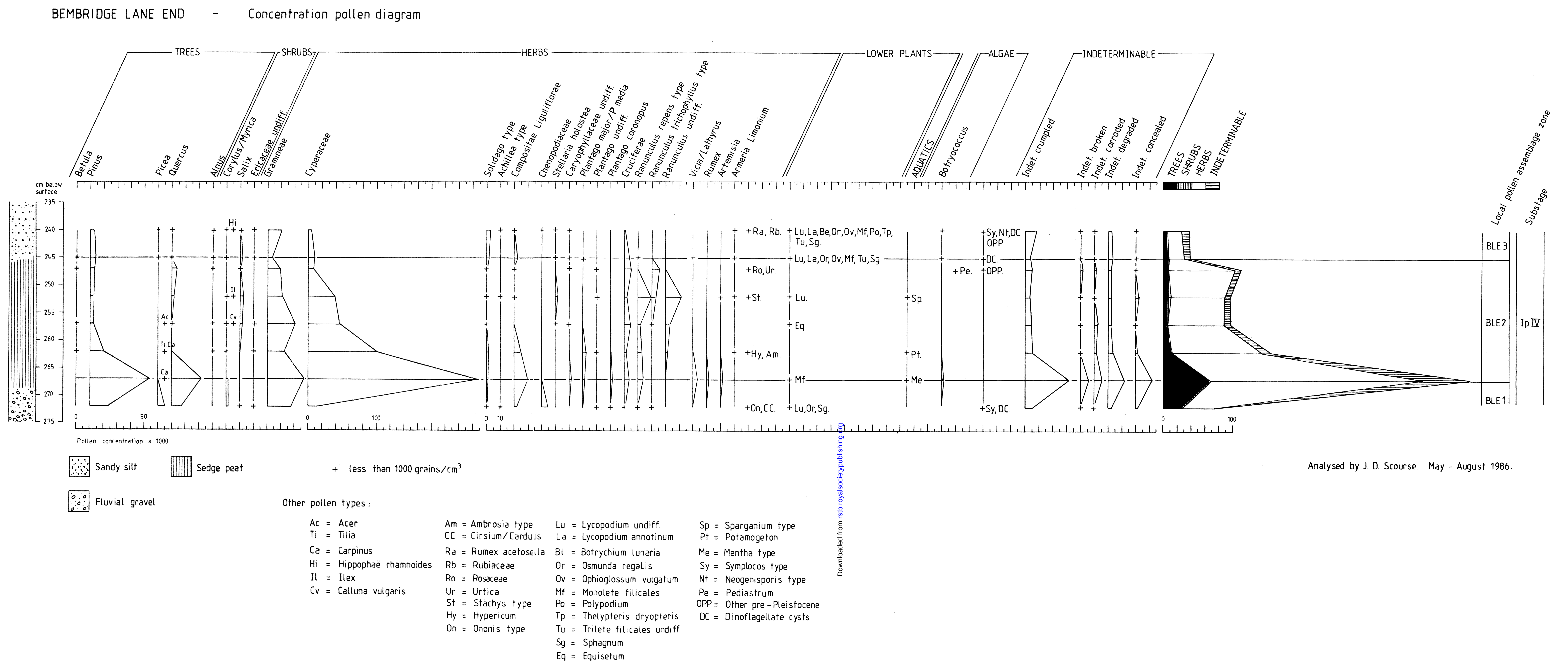


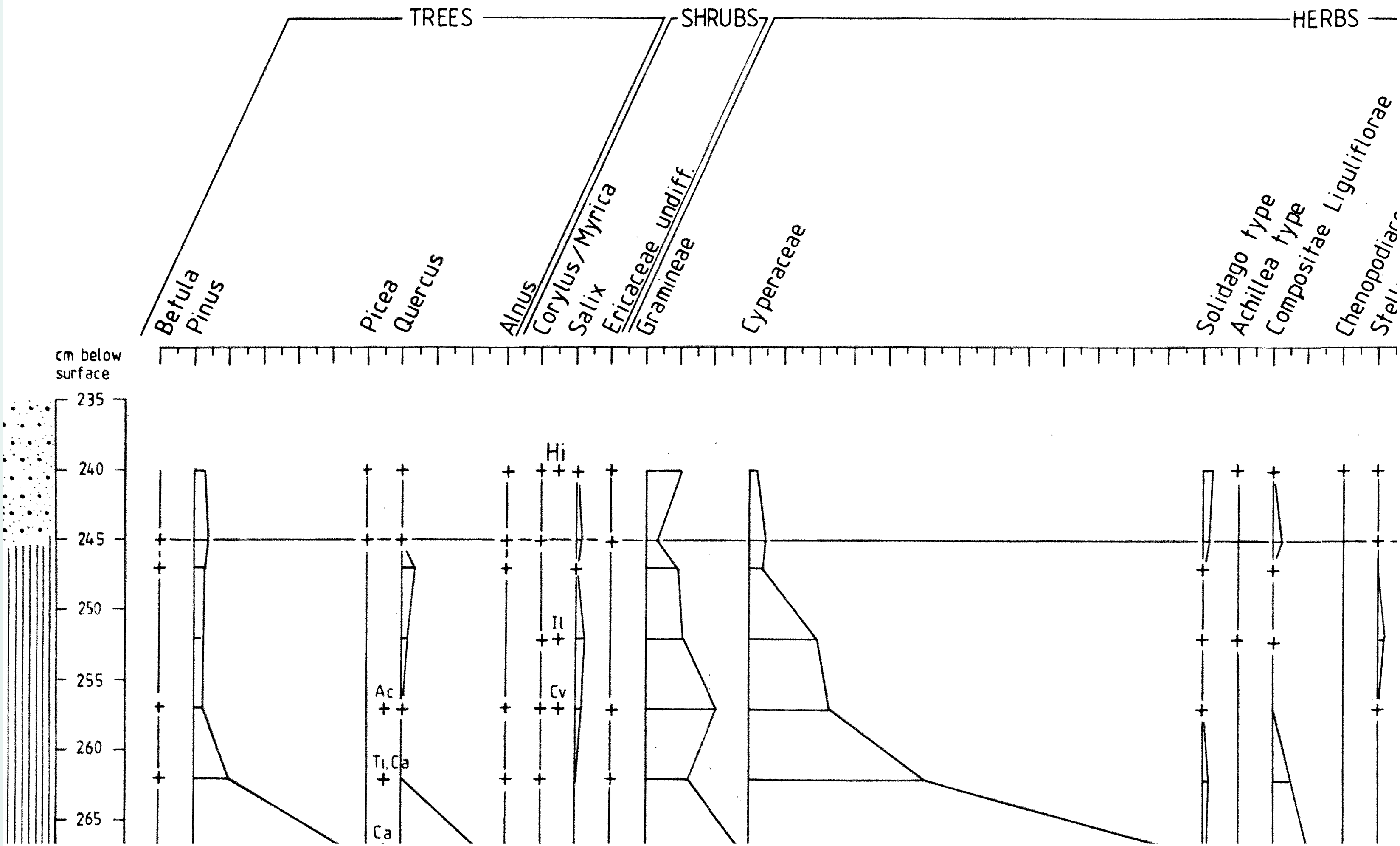
Figure 7. Bembridge Lane End: percentage pollen diagram. Conventions as in figure 5. Analysed by J. D. Scourse, May–August 1986.

Downloaded from rstb.royalsocietypublishing.org

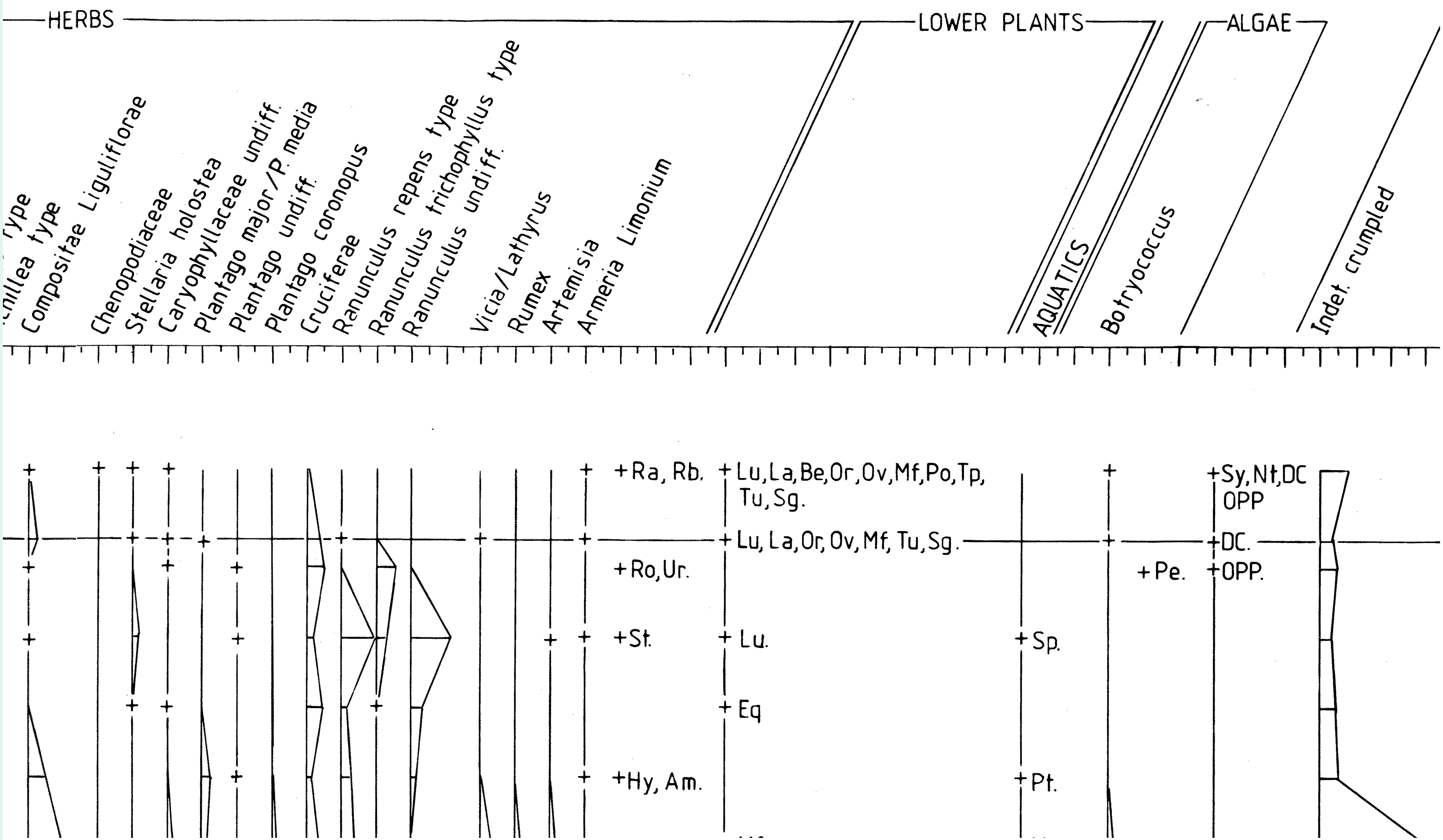
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

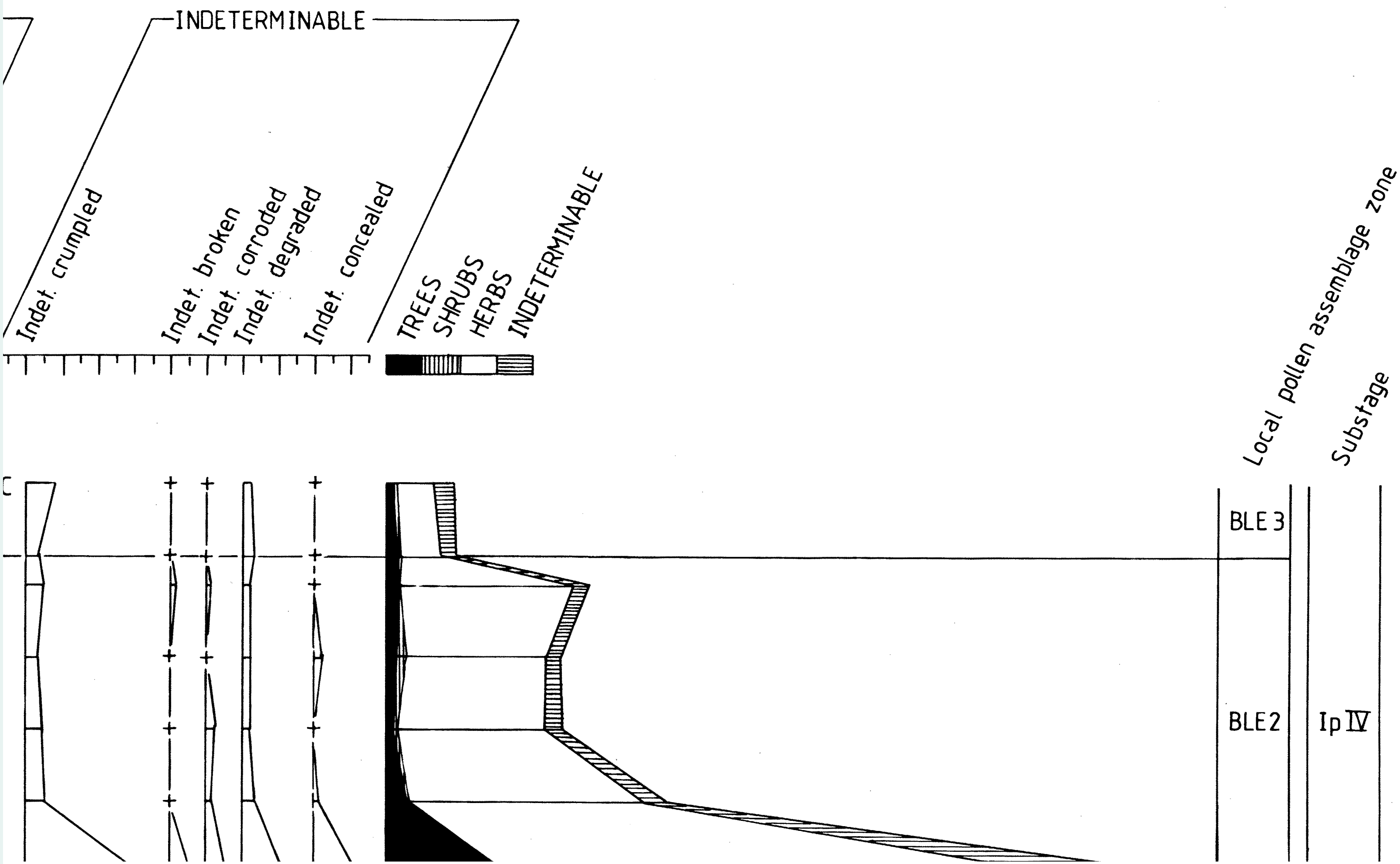
BEMBRIDGE LANE END - Concentration pollen diagram



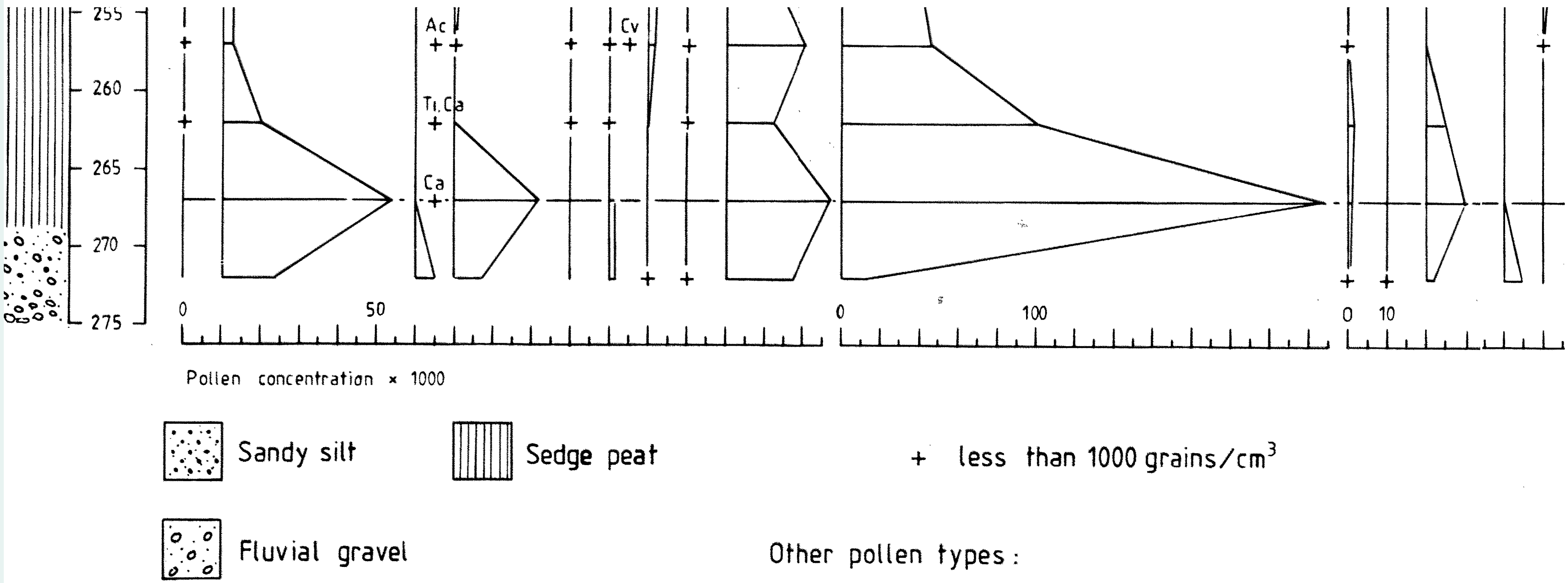
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



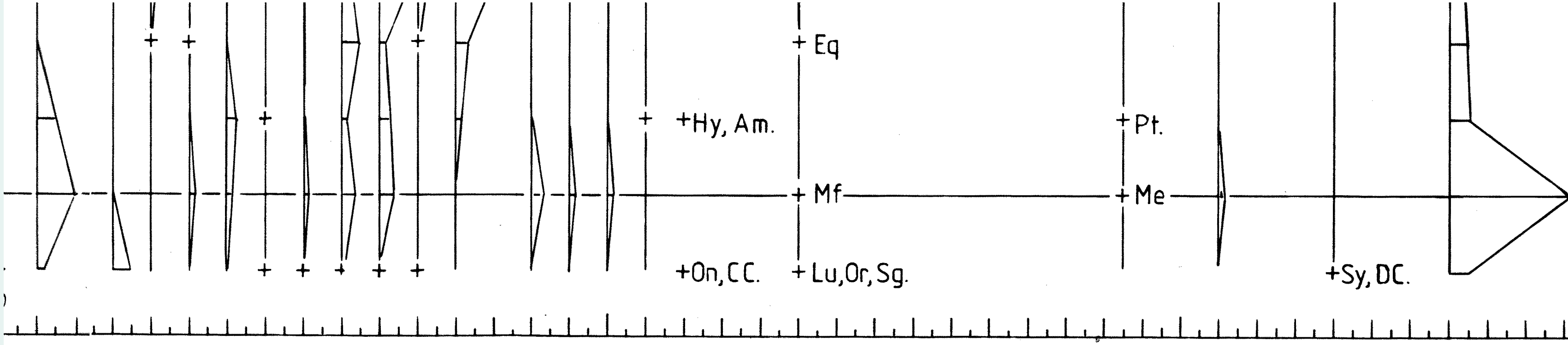
Other pollen types:

Ac = Acer
Ti = Tilia
Ca = Carpinus
Hi = Hippophaë rhamnoides
Il = Ilex
Cv = Calluna vulgaris

Am = Ambrosia type
CC = Cirsium/Carduus
Ra = Rumex acetosella
Rb = Rubiaceae
Ro = Rosaceae
Ur = Urtica
St = Stachys type
Hy = Hypericum
On = Ononis type

Lu
La
Bl
Or
Ov
Mi
Po
Tp
Tu
Sg
Ec

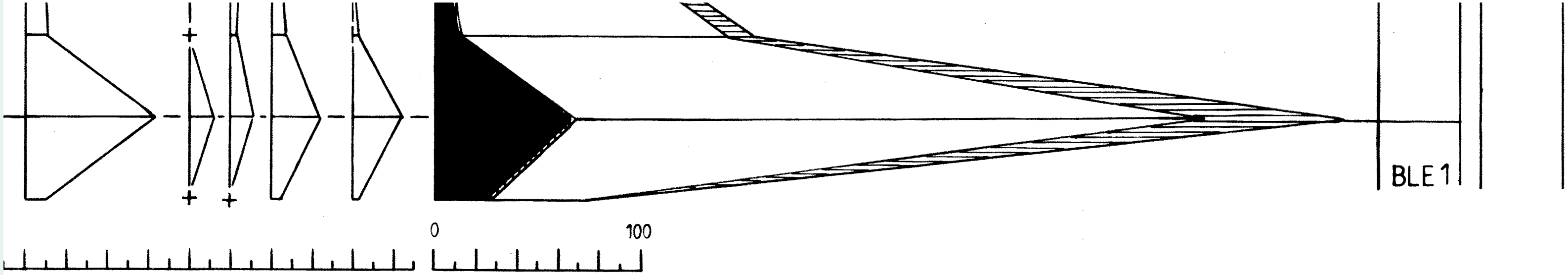
FIGU



ia type	Lu = Lycopodium undiff.	Sp = Sparganium type
/Carduus	La = Lycopodium annotinum	Pt = Potamogeton
acetosella	Bl = Botrychium lunaria	Me = Mentha type
eae	Or = Osmunda regalis	Sy = Symplocos type
ie	Ov = Ophioglossum vulgatum	Nt = Neogenisporis type
	Mf = Monolete filicales	Pe = Pediastrum
s type	Po = Polypodium	OPP = Other pre-Pleistocene
cum	Tp = Thelypteris dryopteris	DC = Dinoflagellate cysts
type	Tu = Trilete filicales undiff.	
	Sg = Sphagnum	
	Eq = Equisetum	

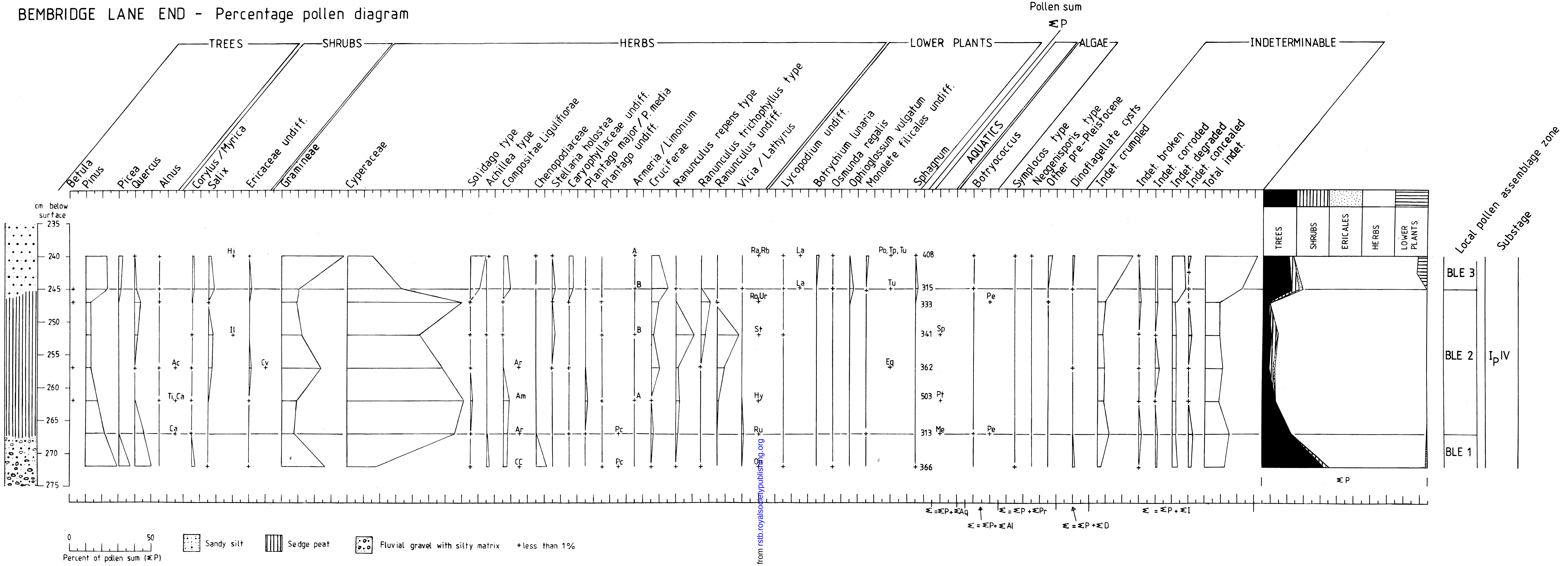
FIGURE 7. Bembridge Lane End: percentage pollen diagram. Conventions as in figure 5. Analysed by J. D. Scourse, May–August 1986.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



Analysed by J. D. Scourse. May - August 1986.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



Other pollen types :-

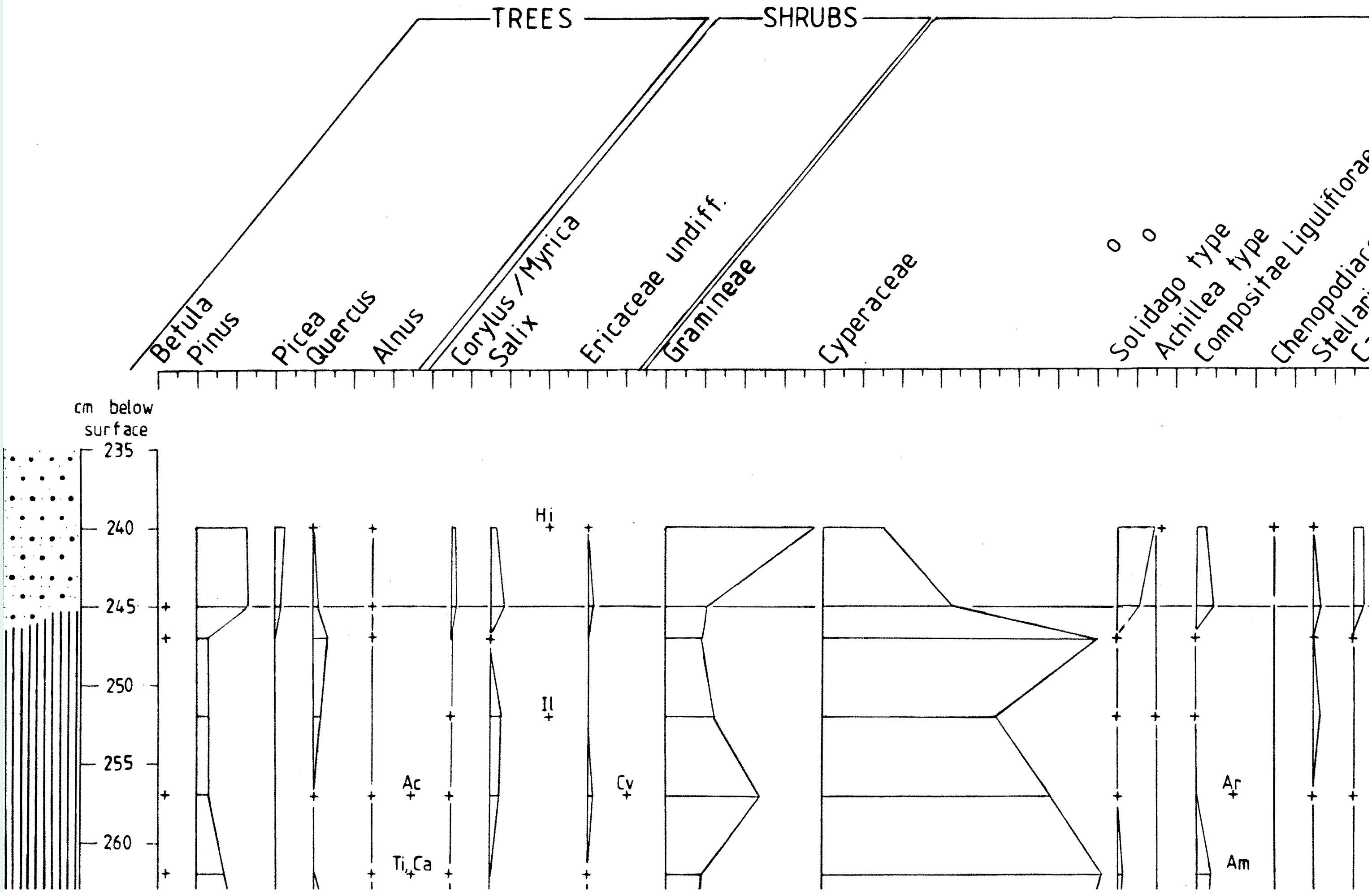
Ac = Acer	Ar = Artemisia	Ra = Rumex acetosella	Hy = Hypericum	Tu = Trilete filicales undiff.
Ti = Tilia	Am = Ambrosia type	Ru = Rumex undiff.	On = Ononis type	Sp = Sparganium type
Ca = Carpinus	CC = Cirsium / Carduus	Rb = Rubiaceae	La = Lycopodium annotinum	Pt = Potamogeton
Hi = Hippophaë rhamnoides	Pc = Plantago coronopus	Ro = Rosaceae	Po = Polypodium	Me = Mentha type
Il = Ilex	A = Type A	Ur = Urtica	Tp = Thelypteris dryopteris	Pe = Pediastrum
Cv = Calluna vulgaris	B = Type B	St = Stachys type	Eq = Equisetum	

Figure 8. Bembridge Lane End: concentration pollen diagram. Conventions as in figures 5 and 6. Analysed by J. D. Scourse, May–August 1986.

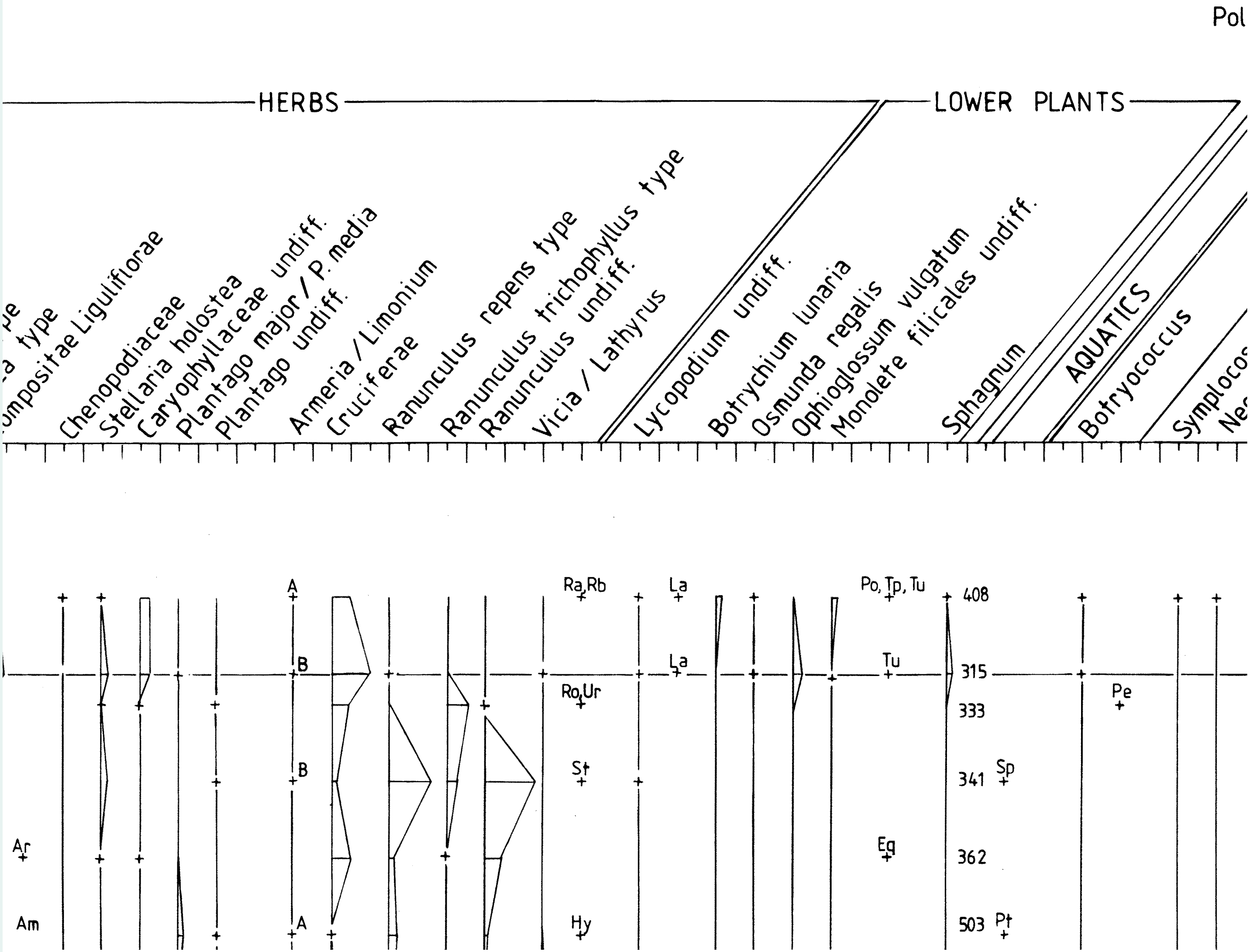
Downloaded from rstb.royalsocietypublishing.org

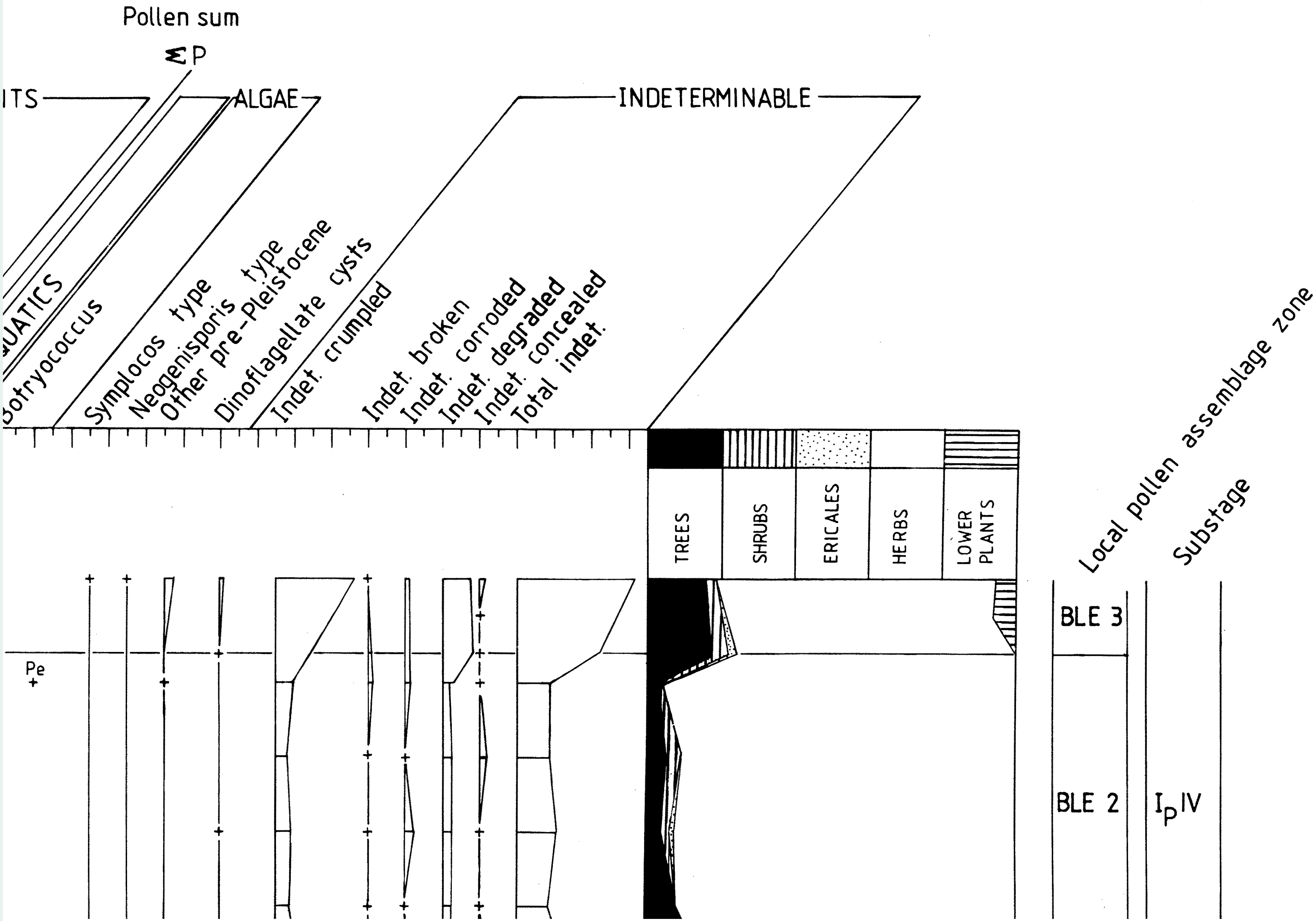
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

BEMBRIDGE LANE END - Percentage pollen diagram



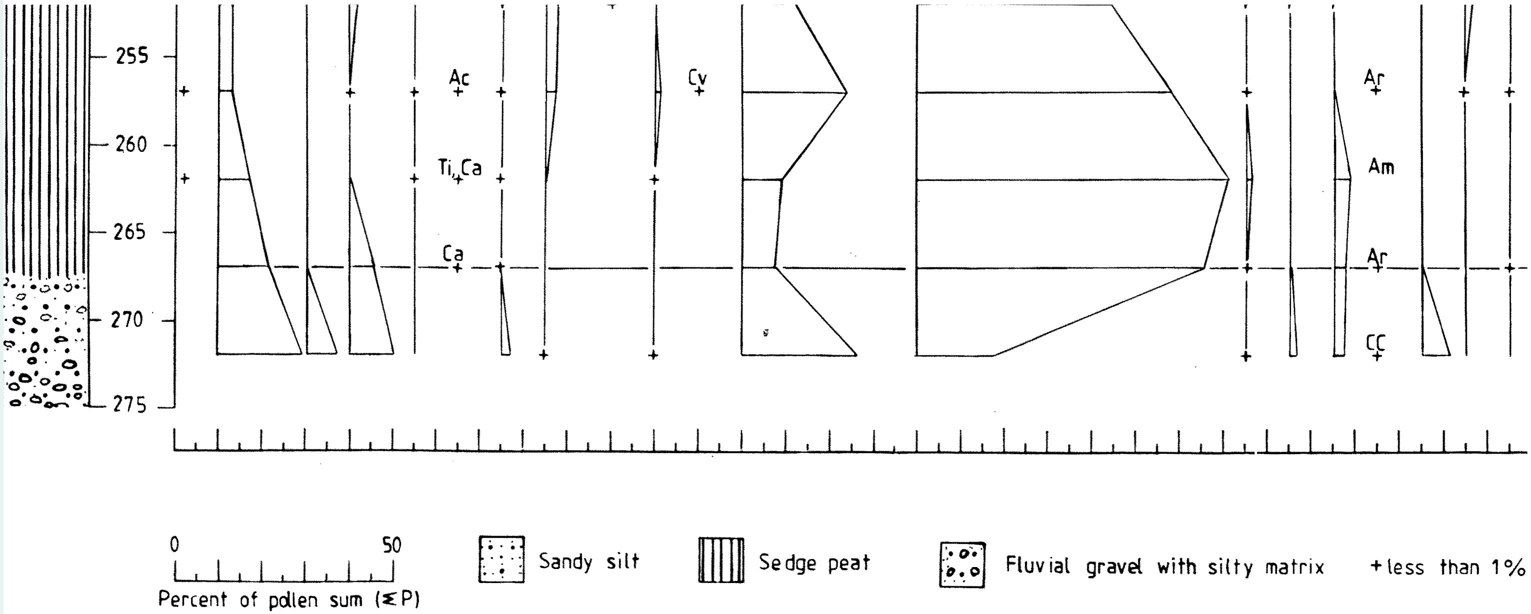
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES





PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY BIOLOGICAL SCIENCES

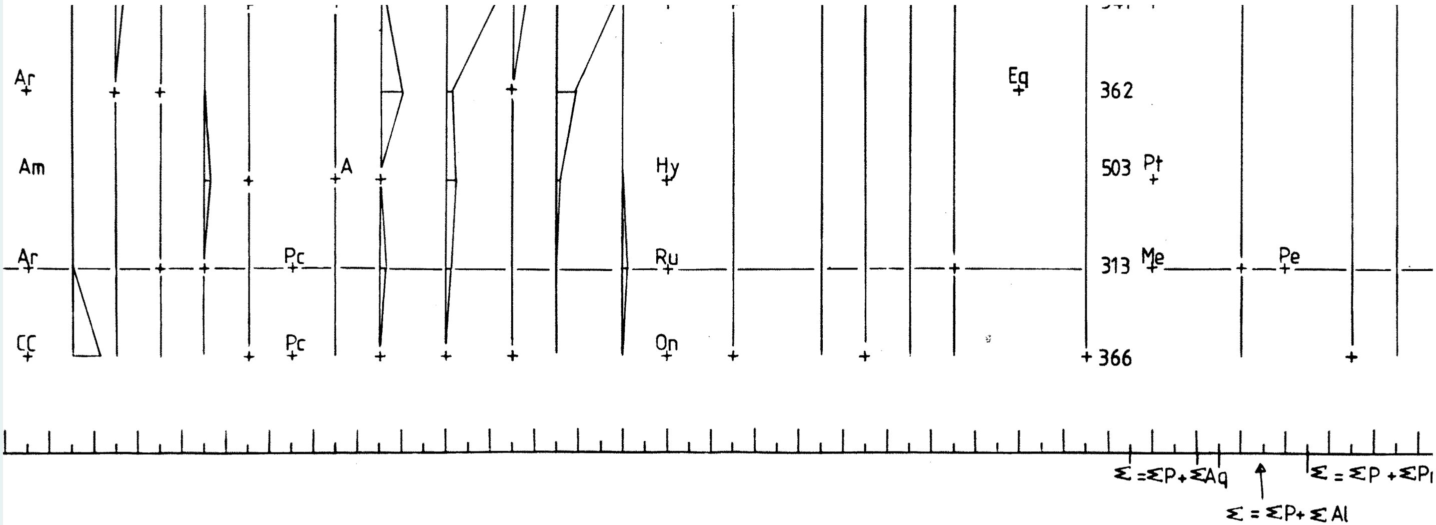


Other pollen types :-

Ac = Acer
Ti = Tilia
Ca = Carpinus
Hi = Hippophaë rhamnoides
Il = Ilex
Cv = Calluna vulgaris

Ar = Artemisia
Am = Ambrosia type
CC = Cirsium / Carduus
Pc = Plantago coronopus
A = Type A
B = Type B

FIGURE 8. Bembridg



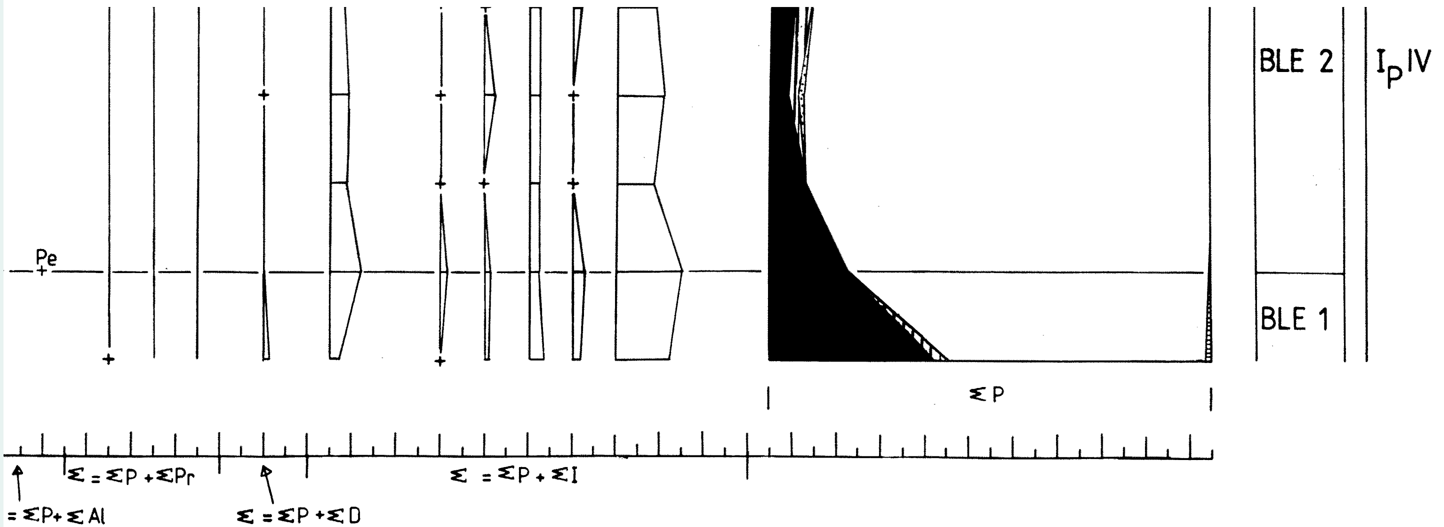
+ less than 1%

ype
Carduus
oronopus

Ra = Rumex acetosella
Ru = Rumex undiff.
Rb = Rubiaceae
Ro = Rosaceae
Ur = Urtica
St = Stachys type

Hy = Hypericum
On = Ononis type
La = Lycopodium annotir
Po = Polypodium
Tp = Thelypteris dryopte
Eq = Equisetum

URE 8. Bembridge Lane End: concentration pollen diagram. Conventions as in figures 5 and 6. Analysed by J. D. Scourse, May–August 19



ricum
s type
odium annotinum
odium
pteris dryopteris
etum

Tu = Trilete filicales undiff.
Sp = Sparganium type
Pt = Potamogeton
Me = Mentha type
Pe = Pediastrum

se, May–August 1986.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

TABLE 6. PLANT MACROFOSSILS FROM THE BEMBRIDGE LANE END SEQUENCE

species	depth/cm below 267	257–267	247–257
Selaginella selaginoides (L.) Link	—	2	—
Ranunculus flammula L.	—	7	—
Ranunculus sceleratus L.	—	1	—
Ranunculus (Batrachian)	26	1	—
Potentilla sp.	—	2	—
Hippuris vulgaris L.	2	—	1
Menyanthes trifoliata L.	14	6	—
Juncus spp.	3	6	—
Eleocharis palustris agg.	9	39	50
Carex cf. *rostrata* Stokes	4	162	2
Carex spp.	—	7	—
Carex (biconvex)	—	—	1
bryophytes	+	+	+
fungi imperfecti: '*Cenococcum*'	—	—	5

The following taxa were recovered: *Elaphrus* cf. *cupreus* Dft., *Dyschirius* sp., *Bembidion* spp., *Hydrobius* spp., *Thanatophyllus* sp., Byrrhidae gen. et sp. indet., *Plateumaris* cf. *sericea* L., and *Notaris* sp. Most of these taxa are typical of freshwater swamps and reed-beds (*Plateumaris*/*Notaris*). They have wide modern ranges but *Plateumaris* is rare or absent from 'cold' faunas. *Thanatophyllus* is a carrion beetle.

(vii) *Discussion*

The Lane End sequence was investigated to elucidate the chronology of Pleistocene sea-level events in the eastern Solent, and, in particular, whether the sequence is directly related to the Bembridge Raised Beach. When taken together, however, the gravel litho-logical/morphological data and the palaeontology clearly indicate that the Lane End sequence is of fluvial or freshwater origin. No marine influences can be discerned. The insects, plant macrofossils and pollen are unanimous in indicating that the sedge-peat is an autochthonous freshwater swamp/marsh deposit. The significant records for *Ranunculus* pollen are supported by recoveries of *Ranunculus* macrofossils, including *R. flammula*, *R. sceleratus* and achenes of batrachian ranunculi, and these indicate quiet, slow-moving water with a muddy substrate. This conclusion is supported by the other macrofossils, and the transition from *Carex rostrata* to *Eleocharis palustris* is a commonly recorded hydroseral relation.

The basal silty gravel was deposited in a muddy, slow-flowing stream, whereas the sedge-peat probably accumulated in a standing water back-channel or cut-off channel of the same system. Slow-flowing water then moved across the area again, depositing first sands and then gravels as the energy conditions increased. The sequence can therefore be explained as a product of local environmental changes within a small floodplain, probably dominated by lateral changes in the position of the main channel. Although most of the taxa have wide tolerances, the palaeontological evidence suggests 'temperate' conditions.

Although mapped as a 'marine gravel' along with the Bembridge Raised Beach on the 1:50,000 Geological Survey map, the gravel at Lane End is clearly quite different from the Raised Beach. It is fluvial in origin, and was probably deposited by a more active forerunner of the stream that now discharges at Lane End. The existence of a fluvial channel cut through

Downloaded from rstb.royalsocietypublishing.org

the underlying Bembridge Raised Beach is also suggested by the presence of a valley extending inland in this area (see figure 1). This may represent a continuation of the buried channel, tending southwest–northeast, that has been discovered offshore by seismic profiling (Dyer 1975).

Although the palaeoenvironment of the Lane End sequence is relatively easy to interpret, the determination of its age is more problematic, because the palaeontology is biostratigraphically undiagnostic. In addition, there are no clear stratigraphic relations with any units of the Bembridge Raised Beach, which are more securely dated. The Lane End sequence remains stratigraphically isolated because its base and full lateral extent are obscured by buildings and coastal protection structures. What little evidence there is, however, would appear to suggest that it belongs to the post-temperate substage of the Ipswichian.

(*b*) *Priory Bay*

The richest Palaeolithic site in the Isle of Wight occurs at Priory Bay, 3 km northwest of Bembridge Foreland (see figure 1). Most of the flint artefacts were found loose amongst modern beach shingle but their source has been traced to the gravel capping the cliffs at the southern end of the Bay, where several have been found *in situ*. Poulton (1909) studied the material collected at the turn of the century, noting the relatively high proportion of unabraded specimens and the frequency of ovates, several of which he figured. Further material, comprising over 300 implements, has been amassed over the last 30 years by a local archaeologist, Mr B. Elcox. Samson (1976) has carried out a preliminary study of this material, concluding that the industry is not purely Acheulian but also contains a Mousterian component. The artefacts await a definitive analysis.

In view of the proximity of Priory Bay to Bembridge, it is obviously important to establish the relation of the gravels at the two sites. In April 1986 a section at SZ 6351589975 in the gravel at Priory Bay was cleaned and levelled. The gravel here rested on Bembridge Marls and occurred between 29.12 and 32.70 m O.D. It was overlain by about a metre of brickearth with the ground surface at 33.71 m O.D. Samples were taken from the upper (Priory 1) and lower (Priory 2) levels of the gravel for lithological and clast-shape analysis (table 5 and figure 4). Several waste-flakes and one worn hand-axe were recovered *in situ* at about the level of 'Priory 1'. A sketch of the latter is included in Preece & Scourse (1987).

Both Priory Bay samples had modal classes in the subangular category (figure 4) and their lithological compositions (table 5) were very similar. However, there are important differences between this gravel and that of the Bembridge Raised Beach. The clasts are less rounded and the diversity of clast lithologies is much more restricted; schorl-rock is entirely absent and, although no igneous clasts were recovered in the analyses, a single fine-grained granite, clearly derived from this gravel unit, has been found at the foot of the section. Even more important is the fact that the gravel at Priory Bay occurs at a substantially higher elevation. Consequently there seems little doubt that the two deposits represent quite different aggradations, despite being mapped as a single 'marine gravel' on the 1:50,000 Geological Survey map. Indeed there is no certainty that the gravel at Priory Bay had a marine origin at all.

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

5. Other related sites in the Solent area

(a) *Boxgrove*

In recent years there has been extensive quarrying in the so-called '100-foot' or 'Goodwood–Slindon' Raised Beach. The site at Amey's Eartham pit near Boxgrove (SU 920085) has proved to be particularly important, demonstrating an *in situ* Acheulian industry both within, and on the surface of, raised beach deposits resting on a wave-cut platform at *ca.* 42 m O.D., and buried by a range of terrestrial deposits of temperate and periglacial origin (Shephard-Thorn & Kellaway 1978; Roberts 1986).

The stratigraphy has been described in detail by Roberts (1986) who has recorded a basal pebble beach overlain by the Slindon Sands, which became less marine in their upper levels. At the invitation of M. Roberts, three samples, two from the Upper Slindon Sands (4a, 4b) and one from the main body of the Slindon Sands (3), were analysed for coccoliths from site GT13 (labelling of beds follows Roberts (1986)).

Sample 4b was devoid of nannofossils, but samples 4a and 3 contained a total of 12 nannofossil species (table 2). The assemblages are dominated by *Gephyrocapsa oceanica*, *G. caribbeanica*, *Reticulofenestra* spp. and *Dictyococcites productus*. Other species (less than 1%) include *Syracosphaera pulchra*, *Pontosphaera* sp., *Coccolithus pelagicus*, *Calcidiscus leptoporus*, *Oolithotus fragilis*, *Discosphaera tubifera* and *Braarudosphaera bigelowii*. Reworked Chalk and Tertiary forms comprise over 31% of the total nannofossil assemblages.

The Steyne Wood Clay and Boxgrove sediments contain similar nannofossil assemblages and both are positively magnetized (2(a)(iii)) and are therefore likely to be similar in age. However, there are differences in the dominant species between the two sites. Because of the close proximity of the two sites, changes in palaeoceanography during the time of deposition are not thought to have caused these differences. The variations in coccolith abundance in the Slindon Sands do not preclude deposition within the same interglacial as the Steyne Wood Clay, as the frequencies of nannofossil species in Quaternary sediments have been shown to be highly variable (Pujos 1985*a*, *b*).

(b) *Earnley*

On the foreshore of Bracklesham Bay, just south of Earnley (SZ 825947), a channel some 200–250 m wide has been cut into soft Eocene clays. It is filled with intertidal shelly sands and clays, which accumulated during the late temperate substage of an early Middle Pleistocene interglacial (West *et al.* 1984).

Calcareous nannofossils have been examined from three samples (NB2:20 cm, 65 cm and 150 cm) kindly provided by Professor R. G. West from the borehole at Earnley previously analysed for other microfossils (West *et al.* 1984). Because of the general scarcity of Pleistocene coccoliths in the sediments, no quantitative data are presented. Four coccolith species were recovered, although only *Reticulofenestra* spp. and *Gephyrocapsa oceanica* were common. Rare forms include *Dictyococcites productus* and *Coccolithus pelagicus*. Preservation of nannofossils ranged from moderate to poor with some evidence of dissolution on many coccoliths, while extensive overgrowth occurred on *C. pelagicus*. Reworked coccoliths were abundant and included both Cretaceous and Tertiary forms.

Reticulofenestra spp. occur in the Steyne Wood Clay, Boxgrove and Earnley assemblages. The forms present are similar to *R. minutula* (Gartner) Haq & Berggren, and *R. haqii* Backman, i.e.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

placoliths with a size range of *ca.* 3.5–6 μm and with a central pore of varying size. Backman (1980) has indicated that these small to medium-sized *Reticulofenestra* spp. have appeared under the following generic combinations: *Gephyrocapsa doronicoides* (Bukry 1973) and *Coccolithus doronicoides* Black & Barnes, 1961. Such forms have a reported FOD in the Middle Miocene, although their last occurrence datum (LOD) is not precisely known because of the confusion with regard to their taxonomic status. Pujos (1985*a*, *b*), however, has reported that two variants of *G. doronicoides* range up into the lower half of the Brunhes epoch, whereas Gard (1986) noted rare occurrences of small *Reticulofenestra* species in late Quaternary sediments in the Arctic.

The absence of *P. lacunosa* in these sediments suggests the maximum age of deposition to be *ca.* 0.475 Ma BP. Whether the sediments are of comparable age with the Slindon Sands and the Steyne Wood Clay cannot be resolved by the nannofossil evidence, although differences in the species diversity might perhaps suggest that they represent different interglacials, a conclusion supported by palynological and altitudinal differences.

A single valve of *Macoma balthica* from the Earnley channel infilling, collected by Mr R. Fowler of East Wittering, was submitted to Dr J. T. Hollin and Dr G. H. Miller (INSTAAR, Boulder, Colorado, U.S.A.) for amino acid analysis. A single analysis on the whole shell yielded a L-isoleucine:D-alloisoleucine ratio of 0.33 (AAL-5499). Because the shell was immature, only the inner layers of the shell were analysed, so that ratio may be slightly lower than might have been obtained from the umbonal area of a mature shell. This ratio falls within the range of possibilities for equivalent ratios from the Steyne Wood Clay, and the two deposits cannot therefore be separated on the basis of these amino acid measurements. The ratio nevertheless suggests a Holsteinian (Hoxnian) or slightly greater age by comparison with the ratios listed in 2 (a)(iv).

(*c*) *Stone*

On the foreshore at Stone Point, Hampshire (SZ 457984), estuarine clays interbedded with *Phragmites* peat are sandwiched between two gravel units, both thought to be of fluvial origin (Brown *et al.* 1975). The upper gravel is in turn blanketed by two units of brickearth. The organic deposits accumulated during the early temperate substage of the Ipswichian (Ip II b) (West & Sparks, 1960; Brown *et al.* 1975).

One sample from the upper levels of the interglacial deposit was analysed for calcareous nannofossils. The sample contained very occasional specimens of *Emiliania huxleyi*, *Gephyrocapsa ericsonii* and *Calcidiscus leptoporus*. Reworked Cretaceous forms were, however, very common.

The occurrence of *E. huxleyi*, albeit rarely, in these sediments indicates that the assemblages may be placed within the NN21 *E. huxleyi* Zone described by Martini (1971). *E. huxleyi* has a FOD of 0.275 Ma BP, within oxygen isotope stage 8, which therefore represents the maximum age for the deposit. *E. huxleyi* has become the dominant coccolith in the world oceans but during the first two thirds of its range it formed only a relatively small component of nannofossil assemblages, which were here dominated by *Gephyrocapsa caribbeanica*. In high-latitude assemblages this dominance reversal has been correlated with the low negative isotopic excursion in oxygen isotope stage 4 at *ca.* 0.073 Ma BP (Thierstein *et al.* 1977). Both *E. huxleyi* and 'open' *Gephyrocapsa* species are small (*ca.* 2–5 μm in diameter) and are often difficult to distinguish when the preservation is poor. In fact, Roth & Berger (1975, p. 88) stated '*Emiliania huxleyi* can only be identified in the SEM with certainty'. Identification was not confirmed here by scanning electron microscope (SEM) study because of the rarity of this species in the Stone

Downloaded from rstb.royalsocietypublishing.org

sediments. In this study, forms attributable to *E. huxleyi* were small (*ca.* 3 μm) 'open' placoliths, lacking a bridge with weak birefringence. Pujos-Lamy (1977*b*) used these criteria to distinguish *E. huxleyi* in cores from the northeast Atlantic.

(*d*) *West Wittering*

The deposits at West Wittering (at about SZ 775975), 10 km northwest of Selsey, were first described by Reid (1892) who recorded a channel on the foreshore, cut into Eocene clay 'to the level of low-water'. This channel was infilled with a basal erratic-rich gravel overlain by a 'laminated peaty clay' containing the molluscs *Corbicula fluminalis* and *Belgrandia marginata*. According to Reid the lower part of this channel was purely freshwater and the upper part estuarine. Reid gives extensive lists of plants and Mollusca that clearly indicate interglacial conditions. New observations and additional species were recorded by Johnson (1901). No-one has located these deposits in recent years, and they have been assumed to correspond with the better known deposits at Selsey (West & Sparks 1960).

As the upper levels of this deposit accumulated under brackish conditions, as indicated by the occurrence of *Cerastoderma edule*, *Scrobicularia plana*, *Macoma balthica*, *Hydrobia ventrosa* and *H. ulvae*, they are relevant to the present study. To establish the age of this deposit, sediment filling the apertures of two *Lymnaea peregra* from West Wittering was carefully extracted and analysed for pollen (table 7). These shells (registration number G22870) are part of the J. P. Johnson collection presented to the British Museum (Natural History) in 1913. None of the brackish-water species had sufficient sediment adhering, so the pollen spectrum does not come from the upper unit but nevertheless relates to the same sedimentary sequence. Pollen concentrations were not calculated, but otherwise the preparation methods and conventions follow those described earlier.

As suggested by the Mollusca, the pollen assemblage indicates temperate conditions, with the development of full deciduous woodland. The dominant thermophilous tree taxa are *Corylus* (18%), *Quercus* (15%), *Pinus* (9%) and *Betula* (5%), with contributions from *Salix* (2%), *Hedera* (2%) and *Ulmus* (1%). The dominant taxon is Cyperaceae (25%), but this, along with the obligate aquatic taxa *Potamogeton*, *Sparganium* type and *Typha latifolia*, is probably representative of local vegetation within the confines of the channel itself. Umbelliferae grains comparable with *Crithmum maritimum*, and the trace of Chenopodiaceae, may point to the proximity of the coast.

As to the age of the deposit, the relative frequencies of *Corylus*, *Quercus*, *Pinus* and *Betula* are consistent with the early temperate substage of the Ipswichian interglacial (Ip IIb). This is further supported by the traces of *Tilia*, *Acer* and *Fraxinus* (West 1980*a*). *Alnus* has been reported at a number of sites during Ip IIb, but it is completely absent from this spectrum. West (1980*a*), however, has noted the variable role of this tree during the Ipswichian, particularly during Ip IIb.

The assemblage is broadly similar to the Ip IIb spectra from Bembridge Foreland (figures 5 and 6), but at Bembridge *Quercus* is dominant over *Corylus*, and *Pinus* and *Betula* are relatively unimportant. These differences, along with the absence of *Carpinus* and *Picea* at this site, suggest that the West Wittering assemblage may represent an earlier part of Ip IIb. This is consistent with the stratigraphy in relation to Ipswichian sea-levels, the pollen assemblage coming from a lower freshwater bed overlain by an upper brackish unit.

Amino acid ratios have also been obtained from shells collected at West Wittering by C.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

TABLE 7. POLLEN SPECTRUM FROM SEDIMENT FILLING APERTURES OF *LYMNAEA PEREGRA* FROM THE WEST WITTERING CHANNEL

(Pollen sum = 309.)

species	count	percentage
Betula	14	4.5
Pinus	28	9.1
Ulmus	3	1.0
Tilia	2	0.6
Fraxinus	1	0.3
Acer	1	0.3
Quercus	46	14.9
total tree	95	30.7
Corylus	57	18.4
Salix	5	1.6
Hedera	5	1.6
total shrub	67	21.7
Gramineae	17	5.5
Cyperaceae	78	25.2
Solidago type	2	0.6
Compositae Liguliflorae	4	1.3
Chenopodiaceae	1	0.3
cf. *Crithmum maritimum*	2	0.6
Ranunculus repens type	1	0.3
total herb	105	34.0
Lycopodium	1	0.3
Polypodium	1	0.3
monolete Filicales	40	12.9
total Pteridophyte	42	13.6
Potamogeton	1	0.3
Sparganium type	5	1.6
Typha latifolia	1	0.3
total aquatic	7	2.2
Pediastrum	1	0.3
zygospores	1	0.3
dinoflagellate cysts	1	0.3
crumpled	20	5.1
broken	8	2.0
degraded	9	2.3
corroded	42	10.7
concealed	6	1.5
total indeterminable	85	21.6

Reid. Results with *Corbicula fluminalis* (M. Bates, personal communication, 1989) have given mean ratios of 0.13 ± 0.025 ($n = 3$) and 0.17 ± 0.012 ($n = 5$) (Laboratory numbers Lond-175 and 176 respectively). These ratios are also consistent with an Ipswichian age assignment.

6. DISCUSSION

(a) *Correlation of deposits*

(i) *High-level deposits*

Various lines of evidence suggest that the Steyne Wood Clay and the Slindon Sands at Boxgrove are of similar, if not identical, age. First, both deposits appear to represent regression from a high interglacial sea-level. They occur today at similar elevations (*ca.* 40 m O.D.), the

Downloaded from rstb.royalsocietypublishing.org

Steyne Wood Clay resting directly on soft Tertiary clays, the Slindon Sands on a wave-cut platform bevelled into the Chalk. Lateral equivalents of the Slindon Sands can be traced at similar elevations eastwards as far as the Arun (Reid 1892; Fowler 1932) and westwards to Ports Down (Prestwich 1872; ApSimon *et al.* 1977), a distance of nearly 40 km. Reid & Strahan (1889) recorded a sand, thought to be marine, at an equivalent altitude ('130 feet') at Ruffin's Copse, near Cowes, which might also be related to this high sea-level event. Second, amino acid ratios from *Macoma balthica*, reported here from the Steyne Wood Clay, are similar to one determined from the same species from Waterbeach at another section in the so-called 'Slindon–Goodwood' or '100 foot Raised Beach' (mistakenly said to have come from Boxgrove itself by Bowen & Sykes (1988)). Third, the Steyne Wood Clay and the Slindon Sands are both normally magnetized. Finally, there are some biostratigraphical similarities, particularly with respect to the diversity and composition of the coccolith assemblages. Although, in isolation, each piece of evidence does not provide conclusive proof of contemporaneity, taken together the case is much stronger and direct correlation seems highly probable. If this is correct, then additional dating evidence from one site can be used to sharpen the dating of the other and vice versa.

An extensive vertebrate fauna associated with a rich Acheulian industry has been recovered from terrestrial sediments (unit 4c) resting directly on top of the Slindon Sands at Boxgrove (Roberts 1986). Several artefacts have also been found stratified within the upper parts of the Slindon Sands themselves, so confirming the contemporaneity of the industry with the high sea-level event. Some terrestrial vertebrates, identical species to those occurring in the overlying unit, have also been recovered from the Slindon Sands and there seems little doubt that dating evidence provided by the vertebrate fauna from the overlying unit, can also be extended to cover the Slindon Sands as well. The vertebrate fauna from unit 4c includes several extinct species, including the rhinoceros *Dicerorhinus etruscus*, the shrews *Sorex savini* and *S. runtonensis* and the voles *Pitymys gregaloides* and *Pliomys episcopalis* (M. B. Roberts, personal communication, 1988). These taxa are unknown from the Hoxnian and subsequent stages. *Mimomys savini*, a vole common at West Runton and present at most Cromerian vertebrate sites, is absent from this fauna, where it is replaced by *Arvicola cantiana*, its putative descendant. Similar vertebrate faunas have been described from the upper levels of cavern infills at Westbury-sub-Mendip, Somerset, U.K. (Bishop 1982), and from organic deposits overlain by Anglian till at Ostend, Norfolk, U.K. (Stuart & West 1976). Opinion is divided as to whether these faunas should be assigned to the late Cromerian (Stuart & West 1976) or belong to an additional interglacial stage between the Cromerian and the Hoxnian (Bishop 1982).

It is at present difficult to choose between these two options, which hinge solely on the belief that this transition represents a chronological sequence. This might have occurred relatively abruptly within a single interglacial, or more slowly and time-transgressively. Indeed, it is by no means certain that all occurrences of *Arvicola* are younger than those of *Mimomys*, as much of the reasoning is circular. Whatever the outcome of this debate, there is no doubt, based on the stratigraphic evidence from Ostend, that these vertebrate faunas are pre-Anglian.

Unlike Boxgrove, the Steyne Wood Clay lacks vertebrates but does contain good pollen. The pollen assemblages here are dominated by *Pinus*, with moderate frequencies of *Picea* and virtually no *Abies*. Although the estuarine depositional environment may have exaggerated the representation of bisaccate taxa, the pollen spectra nevertheless suggest that accumulation occurred during the post-temperate substage of a Middle Pleistocene interglacial (Holyoak &

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Preece 1983). Most of the sediments at Boxgrove are oxidized and have produced only sparse and poorly preserved pollen or else lack pollen entirely. This fact precludes meaningful comparisons. It is noteworthy that the pollen spectra from Ostend (Stuart & West 1976; West 1980*b*) are very similar to those from the Steyne Wood Clay, but this may simply result from a comparable placing within an interglacial cycle (i.e. post-temperate substage) rather than direct time-equivalence.

Although it is clear that both the Slindon Sands and Steyne Wood Clay accumulated under interglacial conditions, both deposits have yielded a few taxa with distinctly northern modern ranges. For example, the Steyne Wood Clay contained the buttercup *Ranunculus hyperboreus* (Reid & Chandler 1924) together with the ostracods *Semicytherura affinis* and *Hemicytherura clathrata*, both now found in the Arctic and along the Norwegian coast, whereas *Baffinicythere*, a widespread circumpolar ostracod genus has been obtained from the Slindon Sands (Shephard-Thorn & Kellaway 1978). However, the preponderance of thermophilous taxa in both deposits militates against the assumption of an arctic climate as Jessen (1949, p. 270) has already argued in the case of the *R. hyperboreus*.

The coccolith assemblages from the Steyne Wood Clay and Slindon Sands contain a diverse flora dominated by *Gephyrocapsa oceanica* and *G. caribbeanica*. This fact, together with the absence of both *Pseudoemiliania lacunosa*, with a LOD at *ca*. 0.475 Ma BP, and *Emiliania huxleyi*, with a FOD at *ca*. 0.275 Ma BP, suggests deposition during this time interval. This implies that the Steyne Wood Clay and the Slindon Sands should be assigned to oxygen isotope stages 9 or 11, given that both deposits accumulated under interglacial conditions. However, this correlation is based largely on a coccolith interval zone defined by absence, and such correlations based on negative evidence are equivocal. Although the coccolith data suggests correlation with stages 9 and 11, the vertebrate evidence would also be consistent with a stage 13 correlation. This would imply that the absence of *P. lacunosa* from the Steyne Wood Clay and Slindon Sands is due to sampling failure and does not represent a 'genuine absence' during this temperate stage. The vertebrate evidence also implies deposition before the Anglian cold stage, which has been correlated with oxygen isotope stage 12 (see, for example, Sarnthein *et al.* 1986; Shackleton 1987), although some workers have correlated the succeeding Hoxnian/Holsteinian interglacial with oxygen isotope stage 7 (see, for example, Linke *et al.* 1985; Miller & Mangerud 1985).

The Brunhes/Matuyama boundary has been placed within the 'Cromerian Complex' in The Netherlands (Zagwijn 1985; de Jong 1988). In the deep-sea oxygen isotope record, this boundary occurs within stage 20 and is dated to 730 ka BP (Berggren *et al.* 1985). Because both deposits under discussion are early Middle Pleistocene, as indicated by the biostratigraphy, and are also both normally magnetized, it is clear that they fall within the early part of the Brunhes epoch.

The age of the Steyne Wood Clay and Slindon Sands is therefore constrained by the palynology, vertebrate, foraminiferal, ostracod and coccolith biostratigraphy and palaeomagnetic data. From this evidence it would appear that these deposits accumulated during an interglacial falling within the latter part of the 'Cromerian Complex' and correlation with oxygen isotope stages 9, 11 or 13 seems likely. Only when the Anglian stage can be securely identified in the oxygen isotope record will it be possible to sharpen these correlations.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

(ii) *Low-level deposits*

Several deposits with evidence of brackish or marine conditions occur at various elevations from about −2 m O.D. to +18 m O.D. in southern Britain (figure 9).

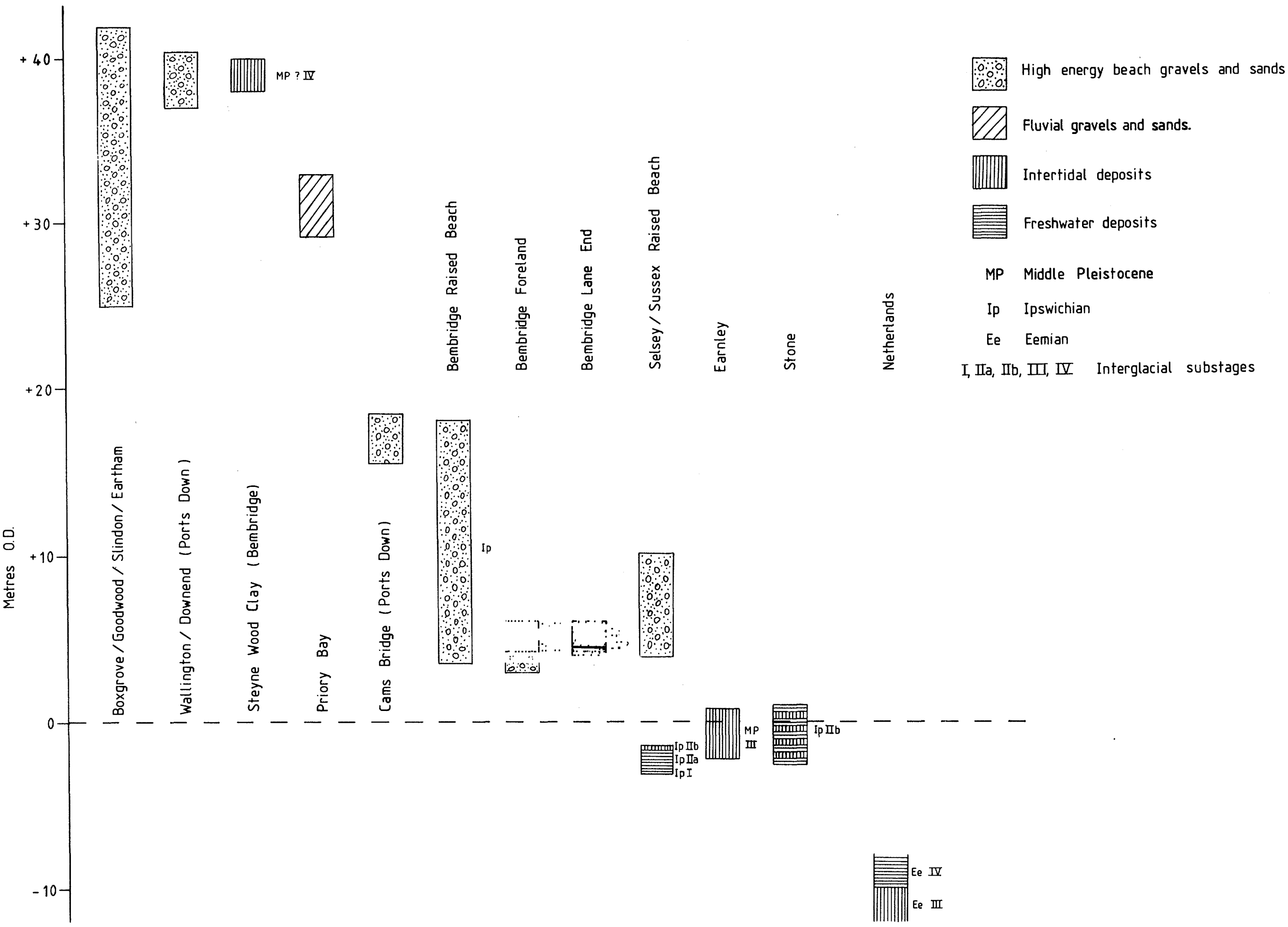


FIGURE 9. Height/lithology diagram for critical Pleistocene sites in central southern England and The Netherlands.

The channel filling at Earnley, on the modern foreshore of Bracklesham Bay, is palaeontologically quite distinct from neighbouring deposits occurring at about the same elevation, and is filled with intertidal sediments of interglacial age that appear to represent a regressive overlap. At the close of sedimentation mean tidal level is estimated to have been 0.7–1 m below its present position (West *et al.* 1984). The pollen spectra are dominated by arboreal taxa and include a range of deciduous trees with *Quercus*, *Carpinus*, *Alnus* and *Corylus* well represented. *Abies* is also well represented at values of between 10% and 15% of the total pollen and the unidentified reticulate tricolpate 'type *x*' also occurs at lower frequencies. The sequence has been assigned to the late temperate substage of a Middle Pleistocene interglacial (West *et al.* 1984).

As discussed above, only a limited coccolith flora has been recovered from these sediments

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

which precludes confident correlation on the basis of nannofossils alone. Moreover, although the amino acid ratio is similar to values obtained from Holsteinian/Hoxnian sites and the palynology is consistent with this correlation, firm attribution to this stage is not yet possible.

Although the Earnley channel infilling and the Steyne Wood Clay are assigned to different substages, there are other important palynological differences, despite that fact that both accumulated in intertidal environments. These differences, together with the enormous discordance in height, suggest that these deposits belong to different interglacials. It appears that Earnley post-dates the high-level deposits but further work is needed to establish precisely how they relate in age.

The other low-level deposits at Stone, Selsey, West Wittering and Bembridge Foreland can all be considered together. These sites have all produced pollen assemblages suggesting accumulation of intertidal sediments during the Ipswichian interglacial (West & Sparks 1960; Brown *et al.* 1975; this study). Stone is the only one of these sites to have yielded coccoliths and these occur only very sparsely. Nevertheless, the occurrence of *Emiliania huxleyi* is consistent with an Ipswichian age. The TL dates from the Bembridge Raised Beach are also consistent with this correlation.

There is no firm evidence, at present, to suggest that these sites belong to stages other than the Ipswichian, which is usually correlated with oxygen isotope stage 5e (Shackleton 1969). However, at Stone, the interglacial organic deposits are overlain by a gravel, regarded as of fluvial origin (Brown *et al.* 1975), which in turn is overlain by two units of brickearth. The basal brickearth (40 cm thick) has palaeoargillic features suggestive of interglacial pedogenesis (Reynolds 1987). Alternatively, it is possible that this episode of pedogenesis may have occurred during an Early or Middle Devensian interstadial when temperatures reached present values (Coope 1977). Amino acid ratios have been obtained from shells of *Corbicula fluminalis* collected from the interglacial deposit at Selsey. These are somewhat higher than comparable ratios determined from other sites of supposedly Ipswichian age and may imply that Selsey is older, although Miller *et al.* (1979) attribute the differences to a more southerly position or their shallow burial on the foreshore. There is no reference to the shells having been heated during preparation.

Differences in amino acid ratios have been used to distinguish raised beaches of supposedly different ages elsewhere in southern and southwestern Britain (Davies 1983; Bowen *et al.* 1985; Davies & Keen 1985). Some of these distinctions are based on quite subtle differences in the ratios and there is currently no general agreement as to the number of beaches represented or their ages.

A number of these aminostratigraphic studies (Davies & Keen 1985; Bowen *et al.* 1985) have indicated that raised beaches at the same elevation may be of very different ages. The Bembridge Raised Beach illustrates the opposite situation. Here is a laterally continuous shingle structure, which was deposited during a single high-stand of sea-level, that extends from less than 5 to 18 m O.D. It is now clear that the elevation of a raised beach deposit is no guide as to its age. Independent biostratigraphic or absolute dating are clearly required before secure correlations can be made.

Raised beach deposits occur in the area at elevations intermediate between the high-level and low-level deposits discussed above (figure 9). The 'Aldingbourne Beach' (Fowler 1932; Calkin 1934) for example, occurs between 28 and 32 m O.D. and, like the Slindon Sands at Boxgrove, it also contains erratics and palaeolithic implements. A new section in this beach has

Downloaded from rstb.royalsocietypublishing.org

recently been exposed and work is in progress to establish its relation with the Boxgrove sediments (M. B. Roberts, personal communication, 1988). Hodgson (1964) has demonstrated that, for the low-level marine sands and gravels of the West Sussex coastal plain, there has been considerable solution of the underlying wave-cut platform where it cuts across the Chalk. This solution, which post-dates the beach, gives a variation in platform height independent of its original slope. This may well account for some of the altimetric variation.

Other deposits at similar intermediate elevations, although mapped as 'marine gravels', may well be of fluvial origin, as was the gravel at Lane End and probably also that at Priory Bay.

(*b*) *Palaeoceanography and palaeogeography of the Pleistocene Solent and adjacent English Channel*

The nannofossil assemblages preserved in the Pleistocene sediments of the Solent throw light on the environment of deposition and palaeoceanography of the English Channel. The occurrence of nannofossils in these sediments indicates that the estuaries all had a full open connection with the marine waters of the central English Channel. The nannofossils were probably flushed into the estuaries as suspended silt on flood tides. Similar processes occur at present in Southampton Water and its adjacent inlets (Houghton 1986). These estuaries, like their modern-day counterparts, therefore acted as sinks for marine silt in the Pleistocene. Such processes were probably common during interglacial high-stands of sea-level.

The occurrence of diverse nannofossil assemblages in the Steyne Wood Clay and Boxgrove sediments, comprising 11 and 12 species respectively, including abundant gephyrocapsids, with subdominant *Calcidiscus leptoporus*, *Syracosphaera pulchra* and *Discosphaera tubifera*, strongly suggests that a thermocline was present in the central English Channel at the time of deposition. These nannofossil species today are only found in the Celtic Sea and western English Channel in sediments underlying a watermass with pronounced thermocline development (Houghton 1986, 1988). Recent sediments in the English Channel deposited from tidally mixed waters contain sparse nannofossil assemblages limited to six or fewer species characterized by dominant *Emiliania huxleyi* and *Coccolithus pelagicus* and rare gephyrocapsids, whereas *C. leptoporus* is absent. Recent sediments in the Solent region are even more neritic, being limited to four species dominated by *C. pelagicus* (over 95%).

The occurrence of a thermocline in the central English Channel may have been influenced by the existence of the Straits of Dover. Smith (1985*a*, 1989) and Gibbard (1988) have both suggested the initial breaching of the Straits of Dover by the drainage of a glacially impounded lake in the southern North Sea during the Anglian glaciation. This therefore suggests that the Straits were closed when the Steyne Wood Clay and Slindon Sands were deposited. The existence of a thermocline in a large 'English Channel embayment' or 'estuary', or in the modern open English Channel, depends on the balance between the seasonal heat exchange at the sea surface and the extent of tidal dissipation, as on the northwest European shelf today (Simpson & Bowers 1981). This in turn depends on the palaeotemperature and palaeotidal régime. The palaeotemperature can be assumed to have been similar to the present for interglacial times. A provisional assessment of the palaeotidal régime has been derived by using existing tidal models for the continental shelf, based on the principal lunar (M2) constituent of the ocean tide, modified to include an altered coastline representing closure of the Straits of Dover. This has then been used to estimate the depth/depth-averaged tidal stream velocity (h/u^3) parameter of Simpson & Hunter (1974), which expresses the degree of stratification or

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

mixing of the water mass. These models reveal that stratification is *more* likely with the Straits of Dover closed (R. Austin, personal communication, 1988), which is consistent with the suggestions of Smith (1985*a*, 1989) and Gibbard (1988).

The development of the eastwards-flowing Solent River during the Tertiary and Quaternary has been dealt with extensively elsewhere (Reid 1902; Everard 1954; Dyer 1975; Keen 1980; West 1980; Jones 1981; Nicholls 1987) and it is not the purpose of this paper to add to these. The main conclusions drawn here do have a number of implications for the origin and development of the river, and of the palaeogeography of the region as a whole.

The submergence of the lower reaches of the river and the formation of broad estuaries during temperate phases, as already indicated by the studies at Stone (Brown *et al.* 1975), Earnley (West *et al.* 1984) and Selsey (West & Sparks 1960) are further supported by the estuarine Steyne Wood Clay and the Ipswichian saltmarsh sediments of the Bembridge Raised Beach. The local geomorphology of the Steyne Wood area has, however, totally changed since the early Middle Pleistocene, as the estuarine sediments there are now found on the summit of a small hill. Presumably a river drained the high land associated with the Chalk monocline to the southwest and reached the sea in the Steyne Wood vicinity.

The gravels at Lane End, which are thought to be fluvial and almost certainly Devensian in age, must have been deposited by a small right-bank tributary of the Solent River during the lowered sea-levels of the last cold stage.

The extensive high-energy shingle of the Bembridge Raised Beach raises some important palaeogeographic problems. The bedding structures and lithological composition of the shingle clearly indicate that material was being transported eastwards up the Channel. The existence of *Rhaxella* chert from the Dorset Portlandian and low-grade metamorphics from South Devon perhaps indicate the continued existence of the Wight–Purbeck Ridge during the Ipswichian, as implied by Everard (1954) and Nicholls (1987). If the Ridge had been breached before the Ipswichian then this material would have been incorporated into shingle structures, such as a proto-Hurst Castle Spit, in the western Solent. The mass of flint in the Raised Beach was almost certainly derived from marine erosion of the Upper Chalk along the coastline to the west.

Although the origin of the material composing the shingle can be explained, the source of the energy required to construct such an extensive shingle barrier beach at the mouth of the proto-Solent estuarine system presents a problem. Analogous modern structures, such as Chesil Bank, Hurst Castle Spit and Dungeness, occur in exposed high-energy situations, but the Bembridge Foreland coast today is a particularly low-energy environment. However, if the coastline to the west, and the palaeobathymetry, were somewhat different from today, then refraction of Atlantic waves of west to southwest fetch could focus energy on this southeast-facing coastline, as in Start Bay today (A. G. Davies, personal communication, 1988). The critical factor would be depth of water inshore off Bembridge, where significant shallowing would control refraction around the southern point of the proto-Isle of Wight. Such a shallowing could have been associated with sand bar or shoals at the mouth of the proto-Solent estuary, or the extensive ledge of Bembridge Limestone that currently outcrops in this area. If the refracted waves were of steep asymmetric type causing residual sediment transport to the northeast, then it would be possible to construct a prograding shingle structure in this area. Alternatively, prevailing wind directions are known to vary and may have been substantially different during the Ipswichian.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

(*c*) *Neotectonic considerations*

Both the Steyne Wood Clay at Bembridge and the Slindon Sands at Boxgrove provide evidence, consisting of intertidal muds and littoral sands respectively, for contemporaneous sea-levels. Both occur at elevations around 38–40 m O.D. and, on the basis of the evidence presented above, are likely to be of the same age. In addition, there are a number of other Pleistocene littoral deposits at, or just below, 40 m O.D. in the area, including the Wallington and Downend (Ports Down) raised beaches (ApSimon *et al.* 1977) (figure 9). Although these are as yet poorly dated, they may well relate to the same high-stand of sea-level responsible for the Steyne Wood Clay/Boxgrove aggradations.

The evidence emerging from a detailed correlation of Pleistocene sea-level records from raised coral terraces with the deep-sea oxygen isotope record (Chappell & Shackleton 1986; Shackleton 1987) is unable to accommodate sea-levels greater than +10 m O.D. during the Middle and Late Pleistocene. Some interglacial stages during this interval may well have had sea-level maxima significantly lower than stage 1 (present). The inevitable conclusion from this is that *regional* tectonic uplift has been active in the eastern Hampshire Basin at some time during or since the Middle Pleistocene. Purely *local* tectonic movements in the Bembridge area have already been discounted (§2*d*).

Given the elevations of the Bembridge/Boxgrove aggradations and their age, rates of uplift can be calculated by using the formula $a = y/z$, where a = uplift rate in metres per 1000 years, z = time of deposition in thousands of years BP; and y = amount of uplift in metres since z. y can be derived from the formula $y = b - c$, where b = mean sea level at z in metres O.D., and c = global eustatic sea-level at z based on Shackleton (1987).

c is assumed to have a minimum value of −10 m O.D. and a maximum value of +10 m O.D. for interglacial high-stand maxima. For the purpose of this discussion the Bembridge/Boxgrove and other aggradations are assumed to have been deposited during the maximum elevation of any specific interglacial high-stand, and uplift is assumed to be have been directionally constant and linear. Maximum sea-levels are assumed to have occurred during the middle of stages 9, 11 and 13; figures for z are based on these mid-points as outlined in table 8. The sedimentation timescale (Shackleton & Opdyke 1973, 1976) is used in the calculations.

To calculate y, it is necessary to provide b, and this relies on using the present tidal range for the eastern Solent. The current spring tidal range at Bembridge is 4.1 m (Admiralty Tide Tables 1988). If it is assumed that the tidal range in the area has remained constant, then the Steyne Wood Clay could have been deposited with the contemporaneous mean sea-level at a current elevation anywhere between 36 and 40 m O.D., given that it is an intertidal deposit. The upper limit is given by the maximum elevation of the intertidal sediments, and the minimum is derived by subtracting 2 m, roughly half the spring tidal range, from the lowest current elevation of the intertidal deposits. If the mean contemporaneous sea-level had been lower than 36 m O.D. then it would not have been possible to have had any marine influence at or above 38 m O.D. Recent palaeotidal modelling of the English Channel, with modified bathymetry and a coastline incorporating the geological evidence for the temperate stages of the Middle Pleistocene, suggests that the tidal range could have been up to 0.5 m greater with the Straits of Dover open, and up to 1 m greater with the Straits closed (R. Austin, personal communication, 1989). This means that y may be between 0.25 and 0.5 m too high and consequently the calculated uplift rates slightly too high.

Downloaded from rstb.royalsocietypublishing.org

To calculate y, c has to be subtracted from b. Given the figures for b and c derived above, then the relevant range for y is 26–50 m. The calculated uplift rates are given in table 8 and expressed graphically in figure 10.

The maximum calculated rate of uplift is therefore 15.5 mm per 1000 years with $z =$ 322 ka BP and $y = 50$ m (maximum uplift over minimum time), and the minimum rate is 5.3 mm per 1000 years with $z = 487$ ka BP and $y = 26$ m (minimum uplift over maximum time).

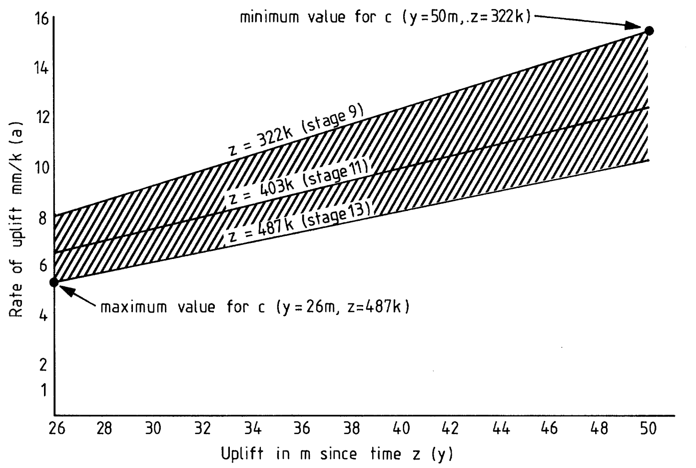


FIGURE 10. Uplift curves for the eastern Solent.

TABLE 8. DATA USED IN THE CALCULATION OF UPLIFT RATES

(Sedimentation rate from Shackleton & Opdyke (1973, 1976); astronomical timescale from Johnson (1982).)

oxygen isotope stage	sedimentation rate timescale mid-point (z) (ka BP)	astronomical timescale mid-point (z) (ka BP)	maximum uplift rate (a)[a] mm per 1000 years	minimum uplift rate (a)[a] mm per 1000 years
9	322	320	15.5	8.0
11	403	390	12.4	6.5
13	487	501	10.3	5.3

[a] $y = 50$ m.
[b] $y = 26$ m.

The relative ages of the Bembridge/Boxgrove and Earnley aggradations have been discussed above. If they are of the same age then some spectacular local tectonic explanations have to be invoked. There is about a 40 m difference in their respective elevations (figure 9), and both the Steyne Wood Clay and the Earnley deposits are thought to represent the later stages (post-temperate and late-temperate respectively) of a Middle Pleistocene interglacial (Holyoak & Preece 1983; West *et al.* 1984). It is not therefore possible to explain them as part of the same regressive phase of one temperate episode. Either they were deposited during the latter part of the same interglacial, which was then succeeded by the formation of a graben-like structure in the eastern Solent, downthrowing Earnley in comparison with Bembridge on the southwest side of the structure and Boxgrove to the northeast, or the central area including Earnley could have remained stable against the relative uplift of Bembridge and Boxgrove on either side. As discussed above, there is no evidence for purely local tectonic activity in the Bembridge area

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

since the Ipswichian, but this might not preclude the existence or formation of a graben in the eastern Solent.

If, as seems likely, the Bembridge/Boxgrove and Earnley aggradations represent different temperate stages, in particular stage 11 and stage 9 respectively, then their altitudinal differences can be seen as the product of temporally separated high-stands superimposed on a steadily uplifting coastline. Rates of uplift, a, have been derived above for $z = 403$ ka BP (stage 11). If the Earnley aggradation was deposited about 322 ka BP (stage 9), then this gives 322 ka years of uplift at rate a. The maximum rate of uplift derived for $z = 403$ ka BP is 12.4 mm per 1000 years and the minimum rate is 6.5 mm per 1000 years producing between 20.9 and 39.9 m of uplift (y) since deposition. Given that the Earnley aggradation indicates that the contemporaneous mean sea-level was around -1 m O.D. (b) (West *et al.* 1984), then 1 m has to be added to y to reconstruct c. This reconstruction indicates that mean sea-level must have stood between -21.9 and -40.9 m O.D. during the maximum transgression of stage 9, and since then the site has been uplifted to -1 m O.D. However, the data in Shackleton (1987) do not indicate that stage 9 was characterized by lower sea-level maxima than stage 11.

There are therefore two working hypotheses which can be invoked to explain the discordant elevations of the Bembridge/Boxgrove and Earnley aggradations. Although these hypotheses require further testing, the latter explanation of regional uplift with aggradation during succeeding interglacial high-stands is thought to have most empirical support at present.

These calculated rates of uplift also shed some light on the elevation of Ipswichian sea levels in the region. Given constant linear uplift, the computed rates should have the effect of slightly raising Ipswichian beach and intertidal deposits from their initial elevations, and thus reconstructed mean sea-levels for the Ipswichian from the eastern Solent may be slightly too high.

If 127 ka BP (z) is taken for the mid-point of oxygen isotope stage 5e based on the sedimentation-rate timescale (Shackleton & Opdyke 1973, 1976), then y can be calculated for computed values of a. For the maximum value of $a = 15.5$ mm per 1000 years, $y = 19.7$ m, and for the minimum value of $a = 5.3$ mm per 1000 years, $y = 6.7$ m. Though there is now widespread shoreline and isotopic evidence to support a eustatic sea-level some metres higher than the present during stage 5e (Cronin 1982), it is probable that the raised elevation of Ipswichian beach and intertidal deposits in southern England is at least partly of tectonic origin.

Both West (1972) and Zagwijn (1983) have considered the differences in elevation between geographically separated Ipswichian/Eemian marine deposits in northwest Europe, and have attributed the differences to subsidence of the southern North Sea during the Pleistocene. In particular, West identifies 9 m of downwarping of the Stutton area of Suffolk relative to Selsey in the eastern Solent, and Zagwijn has computed a rate of downwarping of 142 mm per 1000 years for The Netherlands based on the relative elevations of Eemian deposits there and in the English Channel. In calculating this rate Zagwijn assumes the Channel area to have been tectonically stable since the Eemian, an assumption that must now be seriously challenged. At least part of the difference in elevation is probably the result of uplift in the Channel area.

The highest eustatic sea-level reached during the Eemian/Ipswichian is known from the continent to have occurred in pollen zones f and g (equivalent to zones Ip II b and III). This is estimated at -8 m below mean sea-level in The Netherlands (Zagwijn 1983). The Bembridge Raised Beach sequence indicates that the maximum Ipswichian transgression occurred during or immediately before zone Ip II b, with mean sea-level at around $+4$ m during the latter part

Downloaded from rstb.royalsocietypublishing.org

of zone IIb and the beginning of zone III (*Carpinus* zone). This gives a difference of 12 m between Bembridge and The Netherlands for sea-level during the *Carpinus* zone of the interglacial. Adopting a figure of 127 ka BP for the *Carpinus* zone, this gives a differential rate of movement of 94.5 mm per 1000 years (0.945 cm per 100 years). Because of the apparent uplift of Bembridge this figure cannot totally result from subsidence of The Netherlands. The subsidence rate for The Netherlands can be obtained by subtracting the uplift rate for Bembridge from the total movement rate. This gives figures of 79.0 or 89.2 mm per 1000 years depending on whether the maximum or minimum uplift rate, as calculated above, is subtracted. The important point that emerges from this analysis is that rates of subsidence in The Netherlands since the Eemian are an order of magnitude greater than any uplift of the eastern Solent over the same time period.

The identification of Pleistocene tectonic uplift in this area also has implications for reconstructions of the Solent River (Nicholls 1987). Dyer (1975) concluded that the Solent River, presumably at a late stage in its development, was incised to a base level of at least −46 m O.D., 10 km east-southeast of Bembridge Foreland. If uplift has occurred then this figure must be regarded as a maximum, and the original incision may have been to a base level some metres lower than this.

There are a variety of possible mechanisms to explain this tectonic uplift. The most important of these include hydro-isostasy, deep-seated structural controls, glacio-isostasy and erosional or depositional isostasy. The cyclical flooding and evacuation of the English Channel to a maximum depth of *ca.* 200 m will have influenced the region as a whole. Nevertheless, hydro-isostasy can probably be disregarded as a significant mechanism because the sequences considered here were all deposited towards the end of interglacial stages by which time isostatic equilibrium is assumed to have been attained.

A tendency for subsidence appears to dominate the tectonic history of this part of the central English Channel over long-term geological timescales of 10^6–10^8 years (Smith & Curry 1975) and is known to have been active since the Eocene (Daley & Edwards 1971; Plint 1982). Interestingly, the Pleistocene sites of the eastern Solent lie immediately to the northeast of one of the most important structures of Europe, the Bembridge–St. Valéry line, which appears to link with the Sillon Houiller of the Massif Central. This structural feature is related to the Isle of Wight monocline immediately to the southwest of the Bembridge sites, so the Pleistocene sites are situated on the downthrow side of the structure. However, the mid-Channel fold/fault system, which mirrors the Isle of Wight monocline, has an equally large downturn to the south, and the depth to basement is not always greatest on the downthrow side of the structure. This suggests that movements may not always have been in the same sense, so that the present downthrow side of a structure may have been the upthrow side at an earlier time (Smith & Curry 1975). It is therefore possible that such a reversal has occurred in the deep-seated fault structure that controls the Bembridge–St. Valéry line at the Bembridge end of the structure in Quaternary times.

Examination of the recent tide-gauge evidence (Emery & Aubrey 1985; Woodworth 1987), however, indicates a complicated pattern of change with no obvious links with these established geological structures. From a detailed analysis of tide-gauge records over the last century (10^2 years) from northern Europe, Emery & Aubrey (1985) and Woodworth (1987) have recently concluded that there is currently subsidence of between 5 and 8 mm per year in the eastern Isle of Wight and neighbouring Hampshire Basin, although other workers using Holocene geological data indicate much lower rates of around 1.3 mm per year (Devoy 1982; Heyworth

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

& Kidson 1982; Nicholls 1985). There is some doubt over the validity of Emery & Aubrey's interpretation as it relies exclusively on improperly reduced data from the single tide-gauge at Portsmouth (Webber & Walden 1981; Walden 1982). However, they conclude that this rapid subsidence represents a relaxing peripheral forebulge of glacio-isostatic origin. This implies that even though the Bembridge/Boxgrove aggradation was deposited before the Anglian glaciation, which is widely held to have been the first extensive glaciation of lowland Britain, the current elevation of these deposits is probably at least partly of glacio-isostatic origin. As such, this glacio-isostatically induced subsidence may represent an important tectonic component over timescales of 10^2–10^4 years superimposed on a component of underlying tectonic uplift operating at a slower rate that becomes significant over timescales of 10^5 and longer. Eyles & McCabe (1989) have also recently suggested that some high-level marine deposits in southern Britain, mapped as interglacial, might have a glaciomarine/isostatic origin. Such an origin can be discounted in this case because of the clear temperate status of the deposits.

There is substantial evidence pointing to a broad uplift in southeast England and neighbouring continent during the past few million years as implied by Smith (1985*a*, *b*, 1989). Evidence for this uplift can be seen in the present altitude of late Miocene/Pliocene peneplains and associated deposits. The Coralline and Red Crags are at sea-level in Suffolk, but the late Miocene Lenham Beds of Kent indicate a shoreline of nearly 200 m at Lenham and Beachy Head. No corresponding beds are recorded anywhere else in southeast England, although the Chalk reaches elevations of over 300 m in places. Pliocene beds occur locally at over 100 m near Fécamp, but both Miocene and Pliocene are known near sea-level in the Cotentin (Lautridou 1980) and locally in Brittany. Miocene beds occur at about 150 m on an isolated hill at Cassee, south of Dunkirk, but are at sea-level around Antwerp. This evidence suggests a doming in southeast England – northeast France, which locally may have been as much as 400 m, has continued, albeit probably intermittently, for over a million years. This doming covers a much larger area than the Weald–Artois anticline and may have nothing whatever to do with that feature. The apparent uplift of the eastern Solent by some 40 m over 0.4 Ma is entirely consistent with the known spatial and temporal extent of this doming.

By contrast, the massive subsidence of the southern North Sea is well documented by its thick Pleistocene deposits. It is possible that the central Channel uplift represents a compensation (*mouvement de bascule*) associated with this rapid subsidence (D. Curry, personal communication, 1988). The volumes of uplift and fill in the two areas appear to be roughly comparable.

We thank Professor R. G. West, F.R.S., and Mr R. Fowler for the supply of samples from Earnley and for help in various ways. Dr M. Aalto, Mr R. Austin, Dr T. J. F. Austin, Dr D. R. Bridgland, Dr G. A. Chinner, Dr G. R. Coope, Dr J. T. Hollin, Dr G. H. Miller, Mr D. A. Parks, Dr H. M. Rendell and Mr G. A. Southgate kindly undertook a number of analyses on our behalf as indicated in the text. Earlier drafts of the manuscript were kindly read, either in whole or in part, by the following authorities; Dr J. Backman, Professor D. Curry, Dr R. J. N. Devoy, Dr R. W. Hey, Dr R. J. Nicholls, Dr N. J. Shackleton, F.R.S., and Dr M. J. Sharp. We acknowledge useful discussion with Ms L. Allen, Dr A. G. Davies, Dr G. King and Mr M. B. Roberts, and the help provided in draughting diagrams by Dr J. R. M. Allen. Dr J. D. Scourse gratefully acknowledges the receipt of a Research Fellowship at Girton College, Cambridge.

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Appendix A. Taxonomic notes on certain Ostracoda from the Steyne Wood Clay

By D. N. Penney

Cytheropteron sp.

(Figure 11*g*, *h*, plate 1.)

Cytheropteron sp. is not formally described as insufficient material was present to merit establishment of a new species (three adult and two juvenile valves). None the less, it is probably new as a thorough search of the available literature has not been fruitful. *Cytheropteron* sp. is apparently not a species living in British seas today (compare Whatley & Masson 1979). The right valve of this small (390–400 μm), subrectangular species is very similar in outline to *Cytheropteron alveiformis* Deltel from the Eocene of southwest France, but the left valve of the species is subovate and possesses a downward-turning, triangular ala. *Cytheropteron* sp. also lacks the two curving ribs present in the anteroventral region of *C. alveiformis*. The base of the ala possesses a weak longitudinal rim with three polygonal cells ventrally. The leading edge of the ala is subparallel to the ventral margin and is produced into a double nipple-like spine structure at its extremity. The trailing edge is slightly concave, bearing a large, slightly upturned spine. The ventral surface of the ala is reticulated with a subvertical arrangement of fossae and a deep median sulcus. The posterodorsal part of the dorsal margin possesses a rib parallel to and just below it.

Leptocythere steynewoodensis sp. nov.

(Figure 11*a*–*d*, *f*, plate 1.)

Derivatio nominus

The name is derived from the fact that the species appears to be restricted to the Steyne Wood Clay.

Holotype

British Museum registration number OS 13381.

Paratypes

OS 13382; OS 13383; OS 13384; OS 13385.

Type locality

Bembridge School, Isle of Wight (SZ 64198664)

Type level

Borehole B, sample K; 4.19–4.30 m depth (+39.45 to +39.56 m o.d.; Holyoak & Preece (1983)).

Material

One hundred and forty-six adult and juvenile valves.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

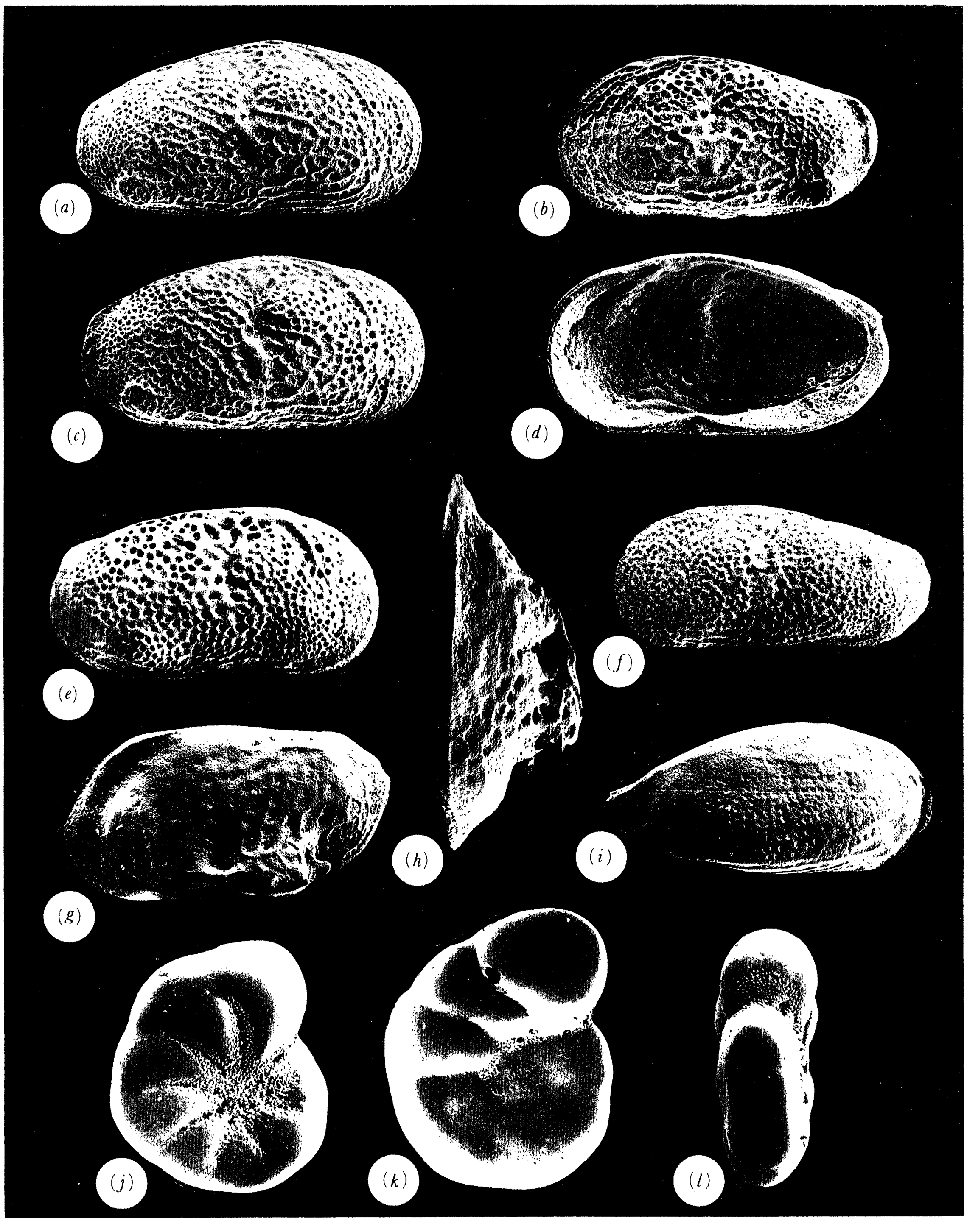


FIGURE 11. Selected ostracod and foraminifer taxa for the Steyne Wood Clay, Bembridge. (*a*)–(*d*), (*f*) *Leptocythere steynewoodensis* sp. nov. (*a*) Female RV, external lateral view, magn. ×121; (*b*) female LV, external lateral view, magn. ×110; (*c*) female RV, external lateral view, magn. ×125; (*d*) female RV, internal lateral view, magn. ×121. (*e*) *Leptocythere castanea* (Sars), female RV, external lateral view, magn. ×81. (*f*) *Leptocythere steynewoodensis* male LV, external lateral views, magn. ×115. (*g*), (*h*) *Cytheropteron* sp. (*g*) Adult LV, external lateral view, magn. ×135; (*h*) adult RV, dorsal view, magn. ×148. (*i*) *Semicytherura affinis* (Sars), adult RV, external lateral view, magn. ×110. (*j*)–(*l*) *Aubignyna perlucida* (Heron-Allen & Earland). (*j*) Spiral view, magn. ×95; (*k*) umbilical view, magn. ×90; (*l*) apertural view, magn. ×90.

(*Facing p.* 470)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

Dimensions

		dimensions/μm		
holotype		length	height	width
LV female	OS 13381	435	230	105
paratypes				
RV female	OS 13382	440	235	100
LV male	OS 13383	430	200	95
RV female	OS 13384	430	230	—
LV male	OS 13385	435	205	100

Diagnosis

A small, inflated species of *Leptocythere* with marked sexual dimorphism; the female possesses a very distinct postero-ventral protuberance, a deep sulcus, and a reticulated pattern of fossae concentrically arranged parallel to the free margin anteriorly and ventrally. The male is narrower with a more weakly developed reticulation and lacking a posteroventral protuberance.

Description

Female: small, inflated medianly, compressed in the posterolateral region, subovate and tapering posteriorly in lateral view. Anterior margin broadly rounded; posterior margin asymmetrically rounded. Dorsal margin curved with a shallow concavity at the posterior extremity of the left valve. Very weak anterior cardinal angle, posterior cardinal angle more marked. Ventral margin sinuous. Greatest height at anterior cardinal angle, greatest length at about mid-height. Ornament reticulate, fossae concentrically arranged anteriorly and ventrally into 4–5 rows parallel to the free margin and separated by muri, particularly parallel to the ventral margin where they are sinuous medianly. Reticulation finer posteriorly and dorsally, arranged diagonally from the posterodorsal part to the central part of the shell across a deep median sulcus. Both valves possess a very prominent posteroventral protuberance. Normal pores large, few in number. Inner lamella relatively broad anteriorly and posteroventrally with prominent selvage. Marginal pore canals not observed. Anterior terminal element of right hinge a subelliptical, dentate bar. Posterior terminal element also slightly curved and divided. Enteromedian tooth in left valve a smooth, elongated, undivided bar. Adductor muscle scars a subvertical row of four. The fulchral point is crescentic and the frontal scar V-shaped. Sexual dimorphism very pronounced. Males much narrower and lacking the posteroventral protuberance. Reticulation more weakly developed with smaller fossae than in the female, arranged subparallel to the free margins, separated by muri only in the ventral region.

Remarks

Leptocythere steynewoodensis differs from *L. porcellanea* (Brady) in its smaller size, constant reticulate pattern, and in the presence of a very prominent protuberance in the posteroventral region in the female. This is positioned much more dorsally and is much larger than a similar structure in *L. porcellanea* (see Horne & Whittaker 1985).

L. steynewoodensis is related to *L. bituberculata* Bonaduce, Ciampo & Masoli (1975) from the Recent of the Adriatic Sea, but the latter is larger, more asymmetrically rounded, has a coarser reticulation, and possesses two very prominent protuberances in the posteroventral region.

The female of *L. pliocenica* Maybury & Whatley from the Upper Pliocene of St Erth, Cornwall also possesses a protuberance in the posteroventral region, but the shape and ornament is different and it is considerably larger (Maybury & Whatley 1980).

Downloaded from rstb.royalsocietypublishing.org

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Appendix B. Thermoluminescence dating of the Bembridge Raised Beach

By G. A. Southgate

Godwin Laboratory, Free School Lane, Cambridge CB2 3RS, U.K.

The sample was washed in 10% (by volume) HCl to remove calcium carbonate and the 4–11 μm fraction extracted. Half of this residue was treated with dilute hydrofluosilicic acid to digest all but the quartz component. The other half was left untreated, resulting in a polyminerallic fraction. This fraction and the quartz fraction were then deposited onto 1 cm Al discs by evaporation of suspensions in methanol. The two fractions were prepared so that the results could be compared and act as a test of the internal validity of the techniques used.

The thermoluminesce (TL) observations were made by using an EMI 9635B photomultiplier tube fitted with a Chance–Pilkington HA-3 filter and a Schott UG-11 filter. The samples were heated in an argon atmosphere at a rate of 5 °C s^{-1}. The UG-11 filter transmits in the near UV region and Debenham & Walton (1983) have shown it enhances the feldspar emission to the detriment of the quartz emission. Thus the TL of the polyminerallic fraction can be considered the TL of the feldspars within the sample.

A preheat of 230 °C held for one minute was used for both fractions. Wintle (1985) originally suggested this technique was applicable for feldspar TL. The trap parameters for quartz suggest that the use of this preheat treatment does not affect the equivalent dose (ED) determinations.

In contrast to a previous study on beach sands (Southgate 1985) only one method of ED determination has been used for the polymineralic fraction: the $N+\beta-I_0$ method of Singhvi *et al.* (1982). The regeneration method of Wintle & Prószynska (1983) was not used as it has been shown to underestimate the age of pre-Devensian sediments (Debenham 1985). Both of these methods were used on the quartz fraction to test whether the same phenomenon also affects the quartz TL.

The polymineralic fraction has a peak of 305 °C, whereas the quartz fraction has its peak at the slightly higher temperature of 315–320 °C. The light levels from the polymineralic fraction are over five times that of the quartz fraction. The residual levels (I_0) are roughly comparable, that is the residual level as a fraction of dose-induced TL is higher for the quartz fraction. The large error terms in the quartz ED determinations are attributed to the low light levels. ED plateaux were obtained in the temperature region associated with the peaks in each case.

The uranium and thorium content of the sample was determined by α-counting. The sealed and unsealed count-rates were within 2% of each other, which indicates that there is no radon loss. The potassium content was obtained commercially. The water content was taken as 0.05 ± 0.05 (mass water/mass dry sediment). The *a*-values were not measured for either fraction; the value assumed in both cases was 0.10 ± 0.02. The median value is one commonly found and the error term is large to account for the normal variation. The complete results are given in table 9.

The results from the $N+\beta-I_0$ methods on both fractions are consistent. The regeneration method produced an ED for the quartz fraction that is considerably lower, probably resulting from a depression of the ED when this method is used. The consistency of the $N+\beta-I_0$ results imply that the method is internally valid. The ages determined by this method indicate that the beach was deposited during the last interglacial, which is in agreement with other data from the site.

Downloaded from rstb.royalsocietypublishing.org

TABLE 9. DETERMINATIONS FOR THE TL DATING ANALYSIS

fraction	total α-count rate (ks^{-1} cm^{-2})	Th (p.p.m.)	U (p.p.m.)	K_2O (%)	dose rate (Gy ka^{-1})	ED/Gy	apparent TL age/ka
raw	0.372±0.009	5.00	1.65	1.06	2.45±0.18	—	—
		±0.90	±0.28	±0.01	—	—	—
polymineralllic quartz	—	—	—	—	—	(i) 281.6±14.7	115.1±10.4
						(i) 255.1±28.9	104.3±14.1
						(ii) 125.4±33.8	51.3±14.3

((i) $N+\beta-I_0$ method; (ii) regeneration method.)

REFERENCES

Admiralty Tide Tables 1988 Volume I. Hydrographer of the Navy. Taunton: HMSO.

Andersen, S. T. 1970 The relative pollen productivity and pollen representation of North European trees and correction factors for tree pollen spectra. *Danm. geol. Unders.* III **96**, 1–99.

ApSimon, A. M., Gamble, C. S. & Shackley, M. L. 1977 Pleistocene raised beaches on Ports Down, Hampshire. *Proc. Hamps. Field Club arch. Soc.* **33**, 17–32.

Arkell, W. J. 1943 The Pleistocene rocks at Trebetherick Point, North Cornwall: their interpretation and correlation. *Proc. Geol. Ass.* **54**, 141–170.

Backman, J. 1980 Miocene–Pliocene nannofossils and sedimentation rates in the Hatton–Rockall Basin, N.E. Atlantic Ocean. *Stock. Contr. Geol.* **36**, 1–91.

Backman, J. 1984 Cenozoic calcareous nannofossil biostratigraphy from the northeastern Atlantic Ocean. In *Initial reports of the Deep Sea Drilling project*, vol. 81 (ed. D. G. Roberts *et al.*), pp. 403–427. Washington: U.S. Government Printing Office.

Bates, C., Coxon, P. & Gibbard, P. L. 1978 A new method for the preparation of clay-rich sediment samples for palynological investigation. *New Phytol.* **81**, 459–463.

Benninghoff, W. S. 1962 Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities. *Pollen Spores* **4**, 332–333.

Berggren, W. A., Kent, D. V. & van Couvering, J. A. 1985 The Neogene. Part 2. Neogene geochronology and chronostratigraphy. In *The chronology of the geological record* (ed. N. J. Snelling). *Geol. Soc. Mem.* **10**, 211–260.

Birks, H. J. B. 1973 *Past and present vegetation of the Isle of Skye – a palaeoecological study.* Cambridge University Press.

Bishop, M. J. 1982 The mammal fauna of the early Middle Pleistocene cavern infill site of Westbury-sub-Mendip, Somerset. *Spec. Pap. Palaeontol.* **28**, 1–108.

Bonaduce, G., Ciampo, G. & Masoli, M. 1975 Distribution of Ostracoda in the Adriatic Sea. *Pubbl. Staz. Zool. Napoli.* **40**, (Suppl. 1), 1–154.

Bonny, A. P. 1972 A method for determining absolute pollen frequencies from lake sediments. *New Phytol.* **71**, 391–403.

Bowen, D. Q., Sykes, G. A., Reeves, A., Miller, G. H., Andrews, J. T., Brew, J. S. & Hare, P. G. 1985 Amino acid geochronology of raised beaches in South West Britain. *Quat. Sci. Rev.* **4**, 279–318.

Bowen, D. Q. & Sykes, G. A. 1988 Correlation of marine events and glaciations on the north-east Atlantic margin. *Phil. Trans. R. Soc. Lond.* B **318**, 619–635.

Brady, G. S. & Norman, A. M. 1889 A monograph of the marine and freshwater Ostracoda of the North Atlantic and north-west Europe. *Trans. R. Dublin Soc.* N.S. **4**, 63–270.

Brown, R. C., Gilbertson, D. D., Green, C. P. & Keen, D. H. 1975 Stratigraphy and environmental significance of Pleistocene deposits at Stone, Hampshire. *Proc. Geol. Ass.* **86**, 349–363.

Browne, M. A. E., Graham, D. K. & Gregory, D. M. 1984 Quaternary estuarine deposits in the Grangemouth area, Scotland. *B.G.S. Rep.* **16**(3), 1–14.

Calkin, J. B. 1934 Implements from the higher raised beaches of Sussex. *Proc. prehist. Soc.* **7**, 33–47.

Carr, A. P. & Blackley, M. W. L. 1973 Investigations bearing on the age and development of Chesil Bank, Dorset and the associated area. *Trans. Inst. Br. Geogr.* **58**, 99–112.

Carter, R. W. G. & Orford, J. D. 1984 Coarse clastic barrier beaches: a discussion of the distinctive dynamic and morphosedimentary characteristics. *Mar. Geol.* **60**, 377–389.

Catt, J. A. 1977 Loess and coversands. In *British Quaternary studies: recent advances* (ed. F. W. Shotton), pp. 222–229. Oxford: Clarendon Press.

Chappell, J. & Shackleton, N. J. 1986 Oxygen isotopes and sea-level. *Nature, Lond.* **324**, 137–140.

Clifford, M. H. 1936 A Mesolithic flora in the Isle of Wight. *Proc. Isle Wight nat. Hist. arch. Soc.* **2**, 582–594.

Codrington, T. 1870 On the superficial deposits of the South of Hampshire and the Isle of Wight. *Q. Jl. geol. Soc. Lond.* **26**, 528–551.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

Coope, G. R. 1977 Fossil coleopteran assemblages as sensitive indicators of climatic changes during the Devensian (Last) cold stage. *Phil. Trans. R. Soc. Lond.* B **280**, 313–340.

Cronin, T. M. 1982 Rapid sea level and climate change: evidence from continental and island margins. *Quat. Sci. Rev.* **1**, 177–214.

Daley, B. & Edwards, N. 1971 Palaeogene warping in the Isle of Wight. *Geol. Mag.* **108**, 399–405.

Davies, K. H. 1983 Amino acid analyses of Pleistocene marine mollusca from the Gower Peninsula. *Nature, Lond.* **302**, 1983–1986.

Davies, K. H. & Keen, D. H. 1985 The age of Pleistocene marine deposits at Portland, Dorset. *Proc. Geol. Ass.* **96**, 217–225.

Debenham, N. C. 1985 Use of u.v. emissions in TL dating of sediments. *Nucl. Tracks* **10**, 717–724.

Debenham, N. C. & Walton, A. J. 1983 TL properties of some wind-blown sediments. *PACT* **9**, 531–538.

Devoy, R. J. 1982 Analysis of the geological evidence for Holocene sea-level movements in South East England. *Proc. Geol. Ass.* **93**, 65–90.

Dyer, K. R. 1975 The buried channels of the 'Solent River', southern England. *Proc. Geol. Ass.* **86**, 239–245.

Emery, K. O. & Aubrey, D. G. 1985 Glacial rebound and relative sea-levels in Europe from tide-gauge records. *Tectonophysics* **120**, 239–255.

Evans, J. 1897 *The ancient stone implements, weapons and ornaments of Great Britain.* London: Longmans, Green & Co.

Everard, C. E. 1954 The Solent River: a geomorphological study. *Trans. Inst. Br. Geogr.* **20**, 4–58.

Eyles, N. & McCabe, A. M. 1989 The Late Devensian (< 22000 BP) Irish Sea Basin: the sedimentary record of a collapsed ice sheet margin. *Quat. Sci. Rev.* **8**, 307–351.

Faegri, K. & Iversen, J. 1975 *Textbook of pollen analysis* (3rd edn). Oxford: Blackwells.

Fisher, P. F. & Bridgland, D. R. 1986 Analysis of pebble morphology. In *Clast lithological analysis* (*Technical Guide No. 3*) (ed. D. R. Bridgland), pp. 43–72. Cambridge: Quaternary Research Association.

Forbes, E. 1856 On the Tertiary Fluvio-marine Formation of the Isle of Wight. *Mem. geol. Surv. G.B.*

Fowler, J. 1932 The 'One Hundred Foot' Raised Beach between Arundel and Chichester, Sussex. *Q. Jl. geol. Soc. Lond.* **88**, 84–99.

French, H. M. 1976 *The periglacial environment.* London: Longmans.

Gard, G. 1986 Calcareous nannofossil biostratigraphy of late Quaternary Arctic sediments. *Boreas* **15**, 217–229.

Gartner, S & Emiliani, C. 1976 Nannofossil biostratigraphy and climatic stages of Pleistocene Brunhes Epoch. *Bull. Am. Assoc. Petrol. Geol.* **60**, 1562–1564.

Gibbard, P. L. 1988 The history of the great northwest European rivers during the past three million years. *Phil. Trans. R. Soc. Lond.* B **318**, 559–602.

Gibbard, P. L., Wintle, A. G. & Catt, J. A. 1987 Age and origin of clayey silt 'brickearth' in west London, England. *J. Quat. Sci.* **2**, 3–9.

Godwin Austin, R. 1855 On land-surfaces beneath the Drift-Gravel. *Q. Jl. geol. Soc. Lond.* **11**, 112–119.

Hall, A. R. 1980 Late Pleistocene deposits at Wing, Rutland. *Phil. Trans. R. Soc. Lond.* B **289**, 135–164.

Hey, R. W. 1967 Sections in the beach-plain deposits of Dungeness, Kent. *Geol. Mag.* **104**, 361–370.

Heyworth, A. & Kidson, C. 1982 Sea-level changes in southwest England and Wales. *Proc. Geol. Ass.* **93**, 91–111.

Hodgson, J. M. 1964 The low-level Pleistocene marine sands and gravels of the West Sussex coastal plain. *Proc. Geol. Ass.* **75**, 547–561.

Holyoak, D. T. & Preece, R. C. 1983 Evidence of a high Middle Pleistocene sea-level from estuarine deposits at Bembridge, Isle of Wight, England. *Proc. Geol. Ass.* **94**, 231–244.

Horne, D. J. & Whittaker, J. E. 1985 On *Leptocythere porcellanea* (Brady). *Stereo-Atlas Ostracod Shells* **12**(19), 99–106.

Houghton, S. D. 1986 *Coccolith assemblages in Recent marine and estuarine sediments from the continental shelf of northwest Europe.* Ph.D. thesis, University of Southampton.

Houghton, S. D. 1988 Thermocline control on coccolith diversity and abundance in Recent sediments from the Celtic Sea and English Channel. *Mar. Geol.* **83**, 313–319.

Huntley, B. & Birks, H. J. B. 1983 *An atlas of past and present pollen maps for Europe: 0–13000 years ago.* Cambridge University Press.

Jackson, J. F. 1924 Description of the Pleistocene deposit near Bembridge. *Proc. Isle of Wight nat. Hist. arch. Soc.* **1**, 292–295.

Jacobsen, G. L. Jr & Bradshaw, R. H. W. 1981 The selection of sites for paleovegetational studies. *Quat. Res.* **16**, 80–96.

Jessen, K. 1949 Studies in Late Quaternary deposits and flora-history of Ireland. *Proc. R. Ir. Acad.* B **52**(6), 1–290.

Johnson, D. W. 1919 *Shore processes and shoreline development.* New York: Wiley.

Johnson, J. P. 1901 The Pleistocene fauna of West Wittering. *Proc. Geol. Ass.* **17**, 261–264.

Johnson, R. G. 1982 Brunhes–Matuyama reversal. *Quat. Res.* **17**, 135–147.

Jones, D. K. C. 1981 *The geomorphology of the British Isles: Southeast and Southern England.* London: Methuen.

de Jong, J. 1988 Climatic variability during the past three million years, as indicated by vegetational evolution in northwest Europe and with emphasis on data from the Netherlands. *Phil. Trans. R. Soc. Lond.* B **318**, 603–617.

Keen, D. H. 1980 The environment of deposition of the south Hampshire plateau gravels. *Proc. Hamps. Field Club arch. Soc.* **36**, 15–24.

Downloaded from rstb.royalsocietypublishing.org

Knudsen, K. L. 1980 Foraminiferal faunas in marine Holsteinian interglacial deposits of Hamburg–Hummelsbüttel. *Mitt. Geol.-Paläont. Inst. Univ. Hamburg* **49**, 193–214.

Knudsen, K. L. 1987 Foraminifera in Late Elsterian–Holsteinian deposits of the Tornskov area in South Jutland, Denmark. *Danm. geol. Unders.* B **10**, 7–30.

Knudsen, K. L. 1988 Marine interglacial deposits in the Cuxhaven area, NW Germany: a comparison of Holsteinian, Eemian and Holocene foraminiferal faunas. *Eiszeitalter Gegenw.* **38**, 69–77.

Lautridou, J. P. 1980 *Stratigraphie du Quaternaire de Normandie et du Bassin Parisien. Bull. Ass. fr. Quat.* **1**, 180–189.

Linke, G., Katzenberger, O. & Grün, R. 1985 Description and ESR dating of the Holsteinian interglacial. *Quat. Sci. Rev.* **4**, 319–331.

Lord, A. R. & Robinson, J. E. 1978 Marine Ostracoda from the Quaternary Nar Valley Clay, West Norfolk. *Bull. geol. Soc. Norfolk* **30**, 113–118.

Lord, A. R., Robinson, J. E. & Moutzourides, S. G. 1990 Ostracoda from Holsteinian deposits in the Hamburg area. *Geol. Jb.* (In the press.)

Martini, E. 1971 Standard Tertiary and Quaternary calcareous nannoplankton zonation. In *Proceedings of the II Planktonic Conference* (*Roma, 1970*) (ed. A. Farinacci), vol. 2, pp. 739–785. Roma: Edizioni Tecnoscienza.

Matthews, J. A. 1969 The assessment of a method for the determinations of absolute pollen frequencies. *New Phytol.* **68**, 161–166.

Maybury, C. & Whatley, R. C. 1980 The ostracod genus *Leptocythere* from the Pliocene deposits of St. Erth and North-West France. *Revta. esp. Micropaleont.* **12**(3), 435–468.

Miller, G. H. & Mangerud, J. 1985 Aminostratigraphy of European marine interglacial deposits. *Quat. Sci. Rev.* **4**, 215–278.

Miller, G. H., Hollin, J. T. & Andrews, J. T. 1979 Aminostratigraphy of U.K. Pleistocene deposits. *Nature, Lond.* **281**, 539–541.

Mottershead, D. N. 1977 The Quaternary evolution of the south coast of England. In *The Quaternary history of the Irish Sea* (ed. C. Kidson & M. J. Tooley), pp. 299–320. Liverpool: Seel House Press.

Neale, J. W. & Howe, H. V. 1975 The marine Ostracoda of Russian Harbour, Novaya Zemlya and other high latitude faunas. *Bull. Am. Paleont.* **65**, 381–431.

Nicholls, R. J. 1985 *The stability of shingle beaches in the eastern half of Christchurch Bay.* Ph.D. thesis, University of Southampton.

Nicholls, R. J. 1987 Evolution of the upper reaches of the Solent River and the formation of Poole and Christchurch Bays. In *Field Guide to the Quaternary of Wessex and the Isle of Wight* (ed. K. E. Barber), pp. 99–114, Cambridge: Quaternary Research Association.

Parks, D. A. & Rendell, H. M. 1988 TL dating of brickearths from S.E. England. *Quat. Sci. Rev.* **7**, 305–308.

Penney, D. N. 1987 Ostracoda of the Holsteinian Interglacial in Jutland, Denmark. *Danm. geol. Unders.* B **10**, 33–67.

Plint, A. G. 1982 Eocene sedimentation and tectonics in the Hampshire Basin. *J. geol. Soc. Lond.* **139**, 249–254.

Poulton, R. W. 1909 An account of discoveries of Palaeolithic implements in the Isle of Wight. In *A guide to the natural history of the Isle of Wight* (ed. F. Morey), pp. 37–41. Newport, Isle of Wight: The County Press.

Powers, M. C. 1953 A new roundness scale for sedimentary particles. *J. sedim. Petrol.* **23**, 117–119.

Preece, R. C. & Scourse, J. D. 1987 Pleistocene sea-level history in the Bembridge area of the Isle of Wight. In *Field Guide to the Quaternary of Wessex and the Isle of Wight* (ed. K. E. Barber), pp. 136–149. Cambridge: Quaternary Research Association.

Prestwich, J. 1859 On the westward extension of the old raised beach of Brighton; and on the extent of the sea-bed of the same period. *Q. Jl. geol. Soc. Lond.* **15**, 215–221.

Prestwich, J. 1872 On the presence of a raised beach on Portsdown Hill, near Portsmouth, and on the occurrence of a flint implement on a high level at Downton. *Q. Jl. geol. Soc. Lond.* **28**, 38–74.

Prestwich, J. 1892 The Raised Beaches, and 'Head' or Rubble-drift, of the South of England: their relation to the Valley Drifts and to the Glacial Period; and on a Late Post-Glacial submergence. *Q. Jl. geol. Soc. Lond.* **48**, 253–343.

Pujos, A. 1985*a* Quaternary nannofossils from the Goban Spur, eastern North Atlantic Ocean, Deep Sea Drilling Project Holes 548 and 549. In *Initial reports of the Deep Sea Drilling Project*, vol. 80 (ed. P. C. Graciansky *et al.*), pp. 767–792. Washington: U.S. Government Printing Office.

Pujos, A. 1985*b* Nannofossils from Quaternary deposits in the high productivity area of the central equatorial Pacific. In *Initial reports of the Deep Sea Drilling Project*, vol. 85 (ed. L. Mayer *et al.*), pp. 553–579. Washington: U.S. Government Printing Office.

Pujos-Lamy, A. 1977*a* Essai d'etablissement d'une biostratigraphie du nannoplancton calcaire dans le Pleistocene de l'Atlantique Nord-oriental *Boreas* **6**, 323–331.

Pujos-Lamy, A. 1977*b* *Emiliania* et *Gephyrocapsa* (Nannoplancton calcaire): biometrie et intérêt biostratigraphique dans le Pleistocene superior marin des Açores. *Revta. esp. Micropalaeontol.* **9**, 69–84.

Reid, C. 1892 The Pleistocene deposits of the Sussex coast, and their equivalents in other districts. *Q. Jl. geol. Soc. Lond.* **48**, 344–361.

Reid, C. 1902 Geology of the country around Ringwood. *Mem. geol. Surv. Engl. Wales.*

Reid, C. & Strahan, A. 1889 The geology of the Isle of Wight. *Mem geol. Surv. Engl. Wales.*

Downloaded from rstb.royalsocietypublishing.org

Reid, E. M. & Chandler, M. E. J. 1924 On the occurrence of *Ranunculus hyperboreus* Rottb. in Pleistocene beds at Bembridge, Isle of Wight. *Proc. Isle Wight nat. Hist. arch. Soc.* **1**, 292–295.

Reynolds, P. J. 1987 Lepe cliff: the evidence for a pre-Devensian brickearth. In *Field guide to the Quaternary of Wessex and the Isle of Wight* (ed. K. E. Barber), pp. 21–22. Cambridge: Quaternary Research Association.

Roberts, M. B. 1986 Excavation of the lower palaeolithic site at Amey's Eartham pit, Boxgrove, West Sussex: A preliminary report. *Proc. prehist. Soc.* **52**, 215–245.

Roth, P. H. & Berger, W. H. 1975 Distribution of coccoliths in the south and central Pacific. In *Dissolution of deep-sea carbonates* (ed. W. V. Slitter, A. W. H. Bé & W. H. Berger) *Cush. Found. Foramin. Res. Spec. Publn* **134**, pp. 87–113.

Samson, F. R. 1976 *Priory Bay: a study of an unstratified Palaeolithic site in the Isle of Wight.* B.A. dissertation, Department of Archaeology, University of Southampton.

Sarnthein, M., Stremme, H. E. & Mangini, A. 1986 The Holstein Interglaciation: time stratigraphic position and correlation to stable-isotope stratigraphy of deep-sea sediments. *Quat. Res.* **26**, 283–298.

Scourse, J. D. 1985 *Late Pleistocene stratigraphy of the Isles of Scilly and adjoining regions.* Ph.D. thesis, University of Cambridge.

Shackleton, N. J. 1969 The last interglacial in the marine and terrestrial records. *Proc. R. Soc. Lond.* B **174**, 135–154.

Shackleton, N. J. 1987 Oxygen isotopes, ice volume and sea level. *Quat. Sci. Rev.* **6**, 183–190.

Shackleton, N. J. & Opdyke, N. D. 1973 Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 and a 10^6 year scale. *Quat. Res.* **3**, 39–55.

Shackleton, N. J. & Opdyke, N. D. 1976 Oxygen isotope and palaeomagnetic stratigraphy of Pacific core V28-239, Late Pliocene to Late Holocene. *Geol. Soc. Am. Mem.* **145**, 449–464.

Shephard-Thorn, E. R. & Kellaway, G. A. 1978 Quaternary deposits at Eartham, West Sussex. *Brighton Polytechnic Geogr. Soc. Mag.* **4**, 1–8.

Simpson, J. H. & Bowers, D. 1981 Models of stratification and frontal movement in shelf areas. *Deep Sea Res.* **28**A, 727–738.

Simpson, J. H. & Hunter, J. R. 1974 Fronts in the Irish Sea. *Nature, Lond.* **250**, 404–406.

Singhvi, A. K., Sharma, Y. P. & Agrawal, D. P. 1982 Thermoluminescence dating of dune sands in Rajasthan, India. *Nature, Lond.* **295**, 313–315.

Smith, A. J. 1985*a* A catastrophic origin for the palaeovalley system of the eastern English Channel. *Mar. Geol.* **64**, 65–75.

Smith, A. J. 1985*b* The English Channel: a response to geological events after the Variscan orogeny. *Ann. Soc. Geol. pol.* **55**, 3–22.

Smith, A. J. 1989 The English Channel – by geological design or catastrophic accident? *Proc. Geol. Ass.* **100**, 325–337.

Smith, A. J. & Curry, D. 1975 The structure and geological evolution of the English Channel. *Phil. Trans. R. Soc. Lond.* A **279**, 3–20.

Southgate, G. A. 1985 Thermoluminescence dating of beach and dune sands: potential of single-grain measurements. *Nucl. Tracks* **10**, 725–730.

Sparks, B. W. & West, R. G. 1970 Late Pleistocene deposits at Wretton, Norfolk. I. Ipswichian interglacial deposits. *Phil. Trans. R. Soc. Lond.* B **258**, 1–30.

Stuart, A. J. & West, R. G. 1976 Late Cromerian fauna and flora at Ostend, Norfolk. *Geol. Mag.* **113**, 469–473.

Takayama, T. & Saito, S. 1986 Coccolith biostratigraphy of North Atlantic. Deep Sea Drilling Project Leg 94. In *Initial reports of the Deep Sea Drilling Project*, vol. 94 (ed. W. F. Ruddiman *et al.*), pp. 651–702. Washington: U.S. Government Printing Office.

Thierstein, H. R., Geitzenauer, K. R., Molfino, B. & Shackleton, N. J. 1977 Global synchroneity of Late Quaternary coccolith datum levels: validation by oxygen isotopes. *Geology* **5**, 400–405.

Thomas, G. S. P. 1985 Ayre raised beach. In *Field guide to the Quaternary of the Isle of Man* (ed. R. V. Dackombe & G. S. P. Thomas), pp. 80–81. Cambridge: Quaternary Research Association.

Troels-Smith, J. 1955 Karakterisering af løse jordarter. *Danm. geol. Unders.* IV **3**(10), 1–73.

Turner, C. & West, R. G. 1968 The subdivision and zonation of interglacial periods. *Eiszeitalter Gegenw.* **19**, 93–101.

Walden, A. T. 1982 The statistical analysis of extreme high sea levels utilising data from the Solent Area. Ph.D. thesis, University of Southampton.

Walton, W. R. 1964 Recent foraminiferal ecology and palaeoecology. In *Approaches to paleoecology* (ed. J. Imbrie & N. D. Newell), pp. 151–237. New York: Wiley.

Webber, N. B. & Walden, A. T. 1981 Rise in mean sea level at Portsmouth. *Dock Harbour Authority* **61**, 385.

West, I. M. 1980 Geology of the Solent estuarine system. In *The Solent estuarine system* (NERC Publication, series C, no. 22), pp. 6–19. Swindon: NERC.

West, R. G. 1972 Relative land–sea level changes in southeastern England during the Pleistocene. *Phil. Trans. R. Soc. Lond.* A **272**, 87–98.

West, R. G. 1980*a* Pleistocene forest history in East Anglia. *New Phytol.* **85**, 571–622.

West, R. G. 1980*b* *The pre-glacial Pleistocene of the Norfolk and Suffolk coasts.* Cambridge University Press.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Downloaded from rstb.royalsocietypublishing.org

West, R. G., Devoy, R. J. N., Funnell, B. M. & Robinson, J. E. 1984 Pleistocene deposits at Earnley, Bracklesham Bay, Sussex. *Phil. Trans. R. Soc. Lond.* B **306**, 137–157.

West, R. G. & Sparks, B. W. 1960 Coastal interglacial deposits of the English Channel. *Phil. Trans. R. Soc. Lond.* B **243**, 95–133.

West, R. G. & Whiteman, C. A. 1986 *The Nar Valley and North Norfolk. Field guide.* Coventry: Quaternary Research Association.

Whatley, R. C. & Kaye, P. 1971 The palaeoecology of Eemian (last interglacial) Ostracoda from Selsey, Sussex. *Bull. Centre Pau-SNPA* **5**, (Suppl.), 311–330.

Whatley, R. C. & Masson, D. G. 1979 The ostracod genus *Cytheropteron* from the Quaternary and Recent of Great Britain. *Revta. esp. Micropaleont.* **11**(2), 223–277.

White, H. J. Osborne 1921 A short account of the Geology of the Isle of Wight. *Mem. geol. Surv. Engl. Wales.*

Wintle, A. G. 1985 Stability of TL signal in fine grains from loess. *Nucl. Tracks* **10**, 725–730.

Wintle, A. G. & Prószynska, H. 1983 TL dating of loess in Germany and Poland. *PACT* **9**, 547–554.

Woodworth, P. L. 1987 Trends in U.K. mean sea level. *Mar. Geod.* **11**, 57–87.

Zagwijn, W. H. 1983 Sea level changes in the Netherlands during the Eemian. *Geologie Mijnb.* **62**, 437–450.

Zagwijn, W. H. 1985 An outline of the Quaternary stratigraphy of The Netherlands. *Geologie Mijnb.* **64**, 17–24.

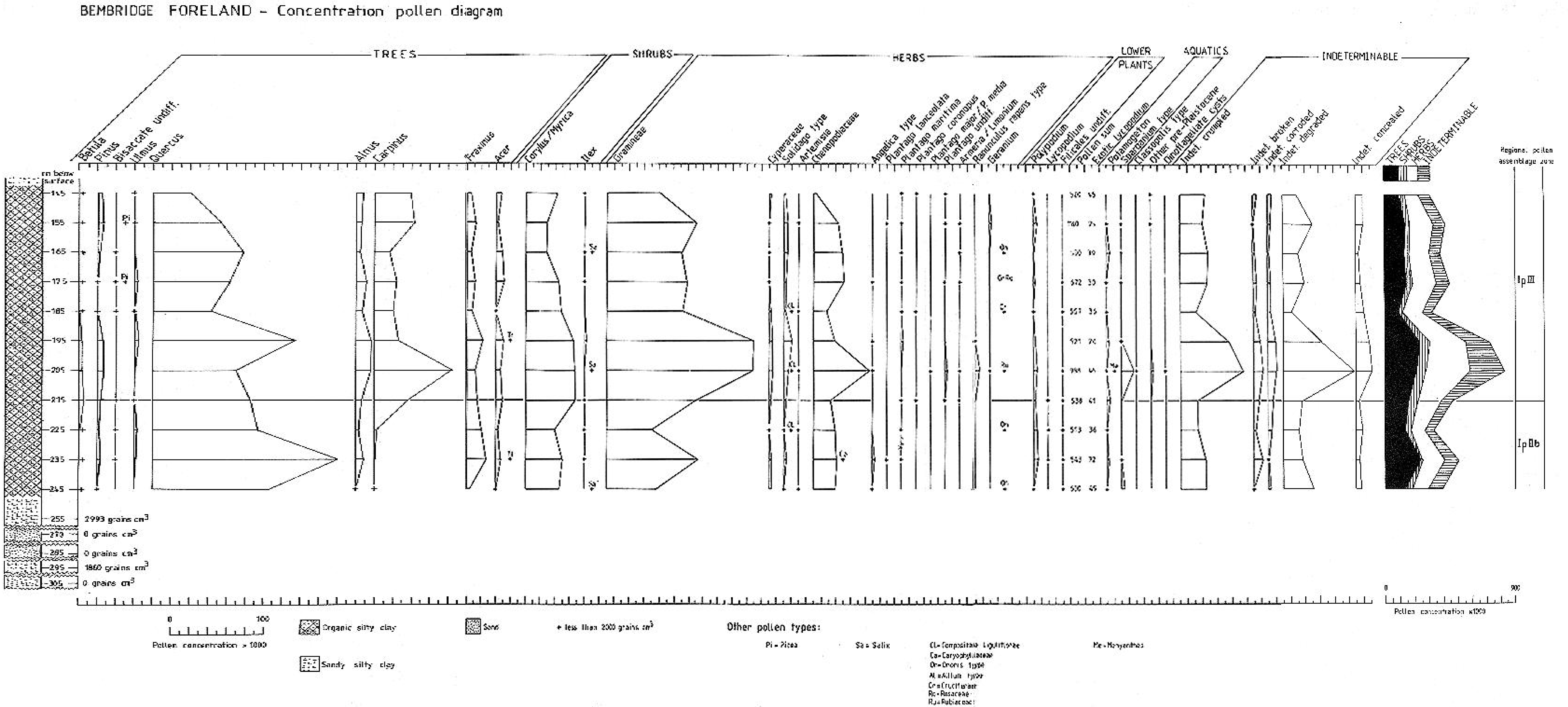


FIGURE 6. Bembridge Foreland: concentration pollen diagram. Pollen concentrations are expressed as grains per cubic centimetre for each taxon. Other conventions as in figure 5. The summary diagram is plotted from concentration calculations. Analysed by J. D. Scourse, February 1986.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

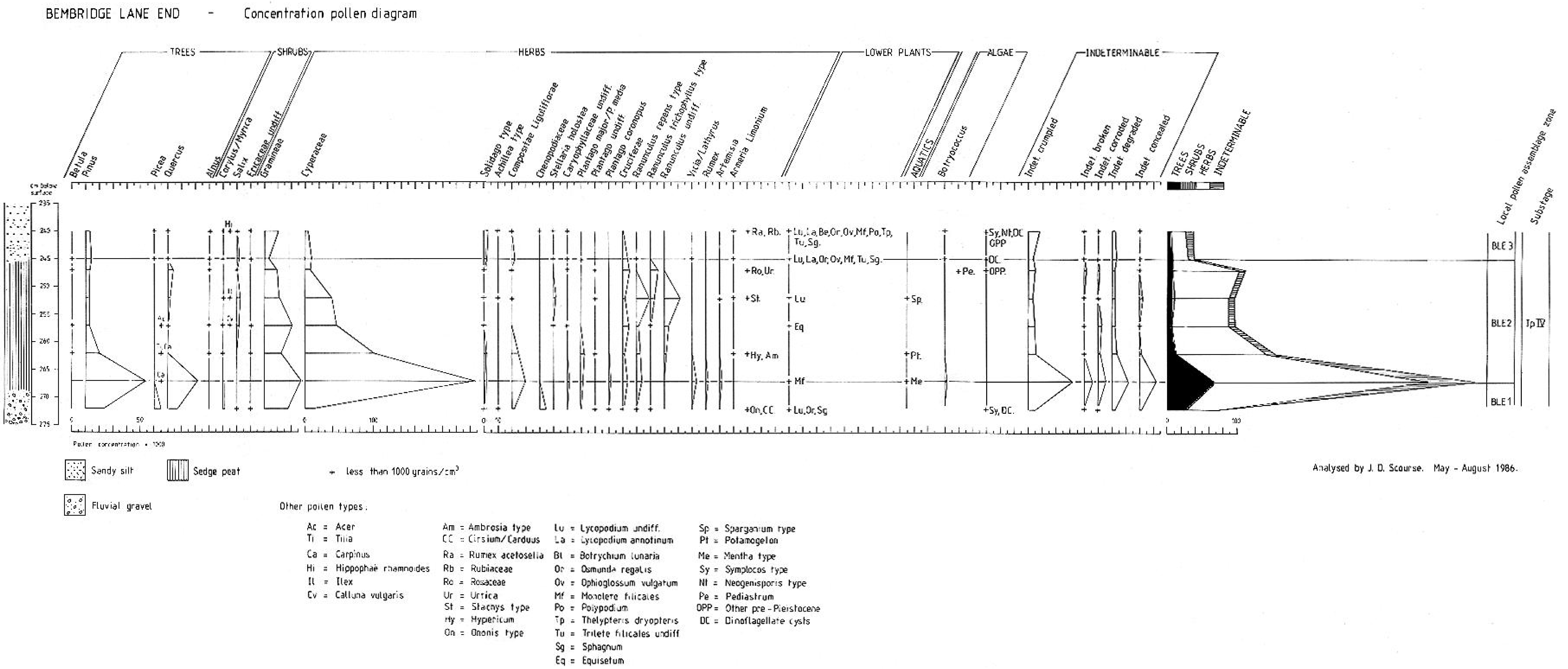
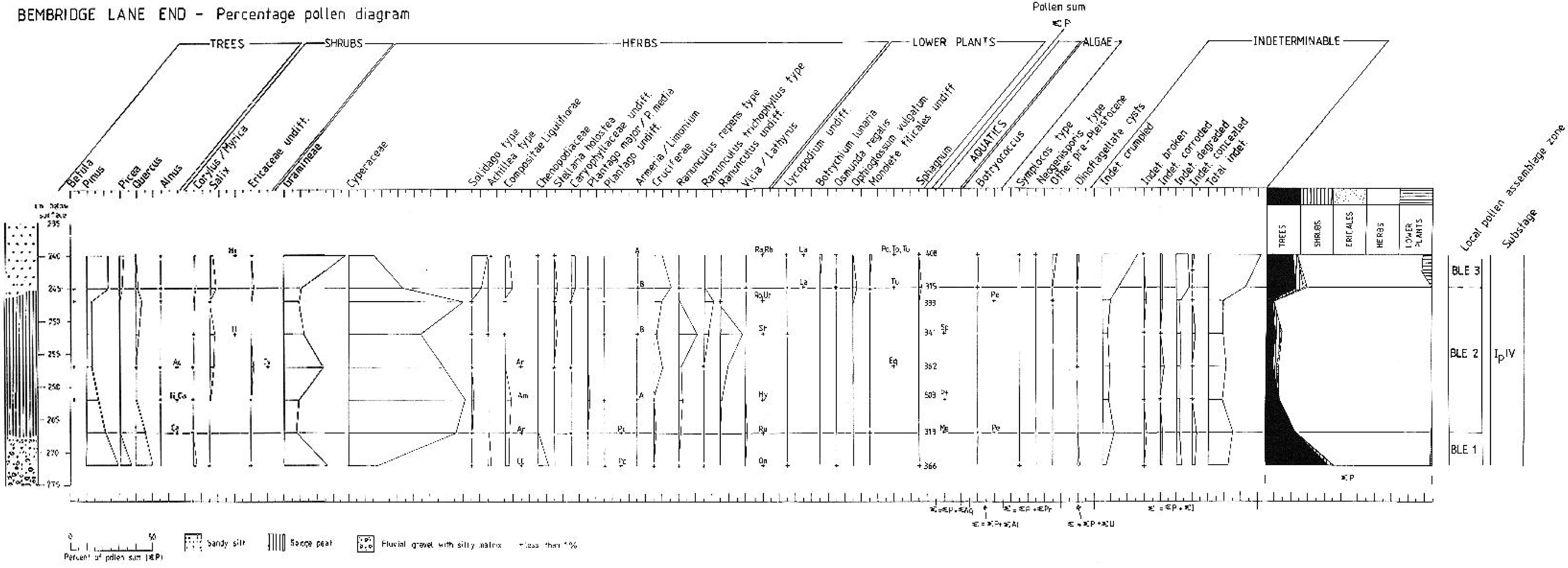


FIGURE 7. Bembridge Lane End: percentage pollen diagram. Conventions as in figure 5. Analysed by J. D. Scourse, May–August 1986.

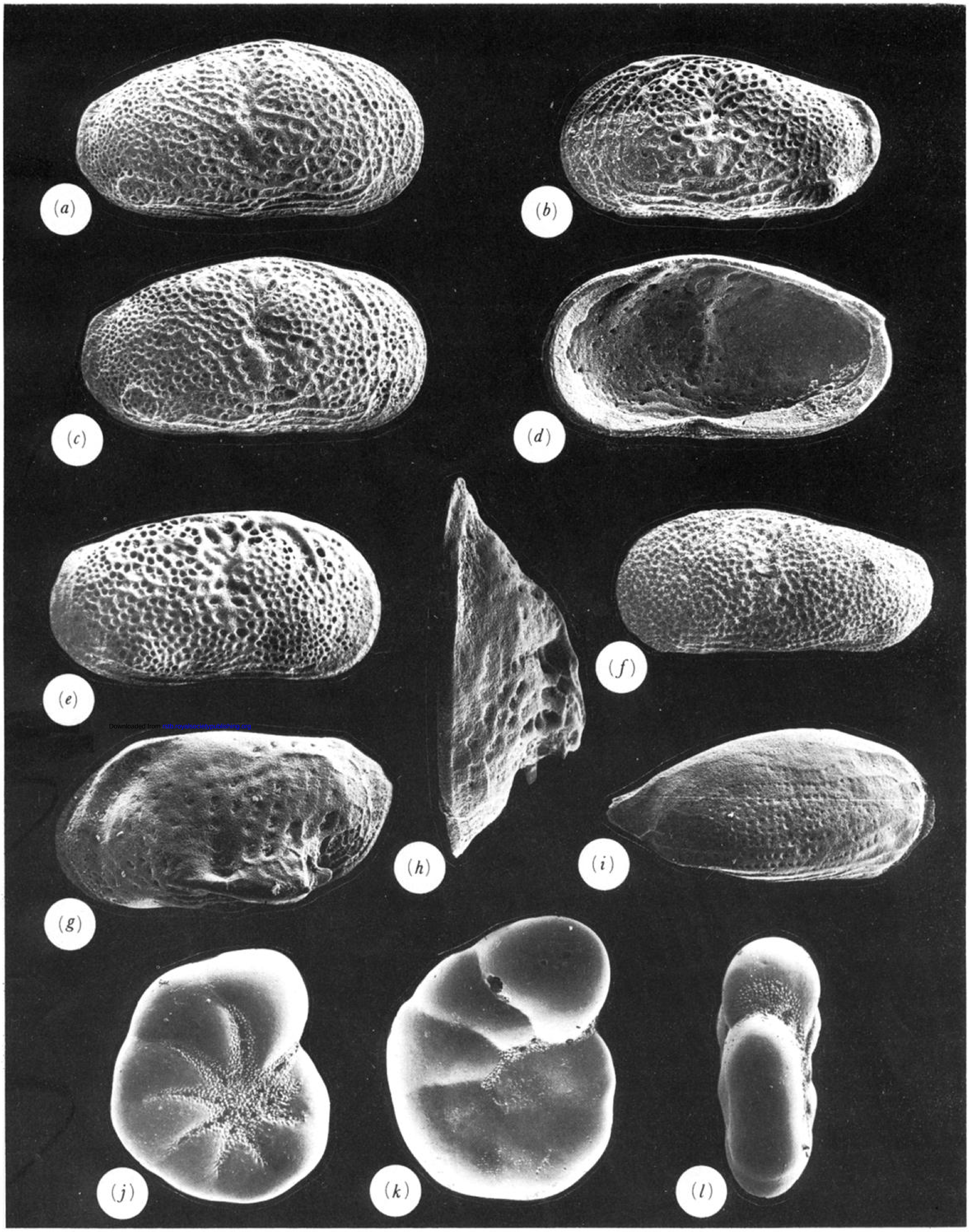


Other pollen types:-

Ac = Acer	Ar = Artemisia	Ra = Rumex acetosella	Hy = Hypericum	Tu = Trilete filicales undiff.
Ti = Tilia	Am = Ambrosia type	Ru = Rumex undiff.	On = Ononis type	Sp = Sparganium type
Ca = Carpinus	CC = Cirsium / Carduus	Rb = Rubiaceae	La = Lycopodium annotinum	Pt = Potamogeton
Hi = Hippophaë rhamnoides	Pc = Plantago coronopus	Ro = Rosaceae	Po = Polypodium	Me = Mentha type
Il = Ilex	A = Type A	Ur = Urtica	Tp = Thelypteris dryopteris	Pe = Pediastrum
Cv = Calluna vulgaris	B = Type B	St = Stachys type	Eq = Equisetum	

Figure 8. Bembridge Lane End: concentration pollen diagram. Conventions as in figures 5 and 6. Analysed by J. D. Scourse, May–August 1980.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



Downloaded from rstb.royalsocietypublishing.org

FIGURE 11. Selected ostracod and foraminifer taxa for the Steyne Wood Clay, Bembridge. (*a*)–(*d*), (*f*) *Leptocythere steynewoodensis* sp. nov. (*a*) Female RV, external lateral view, magn. ×121; (*b*) female LV, external lateral view, magn. ×110; (*c*) female RV, external lateral view, magn. ×125; (*d*) female RV, internal lateral view, magn. ×121. (*e*) *Leptocythere castanea* (Sars), female RV, external lateral view, magn. ×81. (*f*) *Leptocythere steynewoodensis* male LV, external lateral views, magn. ×115. (*g*), (*h*) *Cytheropteron* sp. (*g*) Adult LV, external lateral view, magn. ×135; (*h*) adult RV, dorsal view, magn. ×148. (*i*) *Semicytherura affinis* (Sars), adult RV, external lateral view, magn. ×110. (*j*)–(*l*) *Aubignyna perlucida* (Heron-Allen & Earland). (*j*) Spiral view, magn. ×95; (*k*) umbilical view, magn. ×90; (*l*) apertural view, magn. ×90.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES